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Full Length Research Paper

Agricultural micro-credit repayment performance: Evidence from Minna Microfinance Bank, Nigeria

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Agricultural micro-credit repayment has been a thorny issue in Nigeria, and in particular, Niger State. This study therefore assessed the socio-economic characteristics of Agricultural micro-credit beneficiaries under Minna Micro-finance Bank; determined the volume of micro-credit applications and receipts; ascertained the determinants of micro-credit repayments by beneficiaries and examined the challenges encountered by beneficiaries in obtaining and repaying micro-credits. Multi-stage sampling technique was employed to select 180 respondents for the study while descriptive statistics and Multinomial Binary Logit model were employed for data analyses. The study affirmed that substantial proportion of respondents (42.78%) were smallholders owning between 1.1 to 2.0 ha of land. Ironically, 61.67% do not belong to cooperatives. The Multinomial Logit model revealed that sex, membership of cooperatives, loans granted and duration of micro-credit repayment were positive determinants of repayment, implying that these variables were significantly associated with the classification of beneficiaries under the non-repayment and partial loan repayment groups relative to the group of respondents who had fully repaid their loans. In addition, the elastic variables, namely, sex (3.58), cooperative membership (5.95) and loans granted (2.02) connotes that a unit change in these variables will lead to a more than proportionate change in the probability of classifying respondents into the non-repayment group relative to the full micro-credit repayment group. The study further established that repayment increased with the volume of micro-credit received. Majority (68.89%) of the respondents also indicated that the short period of loan tenor, high interest rate (55%) and loan repayment moratorium (54%) were major obstacles to loan access and repayment. The study concluded that agricultural micro-credit repayment performance by beneficiaries of Minna Microfinance Bank was considerable. Policy option requires that efforts be directed at complementing the resource pool of agricultural micro-credit with long term or idle funds, such as, the pension funds. This will guarantee or create room for reasonable duration for micro-credit repayment to the advantage of beneficiaries while not compromising the sustainability and revolving nature of the scheme. Basing interest rates on social and economic considerations will also go a long way in enhancing repayment among small-holder farmers. Channeling micro-credits through farmer institutions and ensuring effective monitoring will also enhance effective micro-credit recovery.

Key words: Micro-credit, repayment, moratorium, cooperatives.

INTRODUCTION

Over the past decades, the contributions of agriculture to Nigeria's economy has continued to decline; from over 50% of the GDP in the 60s to 23% as at 2014, given the dwindling role of the sector on one hand and the

simultaneous expansion of the other sectors of the economy, particularly, the service sector. Aside this, agriculture has been unable to meet with its other traditional roles such as provision of food for the generality of the populace, raw materials supply, foreign exchange earnings and provision of gainful employment (Olatunji, 2004). Agricultural micro-credit has been a key missing link given the resource poor nature of farmers in Nigeria and in fact in most parts of the sub Sahara Africa. Generally, inadequate credit has been seen as one of the main reasons why many people in developing economies remain poor. Usually, the poor have no access to loans from the banking system given the difficulties in putting up acceptable collaterals, high administrative charges among other factors (Hermes and Lensink, 2011; Awoke, 2004). To redress the situation in the country, several projects and programmes were initiated by successive governments including the on-going Agricultural Transformation Agenda under policy measures. Most of these initiatives provided for a credit component and or technical assistance to meet the financial needs of the resource poor farmers. Some of these interventions included the National Acceleration Food Production Programme (NAFPP), Agricultural Development Programmes (ADPs), Green Revolution (GR), and River Basin Development Authority (RBDA), Directorate for Food, Roads and Rural Infrastructure (DFFRI) (Aku, 1981), the Rural Finance Institutions Building Programme (RUFIN) and most recently, the Nigeria Incentive-based Risk Sharing for Agricultural Lending (NIRSAL) which is pushing a simultaneous implementation and alignment of the commodity value chains with the financial value chain. It is worthy of mention that the recognition that agricultural credit is crucial to the development of the farming sector prompted the adoption of several subtle and overt measures to encourage the flow of bank credit to farmers, beginning with the 1972 fiscal year. In this direction, the Central Bank of Nigeria (CBN) used credit guidelines to prescribe the size of credit allocation by Banks to preferred sectors of the economy including agriculture (Nnanna et al., 2004). In addition, the Bank was involved in various interventions to improve access to needed finance for development, through the Agricultural Credit Guarantee Scheme Fund (ACGSF), under which a total of 1,330 small farmers loans valued at ₦66.5 million ($443, 333) were guaranteed in Niger State in 2005. However, despite the general acceptance of the relevant roles of credit and wide appreciation by most governments of the need for credit, repayment performance has been below par. Numerous researchers have attributed the failures of many government credit programmes to high rate of non-repayment of agricultural loans. Oshuntogun (2007) for instance, observed that most credit institutions in Nigeria were faced with lots of repayment problems, given the weak analysis of borrowers farming operations and repayment potentials. Ajah et al. (2013) further confirmed that credit administration in many parts of Nigeria has not been impressive when placed against their repayment performance. This development therefore prompted the review of repayment performance under Minna Micro-finance Bank. The broad objective of the study was to assess the repayment performance by beneficiaries of Minna Micro-finance Bank. The specific objectives were to: (i) describe the socio-economic characteristics of micro-credit beneficiaries under the Minna Micro-finance Bank; (ii) ascertain the volume of loan applications, receipts and repayments by respondents; (iii) ascertain the determinants of microcredit repayment among beneficiaries of Minna Micro-finance Bank; and (iv) examine the challenges encountered by respondents in obtaining and repaying micro-credits obtained from Minna Micro-finance Bank.

This study is therefore justified given that it will determine how far-off the objectives of micro-credit repayments have been achieved in Minna Micro-finance Bank. In a depressing economy like Nigeria, where several banks and other financial intermediaries have collapsed, many more insolvent, credit control and loan recovery remain a livewire for survival in the money and capital markets (Oyo, 2012). Most importantly, empirical evidence as to what factors determine loan repayment and loan recovery are seldom in Niger State and is yet to be undertaken in Minna Micro-finance Bank, this study has become imperative and will take a step to determine the factors that affect loan repayments with a view to providing necessary information needed to bridge the knowledge gap. The following research hypotheses were tested under the study:

H_o: The explanatory variables included in the Multinomial logit model do not significantly determine micro-credit repayment in Minna Microfinance Bank.
H_a: The explanatory variables included in the Multinomial logit model significantly determine micro-credit repayment in Minna Microfinance Bank.

METHODOLOGY

Area of the study

The study was conducted in Chanchaga Local Government Area of Niger State, Nigeria. The State was created in 1976 out of the then North-Western State. It lies between Latitude 8° 21′ N and 11° 30′N and Longitude 3 30′E and 7°20′E in the North Central Geographical Zone of Nigeria. The State is bordered to the North by Zamfara

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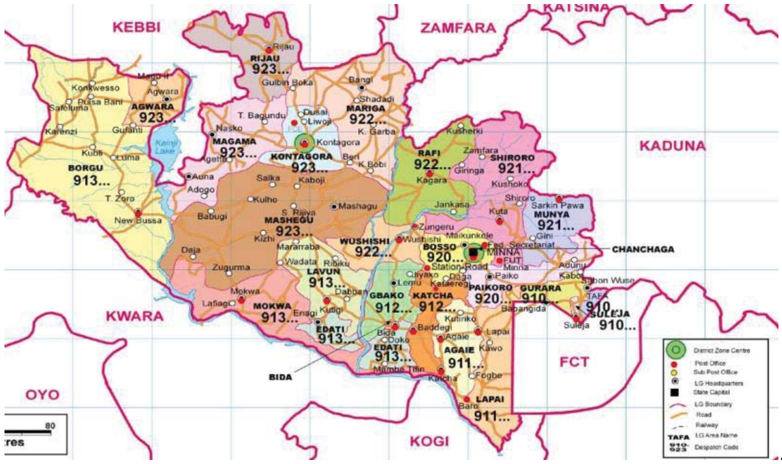

Figure 1. Map of Niger State of Nigeria showing the Study Area (Chanchaga). Source: Open internet window.

Table 1. Sampling frame of beneficiaries in Chanchaga LGA.

S/N	Wards selected	Beneficiaries population	Beneficiaries selected
1.	Limawa A	200	36
2.	Nasarawa A	150	27
3.	Nasarawa C	100	18
4.	Tudun-Wada North	150	27
5.	Minna Central	100	18
6.	Minna South	300	54
	Total	1,000	180

Source: Field survey, 2014.

State to the North-east by Kebbi, to the South by Kogi State, to the South-west by Kwara State while Kaduna State and Federal Capital Territory border the State to the North-east. The State lies in the central Niger Basin. The most prominent features of the State are Rivers Niger and Kaduna which traverse the State in West-east and North-south direction respectively. It has a moderate tropical continental climate. The main features of which are two distinct and pronounced seasons. A dry and wet with rainfall that extend between 5 and 6 months of the year and a steady high temperature. The State has a population of 3,950,249 (National Population Commission, 2006). Of the 7 million hectares cultivable land in the State, only 2.3 million hectares (32%) are under cultivation for production of various food and cash crops (rice, yam, maize, groundnut, cowpea, etc). The State also has 682,000 ha of irrigable land out of which 105,575 (15.5%) have been developed (Niger State Government, 2008) (Figure 1).

Sampling technique

Multi-stage sampling technique was employed for this study. The first stage was the purposive selection of Chanchaga Local Government Area given that most beneficiaries are concentrated in the area. The second stage involved the random selection of 6 out of the 11 benefiting wards, given resource constraint, while the third stage entailed the selection of 180 respondents from a frame of 1,000 beneficiaries (Table 1) using the sample size calculator at 7% precision level and 95% confidence level and p = 5. The formula used in selecting sample size proportionate to the population of micro-credit beneficiaries according to Yamane (1967) is given by:

$$n= N/1+N(e)^2$$

Where, n = sample size, N = the finite population, e = limit of tolerable error,1 = unity.

Method of data collection

Primary and secondary data were used for the study. The secondary data were obtained from the records of Minna Microfinance Bank Limited while the primary data were obtained from respondents through structured questionnaire and oral interviews. Two types of questionnaires were administered, with a view to collecting relevant information from the Bank officials and the loan beneficiaries.

Method of data analysis

Simple descriptive statistics such as mean, frequency distribution,

percentages were used to achieve objectives 1, 2, and 4 of this study. Multinomial logistic model was used to achieve objective 3. The model is appropriate when individuals can choose only one outcome from among the set of mutually exclusive, collectively exhaustive alternatives. The choice of the method was based on the fact that the level of loan repayment (dependent variable) is a categorical variable which can take three levels of classification namely (i) Beneficiary who have fully repaid their loans on what was due; (ii) Beneficiaries who have paid part of what was due; and (iii) Beneficiaries who are yet to pay their due microcredit. The multinomial logit regression model had been used by numerous researchers, namely Budry et al. (2006), Rahji and Fakayode (2009) and Ojo (2013) to express the probability of a farmer or respondent being in a particular category.

In the multinomial logit model, the dependent variable takes the value of 0, 1, and 2. The probability that the respondents belong to the repayment group reduces to:

$$P_{ij} = \frac{e^{\beta_j X_i}}{1 + \sum_{K=j}^{j} e^{\beta_k X_i}} \quad (1)$$

The generalized multinomial model is expressed as:

$$P_{ij} = \frac{e^{\beta_j X_i}}{1 + \sum_{K=0}^{j} e^{\beta_k X_i}} \quad (2)$$

While the probability of being in the base outcome group is:

$$P_{i0} = \frac{1}{1 + \sum_{K=0}^{3} e^{\beta_k X_i}} \quad (3)$$

Where I = 1, 2...n variables k = 0, 1..j groups and B = a vector of parameters that relates X to the probability of being in group j, where there are j+1 groups. The various independent variables included in the final model are as follows:

X_1 = Age of farmer (Yrs), X_2= Gender (1 = Male; 0 = Female), X_3= House hold size (No of persons), X_4= Farm size (Ha), X_5= Group membership (1 =Membership; 0 = Non membership), X_6= Amount of micro-credit received (₦), X_7= Distance from dwelling to the bank (km), X_8= Visit by Loan Officials (1 if visited; 0 if otherwise), X_9= Loan Disbursement Lag (Time between application and actual loan disbursement) in months, X_{10}= Interest on loan (%).

To estimate the model, the coefficients of the base outcome are normalized to zero (0). This is because the probabilities for all the choices must sum up to the unity. Hence, for 3 choices, only (3-1) distinct sets of parameters can be identified and estimated. The natural logarithms of the old ratio of Equations (1) and (2) give the estimating equation as:

$$\text{Ln}\frac{P_{ij}}{P_{i0}} = \beta_i X_i$$

This denotes the relative probability of each of the other groups to the probability of the base outcome. The estimated coefficients for each choice therefore reflect the effects of Xi on the likelihood of the farmers choosing that alternative relative to the base outcome. The estimation was done using STATA statistical analytical software. The final estimates were selected based on the variables that converged during iteration. The coefficients of the base outcome were then recovered in line with Nmadu et al. (2012).

Where β_3 = coefficient of the variable of the base outcome (those who have completely repaid), β_2= estimated coefficient of those who have repaid part of the loans received β_1 = estimated coefficient of those who are yet to repay. In addition, the partial derivatives or marginal effects and quasi-elasticities of the model were obtained from the software. McFadden's (1974) likelihood ratio index (LRI) also known as pseudo R, similar to the R in a convectional regression, was computed as:

lnL= log likelihood function, lnLo = log-likelihood computed with only the constant term.

RESULTS AND DISCUSSION

Descriptive statistics analysis

The descriptive statistics analysis result as detailed in Table 2 indicated that majority (50.56%) of micro-credit beneficiary farmers were between the ages of 31 to 40. This is an indication that the bulk of the farmers are within the middle age group, which is in line with the finding of Ngaski et al. (2009) and Tanko et al. (2010). It is likely that this category of farmers will be more active and productive, which may in turn enhance the repayment of micro-credit received. A total of 65.6% of the respondents were married while 34.4% were single. This suggests that most of the respondents will likely make more responsible farm level decisions which may impact on loan repayment. The analysis further revealed that 42.78% of the respondents owned between 1.1 and 2.0 ha of land, which connotes that most of the beneficiaries of agricultural micro-credit under Minna Microfinance Bank are small-holder farmers. Only, 3% of the households covered, owned above 4 ha of land. The result also shows that 61.67% of the respondents do not belong to cooperatives or farmers' associations. This is an indication that most participants may not have enjoyed the benefits of group cohesion, dynamics, social capital and economic benefits which association participants stand to benefit. Majority (51.67%) of the respondents had a household size of between 6 and 10 family. The Nigerian setting is characterized by large household sizes; while large family sizes could be advantageous in the provision of farm labour. About 67% of the respondents had secondary education, while a negligible portion (1%) was not educated. The level of farmer's education may likely affect the management, utilization and repayment of credit, given that they would have acquired knowledge and capacity to better appreciate the reasons for proper loan management and repayment, all things being equal. The matrix further revealed that participation in the crop sub-sector overcrowded the other farming sub-sectors, given that 57.22% were involved in

Table 2. Distribution of respondents according to socio-economic characteristics.

Variables	Frequency	Percentage
Age		
21-30	33	18.3
31-40	91	50.6
41-50	54	30.0
> 50	2	1.1
Gender		
Male	100	55.6
Female	80	44.4
Marital status		
Married	118	65.6
Single	62	34.4
Farm size		
0.5-1.0	26	14.4
1.1-2.0	77	42.8
2.1-3.0	53	29.4
3.1-4.0	19	10.6
4.1 and above	5	2.8
Coop membership		
No	111	61.7
Yes	69	38.3
Household size		
1-5	79	43.9
6-10	93	51.7
11-15	6	3.3
16-20	1	0.6
21 & Above	1	0.6
Educational status		
None	2	1.1
Adult Education	13	7.2
Primary Education	14	7.8
Secondary Education	117	67.0
Post Sec. Education	34	18.9
Enterprise		
Crop production	103	57.22
Livestock	31	17.22
Fisheries	30	16.17
Mining	1	0.56
Manufacturing	16	8.83

Source: Field survey, 2014.

crop production. The ensuing development is an indication of the weak diversification base of the respondents, in view of the over-emphasis on the crop sub-sector (Table 2).

Table 3. Details of micro-credit requested, disbursed and repaid.

Variables	Frequency	Percentage
Micro-credit requested (N)		
50,000-100,000	127	70.6
100,001-150,000	27	15
150,001-200,000	17	9.4
200,001-250,000	7	3.9
Above-250,000	2	1.1
Micro-credit disbursed (N**)**		
Nil	18	10
50,000-100,000	113	62.8
100,001-150,000	23	12.8
150,001-200,000	17	9.4
200,001-250,000	7	3.9
Above 250,000	2	1.1
Repayment periods		
Nil	18	10
One Month	3	1.7
Two Months	21	11.7
Three Months	20	11.1
Six Months	61	33.9
Twelve Months	18	10
Yet to Repay	39	21.7
Repayments made		
Nil	18	10
50,000-100,000	84	46.7
100,0001-150,000	18	10
150,001-200,000	14	7.8
200,001-250,000	5	2.8
Above-250,000	2	1.1
Yet to Repay	39	21.7

Analysis of micro-credit requested, disbursed and repaid

The analysis of micro-credit received and repayment as detailed in Table 3 showed that 70.56% of the respondents requested for micro-credit volume ranging from ₦50,000 - ₦100,000, 15% applied for loan volumes of above ₦100, 000 - ₦150,000, while only 1.0% requested ₦250,000 and above (Table 2). Of the total who applied for loan, 90% benefitted, comprising mainly 62.78% who received between ₦50,000 and ₦100,000. In terms of repayment, the analysis revealed that repayment increases with the volume of micro-credit received, as 100 and 82% of those who received ₦250,000, and ₦200,000 - ₦250,000 repaid compared to 74.34% of those who received between ₦50,000 and ₦100,000. In addition, over 70% repayment performance was recorded when the total beneficiaries who repaid (fully/partially) are placed against the number of beneficiaries. In terms of repayment periods, substantial numbers (33.89%) made repayment after six months 21.67% are yet to pay while 10% are yet to receive funds. The result is close to the outcome of the study on micro credit repayment among women in Tanzania by Tundui and Tundui (2013) which reported loan repayment difficulties among 19.6% of borrowers. The implication of this result is that most beneficiaries are still limited to small loan volumes which may not be able to entirely cover their enterprise scale.

Determinants of micro-credit repayments among beneficiaries

Table 4 shows the determinants of micro-credit repayment status among beneficiaries of Minna Micro-

Table 4. Estimated Output of Multinomial Logit Model for Determinants of Micro-credit Repayment among Beneficiaries of Minna Micro-finance Bank.

Variables	Micro-credit beneficiaries that partially repaid (Group 1)	Micro-credit beneficiaries that have not repaid (Group 2)	Micro-credit beneficiaries that have fully repaid (Reference Group 3)
Age (Years)	-0.0517	0.5601	0.6118
	(-1.54)	(1.17)	
Sex(Male=1; Female=0)	-0.0223	16.3348	16.3571
	(-0.09)	(2.48)**	
Household Size (No)	0.0472	0.7774	0.7302
	(0.79)	(1.4)	
Farm size (Ha)	0.2106	-12.69	-12.9006
	(1.12)	(-3.83)***	
Distance to Bank (Km)	0.1125	0.1163	0.0038
	(0.64)	(0.11)	
Membership of Coop (Nos.)	0.0608	45.0925	45.0317
	(0.17)	(4.09)***	
Loans granted (Naira)	9.48E-06	0.0001	9.05E-05
	(2.42)**	(2.23)**	
Duration of payment (Months)	-0.0383	1.5857	1.624
	(-0.49)	(3.67)***	
Visits by Bank Officials (No)	0.029	-3.7308	-3.7598
	(0.34)	(-3.43)***	
Constant	-0.2341	-79.0797	
	(-0.18)	(-2.19)**	
No of Observation =173			
Log likelihood =-114.837			
LR Chi-Sq =124.95			
Prob >Chi-sq = 0.0000			
Pseudo R-Squared = 0.1270			

*** = Significant at 1% level of probability; **= Significant at 5% level of probability, Figures in parenthesis are the z values.

finance Bank. The results reveal that sex, membership of cooperative, loans granted and duration of micro-credit repayment are positive and significantly associated with the classification of the two groups (partial payment and non-payment groups) relative to the reference group. The positive sign implies that the probability of a beneficiary belonging to the non-repayment group relative to the full repayment group increases with respondents' sex, membership of cooperative, amount of loans granted and duration of micro-credit repayment, suggesting that these are key variables which should be considered in micro-credit interventions. For the positive significant parameter of loans granted under the partially repayment group, it also implies that the probability of beneficiaries belonging to the partial repayment group relative to the full repayment group increases with the loans granted. On the other hand, for variables like farm size and visits by bank officials with negative significant signs, it implies that the probability of a beneficiary belonging to the non-repayment group decreases with these variables. The result aligns with that of Adegbite (2005); Ajah et al. (2013); Dayanandan and Weldeselassie (2009) and Dadson (2012) who established that loan volume disbursed was a significant determinant of loan repayment among smallholder farmers. However, the results run contrary to that of by Tundui and Tundui (2013); Ugwumba and Omojola (2013) and Edeth et al. (2014) who found no relationship between loan size and loan repayment. The conflict arising from these studies, may likely be due to the peculiarity of the study locations and the type of loan under consideration. The outcome of the study confirms the null hypothesis of this study, given the significance of the loan granted.

Table 5 comprises values of the estimated marginal effects and the quasi-elasticities calculated for the significant variables in Table 4. Aside the partial elasticities of respondents' sex, membership of cooperatives and loans granted which were elastic under

Table 5. Marginal effects and quasi-elasticity estimates.

Variables	Micro-credit beneficiaries that partially repaid (Group 1)	Micro-credit beneficiaries that have not repaid (Group 2)	Micro-credit beneficiaries that have fully repaid (Reference Group)
Sex (Male=1; Female=2)	-0.0260	0.0571	-0.0043
	(-0.0503)	(3. 5809)	(-0.0064)
Farm Size (Ha)	0.0650	-0.0546	-0.0410
	(0. 3693)	(-10.7505)	(- 0.1951)
Members of Coop. (Yes =1; No = 0)	0.0001	0.1899	-0.0523
	(0. 0001)	(5. 9514)	(-0. 0445)
Loans Granted (Naira)	2.30E-06	2.36E-07	-2.04E-06
	(0. 5458)	(2. 0204)	(-0. 4486)
Visits by Bank Officials (No)	0.0043	-0.0126	-0.0042
	(0. 0277)	(-2. 7256)	(-0. 0221)
Duration of Re-payment (Months)	-0.00076	0.0025	0.0069
	(- 0.0905)	(0. 9868)	(0. 0627)

*Marginal effects are above while partial elasticities are in brackets, Source: Field Data Analysis, 2014.

Table 6. Challenges encountered in obtaining and repaying micro-credit.

Variables	Frequency	Percentage
Problem of Guarantor	74	41.11
Loan Repayment Period	97	53.89
Problem of Collateral	74	41.11
Interest Rate	99	55.00
Inability to Read & Write	54	30.00
Short Period of Loan Tenor	124	68.89
Total	**180**	**100**

Source: Field survey, (2014).

the non-repayment group, the partial elasticities under the other two groups were less than 1 and thus, inelastic. For the variables that were elastic, one percent change in these explanatory variables leads to a more than proportionate change in the probability of classification into the non-repayment group relative to the reference group. For the inelastic variables, the probability of classifying the farmers into any particular group is not greatly affected by marginal changes in these variables, as a one percent change in the variables leads to a less than proportionate change in the probability of classification into the two other groups relative to the reference group.

Challenges to micro-credit access and repayment among respondents

Table 4 shows that the distribution of beneficiaries according to the problems faced in accessing and repaying micro-credit. The results revealed that majority (68.89%) of the respondents indicated that the short period of loan tenor was a major obstacle in loan repayment, closely following were the high interest rate (55%) and loan repayment period (54%). The outcome of the result tallies with that of Ugwumba and Omojola (2013) who established that delay in disbursement, high interest rate and excessive bureaucracy were key issues hindering micro-credit repayment in Nigeria (Table 6).

CONCLUSIONS AND RECOMMENDATIONS

The study concluded that repayment performance among beneficiaries of Minna Microfinance Bank was considerable. Based on the outcome of the study therefore, there is the need for proper financial analysis of beneficiaries' enterprise needs with the view to effectively ascertaining the quantum of credit required. This has the two edge advantage of enhancing effective

enterprise implementation and allowing for prompt and full loan recovery and or repayment. Policy option requires that efforts be directed at complementing the resource pool of agricultural micro-credit with long term or idle funds, such as, the pension funds. This will guarantee or create room for reasonable duration for micro-credit repayment to the advantage of beneficiaries while not compromising the sustainability and revolving nature of the scheme. Basing interest rates on social and economic considerations will also go a long way in enhancing repayment among small-holder farmers. Encouraging cooperative participation and channeling micro-credits through this institution will enhance effective loan administration, monitoring and recovery.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Adegbite DA (2005). Quantitative Analysis of the Major Determinants of Loan Repayment under the Nigerian Agricultural Cooperative Bank Small Holders' Loan Scheme Ogun State, Nigeria. Asset Series A 5(1):1-12.

Ajah EA, Eyo EO, Abang SO (2013). Repayment Performance among Cassava and Yam Farmers under Nigerian Agricultural Bank Smallholder Loan Scheme in Cross River State, Nigeria. Brit. J. Econ. Manage. Trade 3(4):453-467.

Aku PS (1981). Problems in the Implementation of Agricultural Credit Guarantee Scheme Fund. A Case Study of Selected Credit Institutions in Kaduna State. An Unpublished M.Sc. Thesis, Department of Agricultural Economics, ABU, Zaria, Kaduna.

Awoke MU (2004). Factors Affecting Loan Acquisition and Repayment Pattern of Small-holder Farmers in Ika North East Delta State, Nigeria, J. Sustain. Trop. Agric. Res. 9:61-64.

Budry B, Curtis MJ, Dennis AS (2006). The Adoption and Management of Soil Conservation Practices in Haiti: the case of rock walls. Agric. Econ. Rev. 7(2):29-39.

Dadson AV (2012). Determinants of Loan Repayment Default among Farmers in Ghana. J. Develop. Agric. Econ. 4(13):339-345.

Dayanandan R, Weldeselassie H (2009). Determinants of Loan Repayment Performance among Small Farmers in Northern Ethiopia. J. Afr. Develop. Stud. 2:1.

Edeth BN, Atairet EA, Nkeme KK, Udoh ES (2014). Determinants of Loan Repayment: A study of Rural Women Fish Traders in Akwa-Ibom State, Nigeria. British J. Econ. Manage. Trade 4(4):541-550.

Hermes N, Lensink R (2011). Microfinance: its impact, outreach, and sustainability. World Dev. 39(6):875-881.

Nnanna OJ, Englama A, Odoko EO (2004). Finance, Investment and Growth in Nigeria, Central Bank of Nigeria Corporate Headquarters, Abuja, FCT.

Ngaski AA, Kamba AA, Senchi ID (2009). Impact of Fadama II Project "pilot asset acquisition scheme" on rural household income and poverty in Yauri Emirate of Kebbi State, Nigeria. Proceedings of the 23rd annual national conference of farm management association of Nigeria, pp. 695-703.

Ojo MA (2013). Analysis of Production Efficiency Among Small Scale Yam and Cassava Farmers in Niger and Kogi States, Nigeria. Unpublished P.hD Thesis Submitted to the Department of Agricultural Economics & Extension Technology, Federal University of Technology, Minna, Nigeria.

Olatunji RT (2004). Sources of Credit Facilities among Small Scale Farmers in Ilorin East Local Government Area of Kwara State: Unpublished B. Tech. (Agric.) Project. Department of Agricultural Economics and Extension Technology, Federal University of Technology, Minna.

Rahji MAY, Fakayode SB (2009). A Multinomial Logit Analysis of Agricultural Credit Rationing By Commercial Banks in Nigeria. Int. Res. J. Fin. Econ. 24:90-100.

Tanko L, Jirgi AJ, Ogundeji AA (2010) Impact of Fadama II Project on income of tomato farmers in Niger State, Nigeria. Afr. J. Agric. Res. 5(15):1937-1942.

Tundui C, Tundui H (2013). Microcredit, Micro Enterprising and Repayment Myth: The Case of Micro and Small Women Business Entrepreneurs in Tanzania. Am. J. Bus. Manage. 2(1):20-30.

Ugwumba COA, Omojola IT (2013). Determinants of Loan Repayment of Livestock Farmers under Agricultural Credit Guarantee Scheme (A.C.G.S.) in Etche Local Government area of Rivers State, Nigeria. Agricultural Advances. www.sjournals.com

Yamane T (1967). Statistics: An Introductory Analysis. (2nd ed.), New York: Harper and Row.

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Quality levels of organic coffee seedlings in black and white nonwoven fabric (NWF) containers of various sizes

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The introduction of organic production in coffee growing has demanded an increase for information on seedling production with standard of quality. Hence, the purpose of the present work was to evaluate how the amount of organic substrate in black and white nonwoven fabric (NWF) bags in four different sizes influences the quality index of *Coffea arabica* L. seedling produced in an organic system. The quality parameters evaluated were leaf area; number of leaves; plant height; collar diameter; dry matter of leaves, stalk, root and total. Whereas the parameters of quantity were the relation between shoot dry matter and root dry matter (RSR); the relation between shoot height and stem diameter (RHD) and the Dickson Quality Index (DQI). Seedlings produced in 1200 mL black containers presented the best results in most of the evaluated parameters. Seedlings produced in 410 mL containers presented Dickson Quality Index of 0.2, which is the index described by other authors as the adequate standard of quality for seedlings.

Key words: *Coffea arabica* L., Dickson quality index, Agropote®, organic composite.

INTRODUCTION

Brazil is the greatest grower, exporter and the second greatest consumer of coffee in the world (USDA, 2014). Coffee growing in Brazil has economic and social relevance. In 2013, Brazil exported around 32 million bags of coffee for U$5.27 billion, generating an estimate number of eight million jobs. Coffee cultivated area in the country is 2.311 million hectares with 6.69 billion coffee plants (CONAB, 2014; BRASIL, 2014).

In this context, coffee production without the use of chemical pesticides and fertilizers in Brazil – that is organic coffee – (Figueira and Lima-Filho, 2012) has increased each year (Della-Lucia et al., 2007), and it continues with high levels of increase (Caixeta and Pedini, 2002).

In order for the production chain of organic coffee to work properly, it is necessary that crops be healthy and economically viable. One of the basic items for the success of coffee crops is the use of good quality seedlings (Favarin et al., 2003). Villar-Salvador et al. (2004) state that the influence of this quality is

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determined by the growth rate of a specific genotype, which determines how adapted it is to the environmental conditions, at transplanting and stress resistance.

During production of organic seedlings, Ministry of Agriculture, Fishing and Supply (MAPA) Normative Instruction n. 007, of 17 May 1999, and Law 10831/03 determine that seeds and seedlings must come from organic systems and, in the absence of those, the grower may use products existing in the market as long as they have been previously evaluated by the certifying institution and do not include genetically modified organisms – GMO/transgenics (BRASIL, 1999; 2003).

However, due to the shortage of seeds and registered nurseries, the normative instruction still allows for the use of seeds and seedlings obtained from conventional growing methods (Moura et al., 2007), as long as the period necessary for the conversion of conventional to organic crop be waited. This way, the introduction of organic production in coffee growing demanded an increase for information on seedling production.

There are various factors that may influence the initial development of coffee growing in the field, such as the seedlings production process and, specially, the container and substrate used (Vallone et al., 2009). Amongst the containers used in conventional coffee seedling production in Brazil, one can first list black polyethylene bags and black hard plastic tubes (Vallone et al., 2010). Both types of containers present a few disadvantages, such as the contamination of the environment by the plastic bags when they are not properly discarded and, in the case of the tubes, the need for returning them to the nursery personnel.

Recently, growers started using bags made of white nonwoven fabric (NWF) called Agropote® as an alternative for the production of seedlings with standard of quality for they present favorable morphological and physiological characteristics responsible for the fast growth of seedlings.

The NWF is a material made from polypropylene and viscose based fabric (standard NBR-13370) (ABINT, 2013). Amongst its main characteristics are the facts that it is non-toxic and semipermeable, besides being classified as a biodegradable product due to be made with polypropylene in which the additive was added oxybiodegradable PDQ-H®, which degrade in a much shorter time than ordinary plastics. Its degradation time in the environment runs from six months to one year (ABINT, 2013).

Previous studies have been published by Matiello et al. (2008) and evaluated the formation and direct planting of coffee seedlings in NWF containers. Nasser et al. (2010) studied the development and quality of coffee seedlings (C*offea arabica* L.) produced in conventional plastic bacs, tubes and NWF bags.

Regarding the substrate, the most common mixture in the production of coffee seedlings using conventional polyethylene bags was formed by soil (70%) and cattle manure (30%), enriched with chemical fertilizers (Dias et al., 2009). Cunha et al. (2006) state that the substrate used must contain biological, physical, and chemical characteristics that fulfill the plant's needs. Besides, the individual cost of the seedling must be considered in relation to its final cost (Dias et al., 2009).

Figueira and Lima-Filho (2012) state that, in organic agriculture, chemical products are substituted by byproducts that come from recycled vegetal and animal organic materials. Hence, the use of cattle, sheep and poultry manure has the potential for composing substrates to be used when preparing coffee seedlings for they are one of the most common sources of essential micro and macronutrients needed for the good development of seedlings. In one of the first technical standards adopted for coffee growing, Souza (1996) already stated that the substrate used in the formation of seedlings should be composed of soil (50%) and manure (50%).

For the organic production of coffee seedlings, the requirements for organic growing imposed by MAPA must be fulfilled. Besides, preventive measures regarding the construction and maintenance of the nurseries must be adopted so that one can get healthy and good quality seedlings (Moura et al., 2005).

The objective of the present work was to evaluate how the volume of organic substrate in white and black NWF bags influence the development and quality index of *C. arabica* L. seedlings produced in an organic system.

The Dickson Quality Index (DQI) is considered a good indicator amongst the parameters of quality of seedlings, especially when it takes into account the robustness and the balance in the distribution of phytomass in the seedlings. Therefore, the DQI results are important parameters to be used when evaluating the quality of seedlings (Fonseca et al., 2002).

MATERIALS AND METHODS

The experiment was carried out from December 2012 to June 2013, in the seedling production sector in the Agrarian Sciences Center at the State University of Londrina (UEL), in Londrina-PR. The region is located at 23° 23'S latitude, 51° 11'W longitude and altitude of 566 m. According to the classification of Köppen, the environment is humid subtropical (Cfa).

Pre-sowing was carried out in December 2012 with seedlings of cultivar 'Iapar 98' at the cotyledonary-leaf stage, known as '*orelha-de-onça'* (ear of Brazilian jaguar), which had been sown in sand beds. The seedlings were placed in raised beds in a nursery covered with shade cloths with shade percentage of 50% and equipped with an automated irrigation system of micro sprinklers of flow rate of 75 L h-1 that were run six times a day for 10 min.

The containers were made with NWF of two colors: 1) black and 2) white; of four different sizes: T1) 8 cm x 15 cm (220 mL); T2) 10 cm x 18 cm (410 mL); T3) 12 cm x 21 cm (750 mL) and T4) 14 cm x 24 cm (1200 mL). The substrate used was a mixture of 50% soil a+ 50% organic composite (mixture of cattle, poultry and sheep manure), both taken from the Farm School of UEL. Soil testing is shown in Table 1.

The experimental design was completely randomized in a factorial scheme with four sizes of NWF bags in two colors, with 4 repetitions and 30 plants per plot. Seedlings growth and quality

Table 1. Soil analysis and the organic compound. Londrina, 2013.

Parameter	Soil	Organic composite
P (mg/dm^{-3})	1,87	847,85
K (cmol$_c$ dm^{-3})	0,09	10,98
Ca (cmol$_c$ dm^{-3})	3,80	16,49
Mg (cmol$_c$ dm^{-3})	1,32	4,48
Ca/Mg (cmol$_c$ dm^{-3})	5,12	20,97
Al (cmol$_c$ dm^{-3})	0,05	0
C (g/kg^{-1})	0,54	5,22
OM (g/kg^{-1})	0,94	9,00
BS (cmol$_c$ dm^{-3})	5,21	31,95
CEC (cmol$_c$ dm^{-3})	9,82	34,49
PBS %	53,05	92,63
pH CaCl	5,00	7,10
pH SMP	4,61	2,54
pH	5,30	7,10

OM = organic matter; BS = base saturation; CEC = cation exchange capacity; V = percentage base saturation; pH SMP = potential acidity.

$$DQI = \frac{TDM(g)}{\frac{HGT(cm)}{DIAM(mm)} + \frac{ShootDM(g)}{RootDM(g)}}$$

Figure 1. Dickson Quality Index Formula (DQI).

evaluations started 94 days after transplanting (DAT). The following characteristics were determined: leaf area (LA) expressed in cm^2, estimated with leaf area measurer LI-COR model LI 3000; b) number of leaves (NL); c) shoot height (HGT), expressed in cm, measured with a millimetric ruler, from the collar to the terminal bud; d) collar diameter (DIAM), expressed in mm, measured using a 0.01 mm precision digital caliper; e) leaves dry mass (LDM), stalk dry mass (SDM) and roots dry mass (RDM), expressed in grams, determined inside a greenhouse with forced air circulation at 75°C; f) total dry mass (TDM), expressed in grams, obtained by the sum of the dry masses of leaves, stalk and root; g) relation between shoot dry matter and root dry matter (RSR); h) relation between shoot height and stem diameter (RHD); i) Dickson Quality Index (DQI)(Figure 1), obtained through the formula of Figure 2 (Dickson et al., 1960).

The data was subject to analysis of variance by the F test and the averages were compared by the Tukey range test at 5% probability. For evaluated characteristics in each category of container color and volume, polynomial models were tested for the effect of time in days after transplanting (DAT) by means of regression analysis. The criteria for the choice of the model were the relevance by the F test at 5% probability of error that presented higher value of the coefficient of determination (R^2).

RESULTS AND DISCUSSION

The results of the analysis of variance regarding the evaluated parameters can be found in Table 2, where the relevant effect of volume and color of the containers can be observed in most of the evaluated characteristics.

Only RHD did not present relevant effect for the size of the NWF seedling heat mat, whereas for the color of the mats, parameters HGT, DIAM, RootDM, RHD and DQI did not present relevant effect. Hence, every other characteristic presented relevant interaction with the sizes and colors at 5% probability level by F test. Marana et al. (2008) when evaluating quality and growth index for coffee seedling in tubes also observed that RSR did not present relevant interaction amongst the studied substrates and doses of slow release fertilizers.

Table 3 presents the averages of the variables analyzed in seedlings considering the volume of the containers by the Tukey range test. Amongst all the evaluated characteristics, only RHD did not show relevant difference for the different volumes of NWF containers. The same was observed by Pereira et al. (2013) when RHD did not preset statistical difference on its numbers. The foresaid authors reached the average value of 7.36 for RHD and characterize such value as excessive growth for seedlings of coffee canephora in height. In the present work, RHD values vary from 6.21 to 6.46.

As a result, while observing the time in T, considering all variables in relation to the volumes of the containers, test F was carried out to determine the level of the equations. A positive linear effect was observed for characteristics DIAM and LDM, whereas for all other characteristics, the effect was quadratic positive (Figure 2 and Table 2).

The 1200 mL container presented the highest statistical difference for all characteristics, and only with DIAM, RoodDM and RSR there were no differences considering volumes 750 and 1200 mL (Tables 3, 4 and Figure 2).

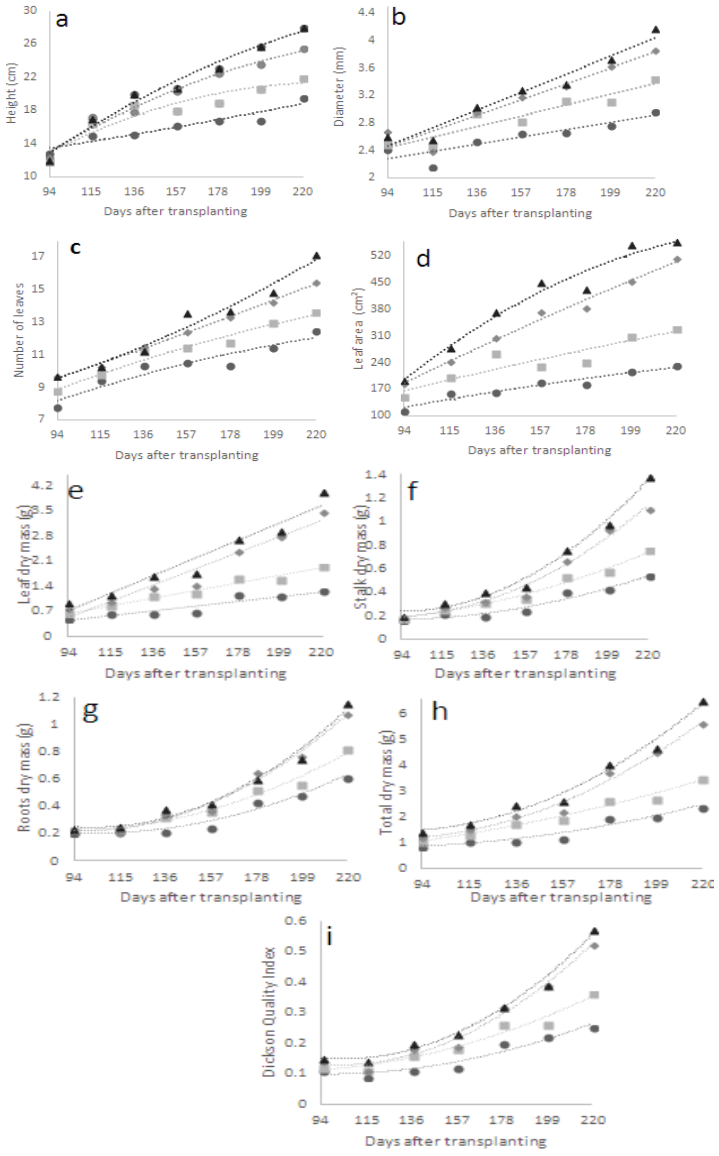

Figure 2. Variation of HGT (a), DIAM (b), NL(c), LA (d), LDM (e), SDM (f), RootDM (g), TDM (h) and DQI (i) of *C. arabica* L. seedlings considering the volumes of the NWF containers in the seven conducted evaluations. Key: ● 220 mL ■ 410 mL ◆ 750 mL ▲ 1200 mL, HGT: height; DIAM: collar diameter; NL: number of leaves; LA: leaf area; LDM: leaf dry mass; SDM: stalk dry mass; RDM: roots dry mass; TDM: total dry mass; DQI: Dickson Quality Index.

In general, all parameters showed an increase in values with the increase of the volume of the containers, the color being irrelevant. Vallone et al. (2010) evaluated different containers and substrates in the production of coffee seedlings and concluded that larger containers provide for more developed seedlings.

Gülcü et al. (2010) evaluated morphological characteristics, such as height, collar diameter, fresh and dry weight of shoot and root, and the shoot/root relations in seedlings of *Juniperus excelsa* Bieb. in polyethylene containers with variation in length and substrate composition. The best results indicated that the greater the length of the container, the better the quality of the seedlings. Therefore, the authors concluded that the best seedlings were produces in 11 cm x 30 cm containers, and the best substrate was formed by forest soil.

The quality of the seedlings is necessary for the success of cultures that demand a growing stage in nurseries. The influence of such quality has been studied considering the performance of such seedlings in the field

Table 2. Analysis of variance of variables HGT, DIAM, NL, LA, LDM, SDM, RootDM, TDM, RSR, RHD e DQI of *C. arabica* L. seedlings in NWF seedling heat mats (Londrina, 2013).

F test	DF	HGT (cm)	DIAM (mm)	NL	LA (cm²)	LDM (g)
V	3	**	**	**	**	**
C	1	NR	NR	**	**	**
T	7	(R^2=0.95)	(R^2=0.92)	(R^2=0.98)	(R^2=0.98)	(R^2=0.95)
VxC	3	NR	NR	NR	NR	NR
VxT	21	**	**	**	**	**
CxT	7	NR	*	NR	NR	*

Teste F	GL	SDM (g)	RootDM (g)	TDM (g)	RSR	HAD	DQI
V	3	**	**	**	**	NR	**
C	1	**	NR	**	**	NR	NR
T	7	(R^2=0.98)	(R^2=0.96)	(R^2=0.96)	(R^2=0.56)	(R^2=0.38)	(R^2=0.96)
VxC	3	NR	NR	NR	NR	NR	NR
VxT	21	**	**	**	NR	NR	**
CxT	7	*	NR	*	NR	NR	NR

** ($p<0.01$) e * ($p<0.05$), NR = non-relevant, V: volume; C: color; T: time; DF: degree of freedom; HGT: height; DIAM: collar diameter; NL: number of leaves; LA: leaf area; LDM: leaf dry mass; SDM: stalk dry mass; RDM: roots dry mass; TDM: total dry mass; RSR: relation between shoot dry matter and root dry matter; RHD: relation between shoot height and stem diameter; DQI: Dickson Quality Index.

Table 3. Averages of variables HGT, DIAM, NL, LA, LDM, SDM, RootDM, TDM, RSR, RHD e DQI of *C. arabica* L. seedlings in NWF seedling heat mats (Londrina, 2013).

Averages	HGT (cm)	DIAM (mm)	NL	LA (cm²)	LDM (g)
8 × 15 cm	16.02^d	2.59^c	10.30^d	178.10^d	0.84^d
10 × 18 cm	18.11^c	2.90^b	11.33^c	246.48^c	1.27^c
12 × 21 cm	19.96^b	3.14^a	12.40^b	349.60^b	1.88^b
14 × 24 cm	21.00^a	3.25^a	12.95^a	404.44^a	2.20^a
Black	18.93^a	3.00^a	11.90^a	301.62^a	1.64^a
White	18.63^a	2.94^a	11.59^b	287.69^b	1.45^b
CV (%)	6.70	8.01	7.82	10.54	20.60

Averages	SDM (g)	RootDM (g)	TDM (g)	RSR	RHD	DQI
8 × 15 cm	0.30^d	0.35^c	1.50^d	3.43^c	6.21^a	0.15^d
10 × 18 cm	0.41^c	0.43^b	2.12^c	4.17^b	6.24^a	0.20^c
12 × 21 cm	0.54^b	0.52^a	2.95^b	4.90^a	6.34^a	0.26^b
14 × 24 cm	0.64^a	0.54^a	3.39^a	5.39^a	6.46^a	0.28^a
Black	0.49^a	0.45^a	2.59^a	4.81^a	6.29^a	0.23^a
White	0.46^b	0.47^a	2.39^b	4.14^b	6.33^a	0.22^a
CV (%)	18.64	21.11	18.30	27.55	15.63	19.49

Averages followed by different letters in the same column differ from one another being relevant by the Tukey range test at 5%. CV: coefficient of variation; HGT: height; DIAM: collar diameter; NL: number of leaves; LA: leaf area; LDM: leaf dry mass; SDM: stalk dry mass; RDM: roots dry mass; TDM: total dry mass; RSR: relation between shoot dry matter and root dry matter; RHD: relation between shoot height and stem diameter; DQI: Dickson Quality Index.

and is a consequence of the time the seedlings have lived from nursery until planting (Del Campo; Navarro; Ceacero, 2010). In this context, the concept of 'target seedlings', which present a minimum standard of quality in order to be planted in the field, has been discussed and applied to the eucalyptus culture (Close, 2012). There is lack of studies applied to coffee seedlings, even though coffee growing presents high importance due to the fact it is a perennial culture.

In order to evaluate the DQI considering the size of the

Table 4. Equations of regression of the parameters studied in the quality of *C. arabica* L. seedlings in NWF seedling heat mats of different volumes, in relation to the evaluation periods (Londrina, 2013).

Parameter	Volume (mL)	Equations of regression	R^2
HGT	220	$y1 = -0.0004x^2 + 0.1803x + 9.3349$	0.9755
	410	$y2 = -0.0004x^2 + 0.1654x + 9.7113$	0.9705
	750	$y3 = -0.0004x^2 + 0.1329x + 10.433$	0.8881
	1200	$y4 = -5E\text{-}05x^2 + 0.0455x + 12.505$	0.876
DIAM	220	$y1 = 0.0106x + 2.2978$	0.9605
	410	$y2 = 0.0092x + 2.317$	0.9089
	750	$y3 = 0.0061x + 2.3509$	0.8637
	1200	$y4 = 0.0042x + 2.2152$	0.7839
NL	220	$y1 = -2E\text{-}05x^2 + 0.052x + 8.4309$	0.9523
	410	$y2 = -7E\text{-}05x^2 + 0.051x + 8.5003$	0.9889
	750	$y3 = -0.0001x^2 + 0.0517x + 7.8512$	0.9753
	1200	$y4 = -1E\text{-}04x^2 + 0.0445x + 7.3416$	0.8981
LA	220	$y1 = -0.0134x^2 + 4.9702x + 98.383$	0.9732
	410	$y2 = -0.0057x^2 + 3.2068x + 121.03$	0.987
	750	$y3 = -0.002x^2 + 1.4271x + 138.7$	0.859
	1200	$y4 = -0.0023x^2 + 1.1507x + 99.392$	0.9446
LDM	220	$y1 = 0.0197x + 0.4046$	0.946
	410	$y2 = 0.0182x + 0.2437$	0.9584
	750	$y3 = 0.0082x + 0.5378$	0.929
	1200	$y4 = 0.0054x + 0.3607$	0.8767
SDM	220	$y1 = 3E\text{-}05x^2 + 0.0011x + 0.18$	0.9763
	410	$y2 = 2E\text{-}05x^2 + 0.0019x + 0.1251$	0.9803
	750	$y3 = 6E\text{-}06x^2 + 0.0027x + 0.1178$	0.9607
	1200	$y4 = 8E\text{-}06x^2 + 0.001x + 0.1329$	0.9158
RootDM	220	$y1 = 3E\text{-}05x^2 + 0.0007x + 0.1785$	0.9598
	410	$y2 = 3E\text{-}05x^2 - 0.0003x + 0.231$	0.9585
	750	$y3 = 1E\text{-}05x^2 + 0.0011x + 0.1839$	0.9416
	1200	$y4 = 2E\text{-}05x^2 - 1E\text{-}17x + 0.19$	0.9333
TDM	220	$y1 = 0.0001x^2 + 0.0124x + 1.1044$	0.9623
	410	$y2 = 9E\text{-}05x^2 + 0.0133x + 0.8074$	0.9708
	750	$y3 = -3E\text{-}06x^2 + 0.0164x + 0.6816$	0.9491
	1200	$y4= 2E\text{-}05x^2 + 0.0068x + 0.67$	0.9027
DQI	220	$y1 = 2E\text{-}05x^2 - 0.0002x + 0.1419$	0.9636
	410	$y2 = 1E\text{-}05x^2 + 6E\text{-}05x + 0.1141$	0.9611
	750	$y3 = 4E\text{-}06x^2 + 0.0009x + 0.0877$	0.9193
	1200	$y4 = 4E\text{-}06x^2 + 0.0003x + 0.0862$	0.9028

HGT: height; DIAM: collar diameter; NL: number of leaves; LA: leaf area; LDM: leaf dry mass; SDM: stalk dry mass; RDM: roots dry mass; TDM: total dry mass; DQI: Dickson Quality Index.

NWF bags, the volume of 1200 mL, with greater dimensions (14 cm x 24 cm), was the one that presented the best result in relation to the index of value 0.28 (Table 3, Table 4 and Figure 2). Hunt (1990) recommended as DQI standard the minimum value of 0.20. Hence, it is interesting observing the seedlings that reached such value, with a substrate value of 410 mL.

Marana et al. (2008) reached DQI valuest hat vary

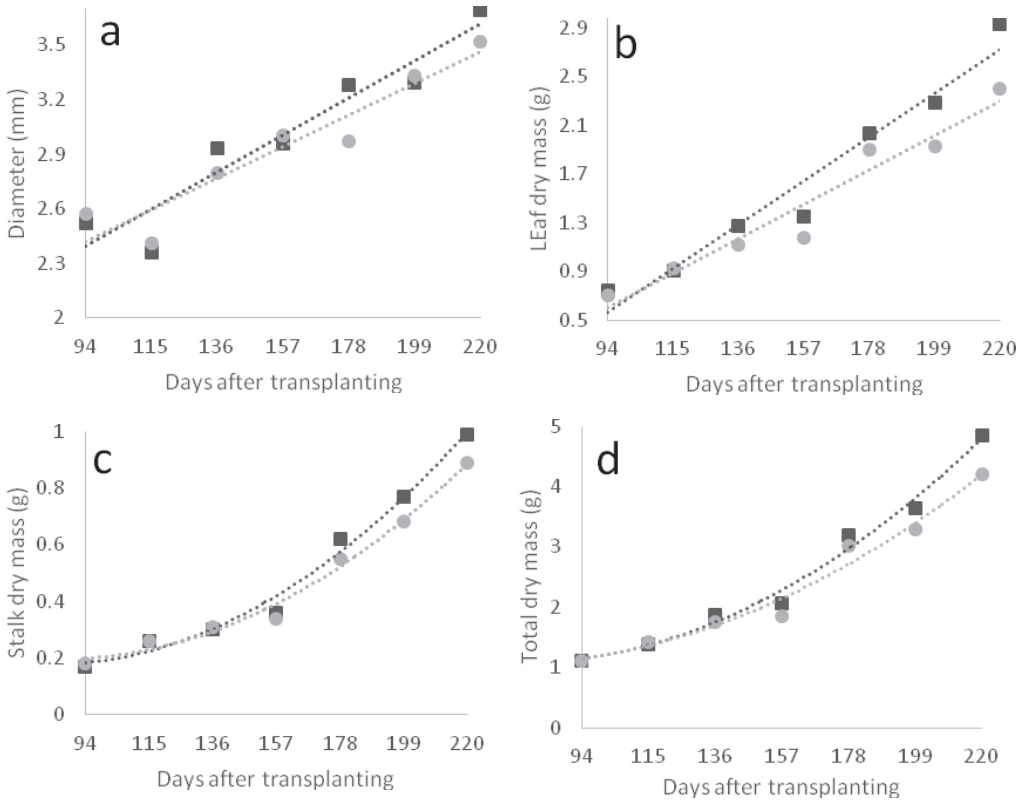

Figure 3. Variation of DIAM (a), LDM (b), SDM (c) and TDM (d) of *C. arabica* L. seedlings considering the colors of the NWF containers in the seven conducted evaluations. Key: ■ Black ● White, DIAM: collar diameter; LDM: leaf dry mass; SDM: stalk dry mass; TDM: total dry mass.

between 0.04 and 0.21 for coffee seedlings produced in tubes. Silva et al. (2012) when evaluating *Eucalyptus urophylla* × *Eucaliptus grandis* seedlings in relation to the substrates at 90 days after staking reached maximum values of DQI 0.19 with vermiculite and coconut fiber based substrate at the same proportion (1:1).

Pereira et al. (2013), when evaluating seedlings that came from four distinct nurseries located in the south of the capital of the state of Espírito Santo, reached DQI values that vary from 0.21 and 0.70. Whereas Binotto (2007), while studying the relations between growth variables and Dickson Quality Index in eucalyptus and pine seedlings reached DQI values of 0.5 for *E. grandis* 120 days after emergence and 0.25 for *Pinus elliotti* 175 days after emergence.

Regarding the colors of the NWF bags in Table 3 and Figure 3, it can be observed that black bags presented greater relevant differences for most of the parameters. Furuta (1960) was pioneer in studies relating the color of the containers with seedlings development. In his study, *Flex crenata rotundifolia* seedlings presented better results in light color containers.

For the interactions between the volume and color of the containers, none of the evaluated characteristics presented relevant effect (Table 2). For the interaction of the volume of the containers with the seven conducted evaluations, only RSR and RHD were not relevant, whereas all other characteristics presented relevant effect, demonstrating that the time factor (DAT) imposes differences to the growth of the plants in the different sizes of the bags. Regarding the interaction of the color with the seven conducted evaluations, only characteristics DIAM, LDM, SDM and TDM presented relevant effect. TDM values vary from 1.50 to 3.39. While Maranata et al. (2008) obtained values for the same parameter between 0.16 and 1.86; one can observe the superiority of the values obtained in seedlings produced in NWF seedling heat mats with organic substrate.

When analyzing the behavior of the functions in Graphs a and b in Figure 3 and Table 3, for the size of the containers, it can be observed that points for maximum growth were reached and correspondent to the evaluated days, which vary from 21 cm for HGT and 3.25 mm for DIAM. Such points did not influence the values for RHD so no relevant difference between the sizes existed. Binotto (2007) state that the variable height is only efficient to indicate the quality of seedlings when it is analyzed together with the collar of the diameter.

According to Graph b in Figure 3 and Table 5, it can be observed that the values for diameter at 115 DAT were

Table 5. Equations of regression of the parameters studied in the quality of *C. arabica* L. seedlings in NWF seedling heat mats of different colors, in relation to the evaluation periods (Londrina, 2013).

Parameter	Color	Equations of regression	R^2
DIAM	Black	y1 = 0.0081x + 2.277	0.8838
	White	y2 = 0.007x + 2.3098	0.9248
LDM	Black	y1 = 0.0145x + 0.3409	0.9624
	White	y2 = 0.0112x + 0.4398	0.9348
SDM	Black	$y1 = 2E\text{-}05x^2 + 0.002x + 0.1212$	0.9751
	White	$y2 = 2E\text{-}05x^2 + 0.0014x + 0.1515$	0.976
TDM	Black	$y1 = 7E\text{-}05x^2 + 0.0121x + 0.8109$	0.9674
	White	$y2 = 4E\text{-}05x^2 + 0.0122x + 0.8262$	0.9552

DIAM: collar diameter; LDM: leaf dry mass; SDM: stalk dry mass; TDM: total dry mass.

smaller, which can be explained due to the fact of the evaluation of the work be carried out in the destructive method, always evaluating different plants at each evaluated period. Because NWF is a material of easy degradation and presenting high porosity, at the first evaluation carried out (94 DAT), it was observed that the 220 mL and 410 mL containers already presented exposed small lateral roots.

At 157 DAT, black containers of all sizes presented exposed lateral roots, whereas this fact was not observed in white containers. In NWF 220 mL bags of both colors – black and white – intertwined roots were present amongst the bags. It was also observed the presence of *'pião-torto',* or the twisting of the main root of the coffee seedling when in contact with the bottom of the container in 220 mL and 410 mL bags.

At 199 DAT, it was observed that lateral roods in all sizes containers and independently of the color were very firm, hard and intertwined amongst the bags. At 220 DAT, only 1200 mL bags presented seedlings with the first pair of plagiotropic branches, due to its bigger volume and consequent providing the seedling with greater nutrient levels for its formation, therefore resulting in greater growth and stronger seedlings.

Due to the fact that coffee is a perennial culture, the production of healthy seedlings, well developed and with high standard of quality is a factor of extreme importance for coffee growing. Therefore, in the present work, it was observed that black 1200 mL NWF bags presented the best results for the evaluated parameters. It is important to highlight that coffee seedling in 410 mL containers presented the minimum value required by the DQI for good quality seedlings.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

ABINT-Associação Brasileira das Indústrias de Não tecidos e Tecidos Técnicos (2013). Nãotecidos. www.abint.org.br

BRASIL (1999). Ministério da Agricultura, Pecuária e do Abastecimento. Instrução Normativa n° 7, de 17 de maio de 1999.

BRASIL (2003). Ministério da Agricultura, Pecuária e do Abastecimento. Lei 10831 de 23 de Dezembro de 2003.

BRASIL (2014). Ministério da Agricultura Pecuária e do Abastecimento. http://www.agricultura.gov.br/vegetal/culturas/cafe/saiba-mais

Binotto AF (2007). Relationship between the growth variables and the Dickson quality index in seedlings of *Eucalyptus grandis* W. Hill ex Maid and *Pinus elliottii* var. elliotti - Engelm. Dissertação Universidade Federal de Santa Maria, Programa de Pós-Graduação em Engenharia Florestal, P. 54 f.

Caixeta IF, Pedini S (2002). Organic coffee marketing. Informe Agropecuário 23:149-152.

Close DC (2012). A review of ecophysiologically-based seedling specifications for temperate Australian eucalypt plantations. New For. 43:739-753. DOI 10.1007/s11056-012-9321-0

CONAB–Companhia Nacional De Abastecimento (2014). Acompanhamento de Safra Brasileira de Café. Safra 2014. Segundo Levantamento. Maio. 2014. ttp://www.conab.gov.br/olalacms/uploads/arquivos/14_05_20_08_49_17_boletim_maio-2014.pdf

Cunha AM, Cunha GM, Sarmento RA, Cunha GM, Amaral JFT (2006). Effect of various substrates on the development of seedlings of *Acacia* sp. Revista Árvore. 30:207-214. http://dx.doi.org/10.1590/S0100-67622006000200007

Della-Lucia SM, Minim VPR, Silva CHO, Minim LA (2007). Organic coffee packaging factors on consumer purchase intention. Food Sci. Technol. 27:485-491. http://dx.doi.org/10.1590/S0101-20612007000300010

Del Campo AD, Navarro RM, Ceacero CJ (2010). Seedling quality and field performance of commercial stocklots of containerized holm oak (*Quercus ilex*) in Mediterranean Spain: an approach for establishing a quality standard. New Forests. 39:19-37. DOI 10.1007/s11056-009-9152-9

Dias R, Melo B, Rufino MA, Silveira DL, Morais TP, Santana DG (2009). Sources and proportions of organic material for the production of coffee seedlings in plastic tubes. Ciênc. Agrotecnol. 33:758-764. http://dx.doi.org/10.1590/S1413-70542009000300014

Dickson A, Leaf A, Hosner JF (1960). Quality appraisal of white spruce and white pine seedling stock in nurseries. For. Chron. 36:10-13.

Favarin JL, Costa JD, Novembre ADC, Fazuoli LC, Favarin MGG (2003). Seed characteristics in relation to their physiological potential and the quality of coffee seedlings (*Coffea arabica* L.). Rev. Bras.

Sement. 25:13-19.http://dx.doi.org/10.1590/S0101-31222003000400003
Figueira TA, Lima-Filho DO (2012). Internationalization of family production of organic coffee of the Espírito Santo/ES. Rev. Ideas 6:83-107.
Fonseca ÉP, Valéri SV, Miglioranza É, Fonseca NAN, Couto L (2002). Quality standard seedlings of *Trema micrantha* (L.) Blume grown under different periods of shading. Rev. Árvore 26:515-523. http://dx.doi.org/10.1590/S0100-67622002000400015
Furuta T (1960). Site preparation and container type: Effects on growth of round-leavel Japanese holly. American nurserymen, 112:6-15. In: Foresty Abstracts (1961) 22:1770.
Gülcü S, Gültekin HC, Çelik S, Eser Y, Gürlevik N (2010). The Effects of different pot length and growing media on seedling quality of Crimean juniper (*Juniperus excelsa* Bieb.) Afr. J. Biotechnol. 9:2101-2107. http://www.ajol.info/index.php/ajb/article/view/78432/68790
Hunt GA (1990). Effect Of Styroblock Design And Cooper Treatment On Morphology Of Conifer Seedlings. In: Target Seedling Symposium, Meeting Of The Western Forest Nursery Associations, General Technical Report Rm-200, Roseburg. Proceedings. Fort Collins: United States Department of Agriculture, Forest Service, 1990, pp.218-222.
Marana JP, Miglioranza É, Fonseca, ÉP, Kainuma RH (2008). Quality Scores and growth of coffee seedlings grown in tubes. Ciência Rural. 38:39-45. http://dx.doi.org/10.1590/S0103-84782008000100007
Matiello JB, Garcia AL, Almeida PC, Andrade RJ, Ramos SV (2008). Training and direct planting coffee seedlings in containers Nonwoven Fabric. In: Congresso Brasileiro de Pesquisas Cafeeiras, 34, Caxambu, 2008. Anais...Caxambu: Mapa/Procafé, pp. 34-35.
Moura WM, Lima PC, Sano P, Condé A, Silva L, Silva T, Garcia Júnior E (2007). Methodology for organic production of coffee seedlings. Rev. Bras. Agroecol. 2:27-30. http://www.aba-agroecologia.org.br/revistas/index.php/rbagroecologia/article/viewFile/6705/4991
Moura WM, Lima PC, Souza HN, Cardoso IM, Mendonça ES, Pertel J (2005). Research on agro-ecological and organic systems of family coffee in the Zona Mata Mineira. Informe Agropecuário. 26:46-75.
Nasser MD, Lima-Júnior S, Gallo PB (2010). Quality of *Coffea arabica* L. seedlings produced in conventional plastic bags, tubes and nonwoven. Omnia Exatas 3:7-12. http://www.fai.com.br/portal/ojs/index.php/omniaexatas/article/view/65/pdf
Pereira LR, Marcilio GS, Mota FM, Sant'ana BT, Dardengo MCJD (2013). Qualidade de mudas do café Conilon Vitória produzidas em viveiros do sul capixaba. Enciclopédia Biosfera. 9:2213. http://conhecer.org.br/enciclop/2013b/CIENCIAS%20AGRARIAS/Qualidade%20de%20mudas.pdf
Silva RBG, Simões D, Silva MR (2012). Quality of clonal seedlings of *Eucalyptus urophylla* x *E. grandis* according to the substrate. Rev. Bras. Engenharia Agríc. Ambiental 16:297-302. http://dx.doi.org/10.1590/S1415-43662012000300010
Souza SP (1966). Cultura do café. Sete Lagoas: IPEACO, 32p. (Circular, 2).
USDA – United States Department of Agriculture (2014). Coffee: World Markets and Trade. June 2014. P. 5. http://apps.fas.usda.gov/psdonline/circulars/coffee.pdf
Vallone HS, Guimarães RJ, Mendes ANG, Souza CAS, Dias FP, Carvalho AM (2009). Containers and substrates in the production of seedlings and initial development of coffee after planting. Ciênc. Agrotecnol. 33:1327-1335. http://dx.doi.org/10.1590/S1413-70542009000500019
Vallone HS, Guimarães RJ, Mendes ANG, Souza CAS, Cunha RL, Dias FP (2010). Different containers and substrates in the production of coffee seedlings. Ciênc. Agrotecnol. 34:55-60. http://dx.doi.org/10.1590/S1413-70542010000100006
Villar-Salvador P, Planelles R, Enriquez E, Peñuelas-Rubira J (2004). Nursery cultivation regimes, plant functional attributes and field performance relationships in the Mediterranean oak *Quecus ilex* L. For. Ecol. Manage. 196:257-266. DOI: 10.1016/j.foreco.2004.02.061

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Dairy cow welfare assessment on Algerian farms

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This study is the first to use the Welfare Quality Assessment Protocol (WQ® AP) in Algerian farms, with all dimensions of welfare considered together. It aims at estimating the welfare level of dairy cows by identifying their positive and negative aspects in order to improve them and prioritize corrective action for their better sustainability. The observations were conducted in 100 dairy farms; scores were calculated for each farm, expressing the degree of conformity with 11 well-being criteria (absence of hunger, thirst, injury, illness, housing conditions, normal behavior). The results showed a level of well-being degraded with 95 farms classified as unacceptable, 4 farms as acceptable and only one as enhanced. The most degraded scores were related to eight criteria: Absence of prolonged hunger (22.8) and thirst (5.6), ease of movement (23.2), comfort around resting (40.7), absence of injury (37.6), absence of disease (31.9), expression of other behavior (12.6) and good human-animal relationship (34.3). The 95 farms classified as unacceptable are related to a high percentage of very lean cows (33.1%), a high frequency of mastitis (33.6%), lameness (33.8%), respiratory diseases associated with cough (15.6%) and a pronounced state of poor cleanliness on: udder (62.6%), hindquarter (60.6%) and hind limbs (60.6%).

Key words: Animal welfare, assessment protocol, dairy cow, sustainability, score.

INTRODUCTION

Issues relating to the animal, its status and its protection have become increasingly important over the past three decades, while the fate of animals was traditionally held or moved to a secondary concern. The ethical reflection on animal status and welfare was developed (Rollin, 1990; Marie, 2006) and protective rules were introduced in legislation. Institutions such as the European Union (EU), which in the Amsterdam Treaty identified animals as sensitive beings and provided to fully take into account welfare requirements, developed several guidelines covering various aspects of animal welfare (including Council Directive 98/58/EC of 20 July 1998 concerning the protection of farm animals).

The OIE, as the international reference organization for animal health, not only develops standards for the welfare of animals, but also accompanies several

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Abbreviations: WQ®AP, Welfare Quality Assessment Protocol; **OIE**, World Organization for Animal Health.

countries through its regional committees for the implementation of strategies for the welfare of animal. Other organizations, such as the United Nations Food and Agriculture Organization (FAO), the International Organization for Standardization (ISO), the International Organizations of Farmers, non-governmental organizations (NGOs), governments and multilateral organizations, accompany this movement. Finally, significant public funding is granted to research institutions that deal with the issue of animal welfare, not only from a fundamental point of view but also through assessment methods for agricultural holdings (Blokhuis et al., 2003).

However, these developments are far from being made by the countries of North Africa (Algeria), where reflection on animal welfare is far from being a priority given the socio-economic problems of a population of over 160 million inhabitants. The countries of this region are striving to meet the strategies of OIE in terms of animal welfare, specifically the improvement of livestock conditions, transportation and protection of animal health and preservation of public health. But it is clear that despite the undeniable efforts, there are still several factors that affect animal welfare. The majority of dairy farms are conducted in intensive mode, with the dominance of permanent tied system which is a constant source of mental (stress) and physical (illness, injury ...) suffering, altering productivity, health and welfare of livestock. These serious constraints influencing dairy farming greatly limit its development, specifically an unfavorable climate due to irregular rainfalls, lack of water resources, insufficient supply of feed resources and existence of very contrasting agro-ecological zones as well as the continued loss of agricultural real estate assets in favor of urbanization that may destroy the entire agricultural real estate heritage, thus jeopardizing wildlife heritage, animal assets and the country's food security. In this general context and in order to propose ways of improvement, it is necessary to identify strengths and weaknesses of these farming systems through a study analyzing in a comprehensive manner their level of animal welfare and to draw conclusions on actions to be taken.

In this respect, several evaluation methods on the farm were developed, some based on the animal environment, for example the Animal Needs Index (Bartussek et al., 2000) and others based on the animal, such as WQAP (2009a). The animal-based indicators are more important and better than those based on resources because they can measure the actual condition of animals regardless of how they are housed and managed (de Vries et al., 2011).

For this, the WQ®AP resulting from the WQ ® project (2009), which has shown its feasibility and reproducibility in many countries (13 European countries and 3 Latin American countries) and on different species (dairy cows, beef, pork and poultry) formed the basis of this study. Its multidimensional nature including both physical and mental health as well as various aspects such as physical comfort, absence of hunger, disease and possibility to express normal behavior (Veissier et al., 2010) can respond to many concerns about the welfare of farm animals.

In this general context and in order to propose ways of improvement, our aim is to apply and analyze the WQ® grid at 100 Algerian dairy farms to assess their actual level and identify their strengths and weaknesses for better sustainability.

MATERIALS AND METHODS

Sample study

The choice of the study sample was made from the list of cattle farmers in the province of Algiers (Northern Algeria) in 2011. This list contains 970 farmers with 12.746 cattle's with 6392 dairy cows (5632 modern and 735 between improved and local dairy cattle) (Agricultural Department of Algiers, 2011). This list contains only the ones selected according to production type (dairy cattle), farms, joining the national milk rehabilitation program (which requires the possession of health approval for enabling them to deliver their milk directly to a government processing unit or milk through a milk collector), the number of dairy cows (≥ 6) (minimum to have a health approval), the availability and cooperation of farmers to collect information. The number of dairy cows owned is a relevant selection criterion affecting in a decisive manner the behavior of farmers with respect to the management and use of new techniques such as mechanical milking etc.

We decided to visit 100 farms due to the limited number of observers (single observer) and the limited study period following the appointment schedule agreed with farmers, who voluntarily accepted to participate in the survey. The farms surveyed were chosen to reflect the diversity of dairy systems in Algeria.

Questionnaire

A survey guide was used as a questionnaire containing qualitative and quantitative variables informing about the status of animals (body condition score), farming practices (maintenance of drinking troughs and functioning, the degree of freedom of cows, access to pasture or exercise area), comfort (cleanliness, injuries, sleeping area,), their health status (diseases) and their behavior (positive and negative), depending on the WQ®AP (2009) for dairy cows.

Survey

The survey was conducted during 2011 over a period of 6 months (15th March to 15th September 2011) on 100 dairy farms with an average of 12.0 ± 7.9 cows / by farm, with a minimum of 6 cows by farm and a maximum of 53 having an average daily milk production of 16 L. These cows belonged to different breeds: Holstein (44.6%), Montbeliarde (34.3%), Fleckvieh (9.7%) and Brown Swiss (11.4%), with an average of 2 breeds per farm. The farms visited are conducted in permanent (53.0) or partial (47.0%) tied stall with access to outdoor loafing area (28.0%) or a pasture (19.0%) from spring to summer. The observations were conducted by the same observer and lasted one day per farm. Data collected on cows and on herd level (depending on type of measurement) started just after the morning milking, and ended in the afternoon.

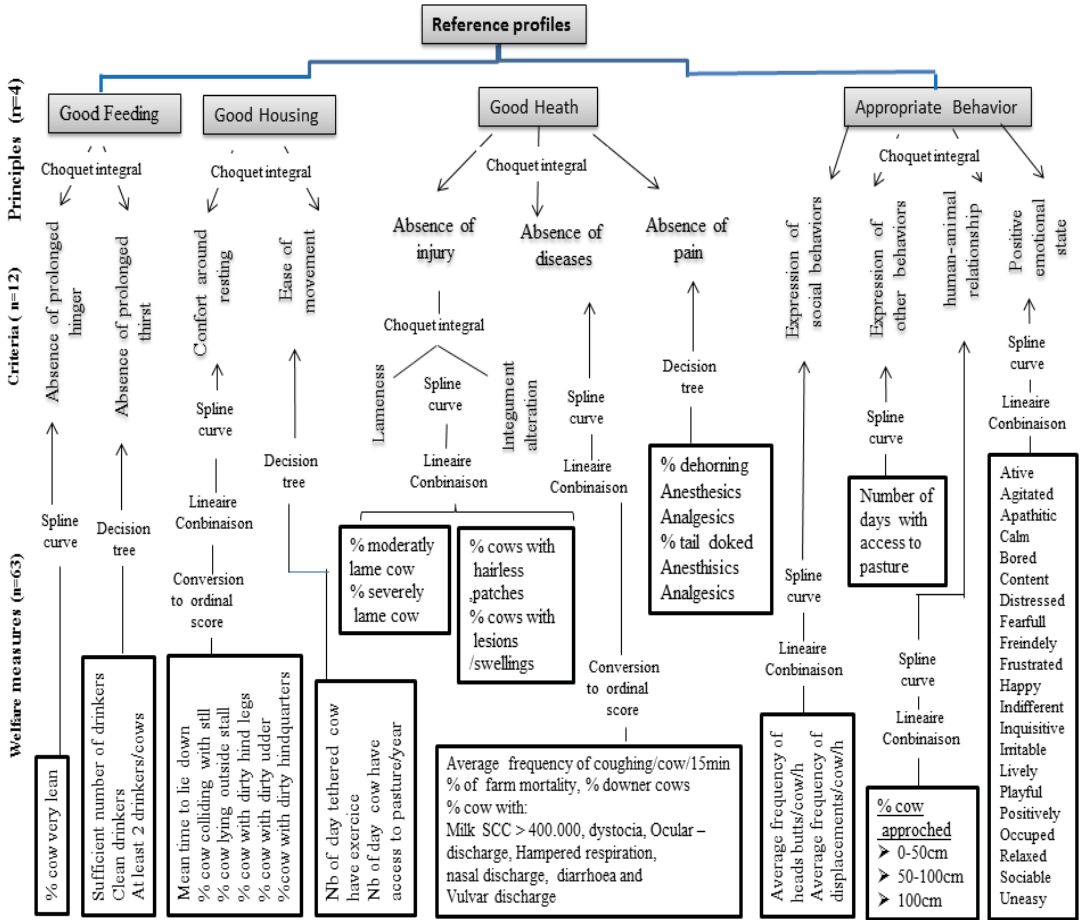

Figure 1. Welfare quality multicriteria evaluation model (Welfare Quality®, 2009).

Measurements and scoring

The data provided by the relevant measures were expressed on different scales and aggregated into 11 criteria. These 11 criteria were aggregated into 4 principles, and the 4 principles were aggregated into 1 classification.

Different types of algorithmic operators were used in this aggregation process: Decision tree, weighted sum, linear combination, conversion to ordinal score, least squares spline curve fitting, and Choquet integral (Figure 1). In the first step of the aggregation process, decision trees were used to aggregate categorical measures into 3 criteria (e.g. absence of prolonged thirst, ease of movement and absence of pain due to management procedures). A decision tree leads to several possible outcomes, each of which was attributed a criterion score (based on expert opinion). For other criteria, welfare measures were first combined into a weighted sum or converted to an ordinal score, for example, no problem, moderate problem, or severe problem. The numbers of moderate and severe problems were then combined into a weighted sum on a scale from 0 (worst) to 100 (best). Finally, cubic functions were then used to transform the weighted sum into the criterion score. In the second step, Choquet integral was used to aggregate the 12 criteria into 4 principles. This integral uses weights to combine the different criterion scores into one principle score (expressed on the 0-100 scale). These weights, therefore, depend on the values of criterion scores; whereas the sum of these weights equals 1 (values for weights were based on expert opinion). Finally, herds were assigned to 1 of 4 welfare classes: unacceptable, acceptable, enhanced, or excellent, based on reference profiles for the 4 principles (Botreau et al., 2009): to be classified as excellent, a herd must score >55 for each principle and >80 for 2 principles; to be classified as enhanced, each principle must be >20 and at least 2 principles must be >55; to be classified as acceptable, each principle must be >10 and at least 3 principles must be >20. Herds that did not comply with the minimum scores were classified as unacceptable (least 1 principle was ≤10 or at least 2 principles were ≤20). Detailed description of the use of algorithmic operators in the construction of criteria of WQ®AP can be found at: http://www.welfarequalitynetwork.net/network/45848/7/0/40.

Statistical analysis

Data processing was performed using Genstat Version 15.0 software (VSN International Ltd., UK), which was used to calculate descriptive statistics: The means and standard error of means for each score (quantitative variable) and the percentage or frequency of dairy cows (qualitative variable).

RESULTS

The implementation of WQ®AP on 100 Algerian dairy

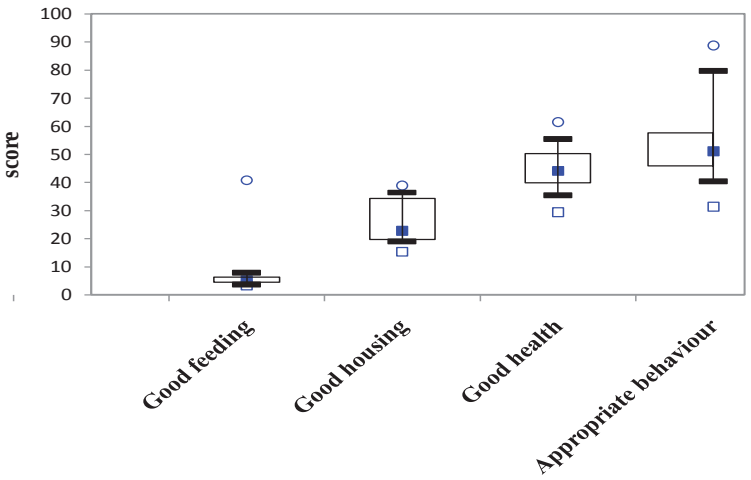

Figure 2. Box-plot representation of the scores of the 4 welfare principles for the 100 farms surveyed. □, mimimum; —, 1st decile; □□□□,1st quartile; □, median; □□□□ , 3rd quartile; —, 9th decile; □, maximum

farms revealed a deteriorated condition of well-being: Indeed, 95 farms were classified unacceptable, 4 as acceptable, one as improved and none as excellent (Figure 2). The 95 degraded farms classified as unacceptable were related to the weakness of eight criteria (Table 1). Absence of prolonged hunger assessed by the percentage of very lean cow estimated through the body condition score according to Edmonson et al. (1989) grid that uses scores of 0 to 5, showed that 81 farms contain very lean cows (BCS<2) with an average prevalence of 33.1% ranging from 5.8% to 51.9%. Absence of prolonged thirst measured by the number of drinkers by cow, their functioning and their cleanliness, showed that 5% of surveyed farms provided only one drinker per cow available at all times, or the drinkers were not clean, resulting in scores between 32 and 60. Conversely, 95.0% of farms did not provide enough drinkers and therefore scored 3. The criterion 'Comfort around resting', evaluated from 6 measurements: lying down time, lying down outside the lying down area, and cleanliness estimated at three body areas (legs, udder and hindquarter), according to alarm and alert thresholds obtained an average score of 40.8. This score showed that the majority of farms visited exceeded the alarm threshold for lying down time (6.3s) and cow cleanliness (which varies from 19.0 to 50.0% according to the part of the body).

The time taken by the cow to lie down

This is the length of the lying sequence: The duration of lying down begins when the animal bends the lower legs and ends when it brings out these lower legs under its abdomen. 41% of visited farms exceeded the alarm threshold and 39% of the alert threshold for the measure 'time taken by the cow to lie down'. Only 20.0% of farms recorded a time of normal sleep. In our study, the average time taken by cows to lie down is 5.9 s (min: 4.0 s and max 8.1 s).

For both measures

Cows lying outside the lying area and equipment collision to equipment, a small proportion of livestock have exceeded the alert threshold which is respectively 2 and 1%. Also, a low average frequency of collision and cows lying outside the supposed lying area setting was observed, which is respectively 3.0 and 2.9%.

Regarding the cleanliness of dairy cows, we noted a high prevalence of cows with dirty udder (62.6%), hindquarter (60.6%) and lower part of the hind limbs (60.6%). Consequently, a large number of farms exceeded alert thresholds for these measures: 100.0% for udders cleanliness, 86.0% for the hindquarter and 63.0% for the hind limbs.

Ease of movement determined in the WQ®AP by the type of housing (tied up or loose). Indeed, the protocol penalized farms conducted in tied up houses (score = 0), unless there is access to outdoor loafing area or pasture. In this case, the number of hours per day or days per year is considered; contrary to the free stall where the score is 100. In farms visited, 53.0% were all the time in tied up stalls (scored 15) against 47.0% in semi-tied up stalls: 28.0% have access in outdoor loafing area with a minimum of 6 hours per day (scored 32) against 19% in pasture (scored 34).

Absence of injuries

High percentages of moderately and severely lames

Table 1. Criterion scores on the 100 dairy farms studied.

Criterion	Farm score (Mean ± standard error)
Absence of prolonged hunger	22.8±10.9
Absence of prolonged thirst	5.5 ± 11.5
Comfort around resting	40.7±10.6
Ease of movement	23.2 ± 8.9
Absence of injuries	37.6 ± 9.8
Lameness*	37.3 ±13.2
Integument alterations*	40.8 ±13.7
Absence of diseases	31.9± 13.3
Absence of pain due to management procedures	100± 0
Expression of social behaviors	68.1± 8.5
Expression of other behaviors	12.6± 26.2
Good human-animal relationship	34.3± 9.2
Positive emotional state	85.5± 15.2

*Means partial score of criterion 'Absence of injuries'.

cows were respectively 18.2 and 15.6%, resulting in a partial score for lameness (37). The percentages of cows with mild and severe integument alterations were 46.6 and 22.9%, resulting in a partial score for integument alterations (40.8).

Absence of disease

Several symptoms highlighted an average percentage of cows with hampered respiration of 15.6% per farm and 0.0% of ocular discharge, nasal discharge and vulvar discharge. The average frequency of coughs was 1 per cow per hour. Farms archived an average prevalence of 33.6% cows with high somatic cell counts (>400 000 cell/ml at least once during the last 3 months), and 10.4% mortality, 2.3% dystocia, 3.6% diarrhea and 4.4% downer cow during previous years .

Expression of other behaviors assessed by accessibility of pasture (based on the number of days per year during which the cows had access to pasture for at least six hours), 19.0% of farms spent an average time of 170 days on pasture per year with an average time of 9 h per day.

Good human-animal relationship (evaluated through the avoidance test towards a foreign person, taking into account the distance at which cows could be approached), showed on average, 29.6% cows could be approached to 50 cm but not touched and 43.0% fleeing between 50 and 1 m, followed by 14.9% fleeing at 1 m. Only, 12.4% cows were touched.

Other welfare criteria used in the classification of farms as acceptable and improved in our study were: agonist interaction between cows (0.1/cow/h) associated to positive emotions (active, friendly, calm, relaxed, happy, and positively occupied,) and the total absence of use of painful methods (dehorning and tail docking) by farmers.

DISCUSSION

The absence of works on the well-being of dairy cows conducted by the WQ®AP in Algeria context led us to compare our results with others conducted in Europe. knowing that welfare problems observed in our surveyed farms, linked to the housing system and husbandry practices (food, health, behavior, comfort,…), have been described previously.

The 95.0% downgraded farms were related to the type of housing system, of which the most dominant in our study was the impeded permanent system (zero grazing), that provided a permanent source of mental (stress) and physical (illness, injury ...) distress, altering productivity, health and well-being of livestock. This fact was observed in American (half on tied up mode), Austrian, Italian, German (Botreau et al., 2009) and Dutch farms (de Vries et al., 2013). This type of housing is dominant in the majority of Algerian farms and is growing more and more with the continuous loss of agricultural land resources for the benefit of urbanization that could destroy the entire agricultural support and endangering wildlife heritage and national food security.

This confirms behavioral problems encountered in surveyed farms and reflects the lowest scores recorded by the criteria ' Ease of movement' (23.2), expression of other behavior '(12.6) and 'Good animal-human relationship' (34.3). Also, the results of the calculation of welfare scores showed that only 19.0% of surveyed farms practicing free grazing on limited periods of the year with less than 6 h per day compared to other farms were mostly hampered (53.0%). These are similar to Tucker et al. (2009), which recorded more than 50.0% of the tie-stall barns in England.

An intense condition of fear in visited farms was also observed overlooked a foreign person. This condition had

a negative impact on livestock productivity and farmers safety. Indeed, fear, whether sudden, intense or prolonged, seriously damaged welfare, productivity and meat quality (Rushen et al., 2007).

The scores for 'Absence of prolonged thirst' (5.5) were the lowest in almost all surveyed farms due to water supply that seemed insufficient in 5 farms, with one water point per cow and absence of water point in 95 farms. This implies that specific attention should be given to this criterion in the study context because water supply was rationed, did not meet the water requirements of dairy cows and induced a reduction in metabolism, food consumption, cow weight and milk production (Cardot et al., 2008). Boudon et al. (2013) showed that a slight under-watering reduced immediately production performance and efficient use of feed resources. It was estimated that 50.0% restriction on the amount of water consumed *ad libitum* by cows caused a loss of 5 kg/day of milk.

The scores for 'Absence of prolonged hunger' (22.8) were low in farms with a high percentage of very lean cows (33%).This percentage of lean cows was specially related to Holstein breed. Therefore, the frequent leanness of Holstein cows should rather be ascribed to their higher milk production that puts them at higher risk of nutritional deficit at least at the beginning of lactation, and difficulty to recover these reserves during critical periods (late of lactation or during the dry period). This percentage was much higher than that found by de Boyer des Roches (2012) in France (16.3%).

Regarding 'Comfort around resting', low scores were mostly related to the high percentage of cows with lying down time exceeding 6.3 s and to high frequency of dirt at different body area of surveyed cows: Udder (62.6%), hindquarter (60.6%) and hind limbs (60.6%). Consequently, a large number of farms exceeded alert thresholds for these measures: 100.0% for udders cleanliness, 86.0% for the hindquarter and 63.0% for hind limbs. These frequencies were much higher than those obtained respectively by Whay et al. (2003) and de Boyer des Roches (2012), related to the frequency of dirt found at udder (20.0, 22.2 and 26.5%) and hindquarters (17.7, 10.7 and 51.5%), while they were lower than those observed in hind limbs (80.4, 100.0 and 100.0%). This high percentage of dirty cows referred to a degraded environment of the animal, a slippery wet lying area, without litter or thick litter indicating poor health conditions.

The majority of visited farms exceeded the alarm threshold for lying down time (6,3s). This was due, on the one hand, to the mismatch between the sleeping area and the movement of sleeping cows and on the other hand to a high percentage of lame cows observed in surveyed farms. It was also noted an average time taken by cows to lie down: 5.9 s (min: 4.0 s and max 8.1 s). This is similar to that reported by de Boyer des Roches (2012) in France: 5.9 (min: 3.1 s, max: 10.7 s) and Brorkens et al (2009): 4.1s (min: 2.3s, max: 8.9 s) in mulched area.

By cons, the lowest percentage for both measures: cows lying outside the lying area (3.0%) and 'collision to equipment'(2.9%), were related to the fact that surveyed farms bump less with infrastructure (feeders, drinkers) in the absence of a separation between cows. These frequencies are similar to those of Brorkens et al. (2009) (1.8%).

The lower score 'absence of injury' was to the weakness of: Absence of lameness (37.3) and alteration of the integument (40.8). The scores 'Absence of lameness', ranged from 0 to 50% with an average frequency of severe lameness (15.8%) against (18.2%) moderate lameness. These were linked to a concrete floor, sliding without bedding and permanent containment of cows in 53 visited farms. These factors represented a constant source of pain and discomfort and thus constituted major damage to their well-being (Whay et al., 2003; Coignard et al., 2013).

The frequency of severe lameness in our study was similar to that of de Boyer des Roches (2012) in France (14.6%). Consequently, the variability of lame cows in our study (0.0 to 50.0%) was lower than that reported by Barker et al. (2010) (0.0 to 79.0%). This divergence was raised in the studies cited above, and reinforced by the work of WQ® (2009) researchers.

The scores of 'Alteration of integument' (40.8) were associated to the average frequency of severe (22.9) and moderate (46.6), ranged between (0-66.6%) for severe alterations and (0-100.0%) for moderate alterations. This percentage was mainly linked to repeated contact of cows with betone floor and prolonged lying of lame cows. Also, their permanent presence in livestock buildings increased the risk of injury. Our result was similar to that found by de Boyer des Roches (2012) in France (38.6) and confirmed the several works that showed that detection of injuries is a necessary practice for health monitoring of the herd.

The lowest scores 'Absence of diseases' (31.9), were more linked to reported cases of mortality (10.4%), to the frequency of respiratory diseases associated with cough (15.6%) and especially to mastitis (33.6%) with high somatic cell counts (>400 000 cell/ml at least once during the last 3 months. This high percentage of mastitis was explained in part, by the almost complete use of mechanical processes and second, by the lack of maintenance and hygiene of milking equipment and the lack of use of cloths for each individual cow. Our percentage was similar to that found by Saidi et al. (2013) in Algeria (29.6%) but was higher than those found by de Boyer des Roches (2012) in France for mastitis cases (20.4%).

The percentage of respiratory diseases was related to the high number of farms that did not meet the standards (dark, current of air and moisture). While, the reported cases of mortality (10.4%), were motivated by: pelvic fractures, dystocia calving and septicemia. This percentage was higher than that found by de Boyer des

Roches (2012) in France (3.2%).

Other pathologies were identified such as diarrhea problems (3.6%), dystocia (2.3%) and cow lying syndrome (4.4%). These high prevalences showed the poor health condition of visited farms, the dominance of certain diseases that referred to the disparity in breeding lines.

The criteria that have contributed to the classification of farms in acceptable and moderate category were related to the average frequency (0.5) of others agonistics interactions displacement, chasing, fighting …). Our results were in accord with the opinion of Bouissou and Boissy (2005), which showed that when the group of animals is together for a long time, the proportion of interactions represented by agonistic interactions decreases and threats, leaks and spontaneous avoidance will express more.

Also, a large number of farms have expressed more positive emotions (active, friendly, calm, relaxed, happy) and fewer negative emotions (restless, anxious, apathetic, scared, frustrated, irritable and indifferent). These results refer to the degree of familiarity and sociability between cows of farms surveyed. By cons, no tail amputation practice was adopted in farms visited. Our results confirm those of de Boyer des Roches in France (2012).

In conclusion, The implementation of the WQ®AP for the first time in Algerian farms showed that cows were exposed to various welfare problems, the most crucial ones (in terms of severity and prevalence) being: Health disorders including diseases, injuries, poor resting comfort and power management. Housing of dairy cows needs improvement to enhance resting comfort and reduce cow injury and disease.

Another study should be conducted at different seasons of the year in order, firstly, to assess risk factors that are associated with the degradation of wellbeing of surveyed farms, and secondly, to bring changes to certain criterions measures such as 'Absence of prolonged thirst'. The latter requires improvements that reflect the real condition of the animals as physiological and blood parameters (hematocrit), in addition to the existing arrangements.

The results of this study support the feasibility and potential of this tool not only for assessment, but also consulting and decision making purposes.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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REFERENCES

Barker ZE, Leach KA, Whay HR, Bell NJ, Main DCJ (2010). Assessment of lameness prevalence and associated risk factors in dairy herds in England and Wales. J. Dairy Sci. 93:932–941. http://dx.doi.org/10.3168/jds.2009-2309

Bartussek H, Leeb CHM, Held S (2000). Animal Needs Index for Cattle: ANI35 L/200 cattle. Research Institute for Agriculture in Alpine Regions, BAL Gumpenstein, Irdning, Austria. Irdning, Austria.

Bouissou MF, Boissy A (2005). The social behaviour of cattle and its consequences on breeding. INRA Prod. An. 18:87–99.

Blokhuis HJ, Jones RB, Geers R, Miele M, Veissier I (2003). Measuring and Monitoring Animal Welfare: Transparency in the food product quality chain. Anim. Welfare 12:445–455.

Boudon A, Khelil Arfa H, Ménard H, Brunschwig JL, Faverdin P (2013). Les besoins en eau d'abreuvement des bovins laitiers: Déterminismes physiologiques et quantification. INRA Prod.Anim. 26:249-262.

Botreau R, Veissier I, Perny P (2009). Overall Assessment of Animal Welfare: Strategy adopted In Welfare Quality. An. Welfare 18:363–370.

Brorkens N, Plesch G, Laister S, Zucca D, Winckler C, Minero M, Knierim U (2009). Reliability testing concerning behavior around resting in cattle in dairy cows and beef bulls and veal calves. Welfare Quality® Reports No11. Cardiff University, UK, London.

Cardot VLE, Roux Y, Jurjanz S (2008). Drinking behavior of lactating dairy cows and prediction of their water intake. J. Dairy Sci. 91:257-2264.http://dx.doi.org/10.3168/jds.2007-0204

Coignard M, Guatteo R, Veissier I, de Boyer des Roches A, Mounier L, Lehébel A, Bareille N (2013). Description and factors of variation of the overall health score in French dairy Cattle herds using the Welfare Quality® Assessment Protocol. Prev. Vet. Med. 112:296-308.http://dx.doi.org/10.1016/j.prevetmed.2013.07.018

De Boyer des Roches A (2012). Atteintes au bien-être des vaches laitières: Etude épidémiologique. Thèse pour l'obtention de grade de docteur d'université en production animale. Université Blaise Pascal de Clermont Ferrand II (France).

De Vries M, Bokkers EAM, Dijkstra T, van Schaik G, de Boer IJM (2011). Invited review: associations between variables of routine herd data and dairy cattle welfare indicators. J. Dairy Sci. 94:3213–3228. http://dx.doi.org/10.3168/jds.2011-4169

De Vries M, Bokkers EAM, Van Schaik G, Botreau R, Engel B, Dijkstra T, De Boer IJM (2013). Evaluating Results of the Welfare Quality Multi-Criteria Evaluation Model for Classification of Dairy Cattle Welfare at the Herd Level. J. Dairy. Sci. 96:6264–6273. http://dx.doi.org/10.3168/jds.2012-6129

Edmonson AJ, Leach LD, Weaver LD, Farver T, Webster G (1989). A body condition scoring chart for Holstein dairy cows. J. Dairy. Sci. 72:68-78. http://dx.doi.org/10.3168/jds.S0022-0302(89)79081-0

Marie M (2006). Ethics: The new challenge for animal agriculture. Livest. Sci. 103:203-207.

Rollin BE (1990). Animal welfare, animal rights and agriculture. J. An. Sci. 68:3456-3461.

Rushen J, Haley DB, De Passille AMB (2007). Effect of softer flooring in tie stalls on resting behavior and leg injuries of lactating cows. J. Dairy. Sci. 90:3647–3651.http://dx.doi.org/10.3168/jds.2006-463

Saidi R, Khelef D, Kaidi R (2013). Bovine mastitis: Prevalence of bacterial pathogens and evaluation of early screening test. Afr. J. Microbiol. Res. 7:777-782.

Tucker CB, Weary DM, Von Keyserlingk MAG, Beauchemin KA (2009). Cow comfort in tie-stalls: increased depth of shavings or straw bedding increases lying time. J. Dairy. Sci. 92:2684–2690. http://dx.doi.org/10.3168/jds.2008-1926

Veissier I, Botreau R, Perny P (2010). Evaluation multicritère appliquée au bien-être des animaux en ferme ou à l'abattoir: difficultés et solutions du projet Welfare Quality®. INRA Prod. An. 23:269-284.

Whay HR, Main DCJ, Green LE, Webster AFJ (2003). Assessment of the welfare of dairy cattle using animal-based measurements: direct observations and investigation of farm records. Vet. Rec. 153:197–202. http://dx.doi.org/10.1136/vr.153.7.197

Welfare Quality (2009a). Welfare Quality Assessment Protocol for Cattle. Welfare Quality®

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Full Length Research Paper

Response of soil-surface dwelling invertebrates to alien invasive and indigenous plant cover in a sub-tropical Nature Reserve, Eastern Cape, South Africa

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The soil-surface dwelling invertebrate assemblage of four sites (habitat patches) in Luchaba Nature Reserve was assessed using pitfall traps. A total of 335 specimens in three phyla (Arthropoda, Annelida and Mollusca) were sampled. Of the nine arthropod orders recorded, four were identified to seven families and ten species while five orders and two phyla (Annelida and Mollusca) were separated into 15 morphospecies. The eucalypt site supported fewer taxa compared to indigenous acacia and grassland patches while the mixed alien patch attracted the highest numbers of invertebrate families, species and individuals. Although species composition across sites was not significantly different (P>0.05), specimen counts showed significant differences (P<0.05). The implications of these preliminary results suggest that habitat-patch level management for conserving action in the short term should consider eradicating the species-poor eucalypt stands from the reserve while replacing all alien plants in the reserve area with native flora in the medium to long term. Furthermore, widespread/abundant species that occurred in all four sites e.g. *Crematogaster* sp, *Pardosa crassipalpis* and *Pheidole* sp. and habitat-restricted taxa can be used as potential bio-indicators for assessing the conservation value of habitat patches in Luchaba Nature Reserve and other protected areas of the King Sabata Dalindyebo Municipality.

Key words: Soil-surface dwelling invertebrates, nature reserve, indigenous plants, alien invasive plants.

INTRODUCTION

Anthropogenic activities tend to accelerate the problem of alien invasions, which in turn affect agriculture, forestry and human health, resulting in biotic homogenization worldwide (Richardson and van Wilgen, 2004; Pimentel et al., 2005; Usio et al., 2009). Apart from the impact on human communities, invasive alien plants are responsible for the local extinction of many indigenous species in South Africa (Samways et al., 1996; Magoba and Samways, 2008), and regarded as the second major threat (after habitat destruction) to the biodiversity of any particular area (Richardson and van Wilgen, 2004; Macdonald et al., 2003; Olckers and Hulley, 1991).

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Theoretically, it is widely expected that invasive plants, simply by occupying a large amount of space, impose a significant impact on the native vegetation and their associated food webs (Gerber et al., 2008). Several studies suggest that invasive plant species generally harbour smaller herbivore assemblages than native plant species (Gerber et al., 2008; Mgobozi et al., 2008). Three theories expounded by Tallamy (2004) explain this scenario. The first one predicts that specialists herbivores should be unable to grow and reproduce on plants with which they share no evolutionary history, the second one predicts that the energy stored by alien plants is not available to indigenous specialist and thus unavailable to higher trophic levels that include the insects in their diets, and the third predicts that these plants may not be palatable to most native insects. Given that there is strong association between most arthropods and native vegetation or the microhabitat it creates (Mgobozi et al., 2008; Olckers and Hulley, 1991), any decrease, extinction or alteration of the physical characteristics of some native plant species or habitats after alien plant colonization may negatively impact on species-specific herbivores (Palmer et al., 2004; Pauchard and Alback, 2004).

Protected areas (nature reserves) in South Africa remain critically important refugia that provide high quality habitat patches for invertebrate biodiversity conservation even though challenges resulting from their size and number do arise (Clark and Samways, 1997). Moreover, most of the country's rich biodiversity lies outside of the approximately 6% of land area under protected area systems (Turpie, 2004; Blanchard and Holmes, 2008), with its native and semi-natural ecosystems also under increasing threats from alien plant invasions (Nel et al., 2004; Gorgens and van Wilgen, 2004; Olckers and Hulley, 1991). Healthy biological communities depend principally on interactions among small organisms (mostly invertebrates and microbes) (Hartley and Rogers, 2010). Over 4.7% of formally protected land in the Eastern Cape Province of South Africa is now biologically invaded, and this proportion is increasing (Masubelele et al., 2009; Foxcroft et al., 2011).

The topography of the Eastern Cape Province ranges in elevation from 0 to 1500 m a.s.l along a 200 km E-W transectin one latitude. The ecology of this area is influenced by montane climate and moist savannah vegetation type at higher elevations, and Afromontane forest with sub-tropical climate along the eastern and southern coasts of the province.

Reserves and non-formally protected areas/landscapes of the King Sabata Dalindyebo Municipality (KSDM) of the Eastern Cape fall within the Albany Centre of Endemism. Although these landscapes are increasingly under threat from local endemic plant extinctions resulting mainly from overgrazing, agriculture and alien plant invasions (Smith and Wilson, 2002), they are nevertheless growing in significance as elements of the matrix where indigenous biodiversity conservation action must be undertaken. However, little is known about the habitat-level impact of invasive alien and native plant cover on soil-surface dwelling invertebrates within protected areas of the municipality at a local spatial scale. The overall aim of this initial study therefore was to determine the response of invertebrates to various types of vegetation cover in Luchaba Nature Reserve(LNR) under the following specific objectives: i) identify the soil-surface-dwelling invertebrate assemblage of the reserve, ii) assess the ecological impact of invasive alien and indigenous plant cover on faunal species composition.

STUDY SITE

The study was carried out in Luchaba Nature Reserve (LNR) (460 ha) situated at 31°35'S, 28°45'E and 758 m a.s.l in the King Sabata Dalindyebo Municipality (KSDM) of the Eastern Cape Province of South Africa (Figure 1). This reserve is an un-proclaimed protected area on state land, managed as a nature reserve by the Operations Directorate of the Eastern Cape Parks Board (ECPB). Climate is characterised by mean winter and summer temperatures of 13 and 26°C respectively, with mean annual precipitation of 634 mm (DWAF, 2005). Natural forest in the reserve is made up of indigenous trees e.g. *Acacia karroo* (Hayne), *Acacia sieberiana* DC., *Acacia xanthophloea* B., *Erythrina caffra* Thunb. and *Zanthoxylumcapense* (Thunb.) Harv. (Moll, 1981; Palgraves, 2002). Common grass species are *Eragrostis curvula* (Schrad) Nees, *E. Plana* Nees, *E. racemosa* (Thumb.), *Paspalum dilatatum* Poir, *Themeda triandra* Forssk and *Pennisetum* Rich species while invasive alien plant species present in the reserve comprise of Eucalypt, black wattle, *Lantana camara* L., bugweed and inkberry. The geology of the reserve comprises predominatly of shales and sandstones of the Beaufort series of the Karoo system. These landforms are interlaced with dolerite dykes (Acocks, 1988).

METHODS

Sampling site design and description

Four sites (habitat patches) that varied in structural and compositional vegetation cover were selected a-priori from a 1500 m^2 land surface in the reserve. Each site measured 30 m^2 and was stratified into four sampling units (Sus), each Su measuring 5 m^2, separated from each other by about 10 m. Percentage estimates of total surface area of Su covered by dominant vegetation types were determined as follows.

(i) Eucalypt plantation (EU) patch with over 90% eucalypt tree cover
(ii) Mixed alien (MA) patch with about 60% cover of *Lantana camara* (L.), Black Wattle and Bug weed, and 30% cover of native herbaceous vegetation,
(iii) Indigenous acacia (IA)patch with about 90% indigenous acacia trees interspersed with indigenous herbaceous plants, sedges and grasses.

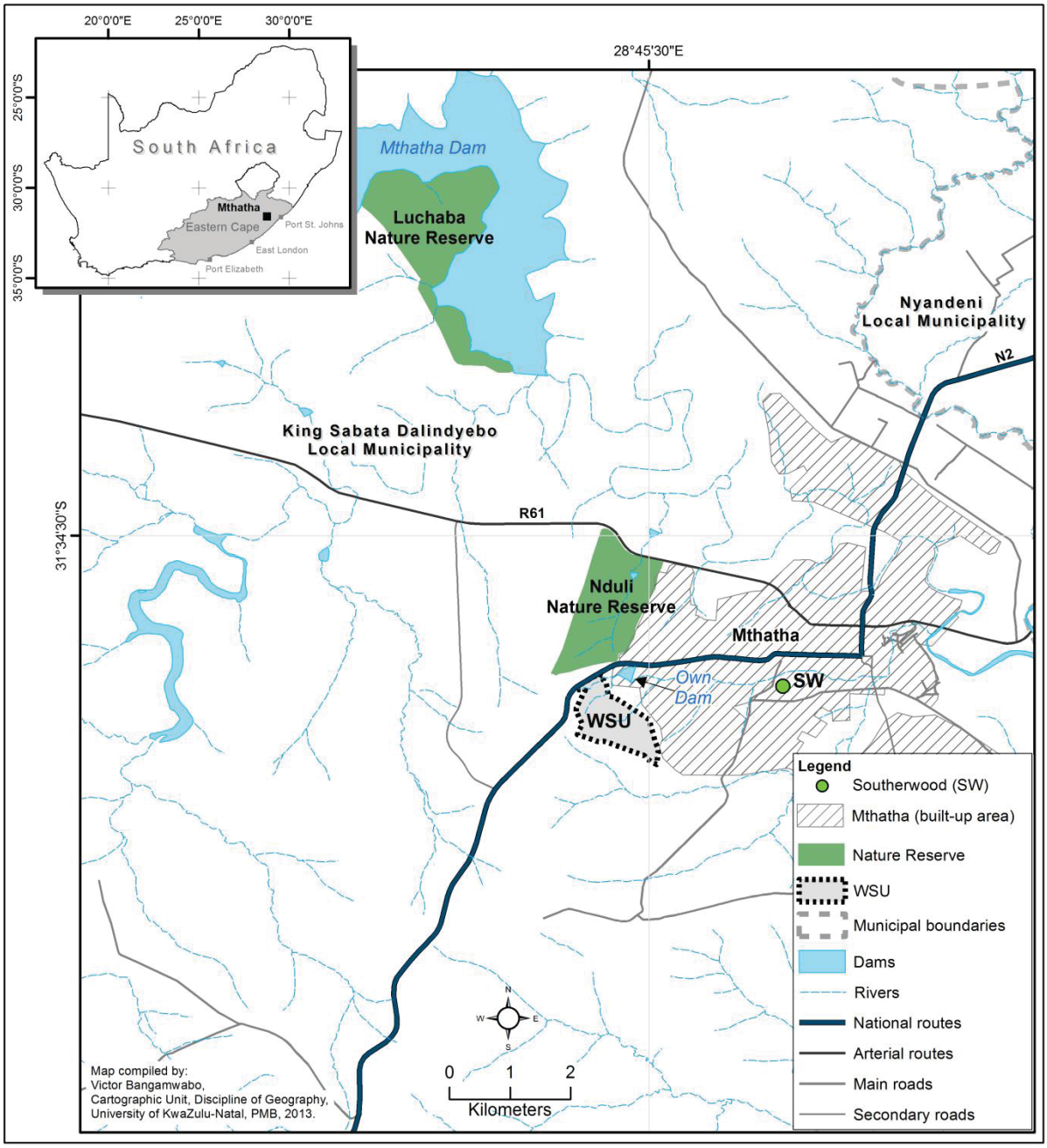


Figure 1. Study area in King Sabata Dalindyebo Municipality, Eastern Cape.

(iv) Indigenous grassland (IG) patch comprising of over 70% grasses, sedges and about 20% herbaceous vegetation cover.

Invertebrate sampling

Two pitfall traps were placed in each Su to capture invertebrate specimens. Traps consisted of 250 ml blue plastic cups with rim diameter of 75 mm and were sunk into the ground with rim openings maintained at the same level with the ground surface. The cups were three-quarter filled with a mixture of soapy detergent and water as a trapping medium, and were then left open in the ground for 24 h to capture soil-surface dwelling invertebrates. Specimens were collected from 32 traps during each of three sampling occasions making 96 records units in all. The sampling technique was according to Southwood and Henderson (2000), and designed to maintain sample independence as soil-surface dwelling invertebrate species are much less mobile or dispersive. Specimens were sorted from other flying arthropods in the traps, preserved in vials with 70% ethanol, and transported to the laboratory for preliminary identification. Specimens were identified using a Zeiss Stereo dissecting microscope Model STEMI DV4 and a field guide by Picker at al. (2004). Spider identities were confirmed by a taxon specialist at the Agricultural Research Council

(ARC) Plant Protection Research Institute (PPRI) in Pretoria, and thereafter using reference works by Dippenaar-Schoeman and Jocque (1997). Ants were identified at the Biosystematics Division of the Agricultural Research Council (ARC), Pretoria while other insects were identified using Carruthers (2008) and Picker et al. (2004). Unidentified (morphospecies) were coded, preserved in 70% alcohol for future identification by taxon specialists. Invertebrate specimen data was collected during species-rich summer months of April (weeks two and three) and May (week 1) in 2011.

Statistical analysis

Data sets were collated for each sampling unit (Su) and arranged in data matrices as proposed by Ludwig and Reynolds (1988) and Clarke and Gorley (2006). The statistical software programs DIVERSE and CLUSTER in PRIMER V6 (Clarke and Warwick, 2001) were used to determine indices of diversity and classification of species data respectively. Species-by-sample unit data matrices were 4^{th} root transformed to balance rarer and common species. The Bray-Curtis measure of similarity (Bray and Curtis, 1957) was then applied to the data to generate sampling unit similarity matrices that were fused successively using group average linking. Results describing patterns obtained using clusters were represented by a dendrogram. Species rank (k-dominance curves) for all four sites were calculated using the programme DOMPLOT (PRIMER V6). Curves extracted information on patterns of relative species abundances without reducing that information to a simple numeric diversity index (Lambshead et al., 1983; Clarke and Gorley, 2006). All invertebrate abundance data across sites was long-transformed to maintain normality and to satisfy the requirement for ANOVA.

RESULTS

Taxonomic profile of invertebrates sampled in Luchaba Nature Reserve

Even though flying arthropod species e.g. flies, wasps and butterflies were also collected in pitfall traps across habitat patches during the study period, these arthropod taxa were not included in the analysis as pitfall trapping was not the conventional method for sampling them. A total of 335 soil-surface dwelling invertebrate specimens in three phyla (Arthropoda, Annelida and Mollusca) were sampled. Of the nine arthropod orders sampled, four were identified to seven families and ten species while the remaining five orders and two phyla (Annelida and Mollusca) were separated into 15 morphospecies. Invertebrate species sampled across the four habitats showed varying degrees of richness and abundance patterns in response to habitat variables such as vegetation structure, composition and disturbance gradients associated with alien and indigenous cover. The highest number of invertebrate species and individuals were recorded at the mixed alien site while the Eucalypt site had the least number of specimen counts (Table 1, Figure 2). Species rank abundance (K-dominance) curves showed that the mixed alien site had a greater species evenness trend than the other three sites while the eucalypt patch had the highest species dominance with *Pardosa crassipalpis* and *Pheidole* spp having above 59% level of dominance (Figure 3a).

The dendrogram (Figure 3b) showed that the mixed alien and indigenous acacia sites had a high percentage similarity at above 80% in terms of species composition and distribution patterns. The orders with most abundant invertebrates individuals were the Araneae, and the Hymenoptera. There were no statistically significant differences ($P>0.05$) among habitat patches in terms of number of faunal species recorded. However, differences in total number of individuals (N) were significant ($P<0.05$). Also, there were statistically significant differences in abundance among sites for Araneae ($P<0.01$), suggesting that the population of this species-rich faunal group responded significantly to habitat patch heterogeneity. In addition to the Araneae, other non-insect arthropods sampled included morphospecies belonging to the orders Diplopoda, Opiliones, Isopoda and morphs of the phyla Annelida and Mollusca.

DISCUSSION

Epigaeic invertebrate distribution pattern across habitat patches

Species sampled across the four habitat patches showed varying degrees and patterns of response to habitat patch characteristics e.g. structure, composition and disturbance gradients associated with invasive and indigenous plant cover. Some groups of invertebrates were probably not affected and/or responded slowly to the presence of invasive vegetation than other groups. The phylum Arthropoda was the most diverse, dominated by ants and beetles while non-insect arthropods were represented by spiders, isopods and centipedes. The phylum Mollusca was represented by *Valloinia*sp. belonging to the family Valonidae while only two morpho-species of the Annelida were sampled. Even though there was no significant difference in number of species sampled across the four habitat patches, the eucalypt patch was more uniform in vegetation structure and composition, attracting the least number and abundance of invertebrate species. Faunal abundance at this site was highly attributed to the fact that a few species e.g. *Crematogaster* sp and *P. crassipalpis* were recorded in high numbers. The other patches were more heterogeneous in vegetation structure and complexity. This scenario probably accounted for greater habitat quality associated with faunal richness and abundance especially at the mixed alien patch.

Sensitivity of invertebrate taxa at sites and conservation implications

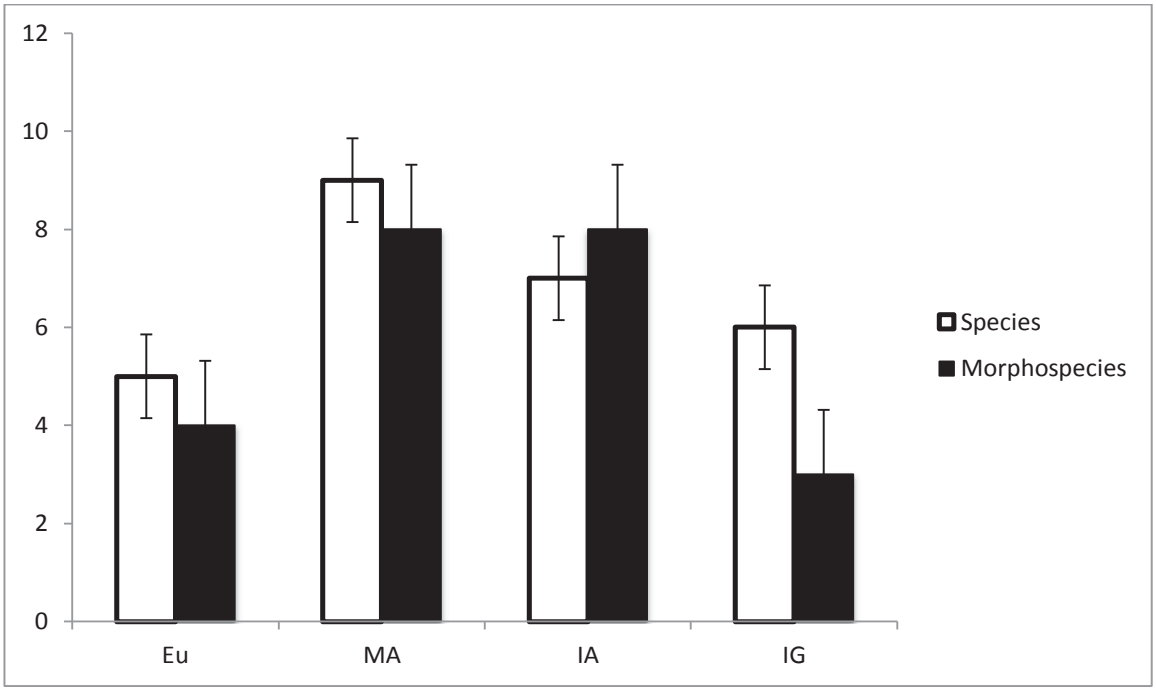
Morphospecies of the orders Diplopoda, Opiliones,

Table 1. Taxonomic profile of invertebrates sampled across Eucalypt (EU), Mixed Alien (MA), Indigenous Acacia (IA) and Indigenous Grassland (IG) sites in Luchaba Nature Reserve.

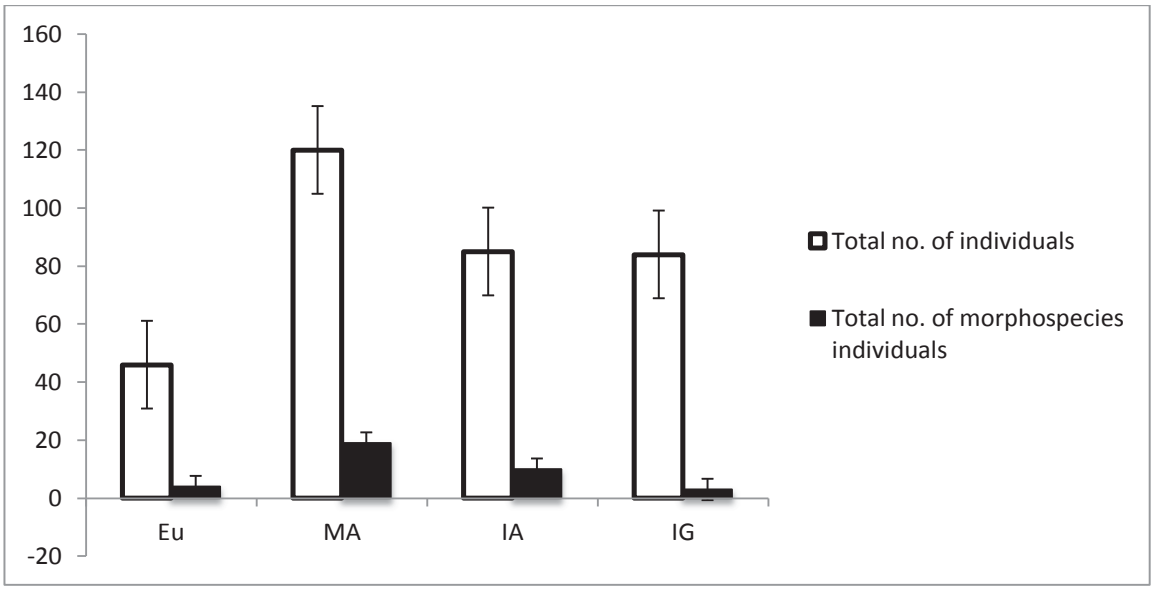
TAXON	Eu	MA	IA	IG	Total	P-value
ARANEAE						
Thomisidae						
Heriaeus crassispinus Lawrence, 1942	3	0	0	5		
Xysticus natalensis Lawrence 1938	0	4	0	0	**144**	**0.01^{s}**
Lycosidae						
Pardosa crassipalpis Purcell, 1903	10	17	10	40		
Hippasa australis Lawrence 1927	0	15	9	0		
Sub-total no. of individuals (n)	**13**	**36**	**19**	**46**		
HYMENOPTERA						
Formicidae						
Crematogaster sp.	7	26	3	5	**161**	**0.11^{ns}**
Pheidole sp.	20	30	40	20		
Sub-total no. of individuals (n)	**27**	**56**	**43**	**35**		
COLEOPTERA						
Carabidae						
Caminara sp.	0	4	4	0	**10**	
Scarabaidae						
Aphodius sp.	0	1	1	0		
Sub-total no. of individuals (n)	**1**	**4**	**5**	0		
DIPLOPODA	1 morph	7(2 morphs)	3morphs	0		
LEPIDOPTERA	0	5L* (2 morph)	2L	1 morph		
OPILIONES	0	0	1 morph	1 morph		
STYLOMMATOPHORA	0	0	0	1 morph		
ISOPODA	0	1 morph	2 (1 morph)	0		
ISOPTERA	0	2 (1 morph)	1 morph	0		
ANNELIDA	3 morphs	4 (2 morphs)	1 morph	0		
ORTHOPTERA						
Gryllidae						
Acanthogryllus fortipes Walker 1867	1	1	8	7		
Gryllotalpidae						
Gryllotalpa africana P.Beauvois	0	4	0	3		
Sub-total no. of individuals (n)	**1**	**5**	**8**	**10**	**24**	**0.10^{ns}**
Species (S)	**5**	**9**	**7**	**6**		**0.30^{ns}**
Total No. of individuals (N)	**46**	**121**	**85**	**84**		**0.01^{s}**
Margalef's (d) Index	**1.306**	**1.467**	**1.588**	**1.315**		
Shannon H' Index	1.098	1.421	1.394	1.179		
PielouJ' Index	0.6126	0.6835	0.6704	0.606		

ANOVA results are reported at P<0.05 % level of probability. S= Significant; ns= non-significant, *L = Larvae.

Isopoda, and the two phyla (Annelida and Mollusca) were sensitive to different habitat types, with the mixed alien and indigenous acacia habitats harbouring a majority of these taxa, and therefore capable of providing ideal and optimal habitat conditions for conserving them. The Coleoptera are known to utilize most trophic niches and comprise about 40% of all insect species (Stork, 1990; Desender et al., 1991; Koch et al., 2001). In this study,



(a)



(b)

Figure 2. Number of invertebrate species and morphospecies (a) and total number of individuals and morpho-species individuals (b) sampled at Eucalyptus (EU), Mixed Alien (MA), Indigenous Acacia (IA) and Indigenous Grassland (IG) site/habitat patches in Luchaba Nature Reserve.

the order was represented by the *Caminara* sp. (Carabidae) and *Aphodius* sp. (Scarabaeidae), and were found to be site-specific, occurring in low populations only at the mixed alien and indigenous vegetation patch. Spiders (Araneae) and ants (Formicidae) have also been used extensively for invertebrate biodiversity conservation assessments in South Africa due to their comparatively low dispersal abilities and therefore their great potential for use as indicators of habitat quality (Lovell et al., 2010; Muelelwa et al., 2010; Parr and Chown, 2001; Dippenaar-Schoeman and Craemer, 2000). Members of this group responded to habitat

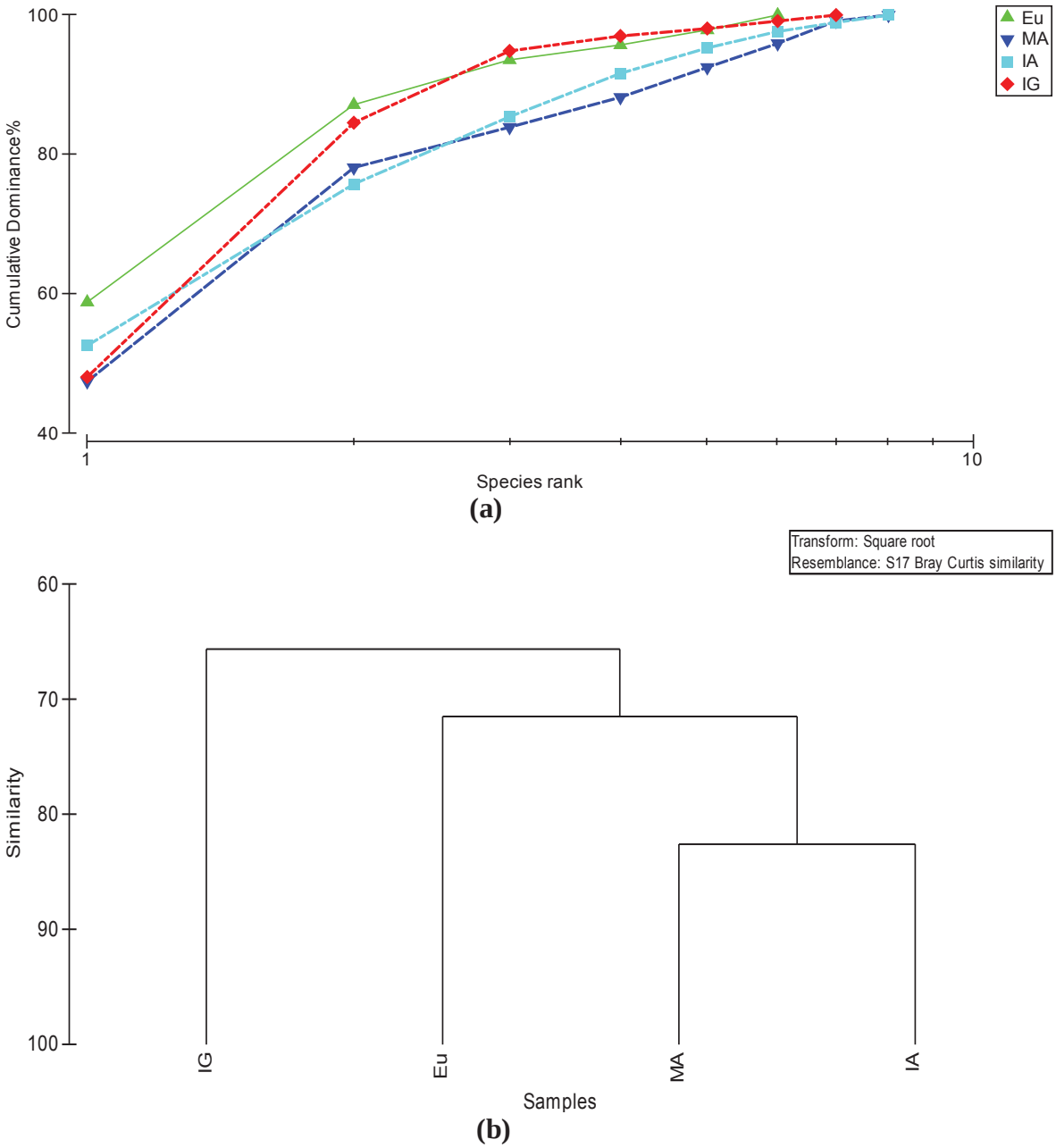


Figure 3. (a) Invertebrate species rank dominance curves for all four sites Eu: Eucalypt, MA: Mix alien, IA: Indigenous Acacia and IG: Indigenous Grassland). Species are ranked in decreasing order of their abundance from the most abundant to the rarest, (b) Dendrogram showing percentage similarity obtained using group-average linking from Bray-Curtis similarity matrices calculated on forth-root transformed invertebrate abundance data for all four sites.

conditions at varying degrees across sites e.g. *P. crassipalpis* was relatively abundant, occurring across all sites as potential habitat indicator species worthy of conservation as a common/widespread species in the reserve area while *Xysticus natalensis* was habitat-specific, and restricted to the mixed alien patch.

Even though maximum invertebrate species richness is not always reached at undisturbed sites, each group displays a specific pattern (Palmer et al., 2004). The mixed alien site attracted the highest number of invertebrate taxa sampled during the study, supporting the finding by Harris et al. (2004) that the impact of invasive plants on native biodiversity is not always negative. Furthermore, biodiversity estimators indicate that undisturbed habitats can be less diverse than invaded habitats (Palmer et al., 2004). The study clearly

showed that the indigenous acacia and indigenous grassland sites harboured comparable numbers of invertebrate taxa and specimen counts that were higher than that found in the eucalypt patch, but lower than counts made at the mixed alien patch. Widespread/abundant species that occurred throughout all four habitat patches e.g. *Crematogaster* sp, *P. crassipalpis* and *Pheidole* sp as well as habitat-restricted species e.g. *X. natalensis* (Table 1) can be used as potential indicators for assessing the conservation value of habitat patches in Luchaba Nature Reserve and other protected areas of the King Sabata Dalindyebo Municipality. However, more data on a broader spatial and temporal scale is needed to support species response patterns reported in this preliminary study, since responses of soil-surface dwelling invertebrate assemblages to invasive alien and native plant cover in the reserve may likely be species-specific.

Most invertebrate species were sampled in the mixed alien and indigenous acacia patches that showed a high level of ecological similarity (Figure 3b) suggesting that habitat patch level management for conservation action in the short term should consider eradicating the species-poor eucalypt stands from the reserve while replacing all alien plants in the reserve area with native flora in the medium to long term.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Acocks JPH (1988). Veld types of South Africa. Memoirs of the Botanical Survey of South Africa 57:1-146.

Blanchard R, Holmes PM (2008). Riparian vegetation recovery after invasive alien tree clearance in the Fynbos Biome. South Afr. J. Bot. 74:421-431.

Bray JR, Curtis JT (1957). An ordination of the upland forest communities of Southern Wisconsin. Ecol. Monogr. 27:325-349.

Carruthers V (2008). The wild life of Southern Africa. The larger illustrated guide to the animals and plants of the region. Struik Publishers, Cape Town.

Clarke KR, Gorley RN (2006). PRIMER V6:User Manual/Tutorial. PRIMER-E Ltd, Plymouth, U.K.

Clarke KR, Warwick RN (2001). Change in Marine Communities: An Approach to statistical Analysis and Interpretation, 2nd ed. Plymouth Marine Laboratory, UK: PRIMER-E LTD.

Desender K, Maelfait JP, Baert L (1991). Carabid beetles as ecological indicators in dune management (Coleoptera: Carabidae). El. Supplement 5:239-47.

Dippenaar-Schoeman AS, Craemer C (2000). The South African national Survey of Arachnida (SANSA). Plant Protect. News 56:11-12.

Dippenaar-Schoeman AS, Jocque R (1997). African spiders: an identification manual. Plant Protection Research Institute. Agricultural Research Council (ARC). Pretoria. Handbook 9.

DWAF (2005). A woodland strategy framework for the Department of Water Affairs and Forestry (DWAF), Pretoria.

Foxcroft LC, Jarosik V, Pysek P, Richardson DM, Rouget M (2011) Protected area boundaries as filters of plant invasions. Conserv. Biol. 25:400-405.

Gerber E, Krebs C, Murrell C, Moretti M, Rocklin R, Schaffner U (2008). Exotic invasive knotweeds (*Fallopia* spp.) negatively affect native plant and Invertebrate assemblages in European riparian habitats. Biol. Conserv. 141:646-654.

Gorgens AHM, Van Wilgen BW (2004). Invasive alien plants and water resources in South Africa: current understanding and predictive ability and research challenges. South Afr. J. Sci. 100:27-33.

Harris RJ, Toft RJ, Dugdale JS, William PA, Rees JS (2004).Insect assemblage in a native (*Kunzeaericoides*) and an invasive (*Ulexeuropaeus*) shrub land.New Zealand J. Ecol. 28:35-47.

Hartley MK, Rogers WE (2010). Comparison of arthropod assemblages on an invasive and native trees: abundance, diversity and damage. Arthropod-Plant Interact. 4:237-245.

Koch SO, Chown SL, Davis AIV, Endrody Y,Van Jaarsveld AS (2001). Conservation strategies for poorly surveyed taxa: a dung beetle (Coleoptera, Scarabaeidae) case study from Southern Africa. J. Insect Conserv. 4:45-56.

Lambshead PJD, Platt HM, Shaw KM (1983). The detection of differences among assemblages of marine benthic species based on an assessment of dominance and diversity. J. Nat. Hist. 17:859-874.

Lovell SJ, Hamer ML, Slotow RH, Herbert D (2010). Assessment of sampling approaches for multi-taxa invertebrate survey in a South African savanna-mosaicecosystem. Austral Ecol. 35:357-370.

Ludwig JA, Reynolds JF (1988). Statistical ecology: a primer on methods and computing. John Wiley & Sons, New York.

Macdonald IAW, Reaser JK, Bright C, Neville LE, Howard GW, Murphy SJ, Preston G (2003). Invasive alien species in Southern Africa. Global Invasive Species Programme. National Reports and Directory of Resources, Cape Town.

Magoba RN, Samways M (2008). Restoration Ecology: Restoration of Aquatic Macro invertebrate Assemblages through Large-scale Removal of Riparian Invasive Alien Trees. J. Insect Conserv. 14(6):627-636.

Masubelele ML, Foxcroft LC, Milton SJ (2009). Alien plant species list and distribution for Camedeboo National Park, Eastern Cape, South Africa. Koedoe 51:515-525.

Mgobozi MP, Somers, MJ, Dippenaar-Schoeman AS (2008). Spider responses to alien plant invasions: the effect of short- & long-term *Chromolaenaodorata* invasion and management. J. Appl. Ecol. 45:1189-1197.

Moll EJ (1981). Palgraves trees of Southern Africa. Struik Publications. Cape Town.

Muelelwa MI, Foord SH, Dippenaar-Schoeman AS, Stam EM (2010). Towards a standardized and optimized protocol for rapid assessments; spider species richness and assemblage composition in two savanna vegetation types. Afr. Zool. 45:273-290.

Nel JL, Richardson DM, Rouget M, Mgidi TN, Mdzeke N, Le Maitre DC, van Wilgen BW, Schonegevel L, Henderson L, Neser S (2004). A proposed classification of invasive alien plant species in South Africa: towards prioritizing species and areas for management action. S. Afr. J. Sci. 100:53-64.

Olckers T, Hulley PE (1991). Impoverished insect herbivore faunas on the exotic bugweed *Solanum mauritanium* Scop. Relative to indigenous solanum species in Natal/KwaZulu and the Transkei. J. Entomol. Soc. S. Afr. 54:39-50.

Palgraves KC (2002). Trees of Southern Africa Random House, Struik Publications.

Palmer M, Linde M, Pons GX (2004). Correlational patterns between

invertebrates composition and the presence of an invasive plant. ActaOecologica 26:219-226.
Parr CL, Chown SL (2001). Inventory and bioindicator sampling: Testing pitfall and Winkler methods with ants in a South African savanna. J. Insect Conserv. 5:27-36.
Pauchard A, Alback PB (2004). Influence of elevation, land use, and landscape context on patterns of alien plant invasions along roadsides in protected areas of South-Central Chile. Conserv. Biol. 18:238-248.
Picker M, Griffiths C, Weaving A (2004). Field guide to insects of South Africa. Struik Publishers.
Pimentel D, Zuniga R, Morrison D (2005). Update on the environmental economic costs associated with alien-invasive species. Ecol. Econ. 53:273-288.
Richardson DM, van Wilgen BW (2004). Invasive alien plants in South Africa: how well do we understand the ecological impacts? South Afr. J. Sci. 100:45-52.
Samways MJ, Caldwell PM, Osborne R (1996). Ground-living invertebrates assemblages in native, planted and invasive vegetation in South Africa. Agric. Ecosyst. Environ. 59:19-32.
Smith N, Wilson SL (2002). Changing land use trends in the Thicket Biome: Pastoralism to game farming, terrestrial Ecosystems Research Unit (TERU). Nelson Mandela Metropolitan University (NMMU), South Africa. Report No. 38.
Southwood TRE, Henderson PA (2000). Ecological methods. 3rd Edition Blackwell Science.
Stork NE (1990). The role of ground beetles in ecological and environmental studies. Andover, UK: Intercept.
Tallamy DW (2004). Do alien plants reduce insect biomass? Conserv. Biol. 18:1689-1692.
Turpie JK (2004). The role of resource economics in the control of invasive alien plants in South Africa. South Afr. J. Sci. 100:87-93.
Usio N, Kamiyama R, Saji A, Takamura N (2009). Size-dependent impacts of invasive alien crayfish on a littoral marsh community. Biol. Conserv. 142:1480-1490.

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Study of reproductive compatibility and morphological characterization of interspecific hybrids in *Sesamum* sp.

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In the present study, three wild species of sesame, *Sesamum alatum*, *Sesamum malabaricum* and *Sesamum radiatum* and one wild variety of *Sesamum indicum*, that is, *S. indicum* var. *yanamalaiensis* were crossed with eight cultivated varieties of *S. indicum* L. in both direct and reciprocal forms. All the wild species exhibited different degrees of cross compatibility with cultivated *S. indicum*. There was no crossed seed set in the direct and reciprocal crosses involving cultivars of *S. indicum* (2n = 26) with *S. radiatum* (2n = 64) and with *S. alatum* (2n = 26). The crosses involving *S. malabaricum* and *S. indicum* var. *yanamalaiensis* having the same chromosome number (2n = 26) as in the cultivated sesame genotypes were fairly successful in producing high percentage of crossed capsules with well filled seeds. The morphology of four wild species along with the cultivated species of sesame and the interspecific hybrids derived were compared. The wild species utilized in the present study differed significantly from the cultivated in branching pattern, leaf pubescence, flower size, color of corolla and anther, size, shape and color of extra floral nectary, capsule size, and shape, texture and size of the seed. All the successful interspecific hybrids showed predominance of wild characters than cultivated *S. indicum*.

Key words: Sesame, wild species, cross compatibility, morphological characterization.

INTRODUCTION

Sesame is known to be the most ancient oilseed crop dating back to 3050-3500 B.C. (Bedigian and Harlan, 1986) because of its ease of extraction, great stability, and drought resistance. It is also considered to be important because of its nutritional and antiaging features of high quality vegetable oil with oil content ranging from 50 to 60% (Chayjan, 2010). The sesame oil is highly resistant to oxidative deterioration due to the presence of antioxidants such as sesamin and sesamolin (Erbas et al., 2009) and also has high percentage of unsaturated

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fatty acids (Yermanos et al., 1972). Though sesame is having all these benefits, the productivity is limited due to low seed yield (Ashri 1989; Pham et al., 2010), frequent occurrence of diseases (El-Bramawy, 2006) and stress factors (Sarwar et al., 2007). Therefore, breeding efforts have mainly concentrated on increasing the seed yield of sesame. One of the important ways for increasing seed yield is utilization of diverse sources, especially the wild species for the exploitation of heterosis as well as to impart biotic and abiotic stress resistance. Hence an attempt was made to study the crossability between the four wild and cultivated species of sesame and to evaluate the hybrid vigour expression in the interspecific crosses.

MATERIALS AND METHODS

The experimental materials comprised of three wild species of sesame, *Sesamum radiatum* (2n = 64), *Sesamum alatum* (2n = 26), *Sesamum malabaricum* (2n = 26) and one wild form of *Sesamum indicum,* that is, *S. indicum* var. y*anamalaiensis* (2n = 26) as reported by Devarathinam and Sundaresan (1990) with eight cultivated varieties of *S. indicum* (Figure 1). This includes CO 1, PYR 1, SVPR 1, VRI 1, VRI(Sv) 2, TMV 3, TMV 4 and TMV 7. The wild species were collected from the Species Garden maintained at Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore, India. The varietal seeds were obtained from the Department of Oilseeds, TNAU, Coimbatore. The seedlings were raised in earthern pots during Summer, 2010. During flowering, the crossing was effected by utilizing the wild species as both male and female parents. This was done by emasculating the female flower buds (removing the corolla with four stamens) in the previous day evening. The just opened male flowers were collected from the respective parents on the following day morning and pollination was done between 6:30 to 8:30 AM. For this, the 1/3rd of the corolla was removed to expose the stamen outside, which was then smeared on the stigma of the emasculated flower. A small paper tag was tied at the base of the pollinated flowers for easy identification of crossed capsules at the later stage. The entire crossing block was raised in the glass house to avoid insect pollination. The seeds were collected from the crossed capsules and the F_1 generation was raised with the parents, in two replications with each entry in two rows of 5 m length and spacing of 15 × 30 cm during Kharif, 2010. All the recommended package of practices was adopted.

RESULTS AND DISCUSSION

Compatibility relationship

Based on the crossing data, it was evident that all the wild species exhibited different degrees of cross compatibility with cultivated *S. indicum*. The details about direct and reciprocal crosses attempted between the cultivars and the wild species are presented in Table 1. From the data on number of flowers pollinated, number of capsules set and number of hybrid seeds obtained, the crossability between the wild species and cultivated varieties were brought out. The overall cross compatibility relationship is given in Table 2.

Between *S. indicum* (2n = 26) and *S. alatum* (2n = 26)

Though *S. indicum* and *S. alatum* are having the same chromosome number, capsule and seed setting was not observed in both direct and reciprocal crosses of *S. alatum* with eight cultivars of *S. indicum*. Kedharnath (1954) could obtain only shriveled and non-viable seeds in *S. indicum* and *S. alatum* combination and presumed an early abortion of young embryo. Similar attempts were made by Amirtha Devarathnam (1965), Sundaram (1968) and Subramanian (1972) who also failed in producing viable hybrids between these two species. Even though these two species are having the same chromosome status (2n = 26), it is probable that a strong mechanism operates, due to which, hybrid seeds were not obtained.

Between *S. indicum* (2n = 26) and *S. radiatum* (2n = 64)

The direct crosses recorded the capsule setting with the maximum of 6.80% in *S. radiatum* × TMV 7 and minimum of 1.02% in *S. radiatum* × VRI 1. There was no seed set in any of the eight direct crosses between *S. radiatum* and *S. indicum*. The reciprocal cross between *S. indicum* and *S. radiatum* was not successful due to the premature dropping of crossed capsules. Hence, no capsule set and seed set was observed in the reciprocal crosses. Earlier studies involving these species also revealed the failure of these crosses (Dhawan, 1946; Ramanathan, 1950; Amirtha Devarathnam, 1965; Subramanian, 1972; Prabakaran, 1992; Vikas, 2006). The failure was attributed to very early collapse of the hybrid endosperm and the subsequent starvation of proembryo, as observed by Dhawan (1946) through embryological studies.

Between *S. indicum* (2n = 26) and *S. malabaricum* (2n = 26)

The crosses involving *S. indicum* cultivars and *S. malabaricum* both having the same somatic chromosome number (2n = 26) were fairly successful in producing good number of crossed capsules with well filled seeds. In the direct and reciprocal crosses effected between eight cultivars of *S. indicum* with *S. malabaricum*, successful capsule and seed setting was observed in all the 16 crosses (Figure 2). Only one crossed seed got germinated in the cross between *S. malabaricum* as female with *S. indicum* genotype SVPR 1, but the seedling was died subsequently in the two leaves stage, probably due to the abiotic factors. In the earlier description by John et al. (1950), *S. malabaricum* was referred as the variety of *S. indicum*, as *S. indicum* var. *malabaricum*, which was highly compatible with other genotypes of *S. indicum*. However, Prabakaran (1992)

Table 1. Details of crosses attempted between *S. indicum* and different species of *Sesamum*.

Crosses	Number of flowers pollinated	Number of capsules set	Percent of capsule setting	Mean no. of seeds per capsule	Remarks
Direct crosses					
S. alatum × SVPR 1	86	0	0	0	No capsule set
S. alatum × TMV 7	106	0	0	0	
S. alatum × VRI (Sv) 2	96	0	0	0	
S. alatum × CO 1	126	0	0	0	
S. alatum × TMV 3	98	0	0	0	
S. alatum × TMV 4	94	0	0	0	
S. alatum × VRI 1	98	0	0	0	
S. alatum × Paiyur 1	106	0	0	0	
S. malabaricum × SVPR 1	84	5	5.9	6.7	Capsule set, and viable seeds
S. malabaricum × TMV 7	143	10	6.9	25.7	
S. malabaricum × VRI (Sv) 2	126	7	5.6	18.9	
S. malabaricum × CO1	132	6	4.6	14.5	
S. malabaricum × TMV 3	102	5	4.9	12.2	
S. malabaricum × TMV 4	136	7	5.2	10.9	
S. malabaricum × VRI 1	127	10	7.9	15.2	
S. malabaricum × Paiyur 1	138	7	5.1	17.9	
S. i. var. *yanamalaiensis* × SVPR 1	105	46	43.8	14.7	Capsule set, and viable seeds
S. i. var. *yanamalaiensis* × TMV 7	121	56	46.3	14.5	
S. i. var. *yanamalaiensis* × VRI(Sv) 2	138	72	52.2	17.9	
S. i. var. *yanamalaiensis* × CO1	124	39	31.5	14.9	
S. i. var. *yanamalaiensis* × TMV 3	100	0	0	0	
S. i. var. *yanamalaiensis* × TMV 4	95	0	0	0	
S. i. var. *yanamalaiensis* × VRI 1	100	5	5.0	7.0	
S. i. var. *yanamalaiensis* × Paiyur 1	97	27	27.8	22.3	
S. radiatum × SVPR 1	94	5	5.3	0	Capsule set, but no viable seeds
S. radiatum × TMV 7	103	7	6.8	0	
S. radiatum × VRI (Sv) 2	135	6	4.4	0	
S. radiatum × CO 1	126	4	3.2	0	
S. radiatum × TMV 3	85	2	2.4	0	
S. radiatum × TMV 4	108	3	2.8	0	
S. radiatum × VRI 1	98	1	1.0	0	
S. radiatum × Paiyur 1	120	2	1.7	0	
Reciprocal crosses					
SVPR 1 × *S. alatum*	98	0	0	0	No capsule set
CO 1 × *S. alatum*	105	0	0	0	
TMV 3 × *S. alatum*	98	0	0	0	
TMV 4 × *S. alatum*	88	0	0	0	
TMV 7 × *S. alatum*	91	0	0	0	
Paiyur 1 × *S. alatum*	80	0	0	0	
VRI 1 × *S. alatum*	84	0	0	0	
VRI(Sv) 2 × *S. alatum*	112	0	0	0	

Table 1. Contd.

SVPR 1 × *S. malabaricum*	95	12	12.6	13.1	
CO 1 × *S. malabaricum*	126	4	3.2	26.9	
TMV 3 × *S. malabaricum*	106	1	0.9	44.5	
TMV 4 × *S. malabaricum*	97	2	2.1	25.7	Capsule set, and viable seeds
TMV 7 × *S. malabaricum*	135	6	4.4	55.1	
Paiyur 1 × *S. malabaricum*	114	7	6.1	14.0	
VRI 1 × *S. malabaricum*	125	7	5.6	22.3	
VRI(Sv) 2× *S.malabaricum*	138	11	7.9	39.4	
SVPR 1 × *S. i.* var. *yanamalaiensis*	99	14	14.1	12.2	
CO 1 × *S. i.* var. *yanamalaiensis*	137	6	4.4	35.2	
TMV 3 × *S. i.* var. *yanamalaiensis*	97	1	1.0	14.6	
TMV 4 × *S. i.* var. *yanamalaiensis*	89	1	1.1	0	Capsule set, and viable seeds
TMV 7 × *S. i.* var. *yanamalaiensis*	108	4	3.7	47.5	
Paiyur 1 × *S. i.* var. *yanamalaiensis*	99	5	5.0	6.34	
VRI 1 × *S. i.* var. *yanamalaiensis*	119	3	2.5	27.0	
VRI(Sv) 2 × *S. i.* var. *yanamalaiensis*	126	5	3.9	39.3	
SVPR 1 × *S. radiatum*	115	0	0	0	
CO 1 × *S. radiatum*	128	0	0	0	
TMV 3 × *S. radiatum*	105	0	0	0	No capsule set
TMV 4 × *S. radiatum*	117	0	0	0	
TMV 7 × *S. radiatum*	94	0	0	0	
Paiyur 1 × *S. radiatum*	100	0	0	0	
VRI 1 × *S. radiatum*	123	0	0	0	
VRI(Sv) 2 × *S. radiatum*	88	0	0	0	

Table 2. Cross compatibility between *Sesamumindicum* and other species of *Sesamum.*

S. indicum	***S. alatum***		***S. malabaricum***		***S. i.* var. *yanamalaiensis***		***S. radiatum***	
	DC	**RC**	**DC**	**RC**	**DC**	**RC**	**DC**	**RC**
SVPR 1	×	×	☑	✓	✓	✓	×	×
CO 1	×	×	✓	✓	✓	✓	×	×
TMV 3	×	×	✓	✓	×	✓	×	×
TMV 4	×	×	✓	✓	×	×	×	×
TMV 7	×	×	✓	✓	✓	✓	×	×
Paiyur 1	×	×	✓	✓	✓	✓	×	×
VRI 1	×	×	✓	✓	☒	✓	×	×
VRI(Sv) 2	×	×	✓	✓	✓	✓	×	×

DC – Direct cross, RC – Reciprocal cross, × - Cross failed to produce viable hybrids, ✓ - Cross in which viable hybrids produced, ☑ - Hybrid seedling not survived, ☒ - Seed not germinated.

referred this as the separate species of sesame as *S. malabaricum*. He reported that *S. malabaricum* had possessed distinct morphological features like longer duration, green stem with purple tinge, leathery leaves, purple corolla, highly rough testa as seen against the cultivated sesame. Also, *S. malabaricum* had shown partial capsule set when crossed with cultivated *S. indicum* (Prabakaran, 1992). The percentage of capsule setting ranged from 4.6% (*S. malabaricum* × CO 1) to 7.9% (*S. malabaricum* × VRI 1) in direct crosses. In reciprocal crosses, it was between 0.9% (TMV 3 × *S. malabaricum*) and 12.6% (SVPR 1 × *S. malabaricum*).

In direct crosses, the mean number of seeds per capsule was the lowest in *S. malabaricum* × SVPR 1 (6.7) and highest in *S. malabaricum* × TMV 7 (25.7). Similarly, the cross SVPR 1 × *S. malabaricum* recorded the lowest number of seeds per capsule (13.1) and the highest was recorded in TMV 7 × *S. malabaricum* (55.1) in reciprocal crosses.

Between *S. indicum* (2n = 26) and *S. indicum* var. *yanamalaiensis*(2n = 26)

The cross-compatibility between *S. indicum* and *S. indicum* var. *yanamalaiensis* both having the same chromosome number of 2n = 26 was confirmed both in direct and reciprocal form (Figure 2). But the capsule set and seed set was not observed in *S. indicum* var. *yanamalaiensis* with TMV 3 and TMV 4. The range of capsule setting was from 0 to 52.2% in *S. indicum var. yanamalaiensis* × VRI(Sv) 2. The seed setting was ranged from 0 to 22.3% (*S. indicum* var. *yanamalaiensis* × Paiyur 1) in direct crosses. In the cross *S. indicum* var. *yanamalaiensis* × VRI 1, crossed seed was obtained but the seeds were small and shriveled and hence not germinated.

In the reciprocal crosses, there was capsule set, but no seed set in TMV 4 × *S. indicum* var. *yanamalaiensis*. The range of capsule setting was from 1.0% (TMV 3 × *S. indicum* var. *yanamalaiensis*) to 14.1% in SVPR 1 × *S. indicum* var. *yanamalaiensis*. The seed setting was ranged from 0 (TMV 4 × *S. indicum var. yanamalaiensis*) to 47.5% (TMV 7 × *S. indicum* var. *yanamalaiensis*). Since the flowering of both parents had not coincided and hence, the pollination was attempted in the later stage of flowering. Due to this, the seed set was not observed in few of the direct and reciprocal crosses between *S. indicum* var. *yanamalaiensis* and cultivated varieties.

Morphological characterization of parents and interspecific hybrids

Parents

The morphology of four wild species and the cultivated species of sesame was compared and given in Table 3. The wild species utilized in the present study differed significantly from cultivated one in the branching pattern, leaf pubescence, flower size, color of corolla and anther, size, shape and color of extra floral nectary and capsules, texture and size of the seed. *S. alatum* was profusely branching with completely lobed basal leaves. The corolla color was maroon and glabrous with dark purple corolla lip. The anther was dark purple with purple colored extra floral nectary. The capsules were long and tapering with small and winged seeds. The branches of *S. malabaricum* were profuse with pubescent leaves. The corolla was pink and densely hairy with dark pink colored corolla lip. The calyx also had dense hairs with flower having purple anther. The glands were yellow colored and prominent. The capsules were medium sized and hairy. The seeds were also medium sized with rough testa.

S. indicum var. *yanamalaiensis* resembled cultivated *S. indicum* in most of the traits. It differed from cultivars in branching pattern, corolla and corolla lip color and in the size of yellow glands. The capsules were medium sized sparsely hairy with small black colored seeds with smooth testa as in the cultivated varieties. The wild species *S. radiatum* differed widely from *S. indicum*. The stem of *S. radiatum* was pubescent with more number of branches. The leaves were dark green, pubescent with serrated margins. The corolla was hairy, purple colored with dark purple corolla lip. The calyx was also pubescent with flowers having big, cream colored anther. The glands were dark colored with densely hairy capsules. The seeds were small with rough testa. These above mentioned specific traits were not observed in the cultivated *S. indicum* genotypes.

Inter-specific hybrids

The observed morphological characters of the direct and reciprocal crosses of wild with cultivated species are given in Table 4. The hybrids developed from the direct and reciprocal crosses involving *S. malabaricum* and *S. indicum* were similar in the expression of qualitative traits. But, the hybrids with *S. malabaricum* as the female parent had taken comparatively more days to germinate, when compared to their reciprocals. This difference was due to the maternal seed traits of the wild parent. The duration taken for germination of hybrids is much more than their cultivar parent.

The hybrids exhibited most of the phenotypic characters of wild parent, indicating the dominant nature of *S. malabaricum*. The direct crosses resembled the wild parent, *S. malabaricum* in branching pattern, leaf pubescence, corolla and corolla lip color, flower having calyx with dense hairs, and light purple colored anther. The nature and color of extra floral nectary resembled the wild parent. The capsules were very small with few seeds, which was medium sized black with rough testa. The crossed seeds had expressed dormancy as in the wild parent and many of the crossed seeds had not germinated for more than two months. The reciprocal crosses had also expressed similar traits as in direct crosses between *S. malabaricum* and *S. indicum*.

The F_1 hybrids involving the eight cultivars of *S. indicum* with *S. indicum* var. *yanamalaiensis*, were evaluated for their morphology and it was found that the 12 hybrids resembled the wild parent in branching pattern, corolla and corolla lip color. From this study, it was found that all the successful interspecific hybrids

Table 3. Morphological characteristics of *S. indicum* and their wild relatives.

Characters	*S. alatum*	*S. malabaricum*	*S. i.* var. *yanamalaiensis*	*S. radiatum*	*S. indicum*
Plant	Annual, erect, indeterminate	Annual, erect, indeterminate	Annual, erect, indeterminate	Annual, erect, indeterminate	Annual, erect, indeterminate
Stem	Green, glabrous, round shaped stem	Green, sparsely hairy, short and straight hair, square shaped stem	Green, glabrous, square shaped stem	Green, sparsely hairy, short and straight hair, round shaped stem	Green, glabrous, square shaped stem,
Branches	Alternate, basal, few branches	Alternate, basal, more primary and secondary branches	Alternate, basal, profusely branching	Alternate, basal, profusely branching,	Alternate, basal, few primary and secondary branches
Leaves	Green, glabrous, opposite, horizontal angled, basal leaves deeply lobed, upper leaves linear and entire.	Green, pubescent, alternate, flat, entire at top and lobed at bottom, horizontal angled, ovate	Green, glabrous, alternate, flat, entire, horizontal angled, lanceolate	Dark green, glabrous, opposite, acute angled, ovate and serrated margins	Green, glabrous, alternate, flat, horizontal angled, ovate at bottom, lanceolate at top,
Infloerescence	One flower per axil	One flower per axil	One flower per axil	One flower per axil	One flower per axil
Calyx	Glabrous, greenish purple calyx tip	Densely hairy, short and straight hairs, green calyx tip	Glabrous, green calyx tip	Medium hairy, short and straight hairs, green calyx tip	Glabrous, green calyx tip
Corolla	Maroon colored, sparsely hairy	Purple colored, densely hairy	Light purple colored, glabrous	Light violet, densely hairy	White colored, glabrous,
Corolla lip color	Dark maroon	Dark purple	Purple	Dark purple	White
Anther	Dark purple anther, light green filament	Purple anther, light purple filament	Cream colored anther, White filament	Light yellow anther, white filament	Cream colored anther, white filament
Style	Greenish purple medium style	White colored, short style	White colored, medium style	Green colored, Medium style	White colored, medium style
Extrafloral nectary	Small, purple colored	Medium, yellow colored	Small, yellow colored	Medium, dark purple colored	Small, yellow colored
Capsules	Tapered at apex, sparsely hairy, mono- capsular, long beak, four loculed, completely shattering	Broad oblong, medium hariy, mono-capsular, short beak, four loculed, partially shattering	Broad oblong, sparsely hairy, mono-capsular, short beak, four loculed, partially shattering	Narrow oblong, densely hairy, mono- capsular, short beak, four loculed, partially shattering	Broad oblong, sparsely hairy, mono capsular, short beak, four loculed, partially shattering
Seeds	Small sized, rough seed coat, dull black, winged	Medium, rough seed coat , dull black, rough testa.	small, black, smooth testa.	Medium sized, bright black, rough seed coat	Medium, different colored, smooth testa
Dormancy	Very high	High	Low	Medium	Low

Table 4. Morphological characteristics of interspecific hybrids.

Characters	*S. malabaricum* × *S. indicum*	*S. indicum* × *S. malabaricum*	*S. i.* var. *yanamalaiensis* × *S. indicum*	*S. indicum* × *S. i.* var. *yanamalaiensis*
Plant	Annual, erect, indeterminate	Annual, erect, indeterminate	Annual, erect, indeterminate	Annual, erect, indeterminate
Stem	Green, sparsely hairy short and straight hair, square shaped stem	Green, sparsely hairy short and straight hair, square shaped stem	Green, sparsely hairy, short and straight hair, square shaped stem,	Green, sparsely hairy, short and straight hair, square shaped stem,

Table 4. Contd.

Branches	Alternate, basal, profusely branching	Alternate, basal, profusely branching	Alternate, basal, profusely branching	Alternate, basal, profusely branching
Leaves	Green, densely hairy, horizontal angled, entire at top and slightly lobed at bottom	Green, densely hairy, alternate, flat, entire at top and lobed at bottom	Green, glabrous, alternate, flat, entire, horizontal angled, lanceolate, slightly lobed at bottom	Green, glabrous, entire at top and slightly lobed at bottom, horizontal angled, lanceolate,
Infloerescence	One flower per axil	One flower per axil	One flower per axil	One flower per axil
Corolla	Purple, densely hairy	Purple, densely hairy	Light purple, medium hairy	Light purple, sparsely hairy
Corolla lip color	Dark purple	Dark purple	Purple	Purple
Calyx	Green, dense, short and straight hairs	Green, dense, short and straight hairs	Green, sparse, short and straight hairs	Green, sparse short and straight hairs
Anther & style	Light purple anther, medium style	Light purple anther, medium style	White anther, medium style	White anther, medium style
Extrafloralnectary	Medium, yellow colored	Medium, yellow colored	Small, yellow colored	Small yellow colored
Capsules	Small, medium hairy, shattering monocapsular, four loculed,	Small, medium hairy, shattering monocapsular, four loculed,	Medium, sparsely hairy, monocapsular, four loculed, shattering	Medium, sparsely hairy, monocapsular, four loculed, shattering
Seeds	Medium, dull black, rough testa	Medium, dull black, rough testa	Small, black, smooth testa	Small, black, smooth testa
Dormancy	High	Medium	Low	Low

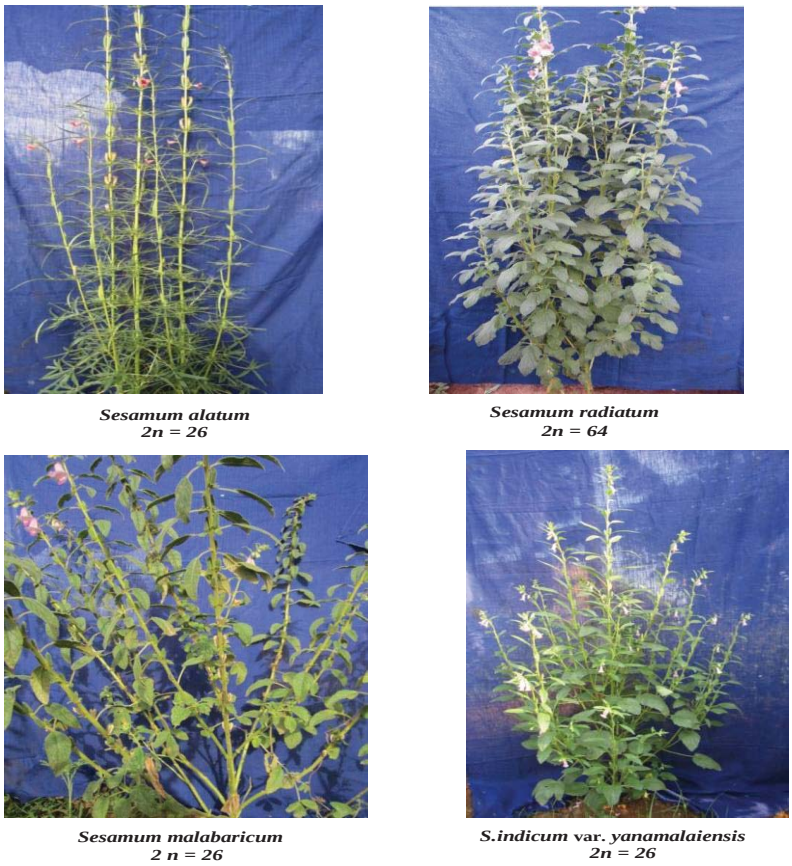
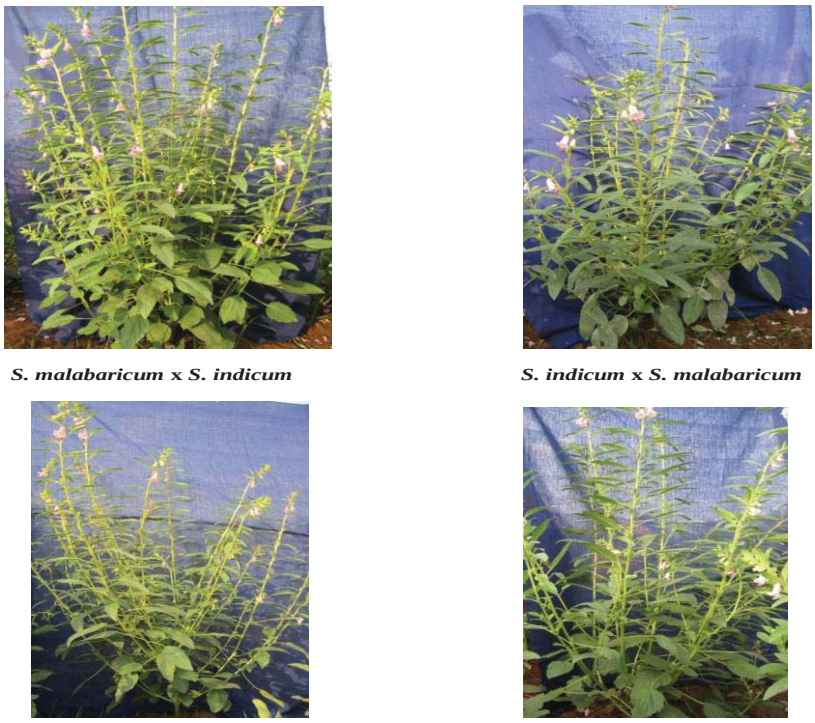


Figure 1. species of sesame.



S. malabaricum x *S. indicum*

S. indicum x *S. malabaricum*

S. i var. *yanamalaiensis* x *S. indicum*

S. indicum x *S. i* var. *yanamalaiensis*

Figure 2. crossed species of sesame.

showed predominance of wild characters than cultivated *S. indicum*. The wild species *viz.*, *S. malabaricum* and *S. indicum* var. *yanamalaiensis* could be effectively utilized for the transfer of essential traits from wild to cultivated through conventional breeding program.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Amirtha Devarathnam A (1965). Studies on interspecific hybridization in Sesamum with special reference to hybrid *S. indicum L.* × *S. laciniatum* Klein and its amphidiploids. M.Sc. (Ag.) Thesis (Unpubl.) Madras Univ.

Ashri A (1989). Oil crops of the world - Sesame, McGraw-Hill, New York, pp. 375-387.

Bedigian D, Harlan JR (1986). Evidence for cultivation of sesame in the ancient world. Econ. Bot. 40:137-154.

Chayjan RA (2010). Modeling of sesame seed dehydration energy requirements by a soft-computing approach. Aust. J. Crop Sci. 4:180-184.

Devarathinam AA, Sundaresan N (1990). A new wild variety of sesamum: *Sesamum indicum* (L.) var. *sencottai* as ADR and NS. compared with *S. indicum* (L.) var. *yanamalai* ADR and MS. and *S. indicum*(L.). J. Oilseeds Res. 7: 121-123.

Dhawan NL (1946). Interspecific hybridization in *Sesamum.* M.Sc. (Ag.) Thesis, Indian Agricultural Research Institute, New Delhi.

El-Bramawy MAS (2006). Inheritance of resistance to Fusarium wilt in some sesame crosses under field conditions. Plant Protect. Sci. 42:99-105.

Erbas M, Sekerci H, Gül S, Furat S, Yol E, Uzun B (2009). Changes in total antioxidant capacity of sesame (*Sesamum* sp.) by variety. Asian J. Chem. 21:5549-5555.

John CM, Narayana GV, Seshadri CR (1950). The wild gingelly of Malabar *Sesamum orientale* Linn. var. *malabaricum*. Madras Agric. J. 37:47-50.

Kedharnath S (1954). Personal communication to Joshi 1961. Sesamum. Indian Control Oilseeds Committee Report 109 p.

Pham TD, Nguyen TDT, Carlsson AS, Bui TM (2010). Morphological evaluation of sesame (*Sesamum indicum* L.) varieties from different origins. Aust. J. Crop Sci. 4:498-504.

Prabakaran AJ (1992). Identification of male sterile sources through wide hybridization and induced mutagenesis in sesame (*Sesamum indicum* L.). Ph.D., Thesis submitted to TNAU, Coimbatore.

Ramanathan K (1950). A note on the interspecific hybridization in sesamum. Madras Agric. J. 37:397-400.

Sarwar G, Haq MA, Chaudhry MB and Rabbani I (2007). Evaluation of early and high yielding mutants of sesame (*Sesamum indicum*L.) for different genetic parameters. J. Agric. Res. 45:125-133.

Subramanian M (1972). Cytogenetical studies on inter specific hybrids in *Sesamum* spp. M.Sc.(Ag.) Thesis (Unpubl.), Tamil Nadu Agricultural Univ., Coimbatore.

Sundaram N (1968). Inter specific hybridization in sesamum. M.Sc.(Ag.) Thesis (Unpubl.) Madras Univ., Tamil Nadu, India.

Vikas VK (2006). Studies on interspecific hybridization with particular reference to development of male sterility in sesame (*Sesamum indicum* L.).Ph.D. Thesis.University of Agricultural Sciences, Dharwad.

Yermanos DM, Hemstreet S, Saleeb W, Huszar CK (1972). Oil content and composition of the seed in the worldcollection of sesame introductions. J. Am. Oil Chem. Soc. 49:20-23.

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Spatial variation of quality traits in Algerian durum wheat cultivated in different environments

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Wheat covers more than 2.5 million hectares in Algeria and is the main staple food crop and income generation for resources-limited farmers. Area cropped in wheat is expanding however, the quality is not well known and varies from region to region. Improvement of durum wheat quality is a major concern in Algeria to better cope with the consumers' needs. Local landraces are highly appreciated for local bread and couscous, while the newly released cultivars quality is often affected by environmental factors. Four local durum varieties were studied in three different regions of Algeria (a sub littoral and two high plateau areas) during 2010/2011cropping season. Protein content, yellow berry and black spots on the grain levels, grain moisture level, thousand kernel weight and grain yield were analyzed. Results showed globally a P<0.01level of spatial variation among all traits, this demonstrated a strong influence of environmental conditions on the majority of durum quality traits; varietal effects were observed in all traits except grain yield at Guelma and Setif. Protein content was higher in Tiaret reaching 17.3%. Grain yield is higher at Setif (4.5 t/ha), one to two tons per hectare more to Guelma and Tiaret. Kernel weight is higher in the high plateau areas 55.87 and 51.2 g. Yellow berry level was high at Guelma and low in the high plateaus. In rainfed conditions of semi arid areas an average production of 3.6 million tons of good quality levels of durum wheat (protein levels >12.5%, low yellow berry and black points levels) has been obtained.

Key words: Durum wheat, rainfed conditions, quality, spatial variation, high plateau, littoral area.

INTRODUCTION

Algeria is the largest country in Africa, covering more than two million square kilometers and 238 million ha but only 3.4% is arable land. Most agricultural activities are in the north of the country. The dominant crops are annual, and mainly field crops such as cereals, forages, food legumes and potatoes. Cereals are the predominant crops grown by Algerian farmers, covering annually 3 to 3.5 million ha, nearly 40% of Algeria's total agricultural land. However, the country depends on imports for 45% of its food because annual cereal production in Algeria is about 3.2 million tons (Benbelkacem, 1996) while the demand is around 8 million tons. During the last decade, wheat represents on average 67.1% of all cereal production. Yields are low due to several abiotic and

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biotic stresses. Scarcity and poor quality of underground water resources, low and erratic rainfall, drought recurrence, high and low temperatures and salinity are the key constraints to agricultural production.

Durum wheat (*Triticum turgidum* L. var. *durum*) is the traditional wheat crop in North Africa. It is used mainly for bread and couscous and freeke - made from immature green seed that is dried, grilled and broken and different sorts of traditional cookies (Abecassis et al., 1990; Desclaux et al., 2005; Kezih et al., 2013). In Algeria, durum wheat is sown annually over 1.2 million ha, with an average consumption of around 75 kg/person/year (Djermoun, 2009). Forty percent of the grain production is used for bread-making, mainly processed at the household level. The local genotypes of durum wheat, still grown by some farmers in the mountainous areas, are highly appreciated for their excellent bread-making and couscous quality. Improving durum wheat grain quality has become, in recent years, one of the main breeding goals in many Mediterranean countries, due to the increase in market demand for good quality durum wheat.

In Algeria, most of breeding efforts are concentrating on maximum yield potential under highly favorable environment but quality aspects have lower priority. A Multi-disciplinary approach has been adopted to promote newly selected varieties for different semi-arid targeted environments (durum and bread wheat, barley and triticale), this research resulted in cultivars able to withstand drought and heat but also responsive to improved moisture supply.

The released varieties during the late seventies have allowed a grain yield gain of at least 35% over the landraces, but their grain quality is highly affected by the environmental factors. The improvement of durum wheat quality to fit different end-uses (bread, couscous, pasta, local cakes, freeke) is an important objective of the research conducted by the National Agricultural Research Institute of Algeria (INRAA) and the collaborating International Centers, CIMMYT and ICARDA (Nachit et al., 1995).

The strong influence of environment and of genotype-environment interactions on grain quality hampered the improvement of durum wheat quality. Several approaches have been carried out on bread wheat to evaluate effects of genotype, environment and their interaction (Peterson et al., 1992; Annicchiarico et al., 2006). However, very little information is available on the relative importance of the effects of genotype, environment, and genotype-environment interaction on the quality characteristics of durum wheat grown in the Mediterranean region. Michelena et al. (1995) studied the stability of 16 durum wheat varieties for different quality parameters under northern Spain conditions and found that spatial and temporal variation was very important for many traits. Juan-Aracil and Michelena (1995) reported that the three order interaction latitude x site x year was the main factor that affected quality parameters. In some other studies from Italy (Mariani et al., 1995; Nachit et al., 1995; Boggini et al., 1997; Novaro et al., 1997) a high influence of environment and genotype-environment interaction in determining durum wheat quality has been reported. This study was carried out in different wheat growing regions of Algeria that differ in climate, soil type and agronomic systems to overview the spatial variation in cereal quality traits of the four more widely cultivated durum wheat varieties conducted in three contrasting sites of Algeria during the 2010/2011.

MATERIALS AND METHODS

Sites description

Two high plateau sites (Setif in eastern and Tiaret in western Algeria), and one interior sub-littoral area (Guelma) representing cereal growing areas of Algeria, have been targeted.

(i) Guelma: situated between latitude 36° 17 and longitude 6° 37' in Eastern Algeria, rainfall amount vary from 500 to 600 mm per year. Littoral region, favorable area for cereal production, fertile deep soils and suitable for cereal seed production. Main constraints: diseases (mainly yellow rust and septoria leaf blotch) and terminal drought.
(ii) Tiaret: Western high plateaus, soils are clay loam to shallow in almost all the area. Rainfall is irregular and averages from 350 to 450 mm. One main cereal growing areas of Algeria where cereal production suffers from early drought and terminal heat stress.
(iii) Setif: Expands over three natural landscapes, the Northern Atlas tell, the central high plains and Hodna highlands in the south where the majority of arable area is situated. Altitude is comprised between 800 to 1300 m above sea level. Cereals constitute the first farmers crop. Climate is of continental type to semi-arid with cold winters (minima -8°C) and hot summer (maxima 41°C). Mean rainfall fluctuates from 200 to 500 mm from South to North. Drought is mainly associated with frost all over winter season.

Material

Four durum wheat genotypes were used in this study, including two local commercial varieties (Waha, Boussellem) and two advanced lines (Gta/Dur69., and Lahn/Ch1.2003) from the CIMMYT–ICARDA durum wheat breeding program.

Traits analyzed

Several commercial and technological quality parameters were determined. Grain-protein content (PROT) was determined by means of a Near Infra Red device. Yellow berry (MITA) was evaluated using a farinotome (grain splitter) by the average of three samples of visual inspection of 100 grains. A grain was considered defective if it was completely or partially starchy (yellow berry) or affected by fungal infections showing black spots (MOUCH) mainly around the embryo area (Autran, 1984). Thousand kernel weight named PMG was calculated as mean weight of three sets of 1000 grains per plot. Grain yield (RDT) is weighed from the total grains harvested from each plot unit. The seed rate was adjusted for a density of 300 viable seedsm^2 in Setif and Tiaret and 350 seeds m^2 in Guelma. Plot size was 12 m^2 (six rows of 10 m long and 20 cm apart).

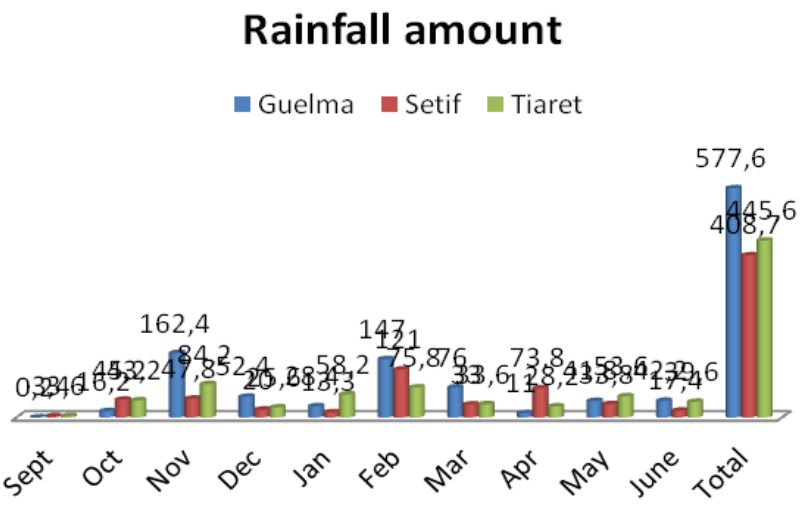

Figure 1. Rainfall amount (Guelma, Setif and Tiaret) in 2010/2011 growing season.

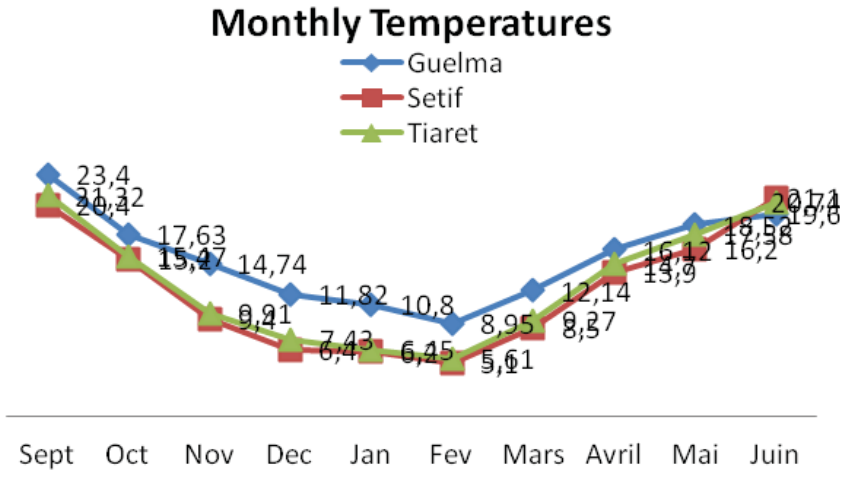

Figure 2. Monthly temperatures in 2010/2011 growing season at the 3 sites.

Statistical methods

In each trial, genotypes were sown in a randomized complete-block design with four replications. A one-way analysis of variance was done to compare more than two means from random independent samples (Dagnelie, 2003). This test was used to compare the different traits among varieties and sites. Mean comparisons between trials for each quality characteristic and a one way ANOVA were performed and least significant difference (LSD) values were calculated at the 5% probability level, groups were classified by the Tukey's test.

RESULTS AND DISCUSSION

Analysis of the climatic conditions

Even though rainfall distribution was not stable, rainfall was normal at Guelma (577.6 mm) in the 2010/2011 growing season; it was above yearly average at Setif and Tiaret sites (445.6 and 408.7 mm) where normal average rainfall is 395 and 382 mm respectively (Figure 1). Most of the precipitations fell in November and February. Temperatures were normal for all sites (Figure 2); they were colder with a high frequency of frosty days exceeding 40 days in the high plateaus during fall and winter and hotter in summer season.

Analysis of variance by site

a) Guelma: Anova results show highly significant differences in all varieties for all traits except for grain yield (Table 1). Grain moisture (12.7%) , protein content

Table 1. Quality traits and grain yield results at Guelma, Setif and Tiaret sites during 2010/2011 season.

Varieties	GUELMA	SETIF	TIARET	General Mean
Grain Moisture	12.7***	12.95***	12.94**	12.86
Prot leyel	11.8***	13***	16.93***	13.91
Black Points	22.22***	11.87***	9.14***	14.4
TKW	42.77***	55.87***	51.2***	49.95
Yellow Berry	26.57***	1.46***	0.29*	9.44
Yld	3.545NS	4.508NS	2.528***	3.527

P>0.05 NS. P≤0.05*. P≤0.01**. P≤0.001***.

Table 2. Response of the four varieties to the different quality and grain yield traits during 2010/2011 season.

Varieties	WAHA	BOUSSELAM	LAHN/CH1 2003	GTA/DUR69	General Mean
Grain Moisture	12.79***	13.1***	12.51***	12.6***	12.86
Prot leyel	14.3***	13.52***	13.79***	13.99***	13.91
Black Points	7.08***	11.32***	9.41***	24.38***	13.05
TKW	47.45***	53.83***	50.36***	48.36***	49.94
Yellow Berry	9.51***	7.31***	9.12***	11.96***	9.37
Yld	3.303**	3.429***	3.971**	3.576***	3.527

P>0.05 NS. P≤0.05*. P≤0.01**. P≤0.001***.

(11.8%), and thousand kernel weight (42.77g) were relatively lower than average mean over sites (12.86, 13.91 and 49.95%). Yellow berry level and black spots on the grain level were high in this site (26.57 and 22.2% respectively) implying a low vitrousness of the grain.

b) Setif: Differences are highly significant in all traits except grain yield. Proteins (13%) look better than in Guelma site, it is on average a little bit lower than the overall mean and much lower than in Tiaret site. Yellow berry had a low level (1.46%) showing a good vitreousness of the grain in this semi arid high plateau site. All other parameters studied are higher than in the other sites or even than the overall average.

(c) Tiaret: In contrast to the other two sites, differences were significant to highly significant in all varieties for all studied quality parameters. In this semi arid site grain yield that was lowest (2.53 t/ha) due mainly to low rainfall frequency and other abiotic stresses (cold in winter and early spring), than elsewhere while excellent results appeared for protein content (16.93%) that was highest with almost no yellow berry in the grain (0.29%), PMG is also high (51.2 g) and black spots level was lower than overall average (9.14 Vs 14.74%). It looks clearly that rainfed conditions in the semi arid sites offer the best opportunity for production of good quality durum wheat.

Genotypes analysis

It is noticed that variations are very important in all varieties for all the traits. Differences are highly very high significant in all parameters for all varieties. Waha showed a lower grain yield (3.3 t/ha), thousand kernel weight and black point or spot level (5.08%) than the other varieties Bousselam, Lahn/Ch12003 and Gta/Dur 69 (Table 2 and Figure 3).

In Bousselam, we also found very highly significant differences for all parameters. Grain yield (3.429 t/ha) was a little higher than in Waha (3.3 t/ha) but still lower than the overall average (3.53 t/ha). Thousand kernel weight (PMG) was highest in this variety released in the setif high plateau (53.83 g) while it ranged from 47.45 to 50.36 g for the other varieties. Yellow berry (MITA) had the lowest level (7.31%) but protein content (PROT) showed the lowest amount (13.52%). The variety Gta/Dur69 one of the newly released genotypes shows also highly significant differences among sites. The homogenous groups are represented in Table 4. The other new variety in the pipeline Lahn/Ch12003 exhibits also same conclusive results as Gta/Dur69. These results conclude that there is in general a spatial variation for all traits in the different sites of study.

G x E interaction analysis

The greatest proportion of variation (Table 3) for protein content was attributed to the site effect which took more than 95% ($p<0.001$) of the total variation. Under rainfed conditions, the year effect on wheat yield and quality parameters have been reported by different authors in Mediterranean environments who showed that this effect

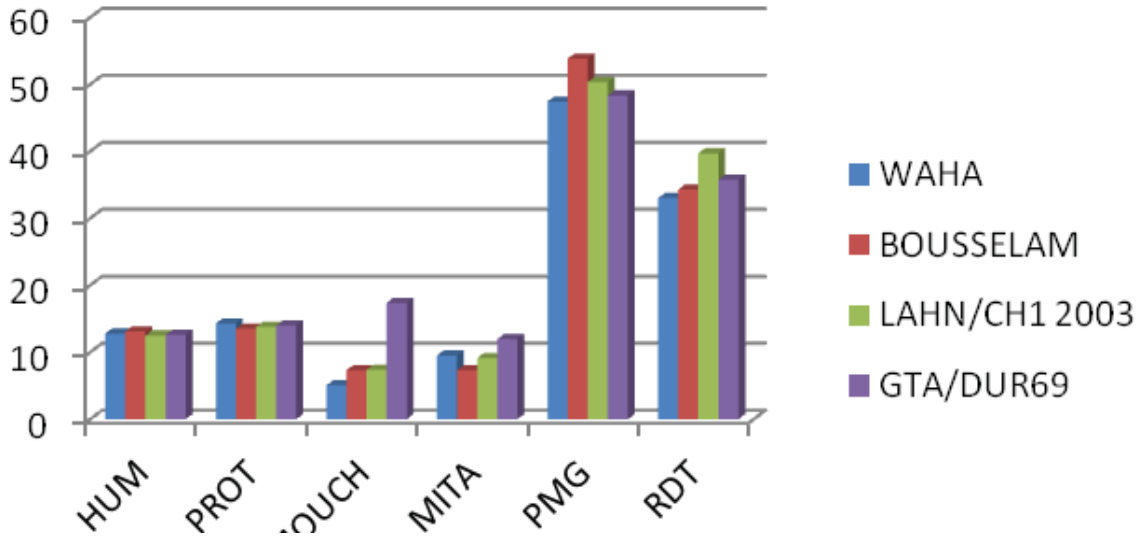

Figure 3. Quality traits and grain yield over sites for the different varieties studied in 2010/2011 season.

is almost the consequence of weather conditions during grain filling and accumulation of assimilates from the stem to the grain (Garrido-Lestache et al., 2005; Elhani et al., 2007; Bahlouli et al., 2008). Efficient water use in highland areas might have promoted plant nutrient uptake and translocation and, consequently, produced better-quality grain (Diacono et al., 2012). This can explain results observed for Tiaret and setif where protein content was higher. When comparing different sites, Tiaret faced drought conditions, while Guelma received the biggest amount of reproductive rainfall during winter season. Setif had the better yields during the studied growing season than Guelma or Tiaret (4.5, 3.5 and 2.5 t/ha, respectively). Drought period in Tiaret resulted in a reduced yield of 2.5 t/ha due to water stress during grain filling (Annicchiarico and Mariani, 1995; Monneveux et al., 2006; Villegas et al., 2010; Rizza et al., 2012). As it is known, yield reduction observed at Tiaret is mainly due to water stress but was associated with highest protein content (Oweis et al., 1999; Rharrabti et al., 2003b; Flagella et al., 2010; Diacono et al., 2012; Hussain et al., 2012). Mean squares were not significant among varieties and on variety by site interaction.

DISCUSSION

Growing conditions were different in each site; they were more favorable in the littoral area rather in the high plateau sites where it is more continental. According to Basso et al. (2012) the growing season vegetative rainfall occurs from December to February and the growing season reproductive rainfall occurs from March to May. Tiaret faced drought conditions with a total of 28.6 mm during booting stage, the most critical stage for spike constitution and early grain filling in this area; this drought period resulted in a reduced average yield (2.52 t/ha) due to water stress. Guelma received the largest amount of reproductive rainfall with a total of 406.6 mm; from boot stage to physiological maturity it received 128.8 mm that made a quite good average grain yield (3.5 t/ha) superior to Tiaret site by one ton on average (Dagnelie, 2003; Basso et al., 2012; Juan-Aracil et al., 1995; Rizza, 2012). Rainfed conditions affected thus wheat yield and quality parameters; this has been reported by different authors in Mediterranean environments who showed that this effect is mainly due to weather conditions during grain filling and assimilates accumulation in the grain (Baenziger, 1985; Bahlouli et al, 2008; Diacono et al., 2012). The spatial variability of durum wheat varieties observed in all sites is probably mainly influenced by soil types (texture, bulk density and organic matter) (Mariani, 1995). During our trials, a similar relationship was expressed between rainfall with grain yield (RDT) and thousand kernel weight (PMG) at Setif, meaning that conditions favored the expression of those parameters simultaneously. As it is known, yield reduction observed at Tiaret was likely due to water stress but on the other hand it was associated with highest protein content measured by the near infra red (Rharrabti et al, 2003; Flagella, 2010; Akman et al, 2013; Mariani, 1995).

Yellow berry level was excellent (very low) in the high plateau sites. High yellow berry percent in the most humid areas on newly released genotypes was probably the result of the reduced uptake of water which has limited the N use efficiency of wheat varieties (Rharrabti, et al 2003; Desclaux, 2000). Yellow berry is generally related to low protein content (Fernandez and Conner, 2011), this was not the case in our study at Tiaret where this trait was lowest for yellow berry but highest for

Table 3. Effect of variety, sites and interaction (% of total meansquare) on durum wheat grain.

Prameters	Site	var	Site*var
Humidity	22.45***	38.59***	38.95***
Proteins	95.79***	0.10***	4.09***
Mouch (Black points)	75.60***	14.68***	9.70***
PMG(TKW)	83.44***	11.32***	5.23***
Mit (Yellow Berry)	97.17***	1.18***	1.63***
RDT (Yield)	96.74***	1.76NS	1.49NS

Table 4. Anova comparison among sites and homogenous groups (Genotype/environment) for all quality traits during 2010/2011 season.

Varietis/location	Yld	TKW	Prot leyel	Yellow Berry	Black Points	Grain Moisture
Waha/Guelma	26.80 ^{b}	44.627^{b}	12.867^{b}	25.604^{a}	0.983 ^{b}	12.800^{ns}
Waha/Setif	45.850 ^{a}	51.887^{a}	12.867^{b}	2.583^{b}	7.050 ^{a}	12.767^{ns}
Waha/Tiaret	26.440 ^{b}	45.853^{b}	17.267^{a}	0.354^{c}	7.200 ^{a}	12.800^{ns}
Boussellem/Guelma	35.53 ^{a}	43.187^{a}	12.167^{a}	20.875^{a}	0.833 ^{a}	12.800 ^{b}
Boussellem/Setif	43.610^{a}	61.553^{b}	11.533^{b}	0.8125^{b}	10.067^{b}	13.500 ^{a}
Boussellem/Tiaret	23.750^{b}	56.757^{c}	16.867^{c}	0.250^{b}	11.067^{c}	13.00 ^{b}
GTA-Dur69/Guelma	37.06 ^{a}	43.057^{a}	10.533^{a}	35.542^{a}	2.066 ^{a}	12.833 ^{a}
GTA-Dur69/Setif	43.970^{a}	52.820^{b}	14.533^{b}	0.229 ^{b}	20.700 ^{b}	12.067 ^{b}
GTA-Dur69/Tiaret	26.271^{b}	49.207^{c}	16.933^{c}	0.104 ^{b}	10.750 ^{c}	12.90 ^{a}
Lahn -Ch1 2003/Guelma	42.53 ^{a}	40.193^{b}	11.633^{b}	24.667^{b}	5.017 ^{b}	12.267 ^{b}
Lahn -Ch1 2003/Setif	46.900^{a}	57.760^{a}	13.067^{b}	2.229 ^{b}	9.660 ^{a}	12.200 ^{b}
Lahn -Ch1 2003/Tiaret	29.687^{b}	53.020^{b}	16.667^{a}	0.479 ^{a}	7.567^{a}	13.067^{a}

protein content. High percent of black point disease observed occurred as expected in wettest environment like in Guelma (Desclaux, 2000; Rharrabti et al., 2003; Fernandez and Conner, 2011; Akman et al., 2013).

Conclusion

Results deriving from different analysis (mean, anova, tukey test) show the high spatial variation existing between the different varieties for all quality parameters considered in this study. The differences were highly significant in all varieties for all traits except for grain yield at Guelma and Setif. This latter trait was lowest at Tiaret (2.5 Vs 4.5 t/ha at Setif). The newly released variety Beni Mestina (Lahn/Ch1 2003) out yielded all the other varieties in all sites. Humidity was in a good range at all sites averaging 12.8%. Protein content reached a high level (16.93%) at Tiaret site; the best overall level was on average in Waha with 14.3%.

It is important to notice that the best yielders did not have the best protein level meaning that the quantity of the product did not match with its quality. Our results showed the excellent results that appeared for protein content with almost no yellow berry in the grain and a high PMG in the high plateau semi arid sites implying clearly that rainfed conditions in the semi arid sites offer the best opportunity for production of good quality durum wheat.

Under rainfed conditions, durum wheat cropping system in Algeria show sensitivity to spatial and climatic variability. Therefore, crops should be managed specifically according to the site where they are cultivated, especially by the use of techniques that improve protein content in their wheat varieties. Spatial analysis of yield and quality parameters allowed for the identification of Tiaret as the best site for grain quality because of its stable rainfall during grain filling period during our experiments. Varieties with shorter cycle and a good water use efficiency or drought tolerance released recently are better in littoral areas whereas varieties with long cycle are suitable in the high plateau sites. Our results suggest that, it is necessary to focus on each specific region with different environment types and select performing genotypes with the expression of best quality parameters for each variety in each site.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Abecassis J, Autran JC, Adda J (1990). La qualité technologique des blés. Le blé à l'INRA : Recherches et innovations. Revue mensuelle INRA. N°4:6-9.

Akman H, Tamkoc, Topal A (2013). Effects on Yield, Yellow berry and Black Point Disease of Fertilization Applications in Hungarian Vetch and Durum Wheat Intercropping System. Digital Proceeding Of THE ICOEST'2013-, Cappadocia. Ozdemir C., Şahinkaya S., Kalıpcı E., Oden M.K. (editors). Nevsehir, Turkey, June 18-21, 2013.

Annicchiarico P, Mariani G (1995). Prediction of adaptability and yield stability of durum wheat genotypes from yield response in normal and artificially drought-stressed conditions. Field Crops Res. 46:71–80. http://dx.doi.org/10.1016/0378-4290(95)00087-9

Annicchiarico P, Bellah F, Chiari T (2006). Repeatable genotype x location interaction and its exploitation by conventional and GIS-based cultivar recommendation for durum wheat in Algeria. Europ. J. Agron. 24:70–81 http://dx.doi.org/10.1016/j.eja.2005.05.003

AUTRAN JC (1984). Identification varietals à partir des constituants protéiques. Guide pratique d'analyses dans les industries des céréales. Coll. Sc. Tech. Agr. Alim. Lavoisier

Baenziger PS, Clements RL, McIntosh MS, Yamazaki WT, Starling TM, Sammons DJ, Johnson JW (1985). Effect of cultivar, environment, and their interaction and stability analysis on milling and baking quality of soft red winter wheat. Crop Sci. 25:5–8. http://dx.doi.org/10.2135/cropsci1985.0011183X002500010002x

Bahlouli F, Bouzerzour H, Benmahammed A (2008). Effets de la vitesse et de la durée du remplissage du grain ainsique de l'accumulation des assimilats de la tigedansl'élaboration du rendement du blédur (*Triticum durum* Desf.) dans les conditions de culture des hautes plaines orientales d'Algérie. Biotechnol. Agron. Soc. Environ 12(1):1–39.

Bahlouli F, Bouzerzour H, Benmahammed A (2008). Effets de la vitesse et de la durée du remplissage du grain ainsi que de l'accumulation des assimilats de la tige dans l'élaboration du rendement du blé dur (*Triticum durum* Desf.) dans les conditions de culture des hautes plaines orientales d'Algérie. Biotechnol. Agron. Soc. Environ. 12(1):31-39.

Basso B, Fiorentino C, Cammarano D, Cafiero G, Dardanelli J, 2012. Analysis of rainfall distribution on spatial and temporal patterns of wheat yield in Mediterranean environment. Europ. J. Agron. 41:52-65http://dx.doi.org/10.1016/j.eja.2012.03.007

Benbelkacem A (1996). Adaptation of cereal cultivars to extreme agroecologic environments of North Africa. Field Crops Res. 45:49-55.http://dx.doi.org/10.1016/0378-4290(95)00058-5

Boggini G, Doust MA, Annicchiarico P, Pecetti L (1997). Yielding ability, yield stability, and quality of exotic durum wheat germplasm in Sicily. Plant Breed. 116:541–545.

Dagnelie P (2003). Principes d'expérimentation. Panification des expériences et analyse de leurs résultats. Les Presses Agronomiques de Gembloux, Belgique, P. 397.PMCid:PMC1773566

Desclaux D (2000). Environmental conditions inducing black-point symptoms in durum wheat. In: Royo C. (ed.), Nachit M. (ed.), Di Fonzo N. (ed.), Araus J.L. (ed.). Durum wheat improvement in the Mediterranean region: New challenges. Zaragoza: CIHEAM, (Options Méditerranéennes: Série A. Séminaires Méditerranéens; 40:501-503.

Desclaux D (2005). Amélioration de la valeur technologique et commerciale du blé dur : vers une réduction des taux de mouchetures et de mitadin. Rapport du projet de recherche. INRA. Montpellier. France, P. 120.PMid:15698076

Diacono M, Castrignanò A, Troccoli A, De Benedetto D, Basso B, Rubino P (2012). Spatial and temporal variability of wheat grain yield and quality in a Mediterranean environment: A multivariate geostatistical approach. Field Crops Res. 131:49–62. http://dx.doi.org/10.1016/j.fcr.2012.03.004

Djermoun A (2009). La production céréalière en Algérie : les principales caractéristiques. Revue Nature et Technologie, 01:45-53

Elhani S, Martos V, Rharrabti Y, Royo C, Garcia del Moral LF (2007). Contribution of main stem and tillers to durum wheat (*Triticum turgidum* L. var. durum) grain yield and its components grown in Mediterranean environments. Field Crops Res. 103:25–35. http://dx.doi.org/10.1016/j.fcr.2007.05.008

Fernandez MR, Conner RL (2011). Black point and smudge in wheat. Prairie Soils. Crops J. 4:158-164.

Flagella Z, Giuliani MM, Giuzio L, Volpi C Masci S (2010). Influence of water deficit on durum wheat storage protein composition and technological quality. Eur. J. Agron. 33:197–207. http://dx.doi.org/10.1016/j.eja.2010.05.006

Garrido-Lestache E, Lopez-Bellido RJ, Lopez-Bellido L (2005). Durum wheat quality under Mediterranean conditions as affected by N rate, timing and splitting, N form and S fertilization. Eur. J. Agron. 23:265–278. http://dx.doi.org/10.1016/j.eja.2004.12.001

Hussain M, Khan AS, Khaliq I, Maqsood M (2012). Correlation studies of some qualitative and quantitative traits with grain yield in spring wheat across two environments. Pak. J. Agric. Sci. 49(1):1-4.

Juan-Aracil J, Michelena A (1995). Durum wheat in Spain. In: diFonzo, N, Kaan, F, Nachit, M. (Eds.), Proceedings of the Seminar on Durum Wheat Quality in the Mediterranean Region. Options Me'diterrane'ennes 22:129–121.

Kezih R, Bekhouche F, Merazka A (2013). Some traditional Algerian products from durum wheat. Afr. J. Food Sci. 8(1):30-34.

Mariani BM, D'Egidio MG, Novaro P, (1995). Durum wheat quality evaluation: influence of genotype and environment. Cereal Chem. 72:194–197.

Michelena A, Romagosa I, Martin JA, Lopez A (1995). Influencia ambiental y varietal en diferentes para'metros de calidad y rendimiento en trigo duro. Invest. Agric. 10:192–201.

Monneveux P, Rekika D, Acevedo E, Merah O (2006). Effect of drought on leaf gas exchange, carbon isotope discrimination, transpiration efficiency and productivity in field grown durum wheat genotypes. Plant Sci. 170:867–872. doi:10.1016/j.plantsci.2005.12.008 http://dx.doi.org/10.1016/j.plantsci.2005.12.008

Oweis T, Pala M, Ryan J (1999). Management alternatives for improved durum wheat production under supplemental irrigation in Syria. Eur. J. Agron. 11:255–266. http://dx.doi.org/10.1016/S1161-0301(99)00036-2

Nachit MM, Baum M, Impiglia A, Ketata H (1995). Studies on some grain quality traits in durum wheat grown in Mediterranean region. In: di Fonzo N, Kaan F, Nachit M. (Eds.), Proceedings of the Seminar on Durum Wheat Quality in the Mediterranean Region. Options Mediterraneennes 22:181–187.

Novaro P, D'Egidio MG, Bacci L, Mariani BM, (1997). Genotype and environment: their effect on some durum wheat quality characteristic. J. Genet. Breed. 51:247–252.

Peterson CJ, Graybosch PS, Baenziger PS, Grombacher AW (1992). Genotype and environment effects on quality characteristics of hard red winter wheat. Crop Sci. 32:98–103. http://dx.doi.org/10.2135/cropsci1992.0011183X003200010022x

Rharrabti YC, Royo D, Villegas N, Aparicio LF, Garcia Del Moral (2003). Durum wheat quality in Mediterranean environments II. Influence of climatic variables and relationships between quality parameters. Field Crops Res. 80:133-140. http://dx.doi.org/10.1016/S0378-4290(02)00177-6

Rharrabti Y, Villegas D, Royo C, Martos-Nunez V, García del Moral LF, (2003b). Durum quality in Mediterranean environments II. Influence of climatic variables and relationships between quality parameters. Field Crop Res. 80:133–140. http://dx.doi.org/10.1016/S0378-4290(02)00177-6

Rizza F, Ghashghaie J, Meyer S, Matteu L, Mastrangelo AM, Badeck F-W, (2012). Constitutive differences in water use efficiency between two durum wheat cultivars. Field Crops Res. 125:49–60. http://dx.doi.org/10.1016/j.fcr.2011.09.001

Villegas D, Casadesus J, Atienza SG, Martos V, Martos F, Karam F, Aranjuelo I, Nogués S (2010). Tritordeum, wheat and triticale yield components under multi-local mediterranean drought conditions. Field Crops Res. 116:68–74. http://dx.doi.org/10.1016/j.fcr.2009.11.012

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Soil and water loss in Ultisol of the Cerrado-Pantanal Ecotone under different management systems

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Soil and water losses were evaluated in dystrophic ultisol of the Cerrado-Pantanal Ecotone cropped with common bean, *Phaseolus vulgaris* L, under different tillage systems. The treatments studied were conventional tillage with primary and double secondary disking (CT), minimum tillage with chisel plow (MT) and no-tillage (NT) systems, the last associated to 4 crop densities: 0, 3, 6 and 9 Mg ha^{-1}. In order to characterize the experimental area, analyzes of water-dispersible clay, flocculation degree, aggregate stability, soil bulk density, soil porosity, soil moisture and surface roughness was carried out. Using the portable rainfall simulator, the plots received application of rainfall of 60 mm h^{-1} to evaluate soil and water loss. The treatments were arranged in a randomized block design with four replications. The soil losses ranging from 11.38 to 380.56 × 10^{-3} kg m^{-2}, while water losses ranging from 4.15 to 31.57 × 10^{-3} m^3 m^{-2}. The highest soil losses occur in CT and the lowest water losses in MT. In NT, the highest level of crop residue deposition on soil surface reduces soil and water loss. Compared to water loss, soil loss is more susceptible to variations in the type of tillage system and levels of plant residues.

Key words: Water erosion, soil conservation, simulated rainfall.

INTRODUCTION

The agriculture and livestock activities in Brazil are still based basically on systems of non-conservative soil management practices. In recent years, the increase in extensive beef cattle husbandry has been linked to deforestation of native areas for the purpose of establishing new pasture areas, which do not receive adequate soil management. The bigger production of the Brazilian agricultural commodities likes grains, fiber and energy source. Sometimes it is planted under conventional soil tillage, increasing soil degradation by water erosion.Areas with higher rainfall and intense land use are more susceptive for water and soil losses (Valipour, 2014). The intensive soil tillage can pulverize the soil aggregates and cause compaction at different positions of the soil profile. This compaction reduces the water infiltration into the soil and promotes runoff which increases the loss of soil, water and nutrients.

Conventional tillage is characterized by complete soil

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turnover before cropping. This practice promotes incorporation of crop residues, but also disaggregates soil (Meijer et al., 2013), decreasing porosity and reducing water infiltration. Other studies report that conventional tillage is not as efficient as conservation tillage in avoiding nutrient, soil and water loss by water erosion (Mello et al., 2003; Carvalho Filho et al., 2007).

Conservation tillage, with low soil disturbance and maintenance of previous crop residues on the soil surface, reduces water and sediment loss (Schick et al., 2000; García-Orenes et al., 2009). Soil cover reduces the possibility of soil surface sealing because it dissipates the kinetic energy from rain and decreases disaggregation of soil particles, in addition to reducing the velocity and erosion capacity of runoff.

The present study evaluated soil and water losses under simulated rainfall in dystrophic ultisol subjected to different soil tillage systems in a bean crop.

MATERIALS AND METHODS

Study area

The experiment was carried out in Aquidauana, MS (20°28'S; 55°40'W; 191 m altitude). The area is part of the Cerrado-Pantanal Ecotone, characterized by hot sub-humid tropical climate with average annual rainfall of 1400 mm and average annual temperature of 24°C. Its soil is classified as dystrophic Ultisol with a sandy texture in Horizon A (750 g kg^{-1} sand, 130 g kg^{-1} silt and 120 g kg^{-1} clay) and sandy loam in Horizon B (610 g kg^{-1} sand, 140 g kg^{-1} silt and 250 g kg^{-1} clay). Terrain is flat to slightly wavy, with mean slope of 0.04 m m^{-1}. The area was cropped with bean (*Phaseolus vulgaris* L.) at a density of 16 seeds per linear meter and 0.45 m space between the planting rows.

Physical attributes of soil

Water-dispersible clay (WDC) and flocculation degree (FD) were determined from soil samples collected only in the 0-0.20 m layer. Soil samples collected at 0-0.20 m and at 0.20-0.40 m were used to determine mean geometric diameter (MGD) and weighted mean diameter (WMD) in order to characterize wet aggregate stability, soil bulk density, macroporosity, microporosity and total porosity.

Calibration of the rainfall simulator

Rainfall simulation with the InfiAsper simulator (Alves Sobrinho et al., 2008) was used to evaluate soil and water loss. The simulator operates using Veejet 80.150 emitters positioned 2.30 m above the ground and at a working pressure of 35.6 kPa, producing drops with a mean diameter of 2.0 mm. The area assigned to rainfall simulation corresponded to a 0.70 m^2 (1 m × 0.7 m) test plot, demarcated with galvanized steel sheets that allowed surface runoff collection.

As adopted in similar studies, the rainfall simulator was regulated to produce a 60 ± 5 mm h^{-1} rainfall intensity (García-Orenes et al., 2009; Oliveira et al., 2010; Donjadee and Chinnarasri, 2013). In addition, plots were pre-wetted using drippers before rainfall was applied in order to provide uniform moisturizing (Cogo et al., 1984). Time to surface runoff, the period between the onset of rainfall application and surface runoff, was recorded for each experimental plot. Each rainfall simulation test lasted 60 min.

Soil roughness, rainfall energy, and evaluation of soil and water loss

Rainfall simulation tests were performed in areas under three soil management systems: Conventional tillage with primary and double secondary disking (0.30 m and 0.10 m in depth) (CT); minimum tillage using a chisel plow with five shanks spaced 0.25 and 0.30 m in depth (MT); no-tillage (NT).

In NT management system, soil and water loss were evaluated in areas covered with four levels of crop residues on the soil surface: No residue (NT-0), 3 Mg ha^{-1} (NT-3), 6 Mg ha^{-1} (NT-6) and 9 Mg ha^{-1} (NT-9).

Surface roughness was determined according to Panachuki et al. (2010). Calculations of the kinetic energy produced in each rainfall event were based on the characteristics of the simulated rainfall.

Assessment of soil and water losses was performed by collecting surface runoff for 1 min, every 2 min, totaling 31 samples per test plot. Runoff depth was obtained from the relation between the volume of water drained and plot area. At the end of each precipitation event, runoff samples were taken to the laboratory to determine soil mass and runoff volume. Each collecting flask was weighed and added with 3 drops of hydrochloric acid to accelerate decantation of solids and facilitate excess water drainage. The flasks were kept in an oven at 60°C until complete water evaporation, and then weighed with the dried soil.

Statistical procedures

The treatments were arranged in a randomized block design with four replications. Data on physical soil attributes, soil and water loss were subjected to ANOVA, and statistically different means contrasted by the Tukey test (α=0.05).

RESULTS AND DISCUSSION

Physical attributes of soil

Soil from CT and MT did not exhibit differences in terms of WDC. FD was also similar among the treatments, and MGD and WMD were higher in NT and MT than in CT (Table 1). Araya et al. (2011) and Garcia-Orenes et al. (2012) consider that conservationist systems, with adequate soil cover, lead to high aggregate stability and decrease rates of soil and water losses during rainfall.

Tavares Filho et al. (2012) highlight the fact that the mechanisms for producing different sized aggregates are affected by the tillage system adopted and specific soil attributes. They also consider that no-till management increases aggregate and macroaggregate stability. The highest clay levels found in NT, as well as the lowest WDC levels, show the importance of clay, together with organic matter, for soil aggregation and structuring, affecting WMD and MGD levels. Stavi and Lal (2011) emphasize that the direct plantation system, with adequate soil covering, reduces the negative impact of the tillage operations on the soil structure and increases the aggregate stability. No-tillage farming favors soil microbiological activity and soil structuring. It facilitates root development, improves the chemical attributes of soil and affects the quality of organic matter. Since it reduces clay dispersion, it also improves the physical conditions

Table 1. Water-dispersible clay (WDC), flocculation degree (FD), mean geometric diameter (MGD) and weighted mean diameter (WMD) of soil under conventional tillage (CT), minimum tillage (MT) or no-tillage (NT).

Soil layer (m)	Treatment	WDC (%)	FD (%)	MGD (mm)	WMD (mm)
0 - 0.20	CT	6.4^{A}	44.3^{A}	1.9^{B}	3.1^{B}
	MT	6.3^{A}	50.2^{A}	2.7^{AB}	3.8^{AB}
	NT	5.1^{B}	52.0^{A}	3.7^{A}	4.4^{A}
0.20 - 0.40	CT	-	-	1.4^{A}	2.3^{A}
	MT	-	-	1.9^{A}	2.8^{A}
	NT	-	-	2.3^{A}	2.9^{A}

Means followed by a same uppercase letter in a column are similar for a same soil layer (Tukey test, P>0.05).

Table 2. Soil density, macroporosity and total porosity as a function of the treatments and depths sampled.

Depth	CT	MT	NT
Soil bulk density (Mg m^{-3})			
0 - 0.10 m	1.38^{Ab}	1.40^{Ac}	1.44^{Ac}
0.10 - 0.20 m	1.42^{Bb}	1.56^{Ab}	1.63^{Ab}
0.20 - 0.40 m	1.63^{Aa}	1.66^{Aba}	1.70^{Aa}
Macroporosity (%)			
0 - 0.10 m	21.12^{Aa}	18.52^{Aa}	15.36^{Ba}
0.10 - 0.20 m	16.76^{Ab}	13.10^{Bb}	8.59^{Cb}
0.20 - 0.40 m	11.03^{Ac}	9.10^{Ac}	6.26^{Bb}
Microporosity (%)			
0 - 0.10 m	18.90^{Aa}	18.62^{Aa}	18.62^{Aa}
0.10 - 0.20 m	19.25^{Aa}	19.32^{Aa}	19.32^{Aa}
0.20 - 0.40 m	18.98^{Aa}	18.68^{Aa}	19.68^{Aa}
Total porosity (%)			
0 - 0.10 m	40.02^{Aa}	37.13^{Ba}	34.63^{Ba}
0.10 - 0.20 m	36.01^{Ab}	32.432^{Bb}	29.11^{Cb}
0.20 - 0.40 m	30.01^{Ac}	28.78^{Ac}	26.55^{Bc}

CT, Conventional tillage; MT, minimum tillage; NT, no-tillage; for each variable, means followed by the same uppercase letter in a row and lowercase letter in a column are statistically similar (Tukey test, P<0.05).

of surface layers in cropped areas.

Topsoil showed the lowest soil density in all the tillage systems (Table 2), but it tended to be higher in NT. With the increasing of the soil depth it was observed an upward trend in the value of the soil density, as verified by Liu et al. (2013) in different tillage systems after three years of cultivation. The increase in soil density can be observed in the subsurface layer, possibly due to the lower organic matter content of deeper layers and the pressure applied by upper layers.

The effects of soil turnover on the top layers must be considered in CT and MT because it increases macroporosity up to the depth reached by the tillage implements that disturb the soil. In addition, at greater depths soil particles naturally adjust to empty spaces over pedogenetic evolution, with layer densification at depth irrespective of human interference.

Soil bulk density was in general lower than the critical limit of 1.85 Mg m^{-3}, proposed by Reinert et al. (2008), for crop development in ultisol. In all the soil tillage systems evaluated, macroporosity was higher in topsoil. Macroporosity was lower in NT at all depths, probably because the lack of soil turnover favors its consolidation. Total porosity was higher in topsoil in all the systems. This result is likely associated to the higher organic matter content in these layers, irrespective of the

Table 3. Mean initial and final soil moisture, soil surface roughness, time to surface runoff, and kinetic energy of the simulated rain.

Soil tillage system and level of plant residue					
CT	MT	NT-0	NT-3	NT-6	NT-9
Initial soil moisture (% mass base)					
17.33[a]	14.60[a]	15.88[a]	15.97[a]	15.61[a]	15.30[a]
Final soil moisture (% mass base)					
20.85[a]	21.42[a]	20.33[a]	19.31[a]	16.83[a]	16.96[a]
Soil surface roughness (mm)					
3.58[b]	11.93[a]	5.39[b]	5.62[b]	6.23[b]	5.42[b]
Time to surface runoff (min)					
6.91 [b]	60.20[a]	7.26[b]	5.65[b]	13.14[b]	18.94[b]
Kinetic energy of simulated rainfall (kJ m^{-2})					
1.62[b]	2.91[a]	1.63[b]	1.58[b]	1.77[b]	1.91[b]

CT, conventional tillage; MT, minimum tillage; NT-0, no-tillage without plant residues; NT-3, no-tillage with 3 Mg ha^{-1} plant residue; NT-6, no-tillage with 6 Mg ha^{-1} plant residue; NT-9, no-tillage with 9 Mg ha^{-1} plant residue. Means followed by a same lowercase letter in a row are statistically similar (Tukey test, $P<0.05$).

management system adopted. The high root volume on the soil surface also favors soil structuring, thereby increasing TP, which is directly associated to macroporosity.

No differences between initial and final soil moisture were observed, corroborating the positive and homogenizing effect of plot wetting prior to the tests (Table 3).

Surface roughness, a major variable affecting water infiltration in soil, was similar between NT and CT. In general, the lower the surface roughness, the lower the time to onset of surface runoff.

In MT, onset of surface runoff was delayed, likely because of the chiseling applied just before soil tillage. This practice disturbs soil, promoting incorporation of crop residues, increasing surface roughness and favoring infiltration. Therefore, soil surface in MT had greater exposure to rainfall and higher kinetic energy was produced by the simulated rain. Castro et al. (2006) observed runoff delay in treatments with rainfall application soon after soil tillage, showing that soil turnover reduces or even avoids soil loss by erosion.

Soil and water losses

Cumulated soil loss was higher in CT than in the other systems (Table 4) because of the lack of residue cover, which allowed higher soil exposure to rainfall action, and effective topsoil turnover, as verified by Meijer et al. (2013).

The efficiency of the conservation tillage systems was especially observed in NT-9, NT-6, NT-3 and MT, which exhibited soil losses of nearly 3, 5, 10 and 6% of that found in CT, respectively. Conservation tillage reduces soil losses compared to non-conservation systems because of the plant residues deposited on the soil surface. Donjadee and Chinnarasri (2013) also concluded that surface runoff volume decreases with the increase in grass load deposited on the soil surface, and that 7.5 Mg ha^{-1} plant residue is the appropriate level to reduce runoff and soil loss. Jordan et al. (2010) evaluating the application of simulated rainfall at different levels of soil covered with wheat residues observed that waste fees exceeding 5 Mg ha^{-1} $year^{-1}$ significantly decreased the rate of runoff. However, it can be considered that, in general, plant residues decrease the runoff speed, promoting the soil consolidation and reducing the soil disaggregation and the transport of the runoff.

Earlier studies showed that soil cover reduces erosion (Mello et al., 2003; Garcia-Estringana et al., 2013). Plant cover provides higher soil protection due to drop interception, increased surface roughness, increased organic matter supply, decreased soil disaggregation index owing to the reduced runoff sediment level and higher soil permeability.

At the onset of surface runoff CT exhibited low soil loss, but it soon increased, maintaining a linear tendency until the end of runoff collection. In the other treatments, soil loss per unit of time was maintained even over rainfall application.

Although soil losses in NT-0 were nearly 20% of those recorded in CT, they can be considered significant in relation to the other treatments, such as NT-9, whose soil loss was seven times lower. This occurs because the large amount of plant residue in NT-9 prevents soil particle disaggregation caused by the impact of

Table 4. Cumulated soil loss in Ultisol under different tillage system and levels of plant residue cover.

Cumulated soil loss (10^{-3} kg m^{-2})					
CT	**MT**	**NT-0**	**NT-3**	**NT-6**	**NT-9**
380.6^{A}	24.5^{D}	76.1^{B}	38.8^{C}	19.8^{D}	11.4^{E}
CV (%) = 21.41 and DMS = 44.22					

CT, Conventional tillage; MT, minimum tillage; NT-0, no-tillage without plant residues; NT-3, no-tillage with 3 Mg ha^{-1} plant residue; NT-6, no-tillage with 6 Mg ha^{-1} plant residue; NT-9, no-tillage with 9 Mg ha^{-1} plant residue. Means followed by a same lowercase letter in a row are statistically similar (Tukey test, P<0.05).

Table 5. Cumulated water loss in Ultisol under different tillage systems and levels of plant residue cover.

Cumulated water loss (10^{-3} m^3 m^{-2})					
CT	**MT**	**NT-0**	**NT-3**	**NT-6**	**NT-9**
31.5^{A}	4.2^{C}	27.1^{A}	31.6^{A}	29.5^{A}	18.9^{B}
CV (%) = 15.1 and DMS = 8.1					

CT, Conventional tillage; MT, minimum tillage; NT-0: no-tillage without plant residues; NT-3, no-tillage with 3 Mg ha^{-1} plant residue; NT-6, no-tillage with 6 Mg ha^{-1} plant residue; NT-9, no-tillage with 9 Mg ha^{-1} plant residue. Means followed by a same lowercase letter in a row are statistically similar (Tukey test, P<0.05).

raindrops. According to Stavi and Lal (2011), the greater susceptibility of farming systems to the erosion process is related to the scarcity of soil covering and the degree of the plowing of the soil surface. Despite the disaggregating action of the chisel plow used in MT, this system exhibited lower soil losses than those obtained in NT-0, NT-3 and CT, probably because water percolation into soil was facilitated by the furrows opened by the tool.

During rainfall simulation tests in MT, surface runoff was not formed in some plots, showing the efficiency of this system in breaking up deeper and compacted layers and increasing surface roughness. This can reduce, in this way, the density of the soil in the areas of preparation and increases the surface roughness which, as Meijer et al. (2013), may favor the deposition of the soil in the microdepressions and, after this, minimize the soil loss. On the other hand, this condition tends to change with an increase in rainfall since the roughness promoted by methods such as MT has a shorter life than that produced by crop residue deposition (Panachuki et al., 2010).

Cumulated water losses were lower in MT (Table 5), corresponding to only 13.2% of those recorded in CT. Mean losses in MT were15.3, 13.2, 14.1 and 21.8% of those observed in NT-0, NT-3, NT-6 and NT-9, respectively. This occurs because of soil scarification, which disrupts soil at depth and increases roughness, reducing surface runoff.

The NT system was less efficient in preventing water than soil losses. In NT-9 treating, the cumulative loss of water was equal to 70, 60 and 64% of the losses observed in treatments NT-0, NT-3 and NT-6, respectively. This indicates that a minimum residue volume is needed for this system to restrain erosion. According to Adekalu et al. (2007), in order to prevent effectively the runoff water in the soil may be required levels of soil cover above 90%, especially in conditions of soils with low organic matter and the presence of compacted layers.

The CT treatment, without any plant residue on the soil surface and with soil surface roughness equivalent to 66; 64 and 57% which are observed in NT-0, NT-3 and NT-6 (Table 3), respectively, showed a cumulative loss of water similar to those observed in these treatments. This is due, possibly, to the effect of soil disturbance that occurred in the CT system and favored, temporarily, the water infiltration in the soil.

Figure 1 shows that the soil and water loss can be explained by the linear regression model, with high values for the coefficient of determination. Thus, it can be considered that under intensity of constantly rain, the rates of the soil and water loss tend to be constant during the occurrence of rain.

In the PC treatment the rates of soil loss were low at the beginning of the runoff, increasing at the first moments and staying with linear trend until the final moment of the rain test. In other treatments the rates of soil loss were similar over time.

Comparing the no-tillage treatments, it was observed that the treatment NT-9 was the most effective one in the controlling of water loss, indicating that it is necessary a minimum amount of plant residue for this system to be effective at stopping the erosion process. Evaluating the three systems of tillage, it can be said that the MT treatment the operation of chiseling resulted in higher infiltration rates that resulted in lower runoff.

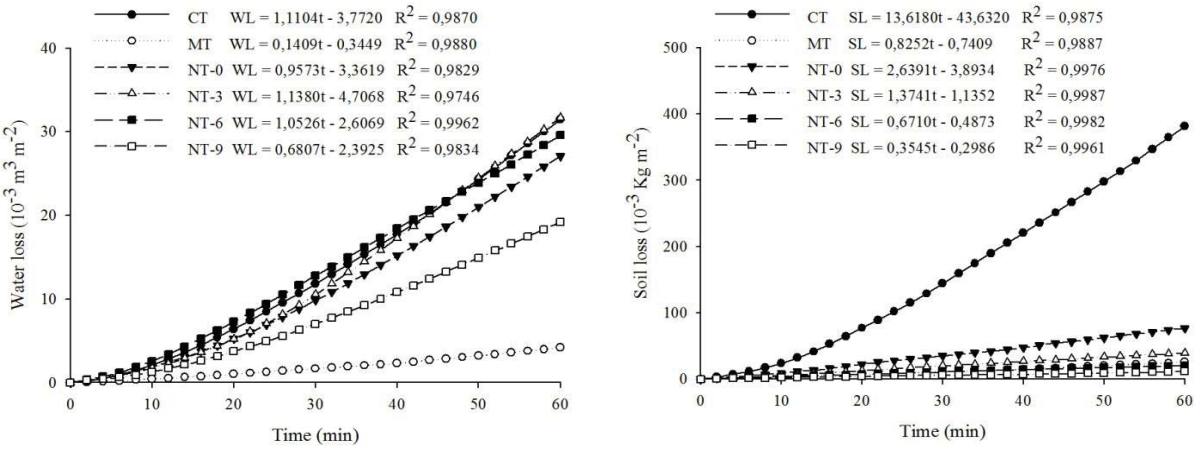

Figure 1. Soil and water loss in ultisol under different tillage systems and residue levels vegetable common bean.

Figure 1 also shows that the rates of water losses were less affected by variations of the level of vegetable residues than the soil losses. This occurs because, according to soil physical attributes, its water holding capacity is limited. Thus, a determined soil management system can decrease runoff rate only up to a certain value, which is defined by the difference between rainfall intensity and stable water infiltration rate. Gómez et al. (2011) consider that the conservative systems of tillage may not be in some cases more efficient in controlling runoff, especially in conditions of low soil cover. Because of this, these systems require practices that can mitigate eutrophication and contamination that fertilizers and pesticides can cause to the water bodies.

Conclusions

In Ultisol cropped with common bean soil loss ranging from 11.38 to 380.56 g m^{-2}, while water loss ranging from 4.15 to 31.57 × 10^{-3} m^3 m^{-2}. The highest soil losses were obtained with CT, and the lowest with minimum tillage (MT). In no-tillage (NT) planting, soil and water losses were more efficiently decreased in treatments applying the highest levels of residual crop on the soil surface, indicating that a minimum residue load is necessary to successfully contain erosion in this system.
Soil loss is more susceptible than water loss to variations in the type of tillage system and levels of plant residue.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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REFERENCES

Adekalu KO, Olorunfemi IA, Osunbitan JA (2007). Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. Bioresour. Technol. 98:912-017. http://dx.doi.org/10.1016/j.biortech.2006.02.044

Alves sobrinho T, Macpherson HG, Gómez JA (2008). A portable integrated rainfall and overland flow simulator. Soil Use Manage. 24:163-170. http://dx.doi.org/10.1111/j.1475-2743.2008.00150.x

Araya T, Cornelis WM, Nyssen J, Govaerts B, Bauer H, Gebreegzhiaber T, Oicha T, Raes D, Sayre KD, Hayle M, Deckers J (2011). Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. Soil Use Manage. 27(3):404-414. http:dx.doi.10.1111/j.1475-2743.2011.00347.x

Carvalho Filho A, Centurion JF; Silva RP, Furlani CEA, Carvalho LCC (2007). Soil tillage methods: alterations in the roughness of the soil. Eng. Agríc. 27(1):229-237. http://dx.doi.org/10.1590/S0100-69162007000100017

Castro LG, Cogo NP, Volk LBS (2006). Alterations in soil surface roughness by tillage and rainfall in relation to water erosion. R. Bras. Ci. Solo 30(2):339-352. http://dx.doi.org/10.1590/S0100-06832006000200014

Cogo NP, Moldenhauer WC, Foster GR (1984). Soil loss reductions from conservation tillage practices. Soil Sci. Soc. Am. J. 48:368-373. http://dx.doi.org/10.2136/sssaj1984.03615995004800020029x

Donjadee S, Chinnarasri C (2013). Vetiver grass mulch for prevention of runoff and soil loss. Proc. Inst. Civ. Eng. Water Manage. 166:144-151. http://dx.doi.org/10.1680/wama.11.00045

Garcia-Estringana P, Alonso-Blazquez N, Marques MJ, Bienes R, Gonzáles-Andrés F, Alegre J (2013). Use of Mediterranean legume shrubs to control soil erosion and runoff in central Spain. A large-plot assessment under natural rainfall conducted during the stages of shrub establishment and subsequent colonization. Catena Special 102:3-12. http://dx.doi.org/10.1016/j.catena.2011.09.003

García-Orenes F, Cerdá A, Mataix-Solera J, Guerrero C, Bodí MB, Arcenegui V, Zornoza R, Sempere JG (2009). Effects of agricultural management on surface soil properties and soil water losses in eastern Spain. Soil Till. Res. 106:117–123. http://dx.doi.org/10.1016/j.still.2009.06.002

García-Orenes F, Roldán A, Mataix-Solera J, Campoy M, Arcenegui V, Caravaca F (2012). Soil structural stability and erosion rates influenced by agricultural management practices in a semi-arid Mediterranean agro-ecosystem. Soil. Use. Manage. 28(4):571-579. http://dx.doi.org/10.1111/j.1475-2743.2012.00451.x

Gómez JA, Llewellyn C, Basch G, Sutton PB, Dyson JS (2011). The effects of cover crops and conventional tillage on soil and runoff loss in vineyards and olive groves in several Mediterranean countries. Soil Use Manage. 27(4):502-514. http://dx.doi.org/10.1111/j.1475-2743.2011.00367.x

Jordan A, Zavala LM, Gil J (2010). Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. Catena 81:77-85. http://dx.doi.org/10.1016/j.catena.2010.01.007

Liu Y, Gao M, Wu W, Tanver SK, Wen X, Liao Y (2013). The effects of conservation tillage practices on the soil water-holding capacity of a non-irrigated apple orchad in the Loess Plateau, China. Soil. Tillage. Res. 130:7-12. http://dx.doi.org/10.1016/j.still.2013.01.012

Meijer AD, Heitman JL, White JG, Austin RE (2013). Measuring erosion in long-term tillage plots using ground-based lidar. Soil Tillage Res. 126:1-10. http://dx.doi.org/10.1016/j.still.2012.07.002

Mello EL, Bertol I, Zaparolli ALV, Garrafa MR (2003). Soil and water losses in different soil tillage systems on a Hapludox under simulated rainfall. R. Bras. C. Solo 27(5):901-909. http://dx.doi.org/10.1590/S0100-06832003000500015

Oliveira JR, Pinto MF, Souza W, Guerra JGM, Carvalho DF (2010). Water erosion in a Yellow-Red Ultisol under different patterns of simulated rain. Rev. Bras. Eng. Agríc. Amb. 14(2):140–147. http://dx.doi.org/10.1590/S1415-43662010000200004

Panachuki E, Bertol I, Alves Sobrinho T, Vitorino ACT, Souza CMA, Urchei MA (2010). Soil surface roughness under different management systems and artificial rainfall. R. Bras. Ci. Solo 34(2):443-451. http://dx.doi.org/10.1590/S0100-06832010000200018

Reinert DJ, Albuquerque JA, Reichert JM, Aita C, Andrada MMC (2008). Bulk density critical limits for normal root growth of cover crops. R. Bras. Ci. Solo 32:1805-1816. http://dx.doi.org/10.1590/S0100-06832008000500002

Schick J, Bertol I, Batistela O, Balbinot Júnior AA (2000). Water erosion in clayey inceptisol in different crop and tillage systems: I. Soil and water losses. R. Bras. Ci. Solo 24:427-436. http://dx.doi.org/10.1590/S0100-06832000000200019

Stavi I, Lal R (2011). Loss of soil resources from water-eroded versus unerod cropland sites under simulated rainfall. Soil .Use. Manage. 27(1):69-76. http://dx.doi.org/10.1111/j.1475-2743.2010.00312.x

Tavares Filho J, Feltran CTM, Oliveira JF, Almeida E, Guimarães MF (2012). Important soil attributes for estimating the aggregate stability index. Pesq. Agropecu. Bras. 47(3):436-441. http://dx.doi.org/10.1590/S0100-204X2012000300016

Valipour M (2014). Land use policy and agricultural water management of the previous half of century in Africa. Applied Water Science. http://dx.doi.10.1007/s13201-014-0199-1

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Full Length Research Paper

Biomass yield and partitioning of greenhouse-grown wild watermelon *Cucumis africanus* in response to different irrigation intervals and NPK fertilizer levels

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A study was conducted during the 2009-2010 summer growing season to determine the effects of varying irrigation frequencies and NPK application rate on biomass yield and partitioning to fractions of Cucumis *africanus*. The experiment was laid out in a split-plot design arrangement and replicated three times. Three irrigation frequencies, namely, 2, 4 and 6 days interval, were the main plots and sub-plot treatments were application rates of three NPK fertilizer levels combined in a ratio 3:2:1and a control treatment of 0 Kg NPK ha^{-1}. Total and plant fraction biomass yield were higher in the four day irrigation frequencies and 120-80-40 kg NPK ha^{-}1 fertilizer rate treatment combination. In conclusion, the results indicate that the plant can produce adequately under conditions of limited water supply provided there are supplemental nutrients available.

Key words: Irrigation frequency, biomass yield, root/shoot ratio, ethnobotanicals.

INTRODUCTION

Wild-watermelon *Cucumis africanus*, is a member of the family Cucurbitaceae. Fresh young leaves of the plant are eaten as a pot herb by many people in the rural communities of South Africa. Other research workers found that the leaves are rich in calcium, iron, nicotinic acid and vitamin C. Harvesting for leafy vegetable is usually carried out in the morning to maintain the full rigidity of the leaves and other fleshy parts of the plant. In South African traditional medicine the roots, shoots or fruits of *C. africanus* is used as an emetic, purgative or enema for various ailments. The boiled leaf is used as a poultice and it is also reported that the plant is useful in animal medicine (Botha and Perinth, 2008).

Considering the growing problem of human population explosion and poor nutrition of foods exhibited among developing countries, the use of indigenous leafy vegetable species as high-mineral and vitamin source, as well as high-quality ethnobotanical linctus producer merits greater research (Tilman et al., 2002). As important sources of Vitamin A and other micronutrients indigenous leafy crops including *C. africanus* deserve pride in the rural economy, laboratory and trial fields (Obadai, 2007). Successful indigenous leafy-vegetable technology and transfer into conventional farming system

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depends on the species potential to germinate and emerge in the given soil physical and chemical conditions, as well as the ability of the seedlings to grow and develop (Linnemann and Craufurd, 1994). Seedling growth covers the period in the life cycle of the plant, from emergence of the radicle through the seed coat until the appearance of enough green leaves to make the plant independent of stored energy (Salisbury and Ross, 1992; Hopkins, 1992).

Dry matter partitioning is the end result of a co-ordinated set of transport and metabolic processes governing the flow of assimilates from source organs via a transport path to sink organs (Marcelis et al., 1998). Gardner et al. (1985) refers to the analysis of biomass distribution to different plant fractions as an important tool in order to understand the physiological principles and processes underlying the portioning of minerals and photosynthetic by-products to the nutritionally and economically significant harvestable plant fractions.

Roots are dependent on shoots for carbohydrates, growth regulators, and some other organic compounds and shoots are dependent on roots for growth regulators such as abscisic acid, cytokinins and gibberellins (Kramer and Boyer, 1995). Severe reduction in leaf area by pruning, insect defoliation, grazing, or diversion of food into fruit and seed production is likely to reduce the root growth. In a similar pattern, damage to root system will reduce water and mineral absorption, which in turn inhibits shoot growth (Summerfield et al., 1997).

The root/shoot a ratio which is the relationship between above- and below-ground biomass gives an indication of the functional, hormone-mediated equilibrium that governs the partitioning of assimilates between roots and shoots which know at the core of most models of plant growth (Hunt, 1979). High root/shoot ratios indicate that the plant is partitioning more assimilates to the roots, while lower ones indicate the opposite. There is a pronounced interdependence of roots and shoots and it is suggested that there might be some optimum ratio of roots to shoots (Stoskopf, 1981). However, root-shoot ratios vary widely among species, with age, and with environmental conditions. These variations results in part from the wide variations in water supply and other environmental factors to which plants often are subjected during a particular growing season, as well as to genetic variations among plants such as grasses and root crops. Perhaps the root-shoot ratio should be considered in terms of root and leaf surface, but it is difficult to measure root surface (Tesar, 1984; Mulvaney, 1996; Marcelis, 1996).

The current study seeks to evaluate and determine agronomic performance of traditional leafy-vegetable and ethnobotanical crop *Cucumis africanus* in terms of biomass yield, biomass partitioning to plant fractions and root/shoot ratios as influenced by irrigation water application frequency and NPK fertilizer application rate under greenhouse regime.

MATERIALS AND METHODS

Site specifications

The experiment was conducted at Horticultural Research Facility of University of Limpopo, Limpopo Province, South Africa (23°53'10'' S; 29°44'15'' E) during the 2009-2010 summer growing season. Ambient day/night temperatures averaged 28/21°C, with maximum temperatures controlled using thermostatically-activated fans. Other greenhouse variables such as relative humidity, photosynthetically active radiation and solar radiation were not measured.

Experimental layout and treatments

The experiment was laid out in a split-plot design arrangement and replicated five times. Three irrigation intervals, namely, 2, 4 and 6 days, were accorded as main plots. During each irrigation interval, 1000 ml tap-water was applied per pot. Irrigation water application treatments were applied seven days after transplanting, using the gravimetric method of irrigation requirement. Sub-plot treatments were accorded to varying NPK application rates which were 0 kg NPK ha^{-1}, 60-40-30 kg NPK ha^{-1}, 120-80-60 kg NPK ha^{-1} and 180-120-90 kg NPK ha^{-1}, the rate were interpolated and applied in accordance to pot size.

Experimental procedures

Seedlings were raised in seedling trays using Mafeo and Mashela's method (2009). Thirty-cm-diameter plastic pots, filled with 10 L steam-pasteurised sand and Hygromix (3:1 v/v), were placed on greenhouse benches at 0.5 m inter-row and 0.6 m intra-row spacing. Uniform three-week-old *Cucumis* seedlings (one seedling per pot) were transplanted to the pots one day after irrigating the growing medium to field capacity. The first experiment was harvested at 40 days after transplanting (DAT) and the second at 60 DAT. NPK fertilizer (2:3:2) was given in split doses. First dose was applied at transplanting of seedlings into 30 cm plastic pots, while the second dose was applied 10 days after the first dose and while the remaining dose was given at 20 days.

Cultural practices, data collection and analysis

Agronomic cultural practices of pest control and weed removal were carried out throughout the growing season as recommended. Plants were harvested 40 days after transplanting (40 DAT) to determine vegetative yield responsiveness. The data was recorded using a standard balance scale for biomass yield, leaf, stem and root, root/shoot ratios and productivity score of fresh samples. The samples were later subjected to oven dry at 65°C for 24 h to determine the dry biomass of the same parameters.

The data of all the above mentioned was extrapolated from dry matter g pot^{-1} to kg ha^{-1} and were individually subjected to the analysis of variance techniques and mean comparisons were done using least significance difference (LSD) at 0.05 level of probability (Gomez and Gomez, 1984; Kuehl, 2000).

RESULTS

The results showed that dry biomass yields were influenced ($P < 0.05$) by the interaction between irrigation frequency and NPK fertilizer application rate (Table 1). Irrigation frequency and NPK fertilizer application rate

Table 1. Analysis of variance for biomass yield of *Cucumis africanus* as affected by irrigation interval and NPK application rate at 40 days after transplanting (40 DAT) during the 2009/10 growing season.

Source of variation	Df	Total Biomass yield (kg ha^{-1})	
		SS	%
Replicate (A)	2	66529	1.06
Irrigation (B)	2	845908	13.46
Error (A*B)	4	1464106	23.30
NPK rate (C)	3	216240	3.44
B*C	6	1827770	29.09**
Error (A*B*C)	18	1863054	29.65
Total	35	6283607	100

**Significant (P< 0.05); Df = degree of freedom; SS = sum of squares.

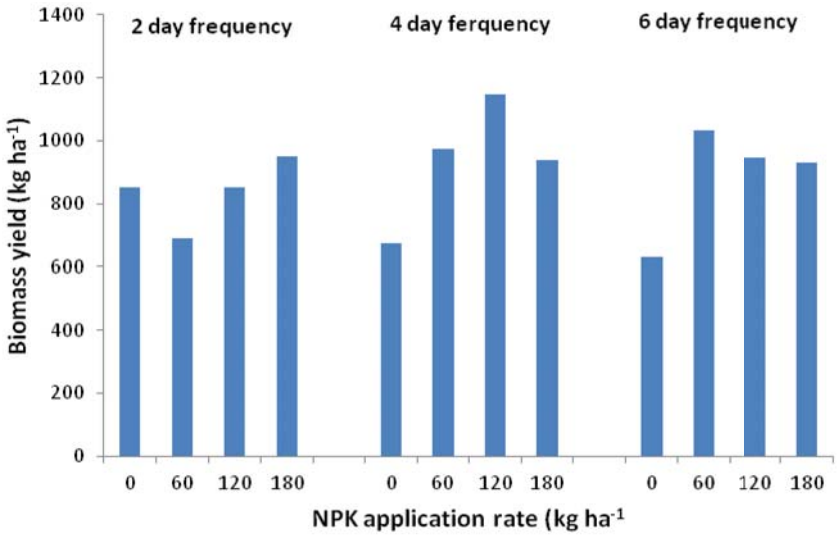

Figure 1. Biomass yield of *C. africanus* as affected by irrigation frequency and rate of NPK application during the 2009/10 summer growing season.

contributed 29% to the total treatment. The highest dry biomass yield was 59% higher than lowest biomass yields (Figure 1).

Significant differences (P< 0.05) were observed on biomass partitioning to stems, leaves and shoots of *C. africanus*, while distribution to roots was non-significant. Stems responded positively to irrigation frequency while leaves responded to NPK fertilizer application rate, both showed response to the interaction between irrigation frequency and NPK fertilizer application rate. Stem biomass was influenced by the interaction between irrigation frequency and NPK application rate which contributed 56% to the total variation (Table 2). The highest stem biomass yields were 414% higher than lowest stem biomass yields (Table 3). NPK application rate contributed 21% while the interaction between irrigation application frequency and NPK application accounted for 30% of the total variation for leaf biomass yields, respectively (Table 2). Leaf biomass yield was 454% higher than lowest yielding treatment (Table 3).

Highly significant (P < 0.01) differences were demonstrated in shoot biomass accumulation in response to irrigation frequency and NPK fertilizer application rate. Interaction between irrigation application frequency and NPK application accounted for 34.69% of the total variation for dry shoot biomass yield, while NPK application rate contributed 15.98% (Table 2). The highest shoot biomass accumulation was 295% higher than lowest yielding treatment (Table 3). Root/shoot ratio showed differences (P < 0.05) as a result of treatment application with NPK fertilizer application rate and the interaction between irrigation frequency and NPK rate contributing 13.6 and 21.76% to total treatment variation, respectively (Table 3).

Table 2. Analysis of variance for biomass partitioning to plant fractions and root/shoot ratios of *Cucumis africanus* as affected by irrigation frequency and NPK application rate during the 2009/10 summer growing season.

Source of variation	Df	Plant fraction (g m^{-2})									
		Roots		Stems		Leaves		Shoot		R:S ratio	
		SS	%	SS	%	SS	%	SS	%	SS	%
Replicate (A)	2	1564.5	6.11	252.2	1.92	1720.0	8.47	2982.0	6.99	1.089	9.79
Irrigation (B)	2	7650.5	29.89^{ns}	1998.9	15.21**	1829.8	9.01	5158.5	12.09	3.523	31.68
Error (A*B)	4	6108.1	23.87	1304.7	9.93	842.9	4.15	2770.2	6.49	1.343	12.08
NPK rate (C)	3	2575.8	10.07^{ns}	356.7	2.71	4241.4	20.88**	6820.2	15.98**	1.508	13.56***
B*C	6	2579.6	10.08^{ns}	7405.1	56.34***	6105.0	30.05**	14811.0	34.69***	2.419	21.76***
Error (A*B*C)	18	5112.0	19.98	1826.7	13.89	5576.1	27.45	10141.7	23.76	1.237	11.13
Total	35	25590.6	100	13144.3	100	20315.1	100	42683.7	100	11.119	100

**Significant (P< 0.05); ***Significant (P< 0.01); Df = degree of freedom; SS = sum of squares; R:S =Root to shoot, ns = non-significant.

Table 3. Biomass partitioning to plant fractions and root/shoot relationships of *Cucumis africanus* as affected by irrigation frequency and NPK application rate at during the 2009/10 summer growing season.

Interval(days)	NPK(kg ha^{-1})	Plant fraction (g m^{-2})				
		Roots	Stems	Leaves	Shoots	Root:Shoot
2	0	19.88b	16.05^{cde}	59.26^{abc}	75.31^{bcdef}	0.316^{b}
	60-40-30	23.58^{b}	13.58^{de}	41.98^{bcde}	55.56^{cdef}	0.244^{b}
	120-80-60	21.11^{b}	25.93^{cde}	48.15^{abcd}	74.07^{bcdef}	0.146^{b}
	180-120-90	24.69^{ab}	24.69^{cde}	45.68^{abcd}	70.35^{bcdef}	0.362^{b}
4	0	49.26^{a}	58.03^{ab}	34.57^{cde}	92.59^{abc}	0.595^{b}
	60-40-30	51.73^{a}	23.46^{cde}	13.35^{e}	35.80^{f}	1.696^{a}
	120-80-60	67.16^{a}	63.58^{a}	74.07^{a}	141.5^{a}	0.475^{b}
	180-120-90	40.62^{ab}	17.28^{cde}	25.93^{de}	43.21^{ef}	1.226^{a}
6	0	28.52^{b}	12.35^{e}	32.10^{cde}	44.44^{def}	0.588^{b}
	60-40-30	27.28^{b}	38.27^{bcd}	67.90^{ab}	106.17^{ab}	0.165^{b}
	120-80-60	26.05^{b}	61.73^{a}	72.84^{a}	133.57^{a}	0.119^{b}
	180-120-90	40.62^{ab}	40.74^{bc}	41.98^{bcde}	82.72^{bcde}	0.580^{b}

Column means with the same letter were not different at 5% level according to the LSD test. ns = none significant. LSD = Least significant difference.

DISCUSSION

Adequate biomass supply of indigenous crops such as *C. africanus* are required for both consumption as a leafy vegetable and use as ethnobotanicals in many rural areas of developing regions (Jansen van Rensburg et al., 2007; Ndlovu and Afolayan, 2008;). The results of the study show that by applying intermediate irrigation frequency and NPK rate substantially high amounts of fresh and dry biomass yields of *C. africanus* that are required by the rural populace can be achieved. Consequently, with the advent of escalating water shortages (Auwalu and Babatunde, 2007) and lack of inorganic fertilizer-inputs supplies (Atta et al., 2011) in rural communities it can be deduced from the above findings that smallholder farmers can produce *C. africanus* with infrequent irrigation episodes and minimal nutrient inputs applications. An additional benefit to diets of indigenous leafy vegetables consumers is that it is reported by several workers that they can contribute with significant amounts of vitamins and minerals, and are especially excellent sources of protein, carotene, iron and ascorbic acid (Van Soest et al., 1997; Luyen and Preston, 2004); an attribute that can greatly assist in the fight against the hidden hunger prevalent in many rural areas.

In our study partitioning of biomass to roots, stems and leaves, was found to be significantly influenced by irrigation frequency and NPK rate at intermediate levels of application. These results agrees with findings by several workers on other vegetable crops, Erdem et al. (2001) in watermelon, Waseem et al. (2008) in cucumber, Khan et al. (2005) in bell pepper, van Averbeke et al.

(2007) in *Brassica rapa* L. subsp. *Chinensis* and *Solanum retroflexum* Dun. In contrast, Sensoy et al. (2007) found good responses with treatments employing greatest frequency and quantity of irrigation in field-grown melon and Singh et al. (2009) found that NPK dose above the recommended was required to minimize the adverse impacts of nutrient shortages in cropping systems.

In this study, highly significant (P≤ 0.05) variances were observed for root/shoot ratio. Applying irrigation at four day frequency and 60-40-30 NPK kg ha^{-1} rate produced the highest root/shoot ratio which was 92.98% higher than the lowest root/shoot ratio, an indication that in this treatment more assimilates where to the roots (Gardner et al., 1985; Hopkins, 1992; Prusinkiewicz, 2004). The lowest root/shoot ratio was given by irrigating on a six day frequency basis and applying 120-80-60 NPK kg ha^{-1} which supported production of above-ground portions as opposed to the below ones. Nonetheless, these treatments were not superior in terms of total and plant fraction biomass yield.

Conclusion

The results of the study showed significant influences that varying irrigation water application frequencies and NPK fertilizer application rates has on biomass yield and portioning, as well as the relationship between the above- and below-ground plant parts. The highest *C. africanus* plant fraction harvest of stem (61.73 g m^{-2}); leaf (72.84 g m^{-2}) and shoot (143.57g m^{-2}) were obtained in the four day irrigation interval and fertilizer combination of 120-80-40 kg NPK ha^{-1} rate. A crop biomass harvest under these conditions produced fresh and dry biomass yields of correspondingly 2049.4 and 1506.2 kg ha^{-1}.

Conflict of Interest

The author(s) have not declared any conflict of interest.

REFERENCES

Atta S, Seyni HH, Bakasso Y, Sarr B, Lona I, Saadou M (2011). Yield character variability in Roselle (*Hibiscus sabdariffa* L.). Afr. J. Agric. Res. 6(6):1371-1377.

Auwalu BM, Babatunde FE (2007). Analysis of growth, yield and fertilization of vegetable Sesame (*Sesamum radiatum* Schum). J. Plant Sci. 2(1):108-112.

Erdem Y, Yűksel AN, Orta AH (2001). The effects of deficit irrigation on watermelon yield, water use and quality characteristics. Pak. J. Biol. Sci. 4(7):785-789.

Gardner FP, Pearce RB, Mitchell RL (1985). Physiology of crop plants. Iowa state university press: Ames pp. 187-209.

Gomez KA, Gomez AA (1984). Statistical procedures for agricultural research 2nd ed. John Wiley & Sons, New York. pp. 146-184.

Hopkins WG (1992). Introduction to Plant Physiology. John Wiley & sons, Inc.: New York pp. 176-189.

Hunt R (1979). Plant growth analysis: The rationale behind the use of the fitted mathematical function. Ann. Bot. 43:245-249.

Khan MH, Chattha TH, Saleem N (2005). Influence of different irrigation intervals on growth and yield of bell pepper (*Capsicum annuum* Grossum Group). Res. J. Agric. Biol. Sci. 1(2):125-128.

Kramer PJ, Boyer JS (1995). Water Relations of Plants. Academic Press: London pp. 158-184.

Kuehl RO (2000). Design of experiments: statistical principles of research design and analysis 2nd ed. Duxbury press, New York. pp. 173-184.

Linnemann AR, Craufurd PQ (1994). Effects of temperature and photoperiod on phenological development in three genotypes of bambara groundnut (*Vigna subterranean*). Ann. Bot. 74:675-681.

Mafeo TP, Mashela PW (2009). Responses of germination in tomato, watermelon and butternut squash to Cucumis bio-nematicide. J. Agric. Environ. Sci. 6:215-219.

Mulvane RL (1996). Nitrogen — Inorganic Forms. In: Sparks D.L. (ed.). Methods of Soil Analysis. Part 3.Chemical Methods. Madison: WI pp. 1-12.

Ndlovu J, Afolayan AJ (2008). Nutritional analysis of the South African wild vegetable *Corchorus olitorius* L. Asian J. Plant Sci. pp. 1-4.

Prusinkiewicz P (2004). Modeling plant growth and development. Cur. Opin. Plant Biol. 7(1):79−83.

Salisbury FB, Ross CW (1992). Plant Physiology, Wadsworth Publishing Company, Belmont, California pp. 126-147.

Sensoy S, Ertek A, Gedik I, Kucukyumuk C (2007). Irrigation frequency and amount affect yield and quality of field-grown melon (*Cucumis melo* L.). Agric. Water Manage. 88:269-274.

Singh S, Kumari R, Agrawal M, Agrawal SB (2009). Modification of growth and yield responses f *Amaranthus tricolor* L. to sUV-B under varying mineral nutrient supply. Sci. Hortic. 120:173-180.

Stoskopf NC (1981). Understanding crop production. Reston publishers Co., Inc.: Reston, Virginia pp. 46-108.

Summerfield RJ, Dart PJ, Huxley PA, Eaglesham ARJ, Minchin FR, Day JM (1997). Nitrogen nutrition of cowpea (*Vigna unguiculata*) I. Effects of applied nitrogen and symbiotic nitrogen fixation on growth and seed yield. Exp. Agric. 13:129-142.

Tesar MB (1984). Physiological basis of crop growth and development.American Soc. Agron., Inc., & Crop Sci. Soc. America, Inc. Madison, Wisconsin, USA. pp. 134-160.

Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S (2002). Agricultural sustainability and intensive production practices. Nature 418:671-677.

van Averbeke W, Juma KA, Tshikalange TE (2007). Yield response of African leafy vegetables to nitrogen, phosphorus and potassium: The case of *Brassica rapa* L. subsp. chinensis and *Solanum retroflexum* Dun. Water SA. 33:355-362.

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Response of vegetative yield characters and yield of biomass fractions of wild-watermelon *Cucumis africanus* to irrigation interval and NPK fertilizer

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Wild-watermelon, *Cucumis africanus,* is among important indigenous crop plants in rural Limpopo Province of South Africa, primarily used as an ethno-botanical crop and a leafy green vegetable. An experiment laid out in a split-plot design and replicated five times was conducted at the Horticultural Research Unit, University of Limpopo, South Africa. The objective was to study the effects of irrigation frequency (2, 4 and 6 day interval) and fertilizer application rate of nutrient mixture containing nitrogen, phosphorus and potassium (NPK) (0 Kg NPK ha^{-1}, 60-40-20 kg NPK ha^{-1}, 120-80-40 kg NPK ha^{-1} and 180-120-60 kg NPK ha^{-1}) on leaf and non-leaf yield characters of *C. africanus*. The treatment of four day irrigation interval and 120-80-40 kg NPK ha^{-1}application rate produced significantly higher ($P \leq 0.05$) vegetative yield characters and biomass of plant fractions than the extreme treatments of short two day irrigation intervals and low 60-40-20 kg NPK ha^{-1}; and long six day irrigation intervals and 180-120-60 kg NPK ha^{-1}. In conclusion, the results of the study indicate that *C. africanus* can be successfully grown using conventional production methods and supply rural households with good yields of a leafy green vegetable as well as providing raw materials needed for ethno-botanical purposes.

Key words: Leafy vegetable, leaf yield characters, root/shoot ratio, ethno-medicine.

INTRODUCTION

Cucumis africanus is an indigenous plant of which the leafy parts are used as vegetables while the remaining parts, stems and roots, are used in ethno-medicine, thereby utilizing the whole plant. There are numerous varied species of indigenous plants used as food and for ethno-medicinal purposes in many rural areas of South Africa (Wehmeyer and Rose, 1983; Van Wyk and Gericke, 2000; Jansen van Resnsburg et al., 2007). Other workers have also found indigenous plants to be an important source of nutrients and vitamins for the rural population (Flyman and Afolayan, 2006). Rural farming communities have cultivated and collected these indigenous plants for generations as an additional food source. Many of these species are not readily amenable

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to conventional agronomic studies as often they are grown in small patches in home gardens (Jansen van Resnsburg et al., 2007; Faber et al., 2010). The indigenous plants of African tradition are being displaced in many areas, leading to a decline in production, use, and diversity of vegetables being grown (Seeiso and Materechera, 2011). Natural selection and farmer-based breeding practices have developed the genetic base of the most important vegetables, but the lack of attention by research and development is leading to the under-exploitation of these vegetables (Misra et al., 2008). The scenario thus far described encourages continuing genetic erosion, and further restricting the development options for the rural poor. This trend will clearly have a detrimental impact on the nutritional status of households, and the incomes of women farmers, in particular, who constitute the primary producers, consumers, and sellers of these vegetables (Smith and Eyzaguirre, 2007). Crucially, from a national and cultural standpoint, these vegetables constitute a most valuable natural resource that needs to be preserved. In recent decades there has been formal research by national agricultural research programmes and international research organizations on cultivation methods of traditional vegetables to improve their yield. Despite this fact responses of many indigenous crops to conventional method of production such as irrigation and fertilizer application are still not yet thoroughly exploited by researchers. Thus, given the role played by indigenous crop plants studies on conventional ways of their production needs urgent attention. The current study seeks to investigate the effect of irrigation and NPK fertilizer application on yield characters that contribute to total plant fraction biomass. These characters are among important determinants of overall plant suitability and compatibility for food and medicinal use. Plants that encounter limited nutrients or water supply are expected to partition more biomass to their roots and less to their stems and leaves.

MATERIALS AND METHODS

Site specifications

Experiments were conducted at Horticultural Research Facility of University of Limpopo, Limpopo Province, South Africa (23˚53'10'' S; 29˚44'15'' E) during the 2009 to 2010 summer growing season. Ambient day/night temperatures averaged 28/21°C, with maximum temperatures controlled using thermostatically-activated fans.

Experimental layout and treatments

An experiment was laid out in a split-plot design arrangement and replicated three times. Three irrigation intervals, namely, 2, 4 and 6 days, were accorded as main plots. During each irrigation interval, 1 000 ml tap-water was applied per pot. Irrigation water application treatments were applied seven days after transplanting. Sub-plot treatments were accorded to varying NPK application rates which were 0 Kg NPK ha^{-1}, 60-40-20 NPK kg ha^{-1}, 120-80-40 NPK ha^{-1} and 180-120-60 NPK ha^{-1}.

Experimental procedures

C. africanus seedlings were raised from seeds collected in the wild by rural women from the Sekhukhune area of the Limpopo Province. Seeds were put in seedling trays filled with Hygromix and irrigated daily until the three leaf stage. Uniform three-week-old *Cucumis* seedlings were transplanted to the pots one day after irrigating the growing medium to field capacity. Thirty centimetre diameter plastic pots, filled with 10 L steam-pasteurised sand and Hygromix (3:1 v/v), were placed on greenhouse benches at 0.5 m inter-row and 0.6 m intra-row spacing. NPK fertilizer (2:3:2) was given in split doses. First dose was applied at transplanting of seedlings into 30 cm plastic pots, while the remaining dose was applied in split applications of equal amounts at 7 and 14 days after the first application.

Data collection

At 40 days after transplanting (40 DAT) plants were harvested. Above- and below-ground plant parts were separated into roots, stems and leaves. Sample pots were emptied and roots carefully separated from the soil mixture using a gentle stream of water. Canopy area was measured using canopy area meter (LI-3100C, LI-COR, Bioscience, Lincoln, NE 68504 USA) and then fresh root, stem and leaf weights were determined using a standard balance scale. The collected data was recorded for the following leaf analysis characters: leaf biomass, shoot biomass, leaf length, Leaf width and canopy area; non-leaf yield characters: root biomass, stem biomass, main vine length, lateral vine length, lateral vine number and root length; and root/shoot ratio.

Data analysis

Analysis of variance of data measured was done using the general linear models procedure of STATISTIX 9 for Split-plot design. Means were separated using Fisher's least significant difference procedure at 0.05 level of probability (Steel and Torrie, 1980; Gomez and Gomez, 1984; Kuehl, 2000). When treatments were significant sum of squares were partitioned to determine the percentage contribution of source of variation to the total treatment variation (Little and Hills, 1981). Percentage increases in yield characters were computed by subtraction the lowest value from the highest and the dividing the result by the lowest value.

RESULTS

Vegetative yield characters of canopy area, leaf length and leaf width were significantly ($P \leq 0.05$) influenced by irrigation frequency and NPK fertilizer application rate, while leaf width was not significant (Table 1). Irrigation contributed 20.8 and 19.8% to variations in canopy area and leaf length, while the interaction between NPK rate and irrigation frequency contributed 30 and 33% to total variation, respectively. The biggest canopy area was 57% bigger than smallest area, while the longest leaf length was 47.5% longer than the shortest leaf length (Table 2). Canopy area ranged from 123.95 to 314.69 mm^2 in the four day irrigation interval with 0 and 120-80-40 kg ha^{-1} NPK fertilizer application, respectively. The ranges in leaf

Table 1. Analysis of variance for Leaf yield characters of *C. africanus* as affected by irrigation frequency and NPK application rate at 40 days after transplanting (40 DAT) during the 2009/2010 growing season.

Source of variation	DF	Leaf yield characters					
		Canopy area (mm^2)		Leaf length (mm)		Leaf width (mm)	
		SS	%	SS	%	SS	%
Replicate (A)	2	18708	9.04	255.61	8.06	2.220	7.63
Irrigation (B)	2	7427	3.59ns	126.82	3.99ns	2.042	7.01ns
Error (A*B)	4	21157	10.22	264.89	8.35	3.228	11.09
NPK rate (C)	3	42988	20.77**	622.66	19.63**	5.081	17.45ns
B*C	6	62554	30.22**	1045.85	32.97**	4.901	16.84ns
Error (A*B*C)	18	54130	26.15	856.36	26.99	11.64	39.99
Total	35	206964	100	3172.19	100	29.11	100

** Significant (P< 0.05), DF=degree of freedom, SS=sum of squares, ns = non-significant.

Table 2. Leaf yield characters of *Cucumis africanus* as affected by irrigation frequency and NPK application rate at 40 days after transplanting (40 DAT) during the 2009/10 growing season.

Interval (Days)	NPK rate (kg ha^{-1})	Leaf yield characters		
		Canopy area	Leaf length	Leaf width
		mm^2	---------- mm ----------	
2	0	213.12^{bc}	19.33^{abcd}	4.967^{abc}
	60-40-20	136.02^{c}	12.03^{bcd}	4.233c
	120-80-40	185.36^{bc}	16.83^{bcd}	5.033^{abc}
	180-120-60	205.99^{b}	21.27^{abc}	4.900^{abc}
4	0	123.95^{c}	7.50^{d}	4.633^{bc}
	60-40-20	234.12^{b}	24.97^{ab}	5.233^{abc}
	120-80-40	314.69^{a}	32.40^{a}	6.033^{a}
	180-120-60	208.27^{bc}	20.83^{abc}	5.067^{abc}
6	0	145.29^{c}	12.83^{bcd}	4.267^{c}
	60-40-20	256.83^{ab}	23.90^{ab}	5.900^{ab}
	120-80-40	265.72^{ab}	24.33^{ab}	5.967^{ab}
	180-120-60	149.45^{c}	9.03^{cd}	5.167^{abc}

Column means with the same letter were not different at 5% level according to the least significant difference (LSD) test.

length and width were respectively 7.5 mm at 4 day interval and 0 NPK to 32.4 mm at 4 day interval and 120-80-40 kg ha^{-1} NPK and 4.233 mm at 2 day interval and 60-40-20 kg ha^{-1} NPK to 6.033 mm at 4 day interval and 120-80-40 kg ha^{-1} NPK.

Non leaf-based yield characters of lateral vine length and root length of *C. africanus* were significantly ($P \leq 0.01$) affected by NPK fertilizer application rate, while the interaction between irrigation interval and NPK fertilizer application rate was only significant ($P \leq 0.01$) on lateral vine length. Main vine length and number of lateral vines exhibited non-significant variances ($P \leq 0.05$) in response to irrigation frequency and NPK fertilizer application rate treatments (Table 3). NPK fertilizer application rate contributed corresponding 14.6 and 29.6% to total treatment variation in lateral vine length and root length. Treatment interaction between irrigation interval and NPK rate contributed 31.8% to total treatment variation on lateral vine length. The longest lateral vines and roots of respectively 93.67 and 53.33 cm were obtained when 6 day interval and 60-40-20 kg ha^{-1} NPK and 4 day interval and 120-80-40 kg ha^{-1} NPK were applied (Table 4).

Biomass yields of plant fractions, roots, stems, leaves and shoots, and the ratio of roots to shoots showed varied ($P \leq 0.01$ and $P \leq 0.05$) differences in response to the Treatments. Roots responded to the treatment interaction which contributed 35.78% to treatment variation, stems responded positively irrigation which contributed 6.11 to total variation in treatment, leaves and shoot yields responded to NPK application and treatment interaction both being responsible for respectively 16.77 and 35.86% of variation in treatments in leaves and 16.09

Table 3. Analysis of variance for Non-leaf yield characters of *C. africanus* as affected by irrigation frequency and NPK application rate at 40 days after transplanting (40 DAT) during the 2009/10 growing season.

Source of variation	DF	Non-leaf yield characters							
		Main vine length		Lateral vine length		Root length		No. vines/plant	
		SS	%	SS	%	SS	%	SS	%
Replicate (A)	2	1923.70	2.7	2809.4	15.1	86.220	2.0	0.167	0.73
Irrigation (B)	2	14597.6	20.6^{ns}	2527.4	13.5ns	522.72	11.9ns	0.500	2.17^{ns}
Error (A*B)	4	10967.8	15.4	1884.6	10.1	191.28	4.4	5.333	23.19
NPK rate (C)	3	6823.20	9.6^{ns}	2720.2	14.6***	1300.3	29.6***	3.667	15.94^{ns}
B*C	6	16323.1	23.0^{ns}	5935.9	31.8***	827.28	18.8^{ns}	0.833	3.62^{ns}
Error (A*B*C)	18	20393.2	28.7	2777.3	14.9	1461.2	33.3	12.50	54.35
Total	35	71028.6	100	18654.9	100	4388.9	100	23.00	100

***Significant (P< 0.01), ** Significant (P< 0.05), DF=degree of freedom, SS=sum of squares, ns = non-significant.

Table 4. Non-leaf yield characters of *Cucumis africanus* as affected by irrigation frequency and NPK application rate at 40 days after transplanting (40 DAT) during the 2009/10 growing season.

Interval (Days)	NPK rate (kg ha^{-1})	Non-leaf yield characters			
		Main vine	Lateral	Root length	No. vines
		---------- cm ----------			
2	0	90.00	42.67^{c}	32.67^{bc}	2.00
	60-40-20	85.33	44.00^{c}	32.33^{bc}	2.67
	120-80-40	104.7	40.00^{c}	50.00^{a}	1.67
	180-120-60	77.33	33.00^{c}	28.67^{c}	1.33
4	0	82.33	35.33^{c}	31.33^{bc}	1.67
	60-40-20	133.7	50.00^{c}	45.33^{ab}	2.00
	120-80-40	158.7	82.00^{ab}	53.33^{a}	1.33
	180-120-60	140.7	52.00^{c}	32.67^{bc}	1.67
6	0	112.0	41.33^{c}	25.67^{c}	2.00
	60-40-20	156.3	93.67^{a}	27.33^{c}	2.33
	120-80-40	95.67	47.00^{c}	34.33^{bc}	1.67
	180-120-60	174.7	56.33^{bc}	38.00^{abc}	1.67
		ns			ns

Column means with the same letter were not different at 5% level according to the least significant difference (LSD) test.

and 33.58 of treatment variation in shoots. The ratio of roots to shoot responded positively to irrigation interval which contributed 19.12% of variation in treatments (Table 5). The highest and lowest plant fraction biomass yields ranged from 65.4 to 213.5 g m^{-2} in roots, 358 to 843.2 g m^{-2} in stems, 251.9 to 992.6 g m^{-2} in leaves and 610 to 1835.8 g m^{-2} in shoots (Table 6).

DISCUSSIONS

Since antiquity to date useful plants have been handled by human societies for medicinal and food purposes. The need for conservation of genetic resources, mostly those of wild relatives of crop plants, which can be useful in case of genetic erosion or for crop improvement, is the driving force behind our interest of studying the wild food plants. *C. africanus* is a multipurpose crop plant with all plant fractions used. The leaves are used as a vegetable, while roots, stems as well as leaves have ethno-medicinal functions (Brandt and Muller, 1995). Thus, for *C. africanus* to be able to fulfil these multi-purpose functions good vegetative yield characters and biomass yields of plant fractions must be produced in sufficient amounts. The exploration of producing these indigenous crop plant using conventional methods of irrigation and fertilizers can yield significant production potentials in smallholder farming systems. In the study the intermediate treatment of four day irrigation interval and 120-80-40 kg NPK ha^{-1}application rate produced significantly higher (P ≤ 0.05) vegetative yield characters than the extreme treatments of short two day irrigation

Table 5. Analysis of variance for fresh biomass yield of plant fractions and root/shoot ratios of *C. africanus* as affected by irrigation interval and NPK application rate at 40 days after transplanting (40 DAT) during the 2009/2010 summer growing season.

Source of variation	Df	Plant fraction (g m^{-2})									
		Roots		Stems		Leaves		Shoot		R:S ratio	
		SS	%	SS	%	SS	%	SS	%	SS	%
Replicate (A)	2	28562	27.33	142136	10.28	225561	9.30	725563	10.23	0.006	8.82
Irrigation (B)	2	2654	2.54	84466	6.11***	149285	6.16	415860	5.87	0.013	19.12**
Error (A*B)	4	2193	2.09	8966	0.65	108182	4.46	168888	2.38	0.003	4.41
NPK rate (C)	3	10026	9.59	206979	14.97	406811	16.77**	1141275	16.09**	0.012	17.65
B*C	6	37388	35.78***	392273	28.37	869727	35.86**	2380591	33.58**	0.008	11.76
Error (A*B*C)	18	23676	22.66	547727	39.62	665690	27.45	2257464	31.84	0.024	35.29
Total	35	104499	100	1382546	100	2425257	100	7089642	100	0.068	100

** Significant (P< 0.05), *** Significant (P< 0.01), Df=degree of freedom, SS=sum of squares, R:S=Root to shoot, ns=non-significant.

Table 6. Fresh biomass yield of plant fractions and root/shoot relationships of *C. africanus* as affected by irrigation interval and NPK application rate at 40 days after transplanting (40 DAT) during the 2009/2010 summer growing season.

Interval (Days)	NPK rate (kg ha^{-1})	Plant fraction (g m^{-2})				
		Roots	Stems	Leaves	Shoots	Root:Shoot
2	0	162.96^{ab}	564.20^{bcd}	648.15^{bc}	1212.3^{bcd}	0.139^{abc}
	60-40-20	111.11^{bcd}	496.30^{cd}	513.58^{bcd}	1009.9^{bcd}e	0.110^{bc}
	120-80-40	162.96^{ab}	535.80^{bcd}	504.94^{bcd}	1040.7^{bcd}e	0.156^{ab}
	180-120-60	134.57^{bc}	459.26^{cd}	402.47^{bcd}	861.70^{cd}e	0.153^{ab}
4	0	65.430^{d}	358.02^{d}	251.85^{d}	609.90e	0.106^{bc}
	60-40-20	108.64^{bcd}	681.48^{abc}	735.80^{ab}	1417.3^{abc}	0.079^{c}
	120-80-40	213.58^{a}	843.21^{a}	992.59^{a}	1835.80^{a}	0.114^{bc}
	180-120-60	106.17^{bcd}	634.57^{abcd}	501.23^{bcd}	1135^{bcd}e	0.098^{bc}
6	0	112.35^{bcd}	464.20^{cd}	455.56^{bcd}	919.80^{bcd}e	0.135^{abc}
	60-40-20	154.32^{abc}	779.01^{ab}	716.05^{ab}	1495.1^{ab}	0.0103^{bc}
	120-80-40	98.770^{cd}	477.78^{cd}	370.37^{cd}	848.10^{cd}e	0.122^{bc}
	180-120-60	139.51^{bc}	470.37^{cd}	319.75^{cd}	790.10e	0.196^{a}

Column means with the same letter were not different at 5% level according to the LSD test. ns = none significant. LSD = Least significant difference.

intervals and low 60-40-20 kg NPK ha^{-1}; and long six day irrigation intervals and 180-120-60 kg NPK ha^{-1}. This was shown by leaf morphological characters of larger canopy area, longer leaf length and wider leaf width, which are good required for photosynthetic assimilates production

and nutrient absorption; thereby yielding of good quality crop. Other workers confirmed that water and nutrient application promote yield in various vegetables, Jefferson (2005) in timothy (*Phleum pratense* L.) cultivars, Li et al. (2008) in leguminous shrub (*Bauhinia faberi* var. *microphylla*), Jilani et al. (2009) in cucumber, Singh (2009) in *Amaranthus tricolor* L., Okorogbona et al. (2011) in Chinese cabbage (*Brassica rapa* L. subsp. *chinensis*), Gupta et al. (2011) in black henbane (*Hyoscyamus niger* L.), Deivasigamani and Thanunathan (2011) in glory lily (*Gloriosa superba* L.). The intermediate category produced higher fresh biomass yields of roots, stems, leaves and shoots, as well as longer root length. In addition, these results indicate that *C. africanus* can be successfully grown using conventional methods to promote food security and help in the fight against the 'hidden hunger', a condition characterized by micro-nutrient deficiencies which are contained in significant amounts in indigenous crop plants (Flyman and Afolayan, 2006). According to several informants wild green leafy vegetables increase the amount of blood in the body which is likely to refer to the high iron content of many wild greens (Misra et al., 2008). However, chemical analyses were beyond the scope of this study, and therefore, the information on the nutrient contents is entirely based on literature. The potential effect of African leafy vegetables on the nutritional status of a particular population will depend, among other things, on the species that are geographically and seasonally available; the species that are known and socio-culturally acceptable or popular as food; and the frequency of consumption and the amount consumed. Most of these traditional leafy vegetables have a potential for income generation but fail to compete with exotic vegetables at present due to lack of awareness. Consumption of traditional diets known to these societies are said to have many beneficial effects such as prevention of some age related degenerative diseases – arteriosclerosis, stroke, etc. (Jansen van Resnsburg et al., 2007). Despite these advantages, most traditional plant foods are generally uncultivated and underutilized.

Conclusion

The intermediate treatment of four day irrigation interval and 120-80-40 kg NPK ha^{-1}application rate ranked superior among the treatments in the study, producing larger canopy area, longer leaf length, wider leaf width, longer root length and higher fresh biomass yields of roots, stems, leaves and shoots. The results of the study indicate that *C. africanus* can be successfully grown using conventional methods for production of leafy greens and provide raw materials needed to produce ethno-botanicals to promote food security and sustainable rural livelihoods. However, more research work still needs to be conducted to determine the effects of water and nutrients on nutritional composition of various plant fractions of *C. africanus* and assessment of its potential use in intercropping with staple cereal crops such as maize, sorghum and pearl-millet.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Brandt HD, Muller GJ (1995). Traditional medicines and acute poisoning. CME 13:1053-1060.

Deivasigamani S, TThanunathan K (2011). Integrated nutrient management for glori lily (*Gloriosa superba* L.). J. Med. Arom. Plants 2(1):6-9.

Faber M, Oelofse A, van Jaarsveld PJ, Wenhold FAM, Jansen van Rensburg WS (2010). African leafy vegetables consumed by households in the Limpopo and KwaZulu-Natal. S. Afr. J. Clin. Nutr. 23(1):30-38.

Flyman MV, Afolayan AJ (2006). The suitability of wild vegetables for alleviating human dietary deficiencies. Botany 72:492-497.

Gomez KA, Gomez AA (1984). Statistical procedures for agricultural research 2nd ed. John Wiley & Sons, New York., pp. 146-184.

Gupta AK, Pandey CS, Kumar V, Kumar J (2011). Effect of integrated nutrient management on herbage yield of black henbane (*Hyoscyamus niger* L.). J. Med. Arom. Plants 2(1):10-14.

Jansen van Rensburg WS, van Averbeke W, Slabbert R, Faber M, van Jaarsveld P, van Heerden I, Wenhold F, Oelofse A (2007). African leafy vegetables in South Africa. Water SA. 33(3):317-326.

Jefferson PG (2005). Leaf and stem nutritive value of timothy cultivars of different maturity at an irrigated site in south-western Saskatchewan. Can. J. Plant Sci. 85:377-383.

Jilani MS, Bakar A, Waseem K, Kiran M (2009). Effect of different levels of NPK on the growth and yield of cucumber (*Cucumis sativus*) under the plastic tunnel. J. Agric. Soc. Sci. 5(3):99-101.

Kuehl RO (2000). Design of experiments: statistical principles of research design and analysis 2nd ed. Duxbury press, New York. pp. 173-184.

Li F, Bao W, Wu N, You C (2008). Growth, biomass partitioning, and water-use efficiency of a leguminous shrub (*Bauhinia faberi* var. *microphylla*) in response to various water availabilities. New Forests 36:53-65.

Little TM, Hills FJ. (1981). Statistical methods in agricultural research. University of California, California pp. 350-356.

Misra S, Maikhuri RK, Kala CP, Rao KS, Saxen KG (2008). Wild leafy vegetables: A study of their subsistence dietetic support to the inhabitants of Nanda Devi Biosphere Reserve, India. J. Ethnobiology Ethnomedicine 8:4-15.

Okorogbona AOM, Van Averbeke W, Ramusandiwa TD (2011). Growth and yield response of Chinese cabbage (*Brassica rapa* L. subsp. *chinensis*) as affected by nutrient availability in air-dried and pulverized different types of animal manure using low biological activity soil. World J. Agric. Sci. 7(1):1-12.

Seeiso TM, Materechera SA (2011). Effects of seed sowing depth on emergence and early seedling development of two African indigenous leafy vegetables. Life Sci. J. 8(2):12-17.

Singh S, Kumari R, Agrawal M, Agrawal SB (2009). Modification of growth and yield responses of *Amarantthus tricolor* L. to sUV-B under varying mineral nutrient supply. Sci. Hortic. 120:173-180.

Smith IF, Eyzaguirre P (2007). African leafy vegetables: their role in the world health organization's global fruit and vegetables initiative. Afr. J. Food Agric. Nutr. Dev. 7(3):1-17.

Steel RGD, Torrie JH (1980). Principles and procedures of statistics. 2nd ed. McGraw- Hill, New York.

Van Wyk BE, Gericke N (2000). People's plants. A guide to the useful plants of southern Africa. Pretoria: Briza Publications P. 349.

Wehmeyer AH, Rose E (1983). Important indigenous plants in the Transkei as food supplements. Bothalia 14:613–615.

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Population, production and improvement of local fowl of southern Nigeria ecotype

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There is paucity of data on local fowls' production in Southern Nigeria. The population and identity of the farmers involved in raising the fowl is lacking. Studies were carried out in the areas that covered Anambra, Oyo and Imo States to ascertain the population, production and improvement of the local fowl. In six hundred households in Anambra State the population of local birds was 4,971. These consisted of 911 (Chicks), 1073 (Growers), 1278 (Cocks) and 1709 (Hens), respectively. Imo State in 6 local government areas (LGAs), 300 households had 2032 local birds comprising 394 (Cocks), 614 (Hens), 478 (Growers) and 546 (Chicks) while in Oyo North LGA feeding trials were conducted to determine nutrient requirements of the fowl. Shank lengths and egg quality showed variations (P<0.05) in different localities. A standard energy and protein levels of 2,700 kcalME/kg of feed and 22% crude protein (CP) at chick phase and 3,000 kcalME/kg of feed and 17% CP at grower phase, respectively, were established for the fowl. Also feed additives such as antibiotics, *prebiotics* and *probiotics* used as growths promoters were assessed. Antibiotics did not show any positive pattern of growth promotion while the *prebiotics* and *probiotics* enhanced performance of local fowl. Plantain peels meal fed at early phase of life moderately enhanced performance of the fowl. To bridge the animal protein deficit in the nutrition of rural populace, local fowl can be used but after improvement of the fowl to commercial birds.

Key words: Local fowl, South Nigeria ecotype, population, production and performance.

INTRODUCTION

The system of managing the local fowl in Nigeria is still the traditional house holder reared mostly by women in a range system where the flocks are allowed to roam in order to feed. The birds appear to be generally heterogeneous with no specific color pattern and non-descriptive both in phenotype and genotype. They have been characterized as hardy highly adapted to the harsh hot and humid native environment (Nwakpu et al., 1999). Some local birds seen in villages may have been crossed with exotic cocks in earlier years through the cockerel exchange programme among others, but such genes may have been dispersed and lost in the population because of unplanned breeding and absence of selection. Thesaurus defined domestic fowl as domesticated gallinaceous bird thought to be descended from the red jungle fowl.

In Nigeria, local fowls are indigenous unselected population of domestic birds that inhabit mostly rural parts of the country. From studies (Ezeokeke and Iyayi, 2001; Ezeokeke, 2008) this stock has not been crossed bred with imported ones. Attempts to improve their

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Table 1. Personal profile of the chicken keepers.

Location	Sex		Education		Occupation		CS	F&T	C&F
	Male	Female	Formal	Informal	Farming	Trading			
Idemili North	12	38	33	17	14	16	5	9	4
Njikoka	39	41	24	26	15	19	6	6	6
Anaocha	12	38	34	16	10	18	10	7	5
Total	63	117	91	59	39	53	21	22	15

CS= Civil Servant; F&T= Farming and Trading; C&F= Civil servant and Farming.

Table 2. Personal profile of the chicken keepers.

Location	Sex		Education		Occupation		CS	F&T	C&F
	Male	Female	Formal	Informal	Farming	Trading			
Anambra East	18	32	33	17	7	5	Nil	19	14
Anambra West	23	27	40	10	8	4	Nil	13	10
Oyi	6	44	41	9	9	6	2	23	10
Total	47	103	114	36	24	15	2	57	34

CS= Civil Servant; F&T= Farming and Trading; C&F= Civil servant and Farming.

Table 3. Personal profile of chicken keepers.

Location	Sex		Education		Occupation		
	Male	Female	Formal	Informal	Farming	Trading	Civil servant
Aguata	30	20	25	15	14	9	12
Onisha	23	27	30	10	14	13	13
Orumba	27	23	20	25	7	13	6
Total	80	70	75	50	35	35	31

Table 4. Personal profile of the chicken keepers.

Location	Sex		Education		Occupation		
	Male	Female	Formal	Informal	Farming	Trading	Civil servant
Ayamelum	25	25	14	36	13	25	12
Idemili South	26	24	15	35	6	29	15
Nnewi	29	21	23	27	18	21	11
Total	80	70	52	98	37	75	38

performance in the past had been by cross breeding them with imported ones in an exchange program failed because heterosis in the offspring was marginal and dismally observed. The inherited traits were lost overtime especially in an uncontrolled breeding environment (Ezeokeke, 2003). The heritability index is low in the fowl and any transferred trait is diminished in the subsequent generation and becomes recessed and eventually lost. Oluyemi and Ogunmodede (1979) described local fowls as a breed or variety of any species of poultry which has developed characteristics peculiar to a geographical location that can be said to be indigenous to that location.

POPULATION AND PRODUCTION OF LOCAL FOWL

The results indicated that most of the household keepers were women (Table 1). This is similar to that published by Gueye (2000); Bagnol (2001) and Das et al. (2008). The highest flock per household was 12 as recorded in Ayamelum (Table 2). The management system was mainly the extensive or scavenging type (Awolola, 1986). But some of the householders provided one type of shelter or another under very unhygienic conditions. Coccidiosis was more rampart than Newcastle (Adler and Damassa, 1980) diseases as observed in these areas (Table 3 to 5). Apart

Table 5. Flock distribution and structure.

Location	Flock distribution					Flock structure/household				
	Cock	Hen	Growers	Chick	Mating ratio	Cock	Hen	Growers	Chick	Total
Idemili North	132	197	71	81	1: 1	2.64	3.94	1.42	1.62	9.62
Njikoka	130	215	79	42	1: 2	2.60	4.30	1.58	0.84	9.32
Anaocha	126	273	110	144	1: 2	2.52	5.46	2.20	2.88	10.18
Anambra East	85	75	71	20	1: 1	1.70	1.50	1.42	0.40	5.02
Anambra West	69	67	78	39	1: 1	1.38	1.34	1.56	0.38	4.66
Oyi	44	42	63	24	1: 1	0.88	0.84	1.26	0.48	3.46
Aguata	74	155	58	36	1: 2	1.48	3.10	1.16	0.72	6.46
Onitsha	80	137	75	69	1: 1	1.60	2.74	1.50	1.38	7.22
Orumba	97	115	51	43	1: 1	1.94	2.30	1.02	0.86	6.12
Ayamelum	137	138	122	172	1: 1	2.74	2.76	2.44	3.44	11.38
Idemili South	146	148	149	171	1: 1	2.92	2.95	2.98	3.42	12.28
Nnewi	158	147	146	70	1: 1	3.16	2.94	2.92	1.40	10.42

from farming most of the keepers engaged in other enterprise (Table 1) and were educated formally and informally. The body weight of chick varied significantly ($P<0.05$) but this might be as a result of having a pull of chicks with different ages (0 to 6wks) together in a group (Tables 7 to 10). Age differential within type might have contributed to the observed differences. The shank lengths differed significantly ($P<0.05$) in all the chicken types (Tables 11 to 17). The flocks were kept by householders who did not keep record of management and production (Table 6). The egg quality was low indicating low management practice no feed and house were provided to the flock in most homes where the birds were raised (Tables 18 to 20).

STUDIES ON IMPROVEMENT OF LOCAL FOWL

Low energy and high protein diet for chicks while high energy and low protein diet for growers enhanced performance of local fowl. The results of the studies are as shown in Tables 21 to 22. For better use of antibiotics, the absorption characteristics of therapeutic antimicrobial substances should be known. The precise mechanism by which antibacterial substances promote growth and mode of action of dissimilar antibiotics as used in combination in the study at sub-optimal level need further investigation (Tables 23 to 26).

Several studies with broilers have indicated that *probiotic* preparations improved live weight gain and feed conversion rate, and markedly reduce mortality (Owings et al., 1990; Jin et al., 1996; Awaad et al., 2001). Dunham et al. (1993) reported that birds treated with *Lactobacillus reuteri* exhibited longer ileal vili and deeper crypts, which are a response, associated with enhanced T cell function, and increased production of anti-salmonella IgM antibodies. *Enterococcus faesium* as used as probiotic like *lactobacillus* could be important in the development of immunity looking at the table of blood metabolites. Immunity resulting from gut exposure to a variety of antigens, such as pathogenic bacteria and dietary protein, is important in defense of young animal against enteric infection (Perdigon et al., 1995). Tables 27 to 29 depicted performance of local birds on diets supplemented with *prebiotics* and *probiotics*. The additives enhanced performance, derived and acquired immunity of the birds. Also on experiment with plantain peels meal at the starter and finisher phases all the parameters measured were not significant ($P>0.05$). But results compared favorably with that reported on broilers by Tewe (1983). The average initial weight of the test birds was 32.00 g and at the end of starter phase attained 133.30 g corresponding to the early stages of growth of the fowl. This potential can be utilized in the improvement of the local birds as table birds. The birds had the capacity to put on weight easily especially when fed with plantain peel meal at the

Table 6. Management practice of local chicken.

Location	Shelter		Medication		Cleaning			Feeding		Water	Not	Diseases encountered	
	Yes	No	Yes	No	daily	Weekly	Monthly	Scavenging	Supplementing	frequent	frequent		
Idemili N	43	7	7	43	9	41	Nil	47	3	24	26	New castle disease	Coccidiosis
												8	Nil
Njikoka	41	9	4	46	10	40	Nil	50	Nil	11	39	Nil	18
Anaocha	43	7	9	41	9	41	Nil	49	1	19	31	Nil	5
Anambra E	45	5	21	29	17	33	Nil	29	21	21	29	2	13
Anambra W	41	9	10	40	19	29	2	41	Nil	12	38	Nil	Nil
Oyi	37	15	17	33	19	30	1	37	15	18	34	Nil	7
Aguata	25	25	11	30	Nil	5	8	39	11	8	24	1	Nil
Onitsha	24	25	9	36	5	5	12	45	5	8	19	Nil	Nil
Orumba	23	27	13	31	6	7	9	40	10	13	17	Nil	Nil
Ayamelum	22	28	20	30	Nil	50	Nil	36	14	15	35	Nil	20
Idemili South	48	2	47	3	45	5	Nil	29	21	30	20	Nil	Nil
Nnewi	20	30	18	32	20	30	Nil	35	15	5	45	15	Nil

Table 7. Weight (kg) of the chickens.

Chicken type	Idemili North	Njikoka	Anaocha	SEM
Cock	1.30[b]	1.43[a]	1.33[b]	0.022
Hen	0.92	0.92	1.00	0.028
Grower	0.33	0.28	0.30	0.032
Chick	0.027	0.026	0.028	0.003

SEM= Standard Error of Mean. Means with different superscript a and b in a row are significantly different ($P<0.05$).

Table 8. Weight (kg) of the chicken.

Chicken type	Anambra east	Anambra west	Oyi	SEM
Cock	1.73	1.76	1.76	0.02
Hen	1.11	1.11	1.26	0.05
Grower	0.55	0,55	0.51	0.03
Chick	0.026	0.025	0.029	0.0004

SEM= Standard Error of Mean.

Table 9. Weight (kg) of the chicken.

Chicken type	Aguata	Onitsha	Orumba	SEM
Cock	1.90	1.97	1.95	0.05
Hen	1.66	1.74	1.73	0.77
Grower	1.37	1.38	1.37	0.60
Chick	0.02	0.02	0.03	0.01

SEM= Standard Error of Mean.

Table 10. Weight (kg) of the chicken.

Chicken type	Ayamelum	Idemili south	Nnewi	SEM
Cock	2.16	2.03	2.06	0.14
Hen	1.81	1.79	1.83	0.08
Grower	1.96	1.71	1.85	0.17
Chick	0.03	0.02	0.03	0.01

SEM= Standard Error of Mean.

Table 11. Shank length (cm) of the chicken.

Chicken type	Idemili north	Njikoka	Anaocha	SEM
Cock	6.00^{b}	6.40^{a}	6.02^{b}	0.040
Hen	5.40^{ab}	5.58^{a}	5.32^{b}	0.069
Grower	4.32	3.46	3.86	0.322
Chick	0.96^{a}	0.52^{b}	1.16^{a}	0.155

SEM= Standard Error Mean. Means with superscripts, a and b in a row are significantly different (P<0.05).

Table 12. Shank length (cm) of the chicken.

Chicken type	Anambra east	Anambra west	Oyi	SEM
Cock	9.07	9.08	8.99	0.65
Hen	7.33^{a}	7.06^{b}	7.13^{b}	0.05
Grower	4.09	4.05	4.15	0.30
Chick	1.26	1.36	1.27	0.15

SEM= Standard Error Mean. Means with a an b superscripts in a row are significantly different (P<0.05).

Table 13. Shank length (cm) of the chicken.

Chicken type	Aguata	Onitsha	Orumba	SEM
Cock	3.59	3.74	3.84	1.18
Hen	2.83^{b}	3.21^{b}	3.44^{a}	0.10
Chick	0.02	0.03	0.01	
Grower	1.37	1.38	1.37	1.60

SEM= Standard Error of Mean. Means with a and b superscripts in a row are significantly different (P<0.05).

early stages of life. The study substituted maize with PPM at 6% inclusion level fed to indigenous chickens at starter (0 to 4 wks) and finisher (5 to 8 wks) phases in order to achieve with the control the same level of performance at a relatively cheaper cost of the diet. The plantain peels meal enhanced performance at early stage

Table 14. Shank length (cm) of the chicken.

Chicken type	Ayamelum	Idemili south	Nnewi	SEM
Cock	3.04	3.14	2.82	0.31
Hen	2.30	2.26	1.73	0.24
Grower	2.06[a]	1.92[b]	2.06a	0.04
Chick	1.22	1.20	1.20	0.01

SEM= Standard Error of Mean. Means with a and b superscripts in a row are significantly different (P<0.05).

Table 15. Personal profile of local chicken rearers.

LGA	Sex		Education		Occupation				
	Male	Female	Formal	Informal	Trading	Farming	Civil servat	Farming/Trading	All
Ehime Mbano	Nil	50	50	Nil	25	4	2	15	4
Isiala Mbano	Nil	50	50	Nil	20	5	10	10	5
Mbaitolu	Nil	50	50	Nil	15	5	15	10	5

Table 16. Flock structure and distribution of local fowl.

LGA	Flock structure				Mating ratio		FLOCK SIZE/HOUSE HOLD			
	Cock	Hen	Growers	Chick	Hen	Cock	Hen	Cock	Growers	Chick
Ehime Mb.	177	79	307	152	2	1	3.54	1.82	6.36	4.02
Isiala Mb.	182	78	227	149	2	1	3.64	1.98	4.54	4.02
Mbaitolu	121	63	233	152	2	1	2.42	1.40	5.16	4.02

Table 17. Management practices of local fowl.

PRO.O.S.			MEDICATION FCP								FEEDING		FW			CDE		
LG	Yes	No	D	W	M	>M	D	W	M	>M	SCA	SUP	FQ	NF	NDC	COC	CRD	OTR
Eh.	42	8	Nil	Nil	Nil	Nil	42	Nil	Nil	Nil	50	Nil	Nil	50	28	4	8	10
Is.	42	8	Nil	Nil	Nil	Nil	42	Nil	Nil	Nil	50	Nil	Nil	50	25	5	15	5
Mb.	46	4	Nil	Nil	Nil	Nil	46	Nil	Nil	Nil	50	Nil	Nil	50	20	5	10	15

PR0.O.S = Provision of shelter. FCP = Frequent cleaning of pen. FW = Frequent of watering. CDE = Common diseases encountered. D = Daily. W = Weekly. M = Monthly. SCA = Scavenging. SUP = Supplement. FQ = Frequent. NF = Not frequent. NDC = New Castle disease. COC = Coccidiosis. CRD = Chronic respiratory disease. OTR = Others.

Table 18. Weight (kg) of flocks.

Chicken types	Ehime Mbano	Isiala Mbano	Mbaitolu	SEM
Hens	0.797	0.791	0.792	0.004
Cocks	1.419	1.304	1.269	0.035
Growers	0.376	0.380	0.375	0.003
Chicks	0.047	0.049	0.047	0.002

SEM = Standard Error of Mean.

Table 19. Shank length (cm) of birds.

Chicken types	Ehime Mbano	Isiala Mbano	Mbaitolu	SEM
Hens	5.844^{b}	5.902^{a}	5.448^{a}	0.057
Cocks	7.214^{a}	7.296^{a}	6.848^{b}	0.062
Growers	3.596	3.634	3.608	0.002
Chicks	2.292	2.300	2.245	0.021

Means in a row with different superscripts are significantly different ($P<0.05$).

Table 20. Egg quality of local fowl.

Parameter	Ehime Mbano	Isiala Mbano	Mbaitolu	SEM
Average egg weight (g)	39.27	38.24	41.04	1.77
Yolk colour	8.00	7.50	7.63	0.67
Yolk index	0.45	0.36	0.37	0.05
Albumen index	0.18	0.19	0.14	0.02
Shell weight (g)	3.91	4.03	4.03	0.20
Shell thickness (mm)	0.34	0.38	0.37	0.03
Haugh unit	33.48^{b}	37.07^{a}	28.02^{c}	0.50
Hen day egg production (%)	47.00	47.00	48.00	1.17

Table 21. Gross composition of experimental diets.

Ingredients (%)	Experimental diets					
	1	2	3	4	5	6
Chicks phase						
Maize	56.60	56.40	51.60	72.80	65.60	61.40
Groundnut cake	26.80	32.40	37.00	23.80	29.00	35.00
Bone meal	2.40	2.40	2.40	2.40	2.40	2.40
Salt	0.20	0.20	0.20	0.20	0.20	0.20
*Premix	1.00	1.00	1.00	1.00	1.00	1.00
Grower phase						
Maize	71,30	67.20	63.81	81.10	76.40	72.40
Groundnut cake	11,70	18.00	22.60	9.40	15.60	20.50

*Premix provided the following per kg of feed: Vitamin A, 8,000,000 IU,vitamin D_3, 1,600,000 IU, vitamin E, 5,000 IU, vitamin K, 2,000 mg, thiamin (B_1), 1,50000 mg, niacin, 15,500 mg , vitamin B_{12}, 10mg, pantothenic acid, 5000 mg, folicacid,500 mg, biotin,20 mg, choline chloride, 200 g, antioxidant, 125 g, manganese, 80 g, zinc, 50 g, iron, 20 g, copper, 5 g, iodine, 1.2 g, selenium, 200 mg, cobalt, 200 mg.

of life of the birds and the cost of feed very effective. The experiment was done under intensive management system. Plantain peels meal may be useful as cost effective ingredient in the ration of local birds at relatively

Table 22. Performance of birds on experimental diets.

Parameter	Diets						
	1	2	3	4	5	6	SEM
Chicks phase							
AFI (g/bird/day)	18.10	19.90	16.40	13.90	15.90	20.20	2.23
EFU (gain/feed)	0.17^b	0.19^a	0.14^b	0.17^b	0.16^b	0.22^a	0.03
ME intake (kcal/day)	46.47^b	57.86^b	35.53^b	38.79^b	41.85^b	75.60^a	13.72
Avg. bdy wt (gat 9wks)	102.90^b	118.30^b	76.20^b	86.40^b	80.50^b	224.40^a	18.48
Body wt gain (g/dy)	3.06^b	3.81^b	2.34^b	2.30^b	2.48^b	4.48^a	0.82
Grower phase							
AFI (g/bird/dy)	37.90^b	47.50^a	35.70^b	38.80^b	39.50^b	48.80^a	4.95
EFU (gain/feed)	0.10^a	0.10^a	0.12^a	0.08^b	0.09^b	0.11^a	0.01
ME intake (kcal/dy)	57.32^b	74.41^b	62.69^b	53.06^b	57.70^b	91.27^a	13.12
Avg. bdy wt(g at 20wks)	422.09^b	519.40^a	402.01^b	357.94^b	357.58^b	578.25^a	82.40
Body wt gain (g/dy)	3.78^b	4.90^a	4.13^a	3.15^b	3.42^b	5.14^a	0.80

Diet 1= 2,700 kcalME/kg, 13%CP; Diet 2= 2,700 kcalME/kg, 15%CP; Diet 3= 2,700 kcalME/kg, 17%; Diet 4= 3,000 kcalME/kg, 13%; Diet 5= 3,000 kcalME/kg, 15%CP; Diet 6 = 3,000 kcal/kg, 17%CP. Means with different superscripts in a row is significantly different ($P<0.05$). SEM= Standard error of mean.

Table 23. Gross composition of experimental diets (%) at starter and grower phases of birds treated with or without antibiotics.

Ingredient	Starters			Growers		
	1	2	3	4	5	6
Maize	67.36	62.28	62.63	72.02	76.72	76.07
Groundnut cake	29.06	34.22	34.14	24.40	19.66	20.60
Bone meal	2.38	2.33	2.15	2.38	2.41	2.22
Common salt	0.20	0.20	0.18	0.20	0.20	0.18
*Premix	1.00	0.97	0.90	1.00	1.01	0.93
Total	100.00	100.00	100.00	100.00	100.00	100.00

The formulated percentages of the ingredients were readjusted to as fed percentages. Diet 1= 2700 kcalME/kg, 18%CP; Diet 2= 2,700 kcalME/kg, 20%CP; Diet 3=2,700 kcalME/kg, 22%CP; Diet 4= 3,000 kcalME/kg,13%CP; Diet 5= 3,000 kcalME/kg, 15%CP; Diet 6= 3,000 kcalME/kg, 17%CP.*Premix provided the following per kg of feed: Vitamin A, 8,000,000 IU, vitamin D_3, 1,600,000 IU, vitamin E, 5,000IU, vitamin K, 2,000 mg, thiamin (B_1), 1,50000 mg, niacin, 15,500 mg , vitamin B_{12}, 10 mg, pantothenic acid, 5000 mg, folicacid,500 mg, biotin, 20 mg, choline chloride, 200 g, antioxidant, 125 g, manganese, 80 g, zinc, 50 g, iron, 20 g, copper, 5 g, iodine, 1.2 g, selenium, 200 mg, cobalt, 200 mg.

Table 24. Gross composition of experimental diet (%) at starter and grower phases.

Ingredient	Starters			Growers		
	1	2	3	4	5	6
Maize	67.36	62.28	62.63	72.02	76.72	76.07
Groundnut cake	29.06	34.22	34.14	24.40	19.66	20.60
Bone meal	2.38	2.33	2.15	2.38	2. 41	2.22
Common salt	0.20	0.20	0.18	0.20	0.20	0.18
*Premix	1.00	0.97	0.90	1.00	1.01	0.93
Total	100.00	100.00	100.00	100.00	100.00	100.00

The formulated percentages of the ingredients were readjusted to as fed percentages. This accounted for the variations in the percentages of the ingredients especially the fixed ones (Bone meal, common salt and premix). *Vitamin mineral premix contained the following per kilogram of diet: Vitamin A (1250 IU), vitamin D3 (2750 IU), vitamin E (15 IU), vitamin K (2 mg), riboflavin (6 mg), pantothenic acid (10 mg), niacin (35 mg), vitamin B12 (0.02 mg), choline (300 mg), biotin (0.05 mg), folic acid (1 mg), thiamine (1.50 mg), pyridoxine (3.50 mg), vitamin C (25 mg), manganese (100 mg), zinc (45 mg), iron (50 mg), copper (2 mg), iodine (1.55 mg), selenium (0.10 mg) and cobalt (25 mg).

Table 25. Performance of birds given diets with or without antibiotics in water at starter phase.

Parameter	With antibiotic			Without antibiotics			
	1	2	3	4	5	6	SEM
MBW (g/bird at 9wk)	130.10^{c}	200.00^{bc}	132.33^{c}	284.30^{b}	318.80^{a}	376.20^{a}	36.76
MBWG (g/bird at 9wk)	1.76^{c}	2.63^{c}	1.62	4.69^{ab}	5.70^{a}	6.78^{a}	1.73
MDFI (g/bird at 9wk)	11.20^{c}	20.72	7.14	39.80^{a}	43.20^{a}	47.80^{a}	4.02
EFU (gain/bird/day)	0.18	0.17	0.19	0.26	0.23	0.24	0.05
MEI (kcal/bird/day)	35.04	39.11	33.63	36.34	39.95	42.30	7.81

MBW= Mean body weight; MBWG= Mean body weight gain; MDFI= Mean daily feed intake; EFU= Efficiency of feed utilization; MEI= Metabolizable energy intake for body maintenance. Means with superscripts a, b and c in a row are significantly (P<0.05) different. SEM= Standard error of mean. SEM= Standard error of mean.

Table 26. Performance of birds given diets with or without antibiotics in water at growers' phase.

Parameter	With antibiotics			Without antibiotics			
	1	2	3	4	5	6	SEM
MBW (g/bird at 14wks)	283.63^{b}	351.75^{b}	279.50^{b}	362.20^{b}	469.70^{a}	533.30	34.59
MBWG (g/bird/day)	6.35	5.39	4.15	4.02	4.85	5.25	2.59
MDFI (g/bird at 14wk)	24.33^{c}	24.33^{c}	20.50^{c}	38.40^{b}	47.20^{a}	44.30	2.71
EFU (gain/feed/bird)	0.33	0.21	0.23	0.11	0.11	0.12	0.13
MEI (kcal/bird/day)	54.44^{c}	69.83^{b}	61.40^{bc}	73.94^{b}	92.21^{a}	102.48^{a}	6.29

MBW= Mean body weight; MBWG= Mean body weight gain; MDFI= Mean daily feed intake; EFU= Efficiency of feed utilization; MEI= Metabolizable energy intake. Means with superscripts a, b and c in a row are significantly (P<0.05) different. SEM= Standard error of mean.

Table 27. Gross composition of experimental diets (%).

Ingredient	Starter diet	Finisher diet
	Diet 1	Diet 2
Maize	51.49	51.91
Soya bean meal	16.11	16.24
Groundnut cake	13.99	2.98
Cassava meal	10.07	20.30
Fish meal	4.93	4.97
Bone meal	2.27	2.28
*Premix	0.90	0.91
Common salt	0.18	0.18
Lysine	0.01	0.13
Methionine	0.05	0.10
Total	100.00	100.00

*Vitamin mineral premix contained the following per kilogram of diet: Vitamin A (1250 IU), vitamin D_3 (2750 IU), vitamin E (15 IU), vitamin K (2 mg), riboflavin (6 mg), pantothenic acid (10 mg), niacin (35 mg), vitamin B_{12} (0.02 mg), choline (300 mg), biotin (0.05 mg), folic acid (1 mg), thiamine (1.50 mg), pyridoxine (3.50 mg), vitamin C (25 mg), manganese (100 mg), zinc (45 mg), iron (50 mg), copper (2 mg), iodine (1.55 mg), selenium (0.10 mg) and cobalt (25 mg).

safe level during the early stages of life of the bird. Therefore, PPM can be used in profitable poultry production.

The composition of feed and performance of the birds fed plantain peels meal are shown in the Tables 30 to 33.

Table 28. Performance of birds on experimental diets at starter and finisher phases.

Parameter	Starter diets			Finisher diets		
	1(+)	2(-)	SEM	3(+)	4(-)	SEM
Average initial bdy wt(g/wk)	31.25	37.50	4.41			
Average body wt (g at 7&12wks)	108.89[a]	75.44[b]	13.92	270.00	186.00	33.45
Average daily feed intake (g/day)	45.35[a]	23.21[b]	7.28	32.78	29.29	5.98
Average body wt gain (g/day)	2.22	1.10	1.04	4.17	3.29	1.29
Efficiency of feed utilz (gain/feed)	0.13	0.09	0.05	0.22	0.16	0.10
*Metz energy intake (cal/day)	20.35	18.04	3.73	34.94	27.64	7.70

Mean with different superscripts in a row are significantly different (P<0.05). += With *prebiotics* and *probiotics* (Inclusion level of 20 mg (*prebiotics*)/kg feed for 3 days and 1g (*probiotics*)/kg of feed *ad libitum*; -= Without *prebiotics* and *probiotics;* SEM= Standard error of mean.

Table 29. Blood metabolites of chicks at finisher phase.

Parameter	Experimental diets			
	1(+)	SEM	2(-)	SEM
Packed cell volume (%)	25.00	0.58	27.33	1.45
Hemoglobin (mg/100ml)	8.13	0.13	9.07	0.52
Red blood cell (x1012/l)	4.04	0.02	4.17	0.08
White blood cell (x109/l)	10.15	0.05	10.37	0.22
Lymphocyte (%)	40.00	2.89	46.67	7.27
Neutrophil (%)	57.33	2.19	53.00	7.23
Total protein (g/l)	5.53	0.27	4.60	0.15
Albumin (g/l)	2.00	0.06	1.33	0.15
Globulin (g/l)	3.53	0.29	3.27	0.29

+= With *prebiotics* and *probiotics*; -= Without *prebiotics* and *probiotics*; SEM= Standard error of mean.

Table 30. Gross composition of experimental diets at starter phase.

Ingredient	Starter diets (%)	
	Control	Test
Maize	46.96	39.54
Groundnut cake	36.93	37.99
Wheat offal	5.00	5.00
Fish meal	2.00	2.00
Bone meal	3.00	3.00
Oyster shell	2.00	2.00
Lysine	1.25	1.25
Methionine	0.86	0.86
Common salt	1.00	1.00
*Premix	1.00	1.00
Plantain peels meal	0.00	6.36
Total	100.00	100.00

*Premix provided the following per kg of feed: Vitamin A, 8,000,000 IU, vitamin D_3, 1,600,000 IU, vitamin E, 5,000IU, vitamin K, 2,000 mg, thiamin (B_1), 1,50000 mg, niacin, 15,500 mg , vitamin B_{12}, 10mg, pantothenic acid, 5000mg, folicacid,500 mg, biotin,20 mg, choline chloride, 200g, antioxidant, 125g, manganese, 80 g, zinc, 50 g, iron, 20 g, copper, 5 g, iodine, 1.2 g, selenium, 200 mg, cobalt, 200 mg.

Table 31. Gross composition of experimental diets at finisher phase.

Ingredient	Finisher diets (%)	
	Control	Test
Maize	57.05	49.53
Groundnut cake	26.84	28.00
Wheat offal	5.00	5.00
Fish meal	2.00	2.00
Bone meal	3.00	3.00
Oyster shell	2.00	2.00
Lysine	1.25	1.25
Methionine	0.86	0.86
Common salt	1.00	1.00
*Premix	1.00	1.00
Plantain peels meal	0.00	6.36
Total	100.00	100.00
Price per kg of feed (N)	95.05	93.05

*Premix produced the following per kg of feed: Vitamin , 8,000,000 IU, vitamin D_3 1,600,000 IU, vitamin E 5,000 IU, vitamin K, 2,000 mg, thiamin (B_1), 1,500 mg, riboflavin (B_2), 4,000 mg, pyridoxine (B_6), 1,500 mg, niacin, 15,500 mg, vitamin B_{12},10 mg, pantothenic acid, 5,000 mg, folic acid, 500 mg, biotin, 20 mg, choline chloride, 200 g, antioxidant, 125 g, manganese, 80 g, zinc 50 mg, iron, 20 g, copper, 5 g, iodine 1.2 g, selenium, 200 mg, cobalt, 200 mg.

Tables 32. Performance of local birds on experimental diets at the starter phase.

Control test	Experiment diets		
			SEM
Initial body wt/ bird(g)	43.75	32.00	8.30
Average body wt/bird at 5wks (g)	134.54	133.30	24.43
Average feed intake/bird/day (g)	16.88	22.4	3.95
Average body wt gain/bird/wk (g)	22.70	25.33	10.91
Average feed conversion ratio/bird	6.05	5.20	1.35

Table 33. Performance of local birds on experimental diets at the finisher phase.

Control test	Experiment diets		
			SEM
Average body wt/ bird at 10wks (g)	423.00	341.70	66.82
Average feed intake/bird/day (g)	35.05	29.52	3.91
Average body wt gain/bird /wk (g)	76.25	44.47	27.48
Average feed conversion ratio	3.89	5.91	2.09

CONCLUSION

The local fowl has suffered neglect until now and may likely be extinct in future since there is no plan in place to sustain their production in Nigeria. At present there is global dwindling of poultry genetic resources attributable to the intense industrialization and near monopoly of industrial stock by a few (Rose, 1997). There is a growing concern and a felt need for conservation (Crawford, 1999). The local fowl in Nigeria is endangered and possesses traits of current and future economic importance and scientific interest. Data on population are

necessary in planning selection and breeding programs aimed at improving the productive potentials and conservation of native chicken. The bulk of animal protein that is consumed in the rural areas is mostly derived from the local fowl.

To bridge the gap in shortage of animal protein, ensure food security and alleviate poverty of rural population in Nigeria, local fowl improvement and production are keys to open doors to better nutrition and rural economic empowerment. Malnutrition, disease and poverty ravage the rural dwellers where an average family lives on an income of less than a dollar per day (FAO, 2008; UNDP, 2007). Domestic chickens essentially contribute to human nutrition, play a crucial role in fundamental and applied research, and provide an enjoyable source of human entertainment and leisure time activities (Delany, 2000). The review presented efforts made towards providing information, establishing standards and enhancing performance on the fowl.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Adler HE, Damassa AJ (1980). Effect of ingested lactobacilli on *Salmonella infantis* and *E. coli* and intestinal flora, pasted vents and chick growth. Avian Dis. 24:868-878.

Awaad A, Ali MA, Zouelfekaar SSA (2001). Project Report: Effect of *probiotics* and combination on *E. coli* infections in broiler chickens. Cairo University, Faculty of Veterinary Medicine, Department of Poultry Diseases. Giza, Egypt.

Awolola MD (1986). A case study on adoption of recommended practices in poultry keeping. A poultry association of Nigeria maiden issue.

Bagnol B (2001). The social impact of New Castle disease control. In: Alders, R,G. & Spradbrow, P.B.(eds) SADC Planning Workshop on New Castle disease control in village chickens. Proceedings of an International Workshop, Maputo, Mozambique, 6-9, March, 2009. ACIAR Proceedings Number 103:69-75.

Crawford RD (1999). Experience with in situ preservation of poultry breeds. In: Gerald Wiener (Ed) Animal Genetic Resources. A global programme for sustainable development FAO Rome pp. 143- 150.

Das SC, Chowdhry SD, Khatun MA, Nishibori M, Isobe N, Yoshimura Y (2008). Poultry production profile and expected future projection in Bangladesh. World Poultry Sci. J. 64:99-117.

Delany M (2000). Importance of biodiversity preservation for research and industry. In: Proceedings of the XXI World's Poultry Congress, Montreal.

Dunham HJ, Williams C, Edens FW, Casas IA, Dobrogosz WJ (1993). *Lactobacillus reuteri* immunomodulation of stressor-associated diseases in newly hatched chickens and turkeys. Poultry Sci. 72(Suppl 2):103.

Ezeokeke CT (2003). Studies on the requirements for energy, protein and feed additives by the local fowl (*Gallus domesticus*). PhD thesis. University of Ibadan, Ibadan, Nigeria. pp. 22-25.

Ezeokeke CT (2008). Effects of *prebiotics* and *probiotics* on the local fowl. Nig. J. Anim. Prod. 35(2):162-169.

Ezeokeke CT, Iyayi EA (2001). Energy and protein requirements for growth of local fowl (*Gallus domesticus*). Tropical J. Animal Sci. 4(1):197-204.

FAO (Food and Agricultural Organization) (2008). The state of food insecurity in the World 2008 FAO of the United Nations, Rome, Italy. www.fao.org/docrep/011/i0291cohtm (accessed 16th January, 2009).

Gueye EE (2000). The role of family poultry in poverty alleviation, food security and the promotion of gender equality in rural Africa. Outlook on Agric. 29(2):129-136.

Jin LZ, Ho YW, Abdullah N, Jalahudin S (1996). Influence of dried *Baccilus subtilis* and *Lactobaccili* cultures on intestinal microflora and performance in broilers. Asian – Australasian J. Animal Sci. 9:387-404.

Nwakpu PE, Odo BI, Omega ASI, Edoga CC (1999). Hatching , performance of three strains of layer-type chicken and their lines. Proceedings of the 26th Annual Conference, NSAP 21st – 25th March, 1999, Ilorin.

Oluyemi JA, Ogunmodede BK (1979). Some physical characteristics of indigenous fowl and duck of Nigeria. Nigerian J. Genetics, Volume 8.

Owings WJ, Reynolds DL, Hasiak RJ, Ferket PR (1990). Influence of dietary supplementation with *Streptococcus faesium* M-74 on broiler body weight, feed conversion, carcass characteristics and intestinal microbial colonization. Poultry Sci. 60:1257-1264.

Perdigon G, Alvarez,S, Rachid M, Aguero G, Gobbato N (1995). Immune system stimulation by *probiotics*. J. Dairy Sci. 78:1597-1696.

Rose SP (1997). Principles of Poultry Science, Wallingford, Oxford, CAB International, P. 3.

Tewe OO (1983). Replacing maize with plantain peels in diets for broilers. Nutrition Report Int. 28(1):23- 29.

UNDP (United Nations Development Program) (2007). Fighting climatic change: Human solidarity in a divided world. Human Development Report 2007/2008, UNDP, New York, USA. hdr.undp.org/en/media/hdr-20072008-en-complete.pdf (accessed 16th January, 2009).

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Full Length Research Paper

Farmers' climate change adaptation options and their determinants in Tigray Region, Northern Ethiopia

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Exploring micro-level evidences is critical to fine tune effective adaptation options to cope with the adverse impact of climate change. In this regard, detailed studies on climate change adaptation options are not available in the study areas. Hence, the objective of this study was to assess farmers' climate change adaptation options and determinant factors that influence their choice. Data were collected from 253 respondents randomly using probability proportional to the sizes (PPS) of the population of each district and peasant association from which sample households to be drawn. Descriptive statistics were employed to assess adaptation options while the multinomial logit model (MNL) was used to identify factors influencing households' choices. The results revealed that farmers use change in crop type /variety, soil and water conservation practices, crop diversification, change in planting date and irrigation practices as climate change adaptation options. Educational level of the household head, age of the household head, sex of the household head, farm income, access to extension service, access to credit, access to climate information and agro-ecological settings were the most important determinant factors that affect significantly the choice of farmers to climate change adaptations. Therefore, an effort that enhances farmers' awareness to climate change and creates the capacity to adopt climate resilient options is an important strategy that should be considered by a variety of societal groups, including policy makers, and farmers support organizations.

Key words: adaptation options, climate change, determinants, multinomial logit model.

INTRODUCTION

There is a general consensus that the Earth's climate is undergoing changes, and observations are consistent with scientific expectations regarding the increasing concentrations of greenhouse gases in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) reported that there is a statistically significant increase in the global mean state of the climate or in its variance, and further increases are expected if carbon dioxide and

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greenhouse gas emissions are not controlled (IPCC, 2007). Human activities, such as burning of fossil fuels and deforestation, have altered the global climate, resulting in increased temperature and alter the amount, intensity and distribution of precipitation and sea level rising.

Like other African countries, Ethiopia is widely held as one of the most vulnerable countries to future climate change (Conway and Schipper, 2011). Ethiopia's economy is built predominantly on agriculture, which contributes 41% of the country's gross domestic product (GDP), employs 80% of the labor force and produces more than 80% of its foreign exchange earnings (You and Ringler, 2010; Gebreegziabher et al., 2011). Agriculture in Ethiopia is mainly rainfed that involves many subsistent and small-scale farmers (Deressa et al., 2009). This condition together with its geographical location, topography and low adaptive capacity, makes the country highly susceptible to the adverse impacts of climate change (Gebreegziabher et al., 2011).

Among the regional states of Ethiopia, Tigray Regional State has been vulnerable to climate change (stable change over a long period of time usually 30 year or more). Climate change is expected to increase the frequency and magnitude of natural disasters and extreme weather events. Observations revealed that mean minimum and maximum temperatures of the region for the period 1954 to 2008 have increased by 0.72 and 0.36°C per decade, respectively indicating that the region is warming faster than the national average of 0.25°C (Gebrehiwot and van der Veen, 2013). Moreover, mean annual rainfall has shown a decreasing trend (Teka et al., 2012; Gebrehiwot and van der Veen, 2013). The onset and rainfall cessation date has changed towards decreasing the length of growing period (Hadgu et al., 2013).

The degree to which an agricultural system is affected by climate change depends on its adaptive capacity. Indeed, adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damage, to take advantage of opportunities, or to cope with the consequences (Sahu and Mishra, 2013; Vincent et al., 2013). Farmers in the study area have a long history of responding to climate variability and change through various strategies. While it is not possible to say that past adaptations will be sufficient in the face of the expanded range of future climate change, they give a better idea of what is required to reduce the negative effects of climate change, and therefore can inform policy and practices (Vincent et al., 2013). Research on adaptation-climate change interaction have been conducted in different parts of Ethiopia (Deressa et al., 2009; Tesso et al, 2012; Legesse et al., 2013; Mulat, 2013; Tessema et al., 2013). However, the information obtained from these studies was not sufficient to represent the study area as most of the previous studies focused on different agroecologies with different social, institutional and ecological settings. Moreover, most of the studies (Deressa et al., 2009; Legesse et al., 2013) focused on issues at national or regional levels and hence lack details at the household or farm level.

Previous studies revealed that adaptation strategies are vary contextually and spatially (within communities and even within individuals) and identified adaptation measures do not necessarily translate from one area to another (Deressa et al., 2009; Legesse et al., 2013). As site-specific issues require site-specific knowledge, it is very important, therefore, to clearly understand what is happening at site or household level. In the absence of local level evidences, it is difficult to fine tune interventions geared towards achieving effective and efficient adaptation options to cope with the adverse impact of climate change at local level. However, detailed studies on climate change adaptation options are not available in the areas identified for this study. Therefore, the objectives of this study were to identify the types of climate change adaptation measures practiced by farmers and assess the determinant factors that influence farmers' choice of adaption options.

METHODOLOGY

Description of the study area

The study was carried out in three districts of the Tigray National Regional State of Ethiopia. The districts are Ganta-afeshum, Alamata and Enderta, which are situated at different agroecological zones. In general, Ethiopia has four traditional agro ecological zones (Deressa et al., 2009). These are *Bereha* (desert, below 500 m a.s.l.), Kolla (low land, 500 to 1500 ma.s.l.), *Weynadega* (middle land, 1500 to 2500 m a.s.l.) and *Dega* (highland, 2500 to 3500 m a.s.l.). Out of the four traditional agroecological settings of Ethiopia, the survey districts fall in three of them (*Dega, Weynadega, Kolla*). Accordingly, Ganta-Afeshum is classified as *dega* and *weynadega* with an altitude ranges from 2461 to 3290 m.a.s.l; and received an average annual rainfall of 584 mm and mean annual maximum and minimum temperature of 23.6 and 6.9°C, respectively.

On the other hand, Enderta district comprised of two major agro-climatic zones. A greater portion lies in the *Weynadega* altitudinal climatic zone with an elevation range between 1500 to 2300 m while a smaller portion in the eastern and western parts lay in the '*Kolla*' altitudinal climatic zone with elevation between 500 to 1500 m (Florence, 2008). This study considers mainly the *Weynadega* part and characterized with mean annual maximum and minimum temperature of 24.3 and 11.3°C, respectively and average annual rainfall of 601 mm and Alamata district is found in the most Southern zone of Tigray. It is located at 12°15'N latitude and 39°35'E longitude (Gebrehiwot, 2005). Topographically, Alamata is divided into western highland and eastern lowlands. The lowland area has an altitude of 1500 m.a.s.l or below (*kola*) and account about 75% of the district, while 25% of the district falls in the intermediate highlands (*weynadega*) and highland (*dega*) with an altitude ranges between 1500 to 3148 m.a.s.l. (Berhane et al., 2010).

In this particular study, the low land part is used to represent the *kola* agro-climatic zone with an average annual rainfall of 752 mm and mean annual maximum and minimum temperature of 29.9 and 15.2°C, respectively.

Table 1. Distribution of sample households in the study area.

District name	Peasant Association	Total No of HH	No of sampled HH	%
Ganta-Afeshum	Buckot	915	32	12
	Beati-Maimesanu	1228	42	17
		18106	74	29
Enderta	Shibta	1606	63	25
	Felegdae'ro	950	37	15
		24571	100	40
Alamata	Selambikalsi	1965	50	20
	Kulugize lemlem	1115	29	11
		19212	79	31
Total		61889	253	100

Source: Finance and Development Offices of the respective woredas (2011).

Data collection

An exploratory study was first carried out in order to have a clear insight and to identify priority issues to be focused for the formal survey. Through this survey, information about the agro-ecological and socioeconomic features of the study area were collected. To supplement the formal survey, checklist was prepared and administered across different social groups and actors of the study communities. The formal survey was then framed based on the insight gained during the exploratory phase. Accordingly, three districts representing all agroecological zones were first selected purposively. Then, two peasant associations from each district were randomly selected. Finally, a total of 253 farm households were sampled randomly using probability proportional to the sizes (PPS) of the population of each district and peasant association from which sample households to be drawn. To select sample households from the selected peasant associations, list of household heads has been used. The distribution of sample households in the study area is presented in Table 1.

Data analysis

Qualitative data obtained from interviews and group discussion and the review of documents were compiled, organized, summarized and interpreted through concepts and opinions. Both descriptive statistics and econometric model were used to analyse the data. Descriptive statistics such as mean, frequency of occurrences and percentage were computed to summarize the adaptation options used by farmers. Analytical tools such as the statistical package for social sciences (SPSS) version-12 and STATA-10 were used to summarize the data.

Econometric analysis

Due to its computational simplicity, the multinomial logit model (MNL) specification was used to model climate change adaptation behavior of farmers involving discrete dependent variables with multiple choices (Deressa et al., 2009; Legesse et al., 2013; Tessema et al., 2013). MNL was employed to estimate the effect of explanatory variables on the choice of adaptation options to climate change and variability. The model is normally estimated using the iterative maximum likelihood estimation procedure, which yields unbiased, efficient and consistent parameter estimates (Deressa et al., 2008, 2009). The formula is given as follows:

$$P(y = j / x) = \frac{\exp(x\beta_j)}{\left[1 + \sum_{h-1}^{j} \exp(x\beta_h),\ j = 1.., J\right]}$$

Where P stands for probability, J stands for adaptation options, X for explanatory variables and β_j = K x 1 is coefficients, j = 1, 2. . , J.

The equation of multinomial logistic regression model requires the independent irrelevant alternative assumption (IIA) as noted in Deressa et al. (2009). It indicates that the probability of using a certain adaptation options by a given household needs to be independent from the probability of choosing another adaptation option. Thus, before data analysis and presentation, the model has been tested for the validity of the IIA assumptions, using the Hausman test for IIA as explained in Hassan and Nhemachena (2008) and Deressa et al. (2009).

Dependent variables

The dependent variable for multinomial logit model used in this study is households' choice decision on climate change adaptation options used by the farmers. The alternative climate change adaptation strategies include crop diversification, changing planting date, changing crop varieties/crop types, soil and water conservation practice and irrigation practices. These are frequently reported climate change adaptation methods in rain-fed agriculture of many African countries (Hassan and Nhemachena, 2008; Deressa et al., 2009). Thus, the dependent variable in the model is a categorical variable taking a discrete value of 1, 2, 3, 4, 5 and 6 representing the above choices, where;

(1) Change in crop and variety: It involves switching to varieties better suited to the new climate such as the use of stress tolerant crops and/or varieties that have a shorter growing period. It also includes cultivating crops better suited to the new climate and growing conditions.

(2) Change in planting dates: It involves the adjustment of planting time better suit the shifts in the growing season by delaying or undertaking early planting/sowing.

(3) Soil and water conservation practices: Includes the adoption of soil and water conservation practices such as terracing, soil/stone

Table 2. Explanatory variables hypothesized to affect the choice of conservation practices.

Variables	Definition	Description	Expected sign
AgroE	Local agro-ecology (Kola)	Dummy, takes the value of 1 if *kola* and 0, otherwise.	±
SexHH	Sex of the household head	Dummy, takes the value of 1 if male and 0, otherwise	+
AgeHH	Age of the household head	Continuous	+
Education	Educational status of household heads	Continuous	+
Family size	Family size of the household	Continuous	±
Farm size	Land holding per family	Continuous	+
FINCOME	Farm income	Continuous	+
TTLU	Total livestock holding in TLU	Continuous	+
Extension	Access to extension service	Dummy, takes the value of 1 if yes and 0, otherwise	+
Credit	Access to credit service	Dummy, takes the value of 1 if yes and 0, otherwise	+
Climate info	Access to climate information	Dummy, takes the value of 1 if yes and 0, otherwise	+

banding, runoff diversion and mulching to improve soil fertility, prevent erosion and conserve soil moisture
(4) Crop diversification: this includes growing of different varieties of crops in the same field through intercropping, mixed cropping, multiple cropping such as dividing of lands for different types of crops to serve as an insurance against complete failure as various crops and varieties respond differently to climatic hazards.
(5) Irrigation: It involves the adoption of farmers to build water harvesting schemes such as traditional hand dug or shallow open wells for the abstraction of groundwater for irrigation, diversion and pumping of spring water to practice irrigation.
(6) No adaptation: It includes if farmers are not taking any of the climate change adaptation options mentioned above.

Independent variables

Independent variables are variables that determine whether or not a household recognizes climate change and take some mechanism used to adapt its impact. Based on the review of literature on adaptation studies, a range of household socioeconomic and demographic characteristics, institutional factors and agro-ecological settings that describe local conditions were hypothesized to influence farmers' adaptation choice in the study area. The expected effect of each of these variables is presented in Table 2.

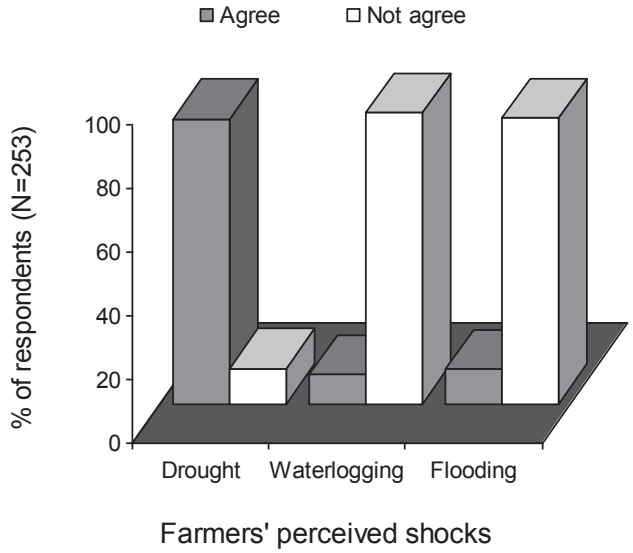

Figure 1. Farmers' perceived climate induced disasters in the study area.

RESULTS AND DISCUSSION

Farmers' perceived shocks

The surveyed households have encountered many environmental shocks such as drought, flooding and water-loggings (Figure 1). The result revealed that most of the contacted households had recognized drought as the major environmental hazard that they have encountered in their life. In line with this, Mengistu (2011) showed that drought was ranked as primary climate hazard by the community of *Adiha*, central Tigray, Ethiopia. Moreover, Deressa (2010) reviewed that between 1965 and 2009 Ethiopia has encountered drought about ten times. During these times, the region was affected by eight of the drought hazards; indicating how susceptible is the region to weather vagaries. Particularly, the 1984 drought (the worst in the modern history of Ethiopia that took one million lives) is still fresh to remember in many families.

These shocks have resulted in a variety of reported losses. Most of the respondents perceived that these shocks have reduced crop production that resulted to food insecurity (Table 3). In line with this, Teka et al. (2012) reported that there was a general perception among rural households that crop and livestock production, and land productivity declined in the last 20 years. Moreover, about 77.1 and 84.9% of the farmers perceived that the amount of water used for irrigation and for home and animal consumption has declined due to decline in rainfall amount, resulted from climate induced impacts. Farmers indicated that deep boreholes are open

Table 3. Perceived effects of climate induced shocks in the study area.

Climate induced disaster	Respondents	
	N=253	Percent*
Crop productivity decline	228	90.1
Shortage of water for irrigation	195	77.1
Shortage of water for home/animal consumption	215	84.9
Emergence/resurgence of new pests (weeds and insects)	185	73.1
Loss of landrace cultivars	189	74.7

*Percentage do not add up to 100 because of multiple responses.

for municipal water services. Thus, this effect might not be due to climate change alone but also due to pressurized underground water utilization. On the other hand, climate shocks such as recurrent drought associated with long dry spell and shortening in the length of growing period have resulted to loss of landrace cultivars (74.7%) and to face with new pests (73.1) including *striga* and *parthenium* weeds. In addition, farmers' also pointed out declined in crop productivity followed by a shortage of water for consumption and irrigation purposes as indicators of climate change.

Farmers' adaptation strategies

The surveyed farm households who claimed to have observed climate change in the last 20 to 30 years were asked if they have responded through adaptations to minimize the impact and/or to optimize opportunities of climate change. Accordingly, farmers used different management practices to reduce the effect of climate change. In this regard, farmers who perceived change in climate have used changing crop type/variety, soil and water conservation, changing in planting date, crop diversifications and irrigation practices as climate change adaptation options (Figure 2). On the other hand, despite their awareness on climate change, 5.5% of the farmers did not use any of the adaptation options indicated earlier. Similarly, Mengistu (2011) also reported that irrigation, changing crop types/varieties and soil and water conservation practice are commonly used climate change adaptation methods by the farming community of *Adiha*. The report further noted that, despite their importance, crop diversification and change in planting date were not common in these communities. A survey carried out in the Nile Basin of Ethiopia also revealed that farmers who claimed to perceive change in climate have used planting trees, soil conservation, use of different crop varieties, changing planting dates and irrigation to reduce the impact (Deressa et al., 2009). Moreover, Legesse et al. (2013) noted that crop diversification together with soil and water conservation and water harvesting practices were commonly used climate change adaptation strategies in eastern Ethiopia.

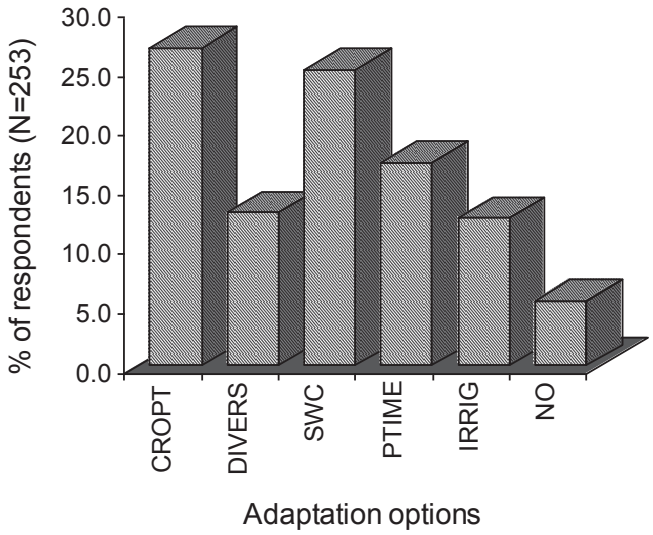

Figure 2. Farmers' adaptation strategies of the study area; CROPT: changing crop type/variety; DIVERS: crop diversification; SWC: soil and water conservation; PTIME: changing planting time; IRRIG: use of irrigation and NO is no adaptation.

Adaptation strategies vary from region to region and/or from place to place depending both on the extent and range of climate change or the exposure of the area to climate change, and the socioeconomic background of the people in the area (Sahu and Mishra, 2013). In general, similar adaptation strategies have been reported in different areas (Nhemachena and Hassen, 2007; Fosu-Mensah et al., 2010) (Figure 2).

Determinants of adaptation options

The Multinomial Logit Model was run taking 'no adaptation' as the base category against which the remaining outcomes compared (Table 4). An important assumption of the MNL is the Independence of Irrelevant Alternatives (IIA) and the model was tested using the Hausman test to see if it fulfills the assumption. The Hausman test supported that the IIA is not violated with

Table 4. Parameter estimates of the multinomial logit climate change adaptation model.

Explanatory variables	Change in crop type/variety			Crop diversification			Soil and water conserve			Irrigation			Adjust planting date		
	Coef	P_{value}	ME	Coef	P_{value}	ME	Coef	P_{value}	ME	Coef	P_{value}	ME	Coef	P_{value}	ME
AgroE	20.24***	0.000	0.3716	-0.3177	0.826	0.1619	-3.83***	0.004	-0.5370	-4.59***	0.001	-0.2334	1.108	0.381	0.236
SexHH	1.028	0.490	0.0006	0.4655	0.729	0.1131	1.138	0.391	0.4633	2.031	0.193	0.1415	-2.77**	0.026	-0.718
Education	0.5803	0.229	-0.0000	0.7820	0.104	0.0169	0.6538	0.174	-0.0214	0.8172*	0.090	0.0141	0.6376	0.178	-0.009
AgeHH	0.2007**	0.010	9.7e-6	0.1979**	0.011	0.0020	.2116***	0.007	0.0127	0.2132***	0.008	0.0029	0.0805	0.268	-0.017
Family size	0.1801	0.658	-0.0001	0.5328	0.190	0.0415	0.2483	0.542	-0.0368	0.1391	0.739	-0.0207	0.4160	0.300	0.016
Farm size	0.9678	0.812	0.0003	-0.4486	0.913	-0.173	0.6773	0.868	0.1222	0.9812	0.811	0.0619	0.3761	0.926	-0.011
FINCOME	0.0008*	0.083	1.7e-7	0.0003	0.478	-0.000	0.0006	0.170	0.0000	0.0007	0.156	8.6e06	0.0007	0.133	0.000
TLU	0.6164	0.293	-0.0001	0.8368	0.155	0.0113	0.7689	0.189	-0.0049	0.8807	0.135	0.0117	0.6700	0.249	-0.017
Extension	2.477*	0.081	0.0007	0.6618	0.610	-0.073	1.323	0.299	0.1514	0.9368	0.498	-0.0077	0.6224	0.606	-0.070
Credit	1.061	0.488	0.0005	0.3880	0.787	0.0616	0.1645	0.907	0.0774	3.500*	0.055	0.2275	-1.55	0.249	-0.367
Climate info	1.136	0.420	-0.001	2.978**	0.033	0.0947	2.681**	0.043	0.1473	3.916**	0.025	0.1085	1.068	0.379	-0.347
Const	-38.8***	0.000		-16.8***	0.000		-15.6***	0.000		-21.2***	0.000		-7.30*	0.056	
Diagnosis															
Base category	No adaptation														
Number of observations	216														
LR chi-square (55)	297.69***														
Log likelihood	-218.78														
Pseudo R^2	0.405														

*, ** and *** indicates statistically significant at 10, 5 and 1%, respectively; ME: marginal effect; Coef: regression coefficient; AgroE: agro-ecology.

χ2 ranging from -31.02 up to 8.88 with probabilities almost equal to 1.0 (data not shown). Moreover, to make sure that the continuous explanatory variables do not create problem of multicollinearity, auxiliary regression was fitted and VIF was calculated. All the VIF values are less than 10 (1.03 up to 1.56), indicating that it is safe to assume the absence of multicollinearity. Likewise, contingency coefficient was calculated for the categorical variables to detect problem of strong association. The values of all coefficients were less than 0.75 (0.076 up to 0.545), indicating absence of strong relationship among the variables (data not shown). Therefore, all the hypothesized continuous and categorical explanatory variables were included in the model.

Model results

The estimated coefficients of the MNL model together with the levels of significance are portrayed in Table 3. The likelihood ratio statistics from the MNL model indicated that χ2 statistics (297.69) was highly significant (P < 0.0001), suggesting the model has a strong explanatory power. As noted earlier, the parameter estimates of the MNL model provide only the direction of the effect of the independent variables on the dependent variables: estimates do not represent the magnitude of change or its probability. Thus, the marginal effects from the MNL, which measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable, are also presented in Table 4. The result showed that the level of education of household head, age of the household head, farm income, extension service, credit service and climate information influence positively in using one or a combination of climate change adaptation strategies identified by farmers. In contrast, gender of the household head found to influence negatively the adoption strategies noted by farmers. Moreover, the agroecological settings where the farmers are

living significantly affect the farmers' choice of climate change coping strategies. On the other hand, family size, farming size and the number of livestock ownership were not found to influence climate change adaptation options. The under mentioned section will discuss on variables that significantly influence climate change adaptation options.

Agroecological settings

Farmers living in different agroecological setting use different climate change adaptation methods. The multinomial logit model revealed that farming in *weynadega* decreases significantly the probability of using irrigation and soil and water conservation by 23.34 and 53.7%, respectively as compared to farming in *kola*. On the other hand, farming in *weynadega* increases significantly the probability of changing crop types and/or varieties by 37.16%, compared to the farmers living in the *kola* area. This difference might be arising due to the difference in soil, climate and other natural resources as well as experience to climate related stresses. The most important characteristic feature of lowland areas that limit crop production is high temperatures, which enhances evapotranspiration loss and create heat stress. Farmers living in this agroecological setup are, therefore, expected to invest management strategies that reduce heat loads while increase availability of moisture in the crop root zone. The positive concomitant between farming in the lowland and adoption of soil and water conservation and irrigation might be justified due to the aforementioned fact. In line with this, Deressa et al. (2009), Tesso et al. (2012) and Legesse et al. (2013) also observed that farmers living in different agroecological settings have different choice of adaptation to climate change impact. The report further revealed that farming in *kola* increases the probability of soil and water conservation and water harvesting practice as adaptation options, compared to *dega* or *weynadega.* On the other hand, farming in *kola* significantly reduces the probability of diversifying crop varieties, planting trees, and irrigation by 21, 13 and 2.3%, respectively, compared with farming in *weynadega* (Deressa et al., 2009).

Gender of the household head

Gender of the household head is one of the most important variables that significantly affect the farmers' choice of climate change adaptation options. As can be seen from Table 3, male headed households increase the likelihood to change crop types and/or varieties, to use crop diversification, to practice soil and water conservation and to use irrigation as climate change adaptation strategies. However, being male headed household reduces significantly the probability of using change in planting date by 71.8%. Overall, male-headed households have greater preferences for these strategies that require labor, finance and information than female-headed households, which relies on common practices known to most farmers, such as change in planting dates. This agrees with the argument that male headed households are more likely to get information about new technologies and take risky business than female headed households (Asfaw and Admassie, 2004). Similarly, Deressa et al. (2009), Legesse et al. (2013) and Mulatu (2013) concluded that being male-headed increases significantly the ability and choice of households' climate change coping strategies.

Age of the household head

Age of the household head, which is considered as a proxy indicator for farming experience, affects positively the farmers' climate change adaptation options. The result revealed that one year increase in the age of the household head significantly increases the probability of adopting change in crop type and/or variety, crop diversification, soil and water conservation and irrigation practices, respectively by <0.001, 1.1, 1.27 and 0.29%. This might be related to the fact that older farmers are able to assess the available technologies, gained enough knowledge and technical expertise on the options, which enable them to make adoption decision (Gbetibouo, 2009). Similarly, Deressa et al. (2009) reported that the probability of adopting change in crop varieties and tree planting was increased with age of the household head. On the other hand, age had no effect on adopting climate change adaptation options by farmers in eastern Hararghe, Ethiopia (Legesse et al., 2013; Tessema et al., 2013).

Education

Education of the household head increases the probability of adapting to climate change. Education significantly increases the use of irrigation practice as climate change adaptation methods. One year increase in the number of years of schooling was associated with a 1.41% increase in irrigation use. Moreover, all adaptation methods have a positive relationship with education. Farmers' with higher education are likely to have more information on climate change, which in turn might promote the probability of adopting climate change adaptation strategies. Furthermore, education is likely to enhance farmers' ability to receive, interpret and comprehend information relevant to making innovative decisions in their farms (Ndambiri et al., 2013). This result was similar to that of Deressa et al. (2009) and Tesso et al. (2012) while in contrast with that of Mulatu (2013), who noted a negative relationship between

education and selection of climate change adaptation options. In the latter case, better educated farmers had left agriculture and the probability of using climate adaptation option was reduced.

Farm income

This variable had positive and significant influence in adopting climate change adaptation options. As farm income increases by one birr the probability of using change in crop type and/or variety as climate adaptation options increase by less than 0.001%. It is well known that adoption of new crop variety requires more financial resource than adoption to crop diversification and changing planting dates. The positive impact of farm income on climate change adaptation options could be associated to the fact that farmers with better financial capacity are more risk averse to crop production, have access to information and longer-time planning horizon (Deressa et al., 2008). Mulatu (2013) also showed that increase in farm income of the household increases the likelihood of adapting to climate change using soil conservation, irrigation and livestock production.

Extension services

As expected, extension visit to the households has positive influence on the probability of adopting the prevailing adaptation options. However, the effect of extension contact on adoption of climate adaptation option was significant only for changing in crop type and/or variety. Result of MNL model showed that a unit increase in extension contact is likely to increase the probability of the farmer to adopt change in crop type and/or variety by 0.07%. This result corroborates with that of Deressa et al. (2008, 2009), Tesso et al. (2012) and Mulatu (2013), where all noted that increase access to extension service has increased the probability of using climate change adaptation options in different parts of Ethiopia. Legesse et al. (2013) also reported a mixed effect, wherein increase in extension contact increase the probability of the household to adapt crop diversifications and the use of soil and water conservation strategy but decreases the probability of adopting water harvesting strategy. This might be due to the fact that water harvesting technologies are capital intensive investments and not necessary influenced by the farmers' awareness on the importance of the technology to adapt climate change impacts.

Credit service

Access to credit service also plays a positive role for farmers to adopt climate change adaptation options. The result revealed that increased access to credit is likely to increase the probability of the household to practice irrigation as climate change adaptation strategy by 22.75%. As already known, irrigation is one of the most effective climate change adaptation strategies; avoids crop failure due to moisture stress and enable farmers to cultivate year round. However, it also requires capital investment, which most of ordinary households could not afford. Therefore, leveraging the cash shortage of households through credit might encourage farmers' to engage in irrigation practices. Deressa et al. (2008, 2009) and Tesso et al. (2012) also noted that increase in credit access significantly enhanced the farmers' choice of climate change adaptation strategies. In contrast, Tessema et al. (2013) reported that credit access has negative influence of the probability of using tree planting as climate change adaptation option.

Climate information

Even though service on climate information delivery is not formal, access to information from different sources had positive influence on the probability of adaptation options to climate change. Access to climate information significantly increased the probability of using crop diversification, soil and water conservation and irrigation practices by 9.47, 14.73 and 10.85%, respectively (Table 3). This result implies the important role of increased institutional support in promoting the use of climate change adaptation options to reduce the negative impact of climate change. This result confirms the finding of Mulat (2013) who showed that increase in access to climate information increases farmers' likelihood to prefer crop diversification and change in planting date as climate change adaptation options. Moreover, Deressa et al. (2009) noted that information on temperature and rainfall has a significant and positive impact on the probability of using different crop varieties by 17.6%.

Conclusions

The results indicated that most of the farmers in the study region undertake soil and water conservation, crop diversification, change in crop type and/or variety, change in planting date and use irrigation practices as adaptation options to counteract the negative impact of climate change. On the other hand, gender of the household head, educational level of the household head, age of the household head, farm income, access to extension of crop and livestock production, access to credit service, access to climate information and agroecological setting of the area have significant impact on the choice of farmers to climate change adaptation options. Based on this result the following policy options are suggested:

(1) Investment in education and yield increasing technology packages that increases farm income in the

rural areas can be underlined as policy options to reduce the negative impacts of climate change.
(2) An effort that improves farmers' awareness on better production techniques, climate change and access to financial system (credit), which enhance capacity to adopt climate resilience adaptation options, is an important policy measure that should be considered.
(3) Future policy options need to fine-tune climate change adaptation technologies based on gender and agroecological settings
(4) Research and development has to focus on developing/adapting crop/livestock varieties resistant to drought and/or heat stress; as climate is expected to be hotter than today.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Asfaw A, Admassie A (2004). The role of education on the adoption of chemical fertilizer under different socioeconomic environments in Ethiopia. Agric. Econ. 30:21 5-228.

Berhane G, Gebrehiwot A, Berhe K, Hoekstra D (2010). Commercialization of vegetable production in Alamata Woreda, Northern Ethiopia: Processes and Impact. IPMS, Ethiopia.

Conway D, Schipper ELF (2011). Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. Glob. Environ. Change 21:227–237.

Deressa TT (2010). Factors Affecting the Choices of Coping Strategies for Climate Extremes. Environment and Production Technology Division. IFPRI Discussion Paper 01032

Deressa TT, Hassan RM, Alemu T, Yusuf M, Ringler C (2008). Analyzing the determinants of farmers' choice of adaptation methods and perceptions of climate change in the Nile Basin of Ethiopia. IFPRI Discussion Paper 00798 September 2008.

Deressa TT, Hassan RM, Ringler C, Alemu T, Yusuf M (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob. Environ. Change 19(2):248-255. doi:10.1016/j.gloenvcha.2009.01.002

Florence (2008). Land evaluation in Enderta district, Tigray, Ethiopia. MSc Thesis, Geomatics and Natural Resources Evaluation, università Degli Studi di Firenze. http://www.iao.florence.it/training/geomatics/Mekele/28_Ethiopia.pdf

Fosu-Mensah BY, Vlek PLG, Manschadi AM (2010). Farmers' perception and adaptation to climate change; A case study of Sekyedumase District in Ghana. World Food System - A contribution from Europe, Tropentag, September 14 - 16, 2010, Zurich.

Gbetibouo GA (2009). Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa. IFPRI Discussion Paper 00849 February 2009.

Gebreegziabher Z, Stage J, Mekonnen A, Alemu A (2011). Climate change and the Ethiopian economy: A computable general equilibrium analysis. Environment for Development Discussion Paper Series P. 24.

Gebrehiwot HB (2005). The economic impact of HIV/aids on smallholder farmers of Alamata district, southern Tigray, Ethiopia. MSc Thesis, Haramaya University, Ethiopia.

Gebrehiwot T, van der Veen A (2013). Assessing the evidence of climate variability in the northern part of Ethiopia. J. Dev. Agric. Econ. 5(3):104-119.

Hadgu G, Tesfaye K, Mamo G, Kassa B (2013). Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception. Acad. J. Agric. Res. 1(6):088-100.

Hassan R, Nhemachena C (2008). Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. Afr. J. Agric. Resourc. Econ. 2(1):83–104.

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland P. 104.

Legesse B, Ayele Y, Bewket W (2013). Smallholder farmers' perceptions and adaptation to climate variability and climate change in Doba district, west Hararghe, Ethiopia. Asian J. Empir. Res. 3(3):251-265.

Mengistu DK (2011). Farmers' perception and knowledge of climate change and their coping strategies to the related hazards: Case study from Adiha, central Tigray, Ethiopia. Agric. Sci. 2(2):138-145.

Mulatu ND (2013). Determinants of farmers' preference for adaptation strategies to climate change: evidence from north shoa zone of Amhara region Ethiopia. MPRA (Munich Personal RePEc Archive) Paper No. 48753 posted 1. August 2013 11:07 UTC available at http://mpra.ub.uni-muenchen.de/48753/, Accessed on 10 Nov, 2013.

Ndambiri HK, Ritho CN, Mbogoh SG (2013). An evaluation of farmers' perceptions of and adaptation to the effects of climate change in Kenya. Int. J. Food Agric. Econ. 1(1):75-96.

Nhemachena C, Hassan R (2007). Micro-level analysis of farmers' adaptation to climate change in Southern Africa. IFPRI Discussion Paper 00714 August 2007.

Sahu NC, Mishra D (2013). Analysis of perception and adaptability strategies of the farmers to climate change in Odisha, India. APCBEE Procedia 5:123-127. Doi: 10.1016/j.apcbee.2013.05.022

Teka K, Van Rompaey A, Poesen J, Welday Y, Deckers J (2012). Impact of climate change on small-holder farming: A case of eastern Tigray, northern Ethiopia. Afr. Crop Sci. J. 20(2):337-347.

Tessema YA, Aweke CS, Endris GS (2013). Understanding the process of adaptation to climate change by small-holder farmers: the case of east Hararghe Zone, Ethiopia. Agric. Food Econ. 1:13.

Tesso G, Emana B, Ketema M (2012). Econometric analysis of local level perception, adaptation and coping strategies to climate change induced shocks in North Shewa, Ethiopia. Int. Res. J. Agric. Sci. Soil Sci. 2(8):347-363.

Vincent K, Cull T, Chanika D, Hamazakaza P, Joubert A, Macome E, Mutonhodza-Davies C (2013). Farmers' responses to climate variability and change in southern Africa – is it coping or adaptation? Climate Dev. 5(3):194-205.

You GJY, Ringler C (2010). Hydro-economic modeling of climate change impacts in Ethiopia. IFPRI Discussion Paper No. 00960 April 2010.

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Chemical constituents of chichá (*Sterculia striata* St. Hil. et Naud.) seeds

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The proximate and mineral composition of chichá seeds was evaluated, as well as protein digestibility, bioactive compounds (phenols and flavonoids) and profiles of organic and fatty acids, in order to provide information to support the dietary use of this seed, adding value to the fruit and contributing to the preservation of the Brazilian Cerrado. Chichá (*Sterculia striata* St. Hil. et Naud.) fruits were collected in the city of Jataí, in the southern Goiás state. The seeds were lyophilized, ground and packed in hermetically sealed vials at -18°C. Composition analyses found high contents (g 100 g^{-1} dry matter [DM]) of proteins (22.34), lipids (23.91), dietary fiber (26.29), and the minerals (mg 100 g^{-1} DM) potassium (1,165.78), phosphorus (701.44), and magnesium (277.32). The *in vitro* protein digestibility was 65.67%. Oleic acid (35.17%), palmitic acid (27.13%) and linoleic acid (16.50%) were the major fatty acids; citric acid was the major organic acid. It is concluded that chichá seeds are a source of many nutrients, which supports their inclusion in the formulation of a healthy diet.

Key words: Chichá, proximate composition, minerals, bioactive compounds, citric acid, fatty acid.

INTRODUCTION

Brazil is one of the largest repositories of native plants in the world, with a high genetic diversity, and the Amazon region is the main reserve, followed by the Cerrado in Central Brazil and the Northeast (Carvalho et al., 2008).

In Brazilian native flora, there are some poorly known species, which have the potential for the seed or nut market. Among them is chichá (*Sterculia striata* St. Hil. et Naud.), a plant with fruits containing seeds that are greatly appreciated by the population of the Cerrado regions in Central Brazil and in the Northeast (Carvalho et al., 2008; Silva et al., 2008); however, chichá seeds are not well known in the national and international markets.

Chichá, also known as xixá, amendoim-de-macaco, castanha-de-macaco, castanheiro-do-mato, arachachá, belongs to the family Malvaceae. It is a plant native to the Cerrado, mainly distributed in the states of Minas Gerais, Goiás, Mato Grosso, Tocantins, Bahia, Piauí and

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Maranhão (Silva and Fernandes, 2011). Its fruits are woody, elongated capsules, appearing at the ends of the branches and, when ripe, they open and display the seeds (Silva and Fernandes, 2011).

The seeds are consumed raw, cooked or roasted by humans, and are consumed fresh by native fauna (Silva et al., 2008; Silva and Fernandes, 2011).

Knowing the chemical characteristics and the nutritional and functional value of the fruits of the Cerrado is of paramount importance to encourage consumption and enable the formulation of new products, besides contributing to their preservation. However, few reports are found in the literature regarding the chemical composition of these fruits and their technological application, underscoring the need for scientific research on the subject (Silva et al., 2008).

Studies on proximate composition, amino acid profile (Oliveira et al., 2000; Silva et al., 2008; Carvalho et al., 2008) and chemical characterization of the oil (Chaves, 2004) of raw chichá seeds are reported. However, there are no records on mineral composition, organic acid profile and protein digestibility.

Furthermore, most reports are on chichá fruits from the Northeast region of Brazil. This study differs by using lyophilized chichá seeds from a southern Cerrado region (in the city of Jatai); in the literature, it is not possible to find studies on chichá seeds of this region.

Given the above, the objective of this study was to characterize chichá seeds from the city of Jataí, in the southern Goiás state, determining their proximate and mineral composition, protein digestibility, contents of phenolic compounds and flavonoids, and profiles of fatty and organic acids, in order to provide information which supports the dietary use of this seed, adding value to this fruit and contributing to the preservation of the Cerrado.

MATERIALS AND METHODS

Sample collection and preparation

Chichá (*Sterculia striata* St. Hil. et Naud.) fruits were collected in the city of Jatai, southern Goiás state, in January 2013, in three replicates, and transported to the laboratory. The almonds were then extracted, lyophilized for 24 h, peeled and crushed in a refrigerated mill until a homogeneous flour was formed; the flour was packed in hermetically sealed vials in a freezer at -18°C.

Proximate composition

Moisture contents were determined in an oven at 105ºC, until constant weight. The ether extract was determined using a Soxhlet continuous extractor. Crude protein was measured by the Kjeldahl method, using the conversion factor of 6.25 (N x 6.25). Ash and fixed mineral residue were obtained from a defined quantity of samples by incineration (550°C) in a muffle furnace, thus determining the percentage of residue. Total, soluble and insoluble dietary fiber were determined by the enzymatic method. Nitrogen-free extract was determined by the difference between 100 and the sum, in dry matter, of ether extract, protein, ash and total dietary fiber. Proximate composition analyses were performed using the methodology described by the Association of Official Analytical Chemists (AOAC, 2005).

In vitro protein digestibility

The samples (with known nitrogen content) were subjected to digestion by the enzymes pepsin followed by pancreatin, at their optimum pH, and digestion was stopped by the addition of trichloroacetic acid. The samples were then centrifuged at 10,000 x g for 15 min, and the content of nitrogen was dosed in the supernatant. Casein was used as a standard (Akeson and Stahmann, 1964). The value obtained for casein digestibility was considered as 100%, and the digestibility values obtained for the samples were calculated based on the value obtained for casein.

Mineral composition

The contents of the following minerals were determined: iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K) and sulfur (S). In order to quantify the minerals, the seed samples were subjected to a nitric-perchloric digestion in digester blocks with temperature control. P and S were determined by colorimetry, K by flame photometry and Ca, Mg, Cu, Mn, Zn and Fe by atomic absorption spectrophotometry. For all analyses, the procedures described by Malavolta et al. (1997) were used.

Phenolic compounds

The extraction of phenolic compounds was carried out with 50% methanol, under reflux for three consecutive times, at 80°C, and the extracts were collected, evaporated up to 25 mL, at 80°C, and submitted to phenolic compound measurement, using the Folin-Denis reagent, and tannic acid as a standard (AOAC, 2005).

Total flavonoids

The contents of total flavonoids were measured using the same extracts used in the phenolic compound analyses, using the aluminum chloride colorimetric method, with catechin used as a standard (Zhishen et al., 1999).

Organic acids

The extraction of organic acids for chromatographic analysis was carried out with 1 g sample in 50 mL ultra pure water, under agitation, for 45 min and, subsequently, filtering through Whatman No. 40 paper. An LC 200 A Shimadzu liquid chromatograph was used, as well as a conductivity detector (CDD-6A), + polarity, using a SHIM-PACK SPR-H(G) pre-column (50 mm x 7.8 mm) and two SHIM-PACK SPR-H columns in series (250mm x 7.8mm). The injection volume was 20 µL. The mobile phase was 4 mmol L^{-1} *p*-toluenesulfonic acid, at a flow rate of 0.8 mL/min and 45°C (Fraguas et al., 2014). Peaks corresponding to each acid were identified by the retention time, using the retention times of the standards as a comparison. The following organic acid patterns were used: citric acid, malic acid, quinic acid, lactic acid, tartaric acid, succinic acid and fumaric acid, all Sigma-Aldrich (St. Louis, MO, USA).

Fatty acid profile

Lipids were extracted according to the methodology proposed by

Table 1. Proximate composition (g 100 g^{-1} dry matter) of chichá seeds.

Chichá constituents	Content
Ether extract	23.91±0.06
Crude protein	22.34 ±1.57
Ash	3.54±0.20
Insoluble dietary fiber	24.52±0.83
Soluble dietary fiber	1.76±0.33
Total dietary fiber	26.28±0.49
NFE[1]	23.93±0.21

Data are the mean of three replicates ± standard deviation. [1]NFE: Nitrogen-free extract. Moisture content of chichá seed flour: 6.86 g 100 g^{-1}.

Table 2. Mineral composition, in mg 100 g^{-1} dry matter, of chichá seeds.

Minerals	Contents
Calcium	nd[1]
Phosphorus	701.44±58.10
Potassium	1,165.78±36.31
Magnesium	277.32±14.52
Sulfur	344.08±7.26
Copper	2.93±0.12
Manganese	0.66±0.01
Zinc	6.20±0.29
Iron	2.18±0.12

Data are the mean of three replicates ± standard deviation. Moisture content of chichá seed flour: 6.86 g 100 g^{-1}; [1]nd: not detected.

Bligh and Dyer (1959), and esterification was performed using the methodology by Joseph and Ackman (1992). The composition of fatty acids was determined by gas chromatography, and the chromatograph GC-2010 (Shimadzu) was used, equipped with a flame ionization detector and a fused silica capillary column (100 m long, 0.25 mm internal diameter), containing polyethylene glycol as a liquid stationary phase. The standard used was a mixture of 37 methyl esters (SupelcoTM 37 Component FAME Mix), from C:4 to C22:6, with a purity of 99.9%. In order to perform the gas chromatography, it was necessary to redissolve the samples in 0.50 mL hexane.

The following operating parameters were used: "split" injection mode, split ratio 1:100; injected volume: 1 µL; detector and injector temperature: 260°C; temperature program: 4ºC/minute up to 140°C, remaining at this temperature for 5 min, keeping the heating ramp in 4°C/min up to 240ºC, remaining at this temperature for 30 min.

The identification of the peaks was performed by a comparative method with the retention times of the standard fatty acid esters, and the results were performed by integration of the peak areas and expressed in area percentage.

RESULTS AND DISCUSSION

The results for proximate composition of chichá seeds are shown in Table 1. In a study on the chemical composition of chichá from the state of Ceará, Oliveira et al. (2000) found a higher content of ether extract (28.65 g 100 g^{-1} dry matter - DM), lower contents of ash (3.03 g 100 g^{-1} DM) and similar contents of proteins (22.50 g 100 g^{-1} DM). On the other hand, Silva and Fernandes (2011), in a study with chichá seeds obtained from the state of Piauí, found results similar to those observed for the lyophilized almond in this study regarding the contents of protein (22.11 g 100 g^{-1} DM) and ash (3.92 g 100 g^{-1} DM); however, they reported higher contents of lipids (26.74 g 100 g^{-1} DM) and lower contents of dietary fiber (13.08 g 100 g^{-1} DM). The difference among seeds of the same species, but from different regions, is explained by the influence that soil, fertilization, climate and other environmental factors have on their composition.

The protein contents of the seeds in this study are higher than other common nuts, such as Brazil nuts (14.00-16.00 g 100 g^{-1}), pine nuts (13.00 g 100 g^{-1}), pecan (9.00 g 100 g^{-1}), cashew nuts (17.50 g 100 g^{-1}), hazelnuts (14.50 g 100 g^{-1}), and pistachio (20.00 g 100 g^{-1}) (Yang, 2009), emphasizing the nutritional value of chichá.

Due to the high content of protein found in this study, an evaluation of *in vitro* protein digestibility of the almonds was performed, and the value found was 65.67% ± 1.85. Protein digestibility is very important, since this parameter provides a measurement of protein susceptibility to proteolysis.

Chichá seeds had a total dietary fiber content of 26.29 g 100 g^{-1} DM, and the content of insoluble fiber was, on average, 14 times higher than that of soluble fiber. Food is considered high in fiber when its content is above 6 g 100 g^{-1}, and is considered a source when its content is higher than 3g 100 g^{-1} (Brasil, 1998); therefore, chichá seeds are rich in fiber, which is important in the prevention and treatment of various diseases, such as diabetes and obesity, among others, and their consumption would improve the nutritional quality of a diet.

The content of nitrogen-free extract (23.92 g 100 g^{-1} DM) of chichá seeds was lower than values reported in the literature, which range from 38.10 to 47.23 g 100 g^{-1} DM (Oliveira et al., 2000; Silva et al., 2008; Silva and Fernandes, 2011).

The seeds had high levels, in mg 100 g^{-1} DM, of potassium (1,165.78), phosphorus (701.44) and magnesium (277.32) (Table 2). Considering the Recommended Daily Allowance (RDA), according to the Dietary Reference Intakes (DRI, 2001) of minerals for adults from 19 to 50 years old (phosphorus: 700 mg; calcium: 800 mg; magnesium: 260 mg; copper: 9 mg; manganese: 23 mg; zinc: 11 mg and iron: 8 mg), chichá seeds, in the amount of 100 g day^{-1}, would supply the need for phosphorus and magnesium, highlighting the potential use of chichá seeds as a food supplement.

Due to the fact that the mineral composition of chichá

Table 3. Phenolic compounds, flavonoids and organic acids of chichá seeds.

Constituents	Contents
Phenolic compounds (mg 100 g^{-1} DM)	305.08±7.80
Flavonoids (mg 100 g^{-1} DM)	9.72±1.26
Maleic acid (µg g^{-1} DM)	262.68±8.35
Citric acid (µg g^{-1} DM)	389.43±17.10
Fumaric acid (µg g^{-1} DM)	8.43±0.71

Data are the mean of three replicates ± standard deviation. Moisture content of chichá seed flour: 6.86 g 100 g^{-1}.

Table 4. Fatty acid composition of chichá seeds.

Fatty acids	Chain	Percentage
Palmitic	C16:0	27.13±0.02
Stearic	C18:0	3.10±0.30
Oleic	C18:1n9c	35.17±1.01
Elaidic	C18:1n9t	1.84±0.01
Linolenic	C18:3	0.10±0.01
Eicosatrienoic	C20:3n3	0.15±0.01
Arachidic	C20:0	0.39±0.02
∑ SFA		30.62
∑MUFA		37.01
∑PUFA		16.75

Data are the mean of three replicates ± standard deviation. ∑SFA = sum of saturated fatty acids; ∑MUFA = sum of monounsaturated fatty acids; ∑PUFA = sum of polyunsaturated fatty acids.

has not been previously reported in the literature, it was not possible to compare these results with other studies of this almond.

The contents of phenolic compounds, flavonoids and organic acids in chichá seeds are presented in Table 3. The contents of phenolic compounds (305.08 mg 100 g^{-1} DM) and flavonoids (9.72 mg 100 g^{-1} DM) for theevaluated chichá seeds were higher than those found by Rocha et al. (2013) (phenolic compounds, 85.37 mg 100 g^{-1}; flavonoids, 2.81 mg 100 g^{-1}) and by Costa et al. (2010) (phenolic compounds, 63.94 mg 100 g^{-1}) in studies conducted with chichá seeds from the state of Piauí. These differences can be explained due to several factors, such as harvest regions, maturation stage of seeds, climate, soil, experimental conditions, among others.

Several epidemiological studies show that phenolic compounds have multiple biological effects, such as antioxidant, anti-allergic, anti-inflammatory, anti-bacterial, antithrombotic, cardioprotective and vasodilatory effects (Rao, 2003; Balasundram et al., 2006; Silvério et al., 2013). Several natural antioxidants have been isolated from different plant materials, such as oilseeds, cereals, legumes, fruits, leaves, roots and herbs (Ramarathnam et al., 1995). However, studies that evaluate the antioxidant activity of seeds of tropical and subtropical fruits have been rarely reported, suggesting the need for studies with these fruits, since this is a vast field to be explored.

The determination of organic acids in chichá seeds showed citric acid (389.43 µg g^{-1} DM) as a major component, and maleic and fumaric acids were also identified.

Organic acids present in food affect taste, odor, color, stability and quality maintenance (Cecchi, 2003). The determination of total acidity in food is very important, since it is possible to obtain valuable data for the evaluation of food processing, as well as its conservation status.

Eight fatty acids were detected in chichá seeds, and oleic acid (35.17%), palmitic acid (27.13%) and linoleic acid (16.50%) were the major ones (Table 4). The proportion of fatty acids was, on average, 30.62% saturated, 37.01% monounsaturated and 16.75% polyunsaturated, with a higher percentage of unsaturated than saturated fatty acids.

The contents of oleic (35.17%) and palmitic acid (27.13%) of seeds in this study were similar to those found in other studies, such as those conducted by Silva and Fernandes (2011) (oleic, 35.28%; palmitic, 28.99%) and Chaves et al. (2004) (oleic, 35.90%; palmitic, 25.50%), who also described oleic and palmitic acids as the major ones in chichá seeds. On the other hand, the content of linoleic acid in this study (16.50%) was higher than that found by Silva and Fernandes (2011) (3.77%) and Chaves et al. (2004) (12.21%).

The variation in the composition of fatty acids for the same species may be due to various reasons, such as different stages of seed maturation, differences among populations, equipment used for quantification and different sampling times.

Monounsaturated fatty acids, such as oleic acid, aid in the reduction of total cholesterol and low density lipoprotein (LDL), without reducing high density lipoprotein (HDL), resulting in health benefits (Lopes et al., 2009).

Linoleic acid is necessary to keep cell membranes, brain function and the transmission of nerve impulses under normal conditions. This fatty acid also participates in the transfer of atmospheric oxygen to the blood plasma, as well as in hemoglobin synthesis and cell division, and is essential, since it is not synthesized by the body from fatty acids from the de novo synthesis (Yehuda et al., 2002; Youdim et al., 2000). Therefore, chichá seeds have important fatty acids to contribute to a healthy diet.

CONCLUSION

Chichá seeds have high contents of proteins, lipids, dietary fiber and the minerals potassium, phosphorus and

magnesium, besides the presence of bioactive substances, such as phenolic compounds and flavonoids. The major organic acid was citric acid. The fatty acid profile indicates that these almonds are a good source of unsaturated fatty acids, mainly oleic and linoleic acids. Therefore, chichá seeds have a chemical composition which supports their use in human diets and can contribute to a considerable extent to the recommended dietary intake, as an alternative source of nutrients.

Conflict of Interest

The author(s) declare that they have no conflict of interest to disclose.

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REFERENCES

Akeson WR, Stahmann MAA (1964). Pepsin pancreatin digest index of protein quality evaluation. J. Nutr. 83(3):257-261.

AOAC (2005). Official methods of analysis of the association of the analytical chemists (17ed) Association of Official Analytical Chemists. Washington, DC, USA.

Balasundram N, Sundram K, Sammar S (2006). Phenolic compounds in plants and agri-industrial by-products: Antioxidant activity, occurrence, and potential uses. Food Chem. 99(1):191-203.

Bligh EG, Dyer WJ (1959). A rapid method of total lipid extraction and purification. Can. J. Biochem. Physiol. 37(8):911-917.

BRASIL. Portaria n° 27, de 13 de janeiro de 1998. Aprova regulamento técnico referente à informação nutricional complementar. Brasilia; 1998 [acesso 2009 Jun 26]. Disponível em: <http://www.anvisa.gov.br>.

Carvalho GM, Costa JMC, Souza VAB, Maia GA (2008). Avaliação dos parâmetros físicos e nutricionais de amêndoas de chichá, sapucaia, e castanha do gurguréia. Rev. Ciênc. Agron. 39(4):517-523.

Chaves MH, Barbosa AS, Neto JMM (2004). Caracterização química do óleo da amêndoa de *Sterculia striata* St. Hil. et Naud. Quim. Nova. 27(3):404-408.

Cecchi HM (2003). Fundamentos teóricos e práticos em análises de alimentos**.** 2. ed. Campinas: Editora da Unicamp.

Costa DA, Chaves MH, Silva WCS, Costa CLS (2010). Constituintes químicos, fenóis totais e atividade antioxidante de *Sterculia striata* St. Hil. et Naudin. Acta Amazônica 40(1):207-212.

DRI – Dietary Reference Intakes Applications in Dietary Assessment (2001). Report of the subcommittee on interpretation and uses of dietary reference intakes and the standing committee of the scientific evaluation of dietary reference intakes, food and nutrition board. Institute of Medicine, Washington P. 306.

Fraguas RM, Simão AA, Silva RL, Santos CM, Rocha DA, Tavares TS, Marques TR, Duarte MH, Marcussi S, Abreu CMP (2014). Chemical composition of processed baru (*Dipteryx alata* Vog.) almonds: lyophilization and roasting. Afr. J. Agric. Res. 9:1061-1069.

Joseph JD, Ackman RG (1992). Capillary column gas chromatography method for analysis of encapsulated fish oil and fish oil ethyl esters: collaborative study. J. AOAC Int. 75:488-506.

Malavolta E, Vitti GC, Oliveira AS (1997). Avaliação do estado nutricional das plantas. Piracicaba: Potafos P. 319.

Oliveira JTA, Vasconcelos IM, Bezerra LCNM, Silveira SB, Monteiro ACO, Moreira RA (2000). Composition and nutritional properties of seeds from *Pachira aquatica* Aubl, *Sterculia striata* St. Hil et Naud. and *Terminalia catappa* Linn. Food Chem. 70(2):185-191.

Ramarathnam N, Osawa T, Ochi H, Kawakishi S (1995). The contribution of plant food antioxidants to human health. Trends Food Sci. Technol. 6(3):75-82.

Rao B (2003). Bioactive phytochemicals in Indian foods and their potential in health promotion and disease prevention. Asia Pac. J. Clin. Nutr. 12(1):9-22.

Rocha MS, Figueirado RW, Araújo AMA, Araújo RSRM (2013). Caracterização físico-química e atividade antioxidante (*in vitro*) de frutos do cerrado piauiense. Rev. Bras. Frut. 35(4):933-941.

Silva MR, Lacerda DBCL, Santos GG, Martins DMO (2008). Caracterização química de frutos nativos do cerrado. Ciênc. Rural 38(6):1790-1793.

Silva MGA, Fernandes FK (2011). Chemical composition and antinutrients of raw and roasted chicha almonds (*Sterculia striata* A. St. Hill & Naudin). Rev. Nutr. 24(2):305-314.

Silvério MDO, Castro CFS, Miranda AR (2013). Antioxidant and inhibitory action on tyrosinase from *Dipteryx alata* Vogel (Baru) leaves. Rev. Bras. Plant Med. 15(1):59-65.

Yang J (2009). Brazil nuts and associated health benefits: A review. LWT - Food Sci. Technol. 42(10):1573-1580.

Yehuda S, Rabinovitz S, Carasso RL, Mostofsky DI (2002). The role of polyunsaturated fatty acids in restoring the aging neuronal membrane. Neurobiol. Aging 23(5): 843-53.

Youdim KA, Martin A, Joseph JA (2000). Essential fatty acids and the brain: Possible health implications. Int. J. Dev. Neurosci. 18(5):383-399.

Zhishen J, Mengcheng T, Jianming W (1999). The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. Food Chem. 64(4):555-559.

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Review

Breeding and biotechnological opportunities in saffron crop improvement

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Saffron (*Crocus sativus* L.) being triploid in nature is propagated by vegetative means through corms. The natural propagation rate of such plant species is relatively low, therefore some breeding and biotechnological technique like introduction, clonal selection, mutagenesis, micro-propagation and molecular markers have been used earlier as an alternative method of propagation for saffron. The creation of a germplasm bank consisting of superior elite clonal selections can be considered as a great achievement and in addition, the identification of selections as sources of variation can play an important role in improvement of this crop. The use of mutagenesis could increase the natural variability for important characters and may help in overcoming sterility barrier in autotriploid saffron by colchinization. Genetic improvement through mutation is one more important research area in saffron crop improvement and efforts made by different scientists have already given a base line idea for the improvement of this crop. Molecular markers have very good potential for study of species/clone level variation within saffron species. Use of molecular markers in saffron crop improvement will help in identifying the accessions and species which will be used for commercial exploitation and making of hybrids. At present we are having very few SSR markers in saffron, therefore both genomic and genic SSR markers need to be developed so that variation at genomic and expression level can be exploited.

Key words: Saffron, hybridization, clonal selection, introduction, mutagenesis, in-vitro regeneration, molecular markers.

INTRODUCTION

Saffron (*Crocus sativus* L.) is an autumn flowering cormose plant, cultivated for numerous properties ascribed to the stigmatic lobes and used as spice, condiment and for medicinal purposes (Figure 1). The corms reproduce annually, only vegetatively as the plant is sterile (Chichiricco, 1984) autotriploid (2n=3x=24) and seeds are unknown. Studies have revealed that the sterility is related to meiotic abnormalities producing both pollen grains, which display low/defective germination, and partially nonfunctional macrospores (Chichiricco, 1989). Sterility in saffron limits the application of conventional breeding approaches for its further improvement. All over the world saffron is known as one cultivar, a descent of certain triploid sterile plant arisen once spontaneously in nature which was caught by sight of man and involved into cultivation (Mathew, 1977). It

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Figure 1. Saffron in full bloom.

has been propagated and still continues to be propagated vegetatively. There is a supposition that saffron as a clone can be scarcely changed genetically and its improvement is hardly possible through clonal selection (Dhar et al., 1988, Piqueras et al., 1999). It is supposed that saffron, a sterile clone of triploid origin that has been cultivated from times immemorial (the period about 3.5 to 4.5 thousand years) has passed an original evolution. Growing in the various countries under various soil-climatic conditions, during many centuries, saffron has been influenced by various stressful factors and has undergone different sorts of mutations. Despite of sterility, genetic changes could partly happen as a result of somatic recombination, deletions, inversions, translocations, polyploidy, incomplete segregation, segregation distortion, mutations, trans-versions, transitions etc.

Each plant that has undergone a genetic change has become a unique, new clone but clones in populations grow together, in a mixture. Thus they never combine genetically because of their sterility (Agayev et al., 2010). Studies in relation to genetic variability and divergence in saffron to generate information on the nature and magnitude of component of phenotypic variability including, heritability, genetic gain, nature of interrelationship among components of economic worth, contribution of different morphological and yield component traits and extent of divergence saffron populations collected from natural saffron growing areas have been studied (Anonymous, 2006). Genetic variation and heritability of agro-morphological and phytochemical traits in saffron populations have been studied and populations were found significantly different for most evaluated traits like leaf number per plant, leaf length, flower number per plot, dry stigma weight per plot, spathe number and the content of crocins, picrocrocin and safranal (Baghalian et al., 2010). Moraga et al. (2009) found that saffron is a monomorphic species as revealed by RAPD, ISSR and microsatellite analyses. Pardo et al. (2004) investigated the distinction and variability of *Crocus sativus* from several geographic areas (Italy, Iran, Greece and Spain) using molecular markers and dry stigmas as plant material. Zubor et al. (2004) used AFLP markers for study of genetic diversity among different saffron species and found close relationship between these species. Retero-transposons have also been used for studying the genetic diversity among different saffron species, genetic variation was observed within and between species and in some cases variation was found among ecotypes of the same species from different geographical regions (Alavi-Kia et al., 2008). Use of molecular markers as a tool for identification of variability among different saffron clones is an important area for improvement of this crop through breeding. Sequencing of corm cDNAs at different developmental stages would increase our knowledge about the physiological processes occurring in this organ. However, little work has so for been done in these areas. Development of gene expression in saffron corm at different time intervals has been studied (Orti et al., 2004). Different ESTs with respect to corm development, signal perception and transduction, defence against pathogen and stress, metabolism, development and gene regulation, cell organization, protein metabolism, transport etc have been identified. EST data base from saffron stigmas has been produced (Agostino et al., 2007) which will be very useful for detecting the level of expression of different components in saffron genotypes. Differential expression of apocarotenoid biosynthetic genes has been observed during different stages of stigma development in saffron (Mir et al., 2012). Beside other factors new high yielding cultivars of saffron are required to solve the problem. It seems that the genetic improvement of saffron and creation of new high yielding cultivars in the past was impossible owing to the complexity of the problem only because the traditional methods of breeding were not promising (Agayev et al., 1975). A lot of work has been carried out using tissue culture (Dhar et al., 1988; Chichiricco, 1999; Munshi and Zargar, 1991; Munshi, 1992; Piqueras et al., 1999). Ascertaining the specified

activities at the same time it should be admitted that for today on arena there is only one cultivar of saffron. The urgency of saffron breeding problems and the necessity to solve them with the application of new extraordinary approaches was stated earlier (Agayev, 1994a, b). Clonal selection independently and in combination with the experimental polyploidy and hybridization involving wild close relatives of *C. sativus* is most promising along with application of the methods of *in vitro* technique and molecular genetics. Thus, we need to exploit different research areas which can decipher the path for improvement of this crop. Following are some opportunistic research areas which need to be studied in detail for qualitative and quantitative improvement of saffron crop.

CLONAL SELECTION OF ELITE GERMPLASM

Clonal selection plays an important role with reference to improving the traits of cultivated saffron. There is a specific belief among some researchers that clonal selection of saffron will not result in large scale success with respect to improving the productivity of saffron because saffron, as a cloned species, does not have sufficient genetic variability for use in plant selection programs. In addition, mutations that have been identified as resulting from experimental or natural mutagenesis are not maintained as they are not heritable; consequently, they disappear in subsequently vegetative generations. There is also the problem of sterility, caused by the triploid nature of saffron, which prohibits its use in hybridization programs. Therefore, methods of conventional breeding are not relevant in terms of saffron breeding programs, and others believe that experimental mutagenesis and *in vitro* techniques must be focused upon. However, to date, both experimental mutagenesis and procedures aimed at doubling a chromosome set of saffron have not lead to encouraging results (Agayev et al., 1975; Bagheri and Vessal 2003; Khan 2004, 2007; Zaffar et al., 2004; Nehvi et al., 2007a, b). Moreover, the decrease of land surface dedicated to saffron crop in many areas has possibly resulted in corresponding genetic erosion that adds up to the limited genetic variation suspected for *C. sativus* due to its sterile habit. Thus, the situation seems dramatic at present time and compromises any attempt of genetic improvement regarding this highly-valued crop (Fernandez, 2004). Consequently, the creation of a germplasm bank consisting of superior elite clonal selections can be considered as a great achievement in the first place. In addition, the identification of selections as sources of variation with respect to some valuable traits like apocarotenoid biosynthetic potential, stigma length variation, variation in stigma number and yield etc can play an important role in improvement of this crop. Therefore superior clones showing better stigma characteristics need to be selected and mass multiplied. Furthermore such genotypes need to be analyzed in detail to find out the active principal behind their superiority, which can be exploited for saffron crop improvement. Therefore, utilization of heterogenity in the natural population which is due to genetic and environmental factors offers a tremendous scope for saffron improvement. Natural variability can occur due to deletions, translocations, inversions at chromosomal level. Changes at DNA level due to transitions and transversions, mutations, SNPs etc will lead to development of stable variants in saffron. Stress and other natural factors can also induce changes which can be useful for breeding programmes.

HYBRIDIZATION WITH CLOSE RELATIVES

C. sativus was generally assumed to be of autotriploid or hybrid origin. Now we have several data that support the alloploidy of *C. sativus* being the parents *C. cartwrightianus* and *C. hadriaticus*, both with 2n=16 and present currently in Greece but not in overlapping areas. Other possible parents, e.g., *C. thomasi*, from Italy and Croatia, *C. mathewii* from Turkey, and *C. pallasii* ssp. *haussknechtii* from Iran-Iraq-Jordan, cannot be excluded. The complexity of the evolutionary history of the genus crocus suggests an intensive species hybridisation and explosive speciation in crocus evolution that could be on the basis of the origin of saffron. We now are sure that saffron is an allopolyploid but the localization of the hybridisation event has not been ascertained so far. If the event took part several times could have generated different amphiploids and, in consequence, different saffron lines. In saffron the potential of the spore mother cells is limited by their triploid genome which causes meitic abnormalities, followed by variations in sporogenesis and gametogenesis, as a result, abnormal gametophytes are generated. However, the reproductive system of the saffron, like that of fertile crocus species, supports inter-specific crosses with related species. This potential cross-compatibility opens the door to breeding programmes for genetic improvement of the saffron. It is therefore possible to transfer the traits from other species into the saffron through hybridization or change the ploidy level of this species through hybridization with close diploid relatives. History suggested that such events led to the development of this crop therefore those events can now further be used to intensify the improvement of this crop.

INTRODUCTION OF ELITE GERMPLASM

Sustained efforts are required towards genetic improvement of saffron to develop high yielding cultivars through mutual exchange of germplasm base across

saffron growing countries of the world, followed by their molecular characterization and further evaluation. Germplasm having tolerance to biotic and a-biotic stresses and possessing high quality flower traits can improve the saffron production and quality. Germplasm susceptible to local biological agents particularly *Fusarium* should not be introduced as such germplasm can have detrimental effects on growth and development of the crop.

MUTAGENESIS FOR INDUCING VARIABILITY AND POLYPLOIDY

Induction of genetic variability through mutagenesis is another very important area of research in this crop. The use of mutagenesis could increase the natural variability for important characters such as high content of active principles per stigma, variability in morphological and flower component traits, change in flowering pattern, increase in stigma number etc. Also mutageneisis may help in overcoming sterility barrier in autotriploid (2n=3x=24) saffron (*Crocus sativus* L.) by colchinization, or any other means. Genetic improvement through mutation is one more important research area in saffron crop improvement. Different efforts made by different scientists (Khan, 2004, Khan 2007; Nehvi et al., 2005) have already given a base line idea for the improvement of this crop. Due to triploid sterile nature of this crop mutation breeding is very helpful in development and isolation of even-ploidy level selections. Saffron being triploid sterile plant and often propagated vegetatively through corms thus allowing the detection, selection and conservation of mutants within the M1-generation. Thus mutation breeding combined with *in vitro* culture techniques may lead to rapid success in generation of stable clones possessing even level of ploidy, which can lead to fertility of this crop. Polyploidy induction has already been studied for generation of stable hexaploids using colchicines (Zaffar et al., 2004).

IN-VITRO REGENERATION SYSTEM

Since the saffron reproduce only vegetative by the corms any attempt to modernize saffron cultivation will therefore require efficient mass production of pathogen free corms. Micro propagation of saffron has therefore been advocated to be the best alternative for its propagation. Thus through *in-vitro* multiplication of somaclonal variants can be obtained which will act as source of variation with respect to different traits in saffron and for induction and isolation of mutant cells, *in-vitro* regeneration system needs to be exploited as a tool. Rapid rates of multiplication and assured health status of propagules that can be attained in culture. Embryo culture is of most interest to the breeder as a means of producing novel inter-specific and inter-generic hybrids. Cultured embryos can be used as experimental systems for studying the biochemistry and molecular biology of storage product synthesis and accumulation as well. The techniques of cell culture and somoclonal variation to select variants mutants for various biotic and abiotic stresses would be fruitful. It is expressed that biotechnology will find higher application in saffron improvement.

OTHER BIOTECHNOLOGICAL INTERVENTIONS

Genetic modification using biotechnological interventions can also lead to variation. Transgenic saffron can be produced having additional traits as a source of variation. But such research areas can only be taken up after standardization of efficient micropropagation protocols and identification of genes and their regulatory behaviour fulfilling the requirements for release. There is very little knowledge on the inheritance of traits of agronomic relevance. Several approaches have been taken to overcome the constraints in the current methodologies for the genetic improvement of saffron. Evaluations at early stages of selection allow for estimates of general combining ability effect or breeding values of parental lines. Molecular markers can play an important role for early stage selection for genetic estimates and for selection of superior saffron clones having potential for utilization in clonal selection programmes. Extent of variability can be searched through exhaustive selection and identification of elite clones will be very useful for improvement of this crop through further breeding programmes. Molecular markers have very good potential for study of species/clone level variation within saffron species. Use of molecular markers in saffron crop improvement is an open area of research. These studies will help in identifying the accessions and species which will be used for commercial exploitation and making of hybrids. At present we are having very few SSR markers in saffron, therefore for scanning large saffron genome which is about 30,000 Mbp development of large number of SSR markers is needed. Both genomic and genic SSR markers need to be developed so that variation at genomic and expression level can be exploited. ESTs can be used for studying the expression level among different species of saffron. Species variation with respect to different metabolites using ESTs data can be studied, which will be very useful in identifying the variants useful for further breeding programmes. Since literature suggests that there is very low level of variability at genomic level but cultivation of saffron is done under different environmental conditions which can lead to induction of variation at transcription level hence utilization of EST-SSR can have more potential for revealing the variability between different saffron clones. Gene expression studies during the development of saffron and between the saffron clones is also an

important area of research. These studies will be very useful for quantitative measurements of genetic diversity of saffron on one hand and identification of different developmental stages of saffron on other hand. Researchers successfully develop *in-vitro* stigma likes structures in saffron (Mir et al., 2010, 2012) having high potential for apocarotenoid biosynthesis. Gene expression studies will be very useful for identifying the actual stage of stigma development under *in-vitro* conditions. Also gene expression during flower development in saffron can be correlated with apocarotenoid biosynthetic gene expression which can help in identifying the clones of high quality stigma with better flowering traits. Saffron genome sequencing partially or as a whole will also help in deciphering different genetic mechanisms which are hidden so for. The origin of saffron from wild Crocus species is not fully proven. So there is need to investigate the structure of genes which are conserved across all plant species thereby to define how the saffron genome is related to other species. Gene annotation will play an important role in identifying the level of synteny between saffron and other species.

DEVELOPMENT OF DESCRIPTOR FOR SAFFRON

There is an immediate need to construct a list of morphological, molecular, phonological, agronomical and biochemical descriptors valid for the genus crocus besides descriptors of susceptibility to stress factors, resistance to diseases and abiotic factors. The creation of collection will contribute not only to slow down the intense genetic erosion but also will make available a wide variety of crocus genotypes of potential carrier of interesting genes for plant breeders, e.g., resistance to biotic and abiotic stress, reserve accumulation, biosynthesis of secondary metabolites, identification of accessions of saffron within the collection those are genetically identical using different levels of indicators etc.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Agayev YM, Muzaferova RS, Savchenko SP (1975). Results of experiments of treatment of saffron corms in colchicines solution. Vestnik Selskokhozyaystvennoi Nauki (Moscow) 10:121–123.

Agayev YM (1994a). Some urgent problems of genetics, cytogenetics and breeding of saffron. Proceedings of the 2nd Symposium on Saffron and Farming of Medicine Plants, (SSFMP'94), Gonabad, Iran P. 12.

Agayev YM (1994b). Origin of saffron and its karyotype analyses. Proceedings of the 2nd Symposium on Saffron and Farming of Medicine Plants, (SSFMP'94), Gonabad, Iran P. 13.

Agayev YMO, Fernandez JA, Zarifi E (2010). Clonal selection of saffron (*Crocus sativus* L.), the first optimistic experimental results. Euphytica 169:81–99.

Alavi-Kia SS, Mohammadi SA, Aharizad S, Moghadam M (2008). Analysis of genetic diversity and phylogenetic relationships in crocus genus of Iran using inter-retrotransposon amplified polymorphism. Biotechnol. Eq. 22:795-800.

Anonymous (2006). Studies in relation to genetic variability and divergence in saffron (*Crocus sativus* L. SKUAST(K), Srinagar, J & K, India.

Baghalian K, Shabani SM, Jamshidi AH (2010). Genetic variation and heritability of agro-morphological and phytochemical traits in Iranian saffron (*Crocus sativus* L.) populations. Ind. Crops Products 31:401-406.

Bagheri A, Vessal S (2003). Saffron improvement in Iran, breakthroughs and barriers. In, Proc 3rd Natl Symp Saffron, Mashhad pp. 1–10.

Chichiricco G (1984). Karyotype and meiotic behaviour of the triploid *Crocus sativus* L. Caryologia 37:233–239.

Chichiricco G (1999). Sterility and perspectives for genetic improvement of *Crocus sativus* L. In, Saffron, *Crocus sativus*. Medicinal and Aromatic Plants – Industrial Profiles. (Ed. By Negbi, M.). Hardwood Academic Publishers P. 127-135.

Agostino DN, Pizzichini D, Chiusano ML, Giuliano G (2007). An EST database from saffron stigmas. BMC Plant Biol. 7:53-53.

Dhar AK, Sapru R, Rekha K (1988). Studies on saffron in Kashmir. 1. Variation in natural population and its cytological behavior. Crop Improve. 15:48-52.

Fernandez JA (2004). Biology, biotechnology and biomedicine of saffron. Recent Res. Dev. Plant Sci. 2:127–159.

Khan IA (2004). Induced mutagenic variability in saffron (*Crocus sativus* L.). Acta Hortic. 650:281–283.

Khan IA (2007). Development of high yielding saffron mutant. Acta Hortic. 739:255-257.

Mathew B (1977). *Crocus sativus* and its allies (Iridaceae). Plant Syst. Evol. 128:89-103.

Mir JI, Ahmed N, Wani SH, Rashid R, Mir H, Sheikh MA (2010). In-vitro development of microcorms and stigma like structures in saffron (*Crocus sativus* L.). Physiol. Mol. Biol. Plants 16(4):369.

Mir JI, Ahmed N, Wafai AH, Qadri RA (2012). Relative expression of CsZCD gene and apocarotenoid biosynthesis during stigma development in *Crocus sativus* L. Physiol. Mol. Biol. Plants 18(4):371-375

Moraga AR, Rambla JL, Ahrazem O, Granell A, Gomez-Gomez L (2009). Metabolite and target transcript analyses during *Crocus sativus* stigma development. Phytochemistry 70:1009–1016.

Munshi AM (1992). Genetic variability for important traits in saffron (*Crocus sativus*.). Crop Res. Hisar. 5:326–332.

Munshi AM, Zargar GH (1991). Variation in natural population of saffron (*Crocus sativus* L.) crop in Kashmir and performance of some selected sub-population. Phytobreedon 7:62–67.

Nehvi FA, Agarwal SG, Mir MA, Dar SA, Mir ZA, Nusrat N (2005). Quality drying of Saffron. SKUAST J. Res. 7(2):343-346.

Nehvi FA, Wani SA, Dar SA, Makhdoomi MI, Allie BA, Mir ZA (2007b). New emerging trends on production technology of saffron. Acta Hortic. 739:375–381.

Nehvi FA, Wani SA, Dar SA, Makhdoomi MI, Allie BA, Mir ZA (2007a). Biological interventions for enhancing saffron productivity in Kashmir. Acta Hortic. 739:25–31

Orti MA, Gómez LG, Rubio Á, Escribano J (2004). Development and Gene Expression in Saffron Corms. Prokisch Proc. Ist IS on Saffron Eds, J.-A. Fernández & F. Abdullaev. Acta Hortic. 650:35-38

Pardo J, Fernández JA, Gómez LG (2004). Development of molecular markers for origin determination in saffron. Acta Hortic. (ISHS) 650:95-98

Piqueras A, Han BH, Escribano J, Rubio C, Hellin E, Fernandez JA (1999). Development of cormogenic nodules and microcorms by tissue culture, a new tool for the multiplication and genetic improvement of saffron. Agronomy 19:603–610.

Zaffar G, Wani SA, Anjum T, Zeerak NA (2004). Colchicine induced variability in saffron. Acta Hort. 650,277–280

Zubor AA, Suranyi G, Gyori Z, Borbely G, Prokisch J (2004). Molecular biological approach of the systematics of *Crocus sativus* L. and its allies. In, Abdullaev F (ed). First International Symposium on Saffron Biology and Biotechnology pp. 85–93.

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Emission of CO_2 and soil microbial activity in sugarcane management systems

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Because of the great importance of sugarcane in the Brazilian agricultural sector, this study was developed in order to evaluate the soil CO_2 flux and the soil microbial activity in the systems of burned sugarcane and green sugarcane. For this end, three areas were evaluated with different histories of sugarcane management: (1) burned sugarcane BS); (2) green sugarcane for 5 years (GS-5); (3) green sugarcane for 10 years (GS-10), considering that both areas of green sugarcane were converted from a scenario of prior burning before harvest. The soil CO_2 flux (FCO_2), basal respiration (BR), carbon of the microbial biomass (CMB), metabolic quotient (qCO_2) and microbial quotient (qMIC) were evaluated in 30 points in a 100 × 100 m sampling grid, amounting to 1 ha. The results indicated higher FCO_2 and CBM in the GS-10 area, and lower in the BS area, whose CO_2 emission and microbial activity were higher in summer. The metabolic and microbial quotients showed a greater balance of the soil microbial activity in the area of green sugarcane for 10 years, fostered mainly by the higher amount of mulch on the soil.

Key words: *Saccharum officinarum*, soil respiration, microorganisms, mulch.

INTRODUCTION

The cycle of sugarcane cultivation has been the subject of studies because of the impacts caused in the soil and atmosphere, related mainly to the sugarcane burning system, which is a common practice in Brazil and whose main objective is to facilitate the manual cutting. To replace the burning system, the green sugarcane system was implemented, in which sugarcane is harvested mechanically, without prior burning, and the waste is deposited on the soil, on an average of 10 to 30 Mg ha^{-1} of mulch (Souza et al., 2005), which benefits the soil (Mendonza et al., 2000; Souza et al., 2005) and provides a favorable microclimate environment for the

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development of biological communities that will act in the subsequent process of decomposition of organic residues (Xu and Qi, 2001; Franchini et al., 2007; Matias et al., 2009).

The green sugarcane system can function as carbon mitigation for the environment, because despite the of CO_2 release during the microbial decomposition of the carbon that would be lost if the sugarcane was burned is incorporated into the soil (Panosso et al., 2008). The CO_2 release is due to the action of microorganisms in the process of decomposition of organic matter stimulated by the greater amount of substrate that the green sugarcane system provides. These organisms are widely used as indicators of soil quality as they are very sensitive to changes in soil management in the short time (Galdos et al., 2009), since physical or chemical attributes are not always sufficient to explain the variations that occur in the soil from the actions of its use and handling.

The influence of temperature and soil moisture on CO_2 emissions has already been reported in several studies (Kosugi et al., 2007; Panosso et al., 2008; Siqueira Neto et al., 2011; Lenka and Lal, 2013; Song et al., 2013); thus, research studies for new factors that have a relationship with CO_2 are of the utmost importance to try to understand the dynamics of this gas in the soil, as well as its stabilization and carbon buildup. Soil microorganisms can clarify many questions on CO_2 emissions, as the microbial activity is primarily responsible for the decomposition of organic residues, nutrient recycling and energy flow in the soil, this way exerting influence on the carbon storage, availability of nutrients for plants and CO_2 emissions (Jenkinson and Ladd, 1981).

The carbon of the microbial biomass and the basal respiration are the most used attributes in studies on the biological indicators of the soil, and microbial biomass is the most active living part of the soil organic matter, formed mainly by fungi and bacteria (Kaschuk et al., 2009), while soil respiration indicates the degree of activity of the biomass. These attributes are considered easy indicators of soil quality because of their high sensitivity to changes in management or climate; however, some attributes show difficulties when being interpreted if evaluated individually (Lopes et al., 2013), such as, for example the basal respiration, since high respiration values do not always indicate desirable conditions in the short term, as a high respiration rate can mean release of nutrients into the soil, and in the long term, loss of organic carbon to the atmosphere.

The short- and long-term temporal monitoring aids in the interpretation of the soil microbiological quality; moreover, Anderson and Domsch (1990) proposed relationships between the attributes aiming at a more interpretative approach and to establish dynamic relationships between biomass and microbial activity, such as metabolic quotient (qCO_2), which calculates the release of CO_2 per unit of biomass for a certain time, and microbial quotient (qMIC), which evaluates the availability of organic carbon for microbial activity. Thus, an ecosystem out of balance will present high values of qCO_2 and low values of qMIC, which indicates greater energy consumption and higher level of stress of the biomass (Anderson and Domsch, 1990; Evangelista et al., 2013; Kuwano et al., 2014).

Biological indicators of the soil have been used in studies on the efficiency of management systems, such as conventional and no-tillage (Martinéz et al., 2013; Alves et al., 2011), of different ecosystems, such as pasture and shrubs (Loureiro et al., 2010), of forestry and agroforestry systems (Silva et al., 2012) and on the comparison of the management systems of green sugarcane and burned sugarcane (Mendonza et al., 2000). In these studies, the soil microbial activity showed sensitivity to management efforts, thus strengthening the use of these attributes in the understanding of the stability of soil carbon. This way, this study aimed to evaluate the soil CO_2 flux and the soil microbial activity in the systems of burned sugarcane and green sugarcane.

MATERIALS AND METHODS

The study was conducted in the northeast of the State of São Paulo, near the coordinates 21°19'8" South and 48°7'24" West. The climate in the region is classified as $B_2rB'4a'$ by the Thornthwaite climate classification criterion. The soil of the area was classified as eutroferric Oxisol, clayey texture, with flat and undulating topography.

The areas evaluated were implanted in three sugarcane management systems: burned sugarcane (BS), green sugarcane implemented for five years (GS-5), one cycle with this system, and green sugarcane implemented for ten years (GS-10), two cycles with this system, being that both green sugarcane areas were converted from the scenario of prior burning before harvest.

We performed a chemical characterization of the soil in the areas before the start of the evaluations (Table 1), whose data showed increased base saturation (SB) in BS, which may be related to the large amount of ash deposited on the soil surface from the prior burning of the sugarcane, thus contributing with the immediate addition of mineral nutrients, such as K, Ca and Mg.

The burned sugarcane area was managed with the burning system since the '80s and in 2011-2012. The area of green sugarcane implemented for five years began to be harvested by the mechanized system from 2006, and the system of mechanized harvesting began in 2001 in the area of green sugarcane implemented for ten years. On the reform of the sugarcane plantation, which occurred in the areas of burned sugarcane (every 6 ratoons) and green sugarcane for ten years (in 2007), there was the mechanical elimination of the ratoon of the previous crop and subsoiling at the depth of 0.45 m in the planting furrows. Soon after, 2 t ha^{-1} of dolomitic limestone were applied. For the planting fertilization, 480 kg ha^{-1} of NPK in the 10-25-20 formulation were used. Over the years, on average, 100 m^{-3} ha^{-1} of vinasse and 300 kg ha^{-1} of urea or 200 kg ha^{-1} of ammonium nitrate were applied in the areas.

The evaluations of the soil CO_2 flux (FCO_2) and soil collection at the 0.00 to 0.10 m layer for biological analyses were performed in 30 points on a sampling mesh at the regular intervals of 1, 2 and 10 m (1 ha), whose points were georeferenced with the aid of a total station (model TC 305 Leica ®) and DGPS (L1/L2 Hiper Lite Plus) (Figure 1). The evaluation of CO_2 was performed simultaneously in the three areas of study in the dry period of 2011 and wet period of

Table 1. Chemical characterization of the soil in the management areas of burned sugarcane, green sugarcane for five years and green sugarcane for ten years, in Pradópolis, São Paulo, Brazil, 2011-2012.

Chemical attributes	Burned sugarcane	Green sugarcane for five years	Green sugarcane for ten years
OM[(1)] (g kg^{-1})	3.93	4.31	3.37
SB[(2)] ($cmol_c$ dm^{-3})	11.44	6.08	5.02
CEC[(3)] ($cmol_c$ dm^{-3})	15.06	10.29	8.43
V%[(4)]	75.93	59.05	58.76
pH	5.22	4.80	4.91
Phosphorus (mg dm^{-3})	16.66	36.30	35.55
Sulfur (mg dm^{-3})	0.81	8.17	0.51
Potassium ($cmol_c$ dm^{-3})	6.08	0.60	6.94
Calcium ($cmol_c$ dm^{-3})	9.00	4.21	3.44
Magnesium ($cmol_c$ dm^{-3})	1.63	1.27	1.06

[(1)]OM = organic matter; [(2)]SB = sum of bases; [(3)]CEC = cation exchange capacity; [(4)]V% = base saturation.

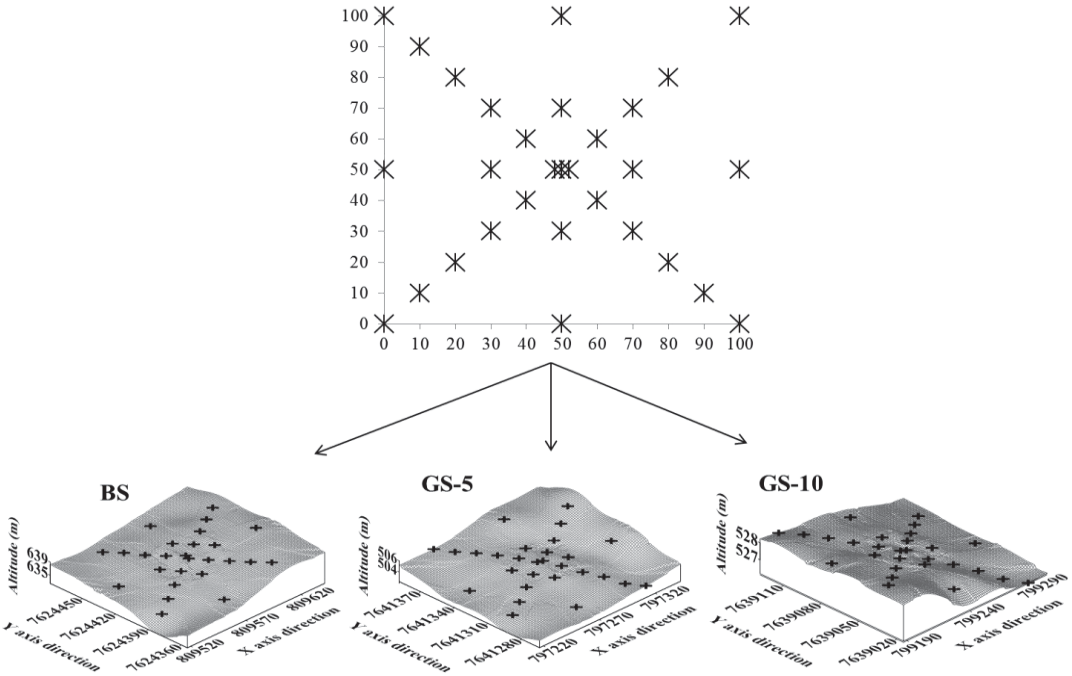

Figure 1. Sampling grid and relief maps of the areas evaluated in Pradópolis, São Paulo, Brazil, 2011-2012. BS = burned sugarcane; GS-5 = green sugarcane for 5 years; GS-10 = green sugarcane for 10 years.

2012 in the mornings (07:00 to 10:00 am). The evaluation was conducted with the aid of ground chambers, of the model LI-8100 (LICOR). The equipment is a closed system with internal volume of 991 cm^3, with contact area with the soil of 71.6 cm^2 and placed on PVC collars previously inserted into the soil at a depth of 3 cm. Soil moisture was measured simultaneously with the measurement of the CO_2 concentration with the aid of a portable TDR (Campbell®).

The CO_2 emission by basal respiration in laboratory was evaluated for comparative purposes with the CO_2 emission evaluated in field, named in this paper as soil CO_2 flux (FCO_2), and the main difference is that the basal respiration calculates the CO_2 from soil microorganisms, whereas the FCO_2 calculates the CO2 from microorganisms and roots.

Sampling for microbiological analysis was performed on the 0.00-0.10 m layer in two days of collection in each period (winter and summer) and area, amounting to 360 samples, which were kept under cooling until the analyses within a maximum of 30 days. The analysis for the carbon of the microbial biomass was carried out according to the fumigation-extraction method proposed by Vance et al.(1987) and the basal respiration according to the respirometry-titration method of Alef and NanniPieri (1995). The metabolic quotient (qCO2) and microbial quotient were determined according to the relation proposed by Anderson and Domsch (1990).

Data on air temperature, rainfall, air humidity (Figure 2A) and soil temperature (Figure 2B) on the days of evaluation are presented below and show variations between the periods analyzed (winter

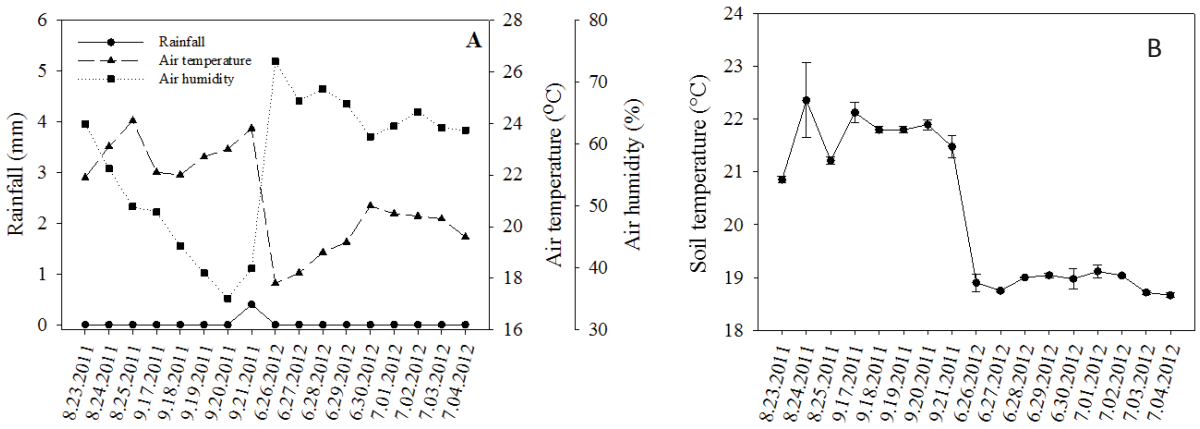

Figure 2. Rainfall, temperature, air humidity (A) and soil temperature (B) on the days of evaluation of soil CO_2 flux in winter and summer.

and summer), with the exception of rainfall, without the occurrence of rain.

Data analysis was performed by descriptive statistics, in which means, standard deviation, maximum and minimum values and coefficient of variation were calculated. To compare the means, the Student's t-test was used at 5% probability. The analysis of variance (repeated measurements over time) and linear regression were used for analysis of the temporal variability with graphical representation made in the software SigmaPlot, version 11.0.

RESULTS AND DISCUSSION

The average FCO_2 flux in the evaluated periods (winter and summer) was significantly higher in the GS-10 area, with 2.37 µmol m^{-2} s^{-1}, compared to the other areas, with 1.69 µmol m^{-2} s^{-1} for BS and 1.10 µmol m^{-2} s^{-1} for GS-5 (Table 2).

We believe that the higher FCO_2 on the GS-10 area is related to the greater amount of plant residue on the soil, which is a result of the mechanized harvesting. The presence of mulch on the soil provides a habitat for microorganisms (Franchini et al., 2007) and serves as substrate for the microbial activity during the process of decomposition of the organic matter, thus reflecting in increased CO_2 emissions (Evanylo and Mcguinn, 2009). In addition, the minimum soil tillage provides favorable conditions for the development of microorganisms in the surface layer of the soil, which increases the microbial biomass and the FCO_2 (Matias et al., 2009).

The evaluation periods influenced the FCO_2 in the green sugarcane areas, being 51 and 18% higher in summer than in winter for the GS-5 and GS-10 areas, respectively, while for the burned sugarcane area, the variation of FCO_2 between periods was less expressive (Figure 3A and B). Studies have shown higher FCO_2 on the wettest period of the year (Xu and Qi, 2001; Kosugi et al., 2007; Song et al., 2013), which may be related to the greater microbial activity stimulated by the soil moisture and/or by the activity of the roots that are in the period of growth and development. Siqueira et al. (2011) verified that the maximum CO_2 emission occurred in the Brazilian Cerrado area in the rainy season (October-March), which was 14 times higher than the minimum emission obtained in the dry season (April-September).

The basal respiration (BR), in winter, was higher in the burned sugarcane with 109.67 µg CO_2 g^{-1} day-1 and, in summer, it was higher in the GS-5 area with 96.05 µg CO_2 g^{-1} day^{-1}, while in the GS-10 area it was lower both in winter and in summer with 50.94 and 40.67 µg CO_2 g^{-1} day^{-1}, respectively (Table 2 and Figure 3C and D). According to Lopes et al. (2013), balanced ecosystems tend to have lower rates of BR, as the vegetation cover on the soil, which is characteristic of these areas, provides material at different levels of decomposition and complexity of plant residues, thus resulting in lower levels of soil respiration.

The analysis of BR, in which the CO_2 emission from the soil was calculated by incubation process in laboratory, presented a divergent trend from the FCO_2 obtained in field (Table 2). It is worth mentioning that the FCO_2 calculates the resulting gas flux resulting from the soil microbial activity and plant roots, while BR takes into account only the respiration of microorganisms, which is one of the reasons for the difference of patterns between FCO_2 and BR. In addition, in the literature, the isolated evaluation of the BR can lead to misunderstandings, since it can be interpreted both in the beneficial sense to the soil, with an accelerated organic matter decomposition process reflecting on nutrient availability to plants, and in the unfavorable sense, with large CO_2 emission, which shows more losses than gains in carbon in the soil (Alves et al., 2011; Evangelista et al., 2013; Lopes et al., 2013).

The carbon of the microbial biomass (CMB) in winter showed no significant differences when compared between the three areas of sugarcane management, with the values of 184, 186 and 197 µg C g^{-1} day^{-1} for BS, GS-

Table 2. Microbiological attributes and soil moisture evaluated in the winter and summer periods on the sugarcane management systems (burned sugarcane, green sugarcane implemented for 5 years and green sugarcane implemented for 10 years) in Pradópolis, São Paulo, Brazil, 2011-2012.

Variablees	Winter					Summer				
	Mean	SD	Min	Max	CV	Mean	SD	Min	Max	CV
Burned sugarcane										
FCO_2	1.69^{Ba}	0.63	0.51	2.95	37.1	1.65^{bA}	0.46	0.56	2.45	29.6
BR	109.6^{Aa}	50.4	47.0	226	45.9	57.6^{bB}	16.3	26.7	116.3	28.4
CMB	184.2^{aB}	42.9	114.0	253.2	23.2	220.6^{bA}	65.9	55.2	346.0	29.8
qCO_2	0.63^{a}	0.31	0.19	2.35	49.9	0.33^{a}	0.22	0.15	0.97	65.9
qMIC	6.93^{a}	1.38	4.26	10.7	17.5	7.57c	1.96	2.94	10.9	25.9
Sm	11.09^{Ab}	1.27	10.2	14.2	9.8	21.35^{bA}	0.65	19.2	31.9	15.1
Green sugarcane-5 years										
FCO_2	$1.10c^{B}$	0.77	0.02	2.40	40.6	2.28^{aA}	0.72	2.34	5.52	31.8
BR	53.4^{bB}	17.4	24.3	92.1	32.6	96.0^{aA}	41.5	36.5	188.3	43.2
CMB	186.7^{aB}	62.3	89.9	424.9	33.4	282.8^{bA}	69.2	171.4	300.6	34.4
qCO_2	0.32^{b}	0.14	0.15	0.75	44.4	0.33^{a}	0.13	0.11	0.73	40.0
qMIC	5.08^{b}	2.02	1.68	9.41	37.3	9.82^{b}	3.14	5.40	16.01	32.0
Sm	11.16^{aB}	1.85	9.00	17	16.6	38.41^{aA}	2.46	32.33	44.78	6.40
Green sugarcane-10 years										
FCO_2	2.37^{aB}	0.76	1.50	4.2	31.9	2.91^{aA}	1.50	0.92	7.0	41.8
BR	50.9^{bA}	17.0	27.2	96.5	33.4	$40.6c^{B}$	15.4	14.8	76.5	37.9
CMB	197.6^{aB}	68.5	90.0	348.3	44.6	321.3^{aA}	65.8	266.7	474.0	30.4
qCO_2	0.32^{b}	0.19	0.16	1.11	60.6	0.10^{b}	0.03	0.04	0.17	35.0
qMIC	7.35^{a}	2.61	3.23	12.5	35.5	12.28^{a}	2.53	9.33	16.10	30.6
Sm	10.17^{aB}	1.42	8.00	14	13.9	29.71^{bA}	2.58	24	35	8.69

FCO_2 = Soil CO_2 flux evaluated in field (µmol m^{-2} s^{-1}); BR = basal respiration – CO_2 emissions evaluated in the Laboratory (µg CO_2 $g^{-1}day^{-1}$); CMB = Carbon of the Microbial Biomass (µg C $g^{-1}day^{-1}$); qCO_2 = metabolic quotient (µg CO_2 µg C-SMB day^{-1}); qMIC = microbial quotient (µg Corg µg C-SMB day^{-1}); Sm = Soil moisture (%). Means followed by the same lowercase letter in the column (management systems) and uppercase letter in the row (evaluation periods) do not differ by the Student's t-test at 5% probability.

5 and GS-10, respectively (Table 2 and Figure 4). However, in summer, the CMB was 6.5 and 5.6% higher in the GS-10 area when compared with the BS and GS-5 areas, respectively. Similar trend was found in the study of Mendonza et al. (2000), who detected values of CMB of 152.1 and 195.6 µg C g^{-1} day^{-1} in the 00-0.05 m soil layer for the areas of burned sugarcane and green sugarcane, respectively, and Galdos et al. (2009) verified that the CMB was 2.5 times higher in the area of green sugarcane compared to the burned sugarcane.

The values of CMB corroborate with the values of FCO_2 evaluated in field, in which the GS-10 area showed the highest amount of microbial biomass, which reflects into a greater soil CO_2 flux (Table 2). Thus, a direct relation between these two attributes can be observed as the CO_2 emitted by the soil is essentially produced by the decomposition of organic matter from the action of microorganisms and the respiration of plant roots (Panosso et al., 2008). The study of Xu and Qi (2001) in soil with pine plantation proved the direct relationship between FCO_2 and CMB during the monitoring of both attributes in the period from J une to October, 1998. The evaluation of the CMB between the periods of evaluation was significant, being greater in summer than winter in the three sugarcane areas evaluated (Table 2 and Figure 4), as the wet period is characterized by conditions of temperature and soil moisture that are more favorable to the soil microbial activity (Mendonza et al., 2000; Zornoza et al., 2007). The optimum humidity is approximately 60 to 80% and the optimum temperature is 30°C. However, the activity decreases as the soil temperature exceeds the optimum temperature (Evanylo and Mcguinn, 2009).

Soil moisture data ranged from 10 to 11% in winter and from 21 to 38% in summer (Table 2), and the soil temperature ranged from 20 to 22°C in winter and from 18 to 19°C in summer (Figure 2B), being the attributes suboptimal, which boosts the mulch factor in the stimulation of the soil microbial activity, mainly in the GS-10 area, which showed the highest CMB. A similar result was obtained by Mendonza et al. (2000), who verified higher CMB in the green sugarcane system than in the burned sugarcane, especially during the rainy season in study under yellow Argisol, which, according to the

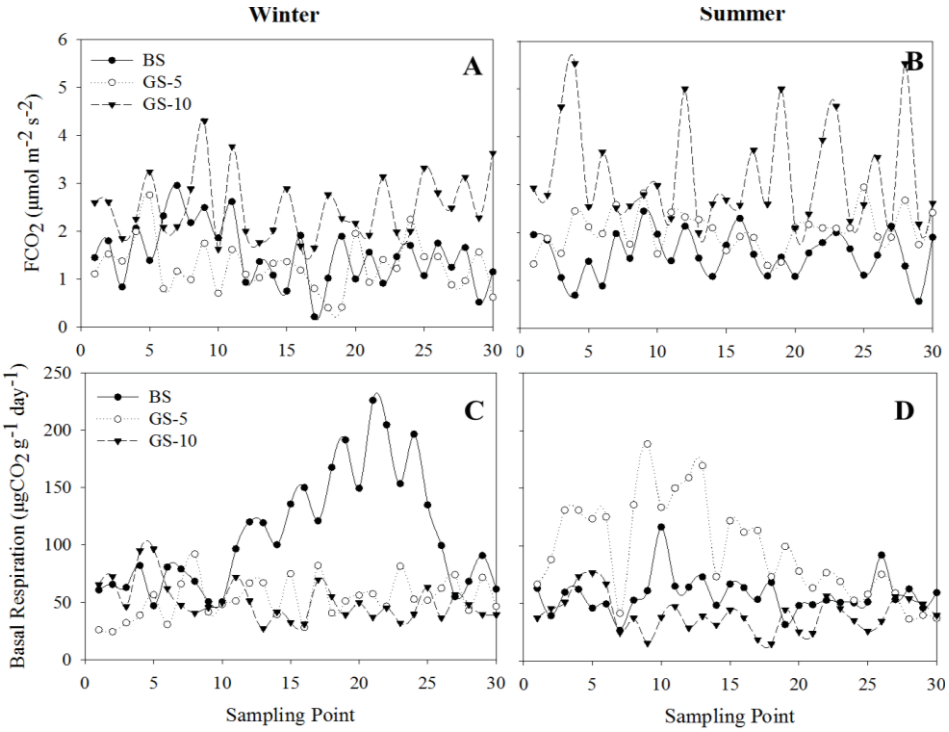

Figure 3. Soil CO_2 flux - FCO_2 (A and B), basal respiration - BR (C and D) of the soil evaluated in winter and summer in the management systems of burned sugarcane (BS), green sugarcane implemented for 5 years (GS-5) and green sugarcane implemented for 10 years (GS-10) in Pradópolis, São Paulo, Brazil, 2011-2012.

authors, together with the favorable climatic factors in the green sugarcane system, would have allowed the microbial biomass to find plenty of substrate for its development in the remaining mulch from the previous year.

The values of qCO_2 ranged from 0.10 to 0.63 µg CO_2 µg C-SMB day^{-1} (Table 2). The low value of qCO_2 indicated economy on energy usage, which reflects a more stable environment or closer to its equilibrium (Anderson and Domsch, 1990). The results show that the cultivation system significantly affected the qCO_2 of the BS and GS-10 areas, with lower qCO_2 in GS-10 (Figure 4), which, according to Partelli et al. (2012), is the evidence of the lower consumption of oxidizable carbon for the maintenance of microorganisms, thus configuring the equilibrium situation of the soil microbial activity.

In a study by Evangelista et al. (2013), the qCO_2 was 49.07% higher in the burned sugarcane area that in the green sugarcane, and, according to the authors, as the microbial biomass becomes more efficient in the use of the ecosystem resources, less CO_2 is lost by the respiration and a higher proportion of carbon is incorporated into the microbial tissues, which results in decreased qCO_2. Kuwano et al. (2014), working with soils under different uses in Northern Paraná, observed that the sugarcane areas under the burning system presented the highest qCO_2, probably as a result of the burning before harvest, which decreases soil carbon inputs; moreover, the disturbance of the soil through heavy tillage on the renovation of the sugarcane plantation disrupts the microbial community not only by the breakdown of soil aggregates, but also by the loss of water from the soil.

The qMIC, obtained by the relationship between CMB and OC, was similar in winter in the BS and GS-10 areas, with 6.93 and 7.35 µg CO_2 day^{-1} µg OC, respectively, which may be related to the similar levels of organic carbon present in these areas, with 2.94 and 2.59 g kg^{-1} for BS and GS-10, respectively (Table 2). In summer, the qMIC was higher in the GS-10 area, with 12.28 µg CO_2 day^{-1} µg OC, and lower in the burned sugarcane area, with 7.57 µg CO_2 day^{-1} µg OC (Figure 4), and a higher qMIC is an evidence of organic matter of better quality, more active and less recalcitrant, with greater availability of organic carbon to the soil microbial activity (Jenkinson, Ladd, 1981).

In some studies, FCO_2 was positively correlated with organic carbon (La Scala et al., 2000; Medeiros et al., 2011; Lenka, Lal, 2013). However, in this study, the GS-10 area showed lower organic carbon content and greater FCO_2. It is possible that the high microbial activity in the GS-10 area has reduced the organic carbon content, as the increase of cycles of decomposition of soil organic matter by microorganisms will result in a low

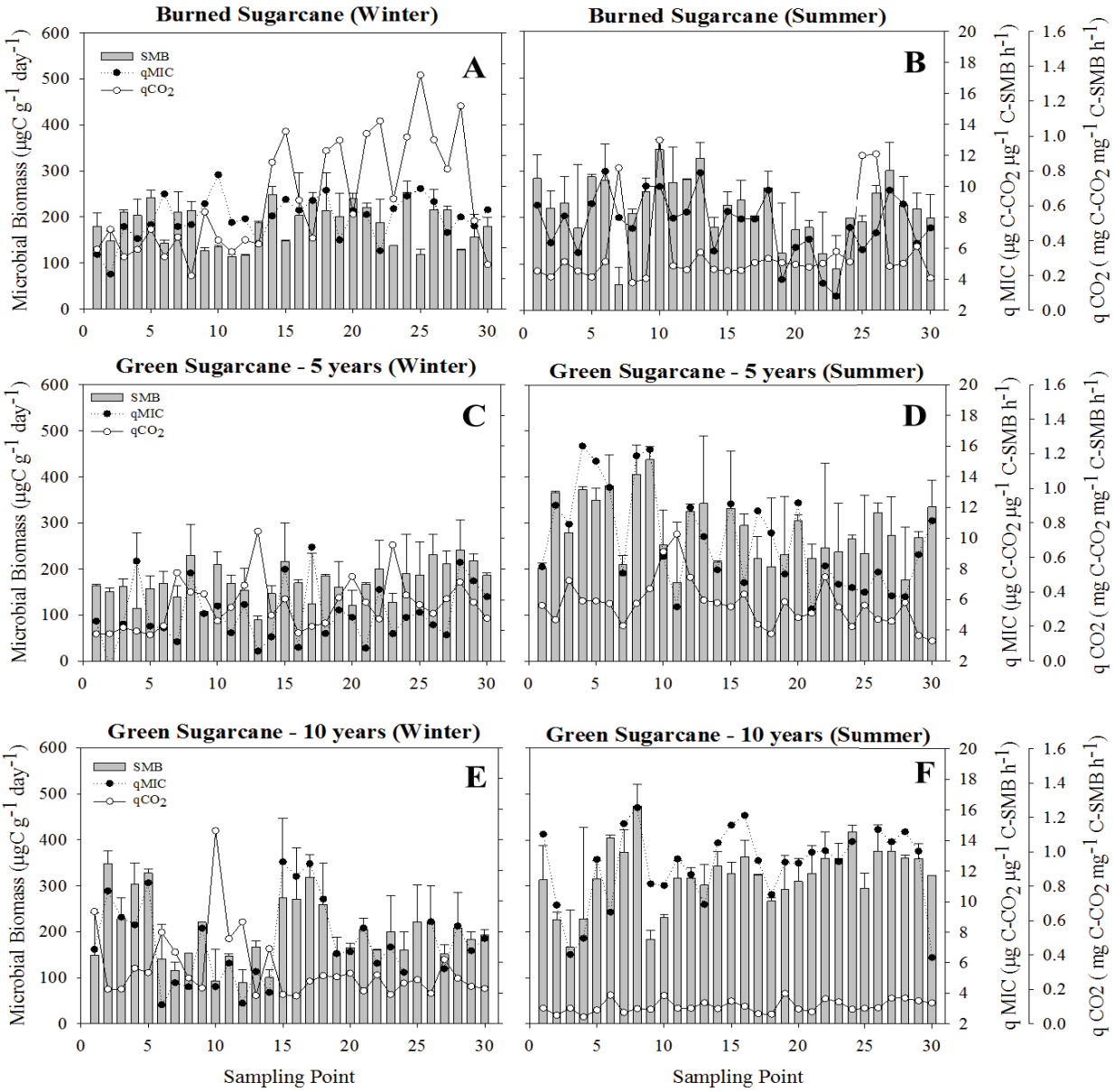

Figure 4. Effect of different sugarcane management systems (burned sugarcane, green sugarcane implemented for 5 years and green sugarcane implemented for 10 years) in the metabolic quotient (qCO_2) and microbial quotient (qMIC) in the summer and winter periods in Pradópolis, São Paulo, Brazil, 2011-2012.

organic carbon content, which is more protected and stabilized within microaggregates (Lenka and Lal, 2013). Corroborating with the result of this study, Fang et al. (1998) detected higher CO_2 emission in regions with lower organic carbon content in soil under pine plantation.

Conclusion

1. Soil CO_2 flux was higher in the area of green sugarcane implemented for 10 years.
2. Soil CO_2 flux and microbial activity were higher in the wet period.
3. The metabolic and microbial quotients showed a greater balance of the soil microbial activity in the area of green sugarcane implemented for 10 years.
4. The presence of mulch on the soil stimulates the microbial activity and increases the soil CO_2 flux.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Alef K, Nannipieri P (1995). Estimation of microbial activities. In: Alef K, Nannipieri P. (ed.). Methods in applied soil microbiology and biochemistry. London: Academic Press. pp. 193-270. http://dx.doi.org/10.1016/B978-012513840-6/50021-5

Alves TS, Campos LL, Elias Neto N, Matsuoka M, Loureiro MF (2011). Biomassa e atividade microbiana de solo sob vegetação nativa e diferentes sistemas de manejos. Acta Sci. Agro. 33:341-347.

Anderson TH, Domsch KH (1990). Application of eco-physiological quotients (qCO2 and qMIC) on microbial biomasses from soils of different cropping histories. Soil Biol. Biochem. 22:251-255. http://dx.doi.org/10.1016/0038-0717(90)90094-G

Evangelista CR, Partelli FL, Ferreira EPB, Pires FR (2013). Atributos microbiológicos do solo na cultura da cana-de-açúcar sob manejo orgânico e convencional. Semina: Ci. Agra. 34:1549-1562.

Evanylo GE, Mcguinn R (2009). Agricultural management practices and soil quality: measuring, assessing, and comparing laboratory and field test kit indicators of soil quality attributes. Virginia: Polytechnic Institute and State University. P. 12.

Fang C, Moncrieff JB, Gholz HL, Clark KL (1998). Soil CO2 efflux and its spatial variation in a Florida slash pine plantation. Plant Soil. 205:135-146. http://dx.doi.org/10.1023/A:1004304309827

Franchini JC, Crispino CC, Souza RA, Torres E, Hungria M (2007). Microbiological parameters as indicators of soil quality under various soil management and crop rotation systems in Southern Brazil. Soil Till. Res. 92:18-29. http://dx.doi.org/10.1016/j.still.2005.12.010

Galdos MV, Cerri CC, Cerri CEP (2009). Soil carbon stocks under burned and unburned sugarcane in Brazil. Geoderma. 153:347-352. http://dx.doi.org/10.1016/j.geoderma.2009.08.025

Jenkinson DS, Ladd JN (1981). Microbial biomass in soil: Measurement and turnover. Soil Biol. Biochem. 5:415-471.

Kaschuk G, Alberton O, Hungria M (2009). Three decades of soil microbial biomass studies in Brazilian ecosystems: Lessons learned about soil quality and indications for improving sustainability. Soil Biol. Biochem. 42:1-13. http://dx.doi.org/10.1016/j.soilbio.2009.08.020

Kosugi Y, Mitani T, Itoh M, Noguchi S, Tani M, Matsuo N, Takanashi S, Ohkubo S, Nik AR (2007). Spatial and temporal variation in soil respiration in a Southeast Asian tropical rainforest. Agric. Forest Meteorol. 147:35-47. http://dx.doi.org/10.1016/j.agrformet.2007.06.005

Kuwano BH, Knob A, Fagotti DSL, Melém Júnior NJ, Godoy L, Diehl RC, Krawulski CC, Andrade Filho G, Zangaro Filho, W, Tavares-Filho J, Nogueira MA (2014). Soil quality indicators in a rhodic kandiudult under different uses in northern Parana, Brazil. R. Bras. Ci. Solo. 38:50-59.http://dx.doi.org/10.1590/S0100-06832014000100005

La Scala Júnior N, Marques Júnior J, Pereira GT, Corá JE (2000). Carbon dioxide emission related to chemical properties of a tropical bare soil. Soil Biol. Biochem. 32:1469-1473. http://dx.doi.org/10.1016/S0038-0717(00)00053-5

Lenka NK, Lal R (2013). Soil aggregation and greenhouse gas flux after 15 years of wheat straw and fertilizer management in a no-till system. Soil Till. Res. 126:78-89. http://dx.doi.org/10.1016/j.still.2012.08.011

Lopes AAC, Sousa DMG, Chaer G, Reis Júnior FB, Goedert WJ, Mendes IC (2013). Interpretation of microbial soil indicators as a function of crop yield and organic carbon. Soil Sci. Soc. Am. J. 25:461-472. http://dx.doi.org/10.2136/sssaj2012.0191

Loureiro DC, Polli H, Ceddia MB, Aquino MA (2010). Spatial variability of microbial biomass and organic matter labile pools in a haplic planosol soil. Bragantia. 69:85-95. http://dx.doi.org/10.1590/S0006-87052010000500010

Martinéz E, Fuentes JP, Pino V, Silva P, Acevedo E (2013). Chemical and biological properties as affected by no-tillage and conventional tillage systems in an irrigated Haploxeroll of Central Chile. Soil Till. Res.126:238-245. http://dx.doi.org/10.1016/j.still.2012.07.014

Matias MCBS, Salviano AAC, Leite FD, Araujo SF (2009). Biomassa microbiana e estoques de C e N do solo em diferentes sistemas de manejo, no Cerrado do Estado do Piaui. Acta Sci. Agro. 31:517-521.

Medeiros JC, Silva AP, Cerri CEP, Fracetto FJC (2011). Linking physical quality and CO2 emission under long-term no-till and conventional-till in a subtropical soil in Brazil. Plant Soil, 338:5-15. http://dx.doi.org/10.1007/s11104-010-0420-4

Mendonza HNS, Lima E, Anjos LHC, Silva LA, Ceddia MB, Antunes, MVM (2000). Propriedades químicas e biológicas de solo de tabuleiro cultivado com cana-de-açúcar com e sem queima da palhada. R. Bras. Ci. Solo. 24:201-207. http://dx.doi.org/10.1590/S0100-06832000000100022

Panosso AR, Pereira GT, Marques Junior J, La Scala Junior N (2008). Variabilidade espacial da emissão de CO2 em Latossolos sob cultivo de cana-de-açúcar em diferentes sistemas de manejo. Eng. Agric. 28:227-236.

Partelli FL, Vieira HD, Ferreira EPB, Viana AP, Martins MA, Urquiaga S (2012). Chemical and microbiological soil characteristics under conventional and organic coffee production systems. Commun. Soil Sci. Plant Anal. 43:847-864. http://dx.doi.org/10.1080/00103624.2012.648470

Silva MSC, Silva EMR, Pereira MG, Silva CF (2012). Estoque de serapilheira e atividade microbiana em solo sob sistemas agroflorestais. Floresta Ambient. 19:431-441. http://dx.doi.org/10.4322/floram.2012.058

Siqueira Neto M, Piccolo MDC, Costa Junior C, Cerri CC, Bernoux M (2011). Emissão de gases do efeito estufa em diferentes usos da terra no bioma Cerrado. R. Bras. Ci. Solo. 35:63-76.

Song Z, Yuan H, Kimberley MO, Jiang H, Zhou G, Wang H (2013). Soil CO2 flux dynamics in the two main plantation forest types in subtropical China. Sci. Total. Environ. 444:363-368. http://dx.doi.org/10.1016/j.scitotenv.2012.12.006 PMid:23280294

Souza ZM, Prado RM, Paixão ACS, Cesarin LG (2005). Sistemas de colheita e manejo da palhada de cana-de-açúcar. Pesq. Agropec. Bras. 40:271-278. http://dx.doi.org/10.1590/S0100-204X2005000300011

Vance ED, Brookes PC, Jenkinson, DS (1987) An extraction method for measuring soil microbial biomass C. Biol. Biochem. 19:703-707. http://dx.doi.org/10.1016/0038-0717(87)90052-6

Xu M, Qi Y (2001). Soil-surface CO2 efflux and its spatial and temporal variations in a young ponderosa pine plantation in northern California. Glob Chang Biol. 7:667-677. http://dx.doi.org/10.1046/j.1354-1013.2001.00435.x

Zornoza R, Guerrero C, Mataix-Solera J, Arcenegui V, García-Orenes F, Mataix-Beneyto J (2007). Assessing the effects of air-drying and rewetting pre-treatment on soil microbial biomass, basal respiration, metabolic quotient and soluble carbon under Mediterranean conditions. Eur. J. Soil Biol. 43:120-129. http://dx.doi.org/10.1016/j.ejsobi.2006.11.004

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Rainfall variability analysis and its impact on crop production in Bihar

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Rainfall of Pusa, Purnia, Sabour and Gaya representing different Agro-ecological zones (Zone I, II, IIIA, IIIB respectively) of Bihar were analyzed on monthly, seasonal and annual time scales using long period data. Mann-Kendall non-parametric test was employed for observational trend detection of monthly, seasonal and annual precipitation for different period viz. 1971-1980 (DP1), 1981-1990 (DP2), 1991-2000 (DP3), 2001-2010 (DP4) and for long period 1971-2010 (LP). Zone IIIA shows significant decreasing trend of 42.85 mm/year annual rainfall in recent decadal period (DP4). Zone III B shows significant decreasing trend of annual rainfall during long period (LP) but there is increasing trend of 4.57 mm/year during recent decadal period (DP4) and 0.43 mm/year during long period (LP) in pre monsoon/summer season. August and September months show significant decreasing trend of 2.12 and 2.62 mm/year rainfall respectively in LP in Zone III B, which may affect the transplanting/vegetative phase of the rice crop. Decreasing trend of rainfall in post monsoon season in all the zones during recent decadal period (DP4) as well as LP is delaying/affecting the sowing of wheat crop.

Key words: Rainfall, trend, Mann-Kendall test, least-squares, periods, agro ecological zones.

INTRODUCTION

The water and agricultural sectors are likely to be worst affected by changing climate. Under warmer climate, the arid and semiarid regions could experience severe water stress due to decline in soil moisture. The critical values of extreme temperature indices during rice and wheat growing months provide an indicator to assess the vulnerability of rice-wheat productivity to temperature for Patna and Samastipur districts of Bihar and there is a need to prepare an adaptive strategy (Subhash et al., 2013). The spatial distribution and magnitude of rainfall trends would be highly relevant and useful from an agricultural and water management point of view. A long term rainfall data is very useful in making decision about agriculture water management and crop pattern and to locate the drought prone areas (Valipour, 2012). Even yield predictions of rice have been made by the Models based on water requirement calculations and rainfall data in agro climatic zones of Bihar (Dutta et al., 2001). In India, long term time series of summer monsoon rainfall has no discernible trends, but decadal departures are found above and below the long time average alternatively for three consecutive decades and the same study employing non-parametric methods showed a decreasing trend for rainfall variables (Kothyari and

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Table 1. Selected meteorological stations representing different agro-ecological zones of Bihar.

Station	Agro- ecological zone	Latitude(°N)	Longitude (°E)	Elevation
Pusa	I	25.98	85.13	47
Purnia	II	25.98	87.80	37
Sabour	IIIA	25.23	87.70	37
Gaya	IIIB	24.98	85.00	107

Singh, 1998). Sadhukhan et al. (2000) and Kothawale et al. (2010) studied trends of annual and seasonal rainfall at many locations and at different scales over India. Recent decades have exhibited an increasing trend of rainfall in Central north east India during pre monsoon (Subhash et al., 2010). In recent years, in Bihar, the rainfall distribution is becoming erratic resulting in frequent crop failure by the way of submergence or prolonged drought. In increasing frequent drought condition in Bihar farmers preferences are increasing for drought tolerant rice varieties (Patrick et al., 2014). The chances of occurrence of intense rainfall events in near future will also increase proportionally and efforts should be made to prepare detailed site specific management plan (Subhash et al., 2011). The frequent aberrations necessitate studying the rainfall trend during crop planning. It is essential to plan agriculture on a scientific basis for making best use of rainfall pattern of this area. The future area equipped for irrigation can be estimated by study of agricultural water management of long term (Valipour, 2014). Most of the studies are confined to only seasonal and annual rainfall. However, on a monthly basis, analysis has been very little. This study investigates the trends of rainfall in data series of monthly, seasonal and annual rainfall with their percentage contribution to the total annual rainfall for four agro climatic zones (I, II, IIIA and IIIB) of Bihar state using Mann- Kendall non parametric test. The slopes of the trend lines were determined using the method of least square linear fitting.

MATERIALS AND METHODS

Study sites

Four study sites were selected in the state which represents different agro ecological regions of the state. The sites were Pusa (Zone I), Purnia (Zone II), Sabour (Zone IIIA) and Gaya (Zone IIIB). The daily rainfall data of four stations of Bihar for the period from 1971 to 2010 from Indian meteorological department, Pune and meteorological observatories at Sabour and Pusa were used (Table 1). The daily rainfall data were checked thoroughly for homogeneity, outliers and missing records. After performing this quality check the daily records were processed for monthly, seasonal and annual rainfall. Seasonal trend was observed for four seasons viz., Winter (December- February), Pre monsoon (March-May), Monsoon (June- September) and Post monsoon (October-November). Statistical analysis was done to work out monthly, annual and seasonal variability, contribution and trend by calculating different descriptive viz., mean, Standard deviation (SD) and coefficient of variation (CV). The long term trend was calculated on monthly, annual and seasonal for four periods viz.1971-1980 (DP1), 1981-1990 (DP2), 1991-2000 (DP3), 2001-2010 (DP4) and long period 1971-2010 (LP) to know whether there is variability of rainfall during the study period. The percent contribution of monthly and seasonal rainfall to annual rainfall was also calculated for four periods and as well as for the entire period to know whether there is any change in the shift of rainfall pattern. The Mann Kendal non parametric test, as described by Sneyers (1990), was applied in order to detect the presence of any trend. This test was used by several researchers to detect trends in hydrological time series data (Serrano et al., 1999; Brunetti et al., 2000a, b; Luo et al., 2008). The Mann Kendal test was used, assuming the observations in time series are serially independent and there is no serial correlation (persistence). The test determines whether the observations in the data tend to increase or decrease with time. The slopes of the trends were calculated by fitting the data series into method of least square linear fitting. This method calculates the best fitting line for the observed data by minimizing the sum of the square of the vertical deviations from each data point to the line. Test of significance was carried out for the slopes at 95% significant level (confidence interval). The least square method slope was presented to show the linear slope.

RESULT AND DISCUSSION

General rainfall statistics of the study area

Among the agro ecological regions, Zone II receives the highest annual rainfall of 1466.7 mm (Table 3) with coefficient of variation (CV) of 25.8%, followed by Zone I (1246.9 mm) (Table 2) with coefficient of variation 30.8%. The Zone IIIB receives the lowest annual rainfall of 1031.0 mm with coefficient of variation 23.7 % (Table 5). As far as different decadal periods are concerned, it is clear that Zone I received higher annual rainfall in all periods except DP3 compared to LP average. Zone II received lower annual rainfall in DP2 and DP4 than long term average. Zone IIIA received lower annual rainfall in all the periods except DP3 where as Zone IIIB received lower rainfall in DP3 and DP4. All the zones in recent decadal period (DP4) received lower annual rainfall than long term period (LP) average rainfall except Zone I.

Trends in monthly rainfall

The rainiest month during all the decadal periods for all the zones was July followed by August except DP3 in

Table 2. Monthly, annual and seasonal trend of rainfall at Pusa (Zone I) of Bihar.

Periods	1971-1980		1981-1990		1991-2000		2001-2010		1971-2010	
Monthly	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**
January	15.8	-1.11	7.6	-2.39	11.5	-2.17	7.7	-0.95	10.7	-0.30
February	17.6	-1.10	8.5	1.58	15.8	-0.51	12.3	-1.72	13.6	-0.11
March	7.8	1.66	5.5	-0.64	3.7	-0.59	4.2	-0.69	5.3	-0.12
April	19.0	-2.04	16.7	-3.15	17.9	3.61	22.3	-3.52	18.9	0.02
May	69.4	5.69	67.3	1.58	59.8	9.76	103.7	2.72	74.4	1.20
June	149.4	-4.82	152.0	-1.71	186.3	29.82	181.1	-9.21	166.9	1.43
July	355.6	24.38	428.4	15.74	250.5	25.60	365.7	1.91	349.7	-0.34
August	326.2	-8.31	269.4	-9.51	329.5	2.57	273.9	7.93	300.3	-1.02
September	235.7	-11.76	266.0	0.01	182.6	2.00	226.5	-5.68	227.8	-1.28
October	106.2	-10.76	31.0	-0.19	49.7	3.66	77.4	-7.19	65.8	-0.86
November	10.0	1.32	3.8	0.00	14.0	-1.26	1.9	0.34	7.5	-0.13
December	4.3	1.01	10.4	1.28	7.5	-0.21	1.3	-0.01	6.0	-0.08
Annual	1316.9	-5.83	1266.6	2.62	1128.8	72.29	1278.0	-16.08	1246.9	-1.57
Seasonal										
Winter	37.7	-1.20	26.6	0.48	34.8	-2.89	21.3	-2.69	30.3	-0.48
Pre monsoon	96.1	5.32	89.5	-2.21	81.4	12.78	130.2	-1.49	98.6	1.10
Monsoon	1066.8	-0.51	1115.8	4.54	948.9	59.99	1047.3	-5.05	1044.7	-1.20
Post monsoon	116.2	-9.44	34.8	0.19	63.7	2.40	79.3	-6.86	73.3	-0.99

Table 3. Monthly, annual and seasonal trend of rainfall at Purnia (Zone II) of Bihar.

Periods	1971-1980		1981-1990		1991-2000		2001-2010		1971-2010	
Monthly	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**
January	4.9	-1.39	5.4	-2.28	6.9	-0.01	7.8	-0.13	6.2	0.04
February	10.3	-3.02	8.0	1.58	7.4	0.66	11.0	-0.46	9.2	0.00
March	11.4	-0.90	14.3	-2.14	10.6	-1.68	6.5	1.40	10.7	-0.23
April	38.1	-4.49	44.4	-10.67	30.2	2.96	47.2	-6.83	40.0	-0.17
May	114.2	14.04	151.3	5.76	115.7	10.77	118.1	0.28	124.8	0.25
June	272.6	11.97	197.4	0.30	223.0	18.06	262.3	-12.49	238.8	0.23
July	360.6	29.21	410.2	7.14	357.4	13.63	371.7	32.01	375.0	1.09
August	264.1	1.00	248.5	-5.60	386.3	2.60	230.4	14.92	282.3	0.54
September	250.2	-11.35	293.7	34.66	327.4	-6.81	245.7	-2.77	279.2	0.40
October	124.8	-16.99	77.0	7.38	47.5	3.01	103.2	-8.28	88.1	-1.11
November	11.4	1.49	1.7	-0.26	12.2	-0.24	3.6	1.26	7.2	-0.09
December	8.5	3.05	4.5	-0.14	5.8	-0.01	1.7	-0.26	5.1	-0.14
Annual	1471.0	22.61	1456.3	35.71	1530.3	42.94	1409.2	18.64	1466.7	0.81
Seasonal										
Winter	23.7	-1.36	17.9	-0.85	20.1	0.65	20.6	-0.85	20.6	-0.10
Pre monsoon	163.7	8.65	210.0	-7.05	156.4	12.04	171.8	-5.15	175.5	-0.14
Monsoon	1147.5	30.83	1149.7	36.49	1294.1	27.48	1110.1	31.66	1175.3	2.26
Post monsoon	136.2	15.50	78.6	7.12	59.7	2.77	106.8	-7.02	95.4	-1.20

Zone I, in which August was the rainiest month. The long term average also shows that July is the rainiest month followed by August for all the zones. For all the zones during all decadal periods, January month shows decreasing trend of rainfall. There is a significant decreasing trend of 1.39 mm/year for Zone II during DP1, 5.98 mm/year for Zone IIIB during DP2 and 2.35 mm/year during recent decadal (DP4) period in Zone IIIA during

Table 4. Monthly, annual and seasonal trend of rainfall at Sabour (Zone III A) of Bihar.

Periods	1971-1980		1981-1990		1991-2000		2001-2010		1971-2010	
Monthly	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**
January	13.5	-1.51	14.5	-3.45	17.1	-2.52	9.9	-2.35	13.7	-0.23
February	17.0	-0.60	10.0	1.58	14.4	1.70	14.4	-2.59	13.9	-0.03
March	10.1	0.76	12.1	0.07	11.3	1.15	10.8	-0.40	11.1	0.03
April	33.3	-11.86	26.8	-2.56	30.2	3.41	21.0	-4.90	27.8	-0.56
May	82.4	-2.33	76.5	0.23	81.3	15.29	115.5	-7.39	88.9	1.07
June	141.5	-5.10	204.6	-3.25	229.5	6.87	149.0	-2.28	181.1	0.39
July	290.5	7.37	346.3	20.76	323.0	18.96	316.6	-4.87	319.1	1.17
August	278.4	-15.23	261.4	13.29	301.5	2.58	242.9	-4.68	271.1	-0.69
September	174.1	-3.57	166.9	4.38	253.7	4.42	198.8	-4.58	198.4	1.52
October	103.2	-6.31	94.1	5.45	80.4	13.40	86.3	-9.19	91.0	-0.55
November	4.5	-0.54	3.4	-0.95	22.9	-0.26	1.8	0.66	8.1	0.09
December	55.2	1.16	8.5	-2.45	13.4	-2.22	1.2	-0.31	7.1	-0.14
Annual	1153.9	-37.77	1224.9	32.91	1378.7	62.78	1168.2	-42.85	1231.4	2.08
Seasonal										
Winter	36.0	-0.95	33.0	-4.32	44.8	-3.04	25.5	-5.24	34.8	-0.39
Pre monsoon	125.8	-13.43	115.3	-2.26	122.9	19.85	147.3	-12.67	127.8	0.54
Monsoon	884.5	-28.19	979.2	34.98	1107.7	32.83	907.4	-16.40	969.7	2.39
Post monsoon	107.6	-6.85	97.5	4.50	103.3	13.13	88.1	-8.53	99.1	-0.46

January month. In the month of February, there is significant increasing trend of 1.58 mm/year during DP2 and decreasing trend of 3.02 mm/year during DP1 in zone I and zone II respectively. There is significant increasing trend of 1.4 mm/year during the recent decadal period (DP4) in Zone II during March. In the month of April, there is significant decreasing trend of 3.15 mm/year during DP2 in Zone I. For May, there is significant increasing trend of 10.77 and 7.10 mm/year in Zone II and Zone IIIB respectively during DP3. There is significant increasing trend of 29.82 mm/year for the month of June in Zone I during DP3. For the month of July, there is increasing trend of 1.09 mm/year during recent decadal period (DP4) in Zone II and 33.65 mm/year during DP3 in Zone IIIB. In the month of August, there is significant decreasing trend of 15.6 mm/year during DP3 and of 2.12 mm/year during long term period (LP) in Zone IIIB. There is also significant decreasing trend of 2.62 mm/year during LP in Zone IIIB in the month of September. For October, November and December all zones show decreasing trend except for November in Zone IIIA, which shows increasing trend during LP, but statistically not significant. The decrease of rainfall in these months may hamper sowing of wheat, which is the important *rabi* crop of this area.

Trends in seasonal rainfall

There is a decreasing trend of winter rainfall in all zones, which is affecting the wheat crop in the area. In pre monsoon season, there is increasing trend of rainfall for all the zones except Zone II, though it is statistically not significant. There is significant increasing trend of 4.57 mm/year during recent decadal period (DP4) and 0.43 mm/year during LP in pre monsoon /summer season in Zone IIIB (Table 5). During recent decadal period (DP4), there is decreasing trend of rainfall in monsoon season for all the zones except Zone II, though it is statistically not significant. But in long duration (LP), there is decreasing trend of monsoon rainfall, in Zone I and IIIB, which may hamper the rice crop in the area. Decreasing trend of rainfall in post monsoon season in all the zones during recent decadal period (DP4) as well as during (LP) are affecting the sowing of wheat crop. Rice and wheat crop which are major crops of the area has been affected drastically due to decreasing trend of rainfall in monsoon and post monsoon season during recent decadal period (DP4). Zone I and IIIA, show decreasing trend of rainfall in all the seasons during (LP), which may affect the water availability for the crop in the area.

Trends in annual rainfall

There is significant increasing trend of 62.78 mm/year during DP3 but during recent decadal period (DP4) annual rainfall shows decreasing trend of 42.85 mm/year in the Zone IIIA (Table 4). Though during LP there is no significant decreasing trend. The long-term (LP) annual

Table 5. Monthly, annual and seasonal trend of rainfall at Gaya (Zone III B) of Bihar.

Periods	1971-1980		1981-1990		1991-2000		2001-2010		1971-2010	
Monthly	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**	**Mean**	**Slope**
January	14.7	-0.59	18.7	-5.98	23.5	-3.24	10.0	-0.11	16.7	-0.23
February	19.2	0.53	13.0	-1.31	12.5	0.82	11.6	0.73	14.1	-0.19
March	8.8	0.84	18.8	-0.41	13.3	-1.63	5.3	-0.17	11.5	-0.17
April	14.3	-5.11	12.6	-1.65	4.8	0.00	10.2	0.84	10.5	-0.26
May	11.2	-0.07	23.4	1.84	29.6	7.10	33.6	3.90	24.4	0.88
June	144.1	5.84	117.1	2.48	142.1	7.03	178.1	-5.88	145.4	1.34
July	324.8	-0.71	354.3	4.84	273.2	33.65	248.6	-0.14	300.2	-2.32
August	265.5	-4.62	286.3	6.97	272.6	-15.61	206.4	-8.17	257.7	-2.12
September	227.2	-2.16	199.6	0.07	152.5	-2.54	151.8	0.70	182.8	-2.62
October	72.7	-1.81	55.6	-4.13	52.2	0.03	47.3	-13.13	57.0	-1.04
November	8.5	-0.78	6.5	-1.47	13.1	-2.08	1.9	0.35	7.5	-0.19
December	3.3	0.86	5.4	0.31	2.5	0.10	1.8	-0.31	3.2	-0.06
Annual	1114.5	-7.76	1111.3	1.55	991.9	23.63	906.5	-21.39	1031.0	-7.04
Seasonal										
Winter	37.3	0.80	37.1	-6.97	38.5	-2.32	23.3	0.31	34.0	-0.51
Pre monsoon	34.3	-4.33	54.8	-0.23	47.7	5.47	49.1	4.57	46.4	0.43
Monsoon	961.7	-1.64	957.3	14.35	840.4	22.53	784.9	-13.49	886.1	-5.74
Post monsoon	81.2	-2.59	62.1	-5.60	65.3	-2.04	49.2	-12.78	64.5	-1.23

rainfall of Zone IIIB shows significant decreasing trend of 7.04 mm/year (Table 5). In Zone I, during LP, it also shows decreasing trend but statistically non significant. There is increasing trend of annual rainfall in Zone II during LP but statistically not significant. In all the zones except Zone II, there is decreasing trend of annual rainfall during recent period (DP4), though it is not statistically significant.

Trends in seasonal contribution

Study reveals that there is increasing trend of contribution of pre monsoon rainfall in annual rainfall (Figure 1). Increasing contribution of pre monsoon rainfall in annual rainfall for all the zones indicates that there is possibility of summer crop in the region which may be introduced. There is decreasing trend of contribution of monsoon and post monsoon rainfall in annual rainfall in all the zones except Zone II. Though there is no significant trend in the seasonal contribution but shifting of rainfall from monsoon and post monsoon season towards pre monsoon season needs further study so that planners and managers can chalk out strategy to tap maximum available natural resources at appropriate time to enhance agricultural productivity, thereby sustain food security.

Impact on crop production

Long term decreasing trend of rainfall indicates that Zone I, IIIA and IIIB will face water scarcity problem, which need suitable cropping system in the condition of less water availability and Zone II shows increasing trend of precipitation where water availability will impact positively agriculture of the region by increased length of growing period with water availability to agriculture. Unequal distribution of precipitation may cause drought in one area and flood in another area. The precipitation decrease in most of the zones in Bihar will impact negatively on rice-wheat cropping system, which is the major cropping system in the area. Not only decrease in rainfall but also abnormal, irregular or excessive amounts of rainfall seriously reduce the quality and quantity of the yield in rainfed *rabi* crops.

Conclusion

The study reveals that there is decreasing trend of rainfall in monsoon and post monsoon season in most of the zones in Bihar during long period. Zone IIIB shows significant decreasing trend of annual rainfall during LP. There is significant increasing trend of 4.57 mm/year during recent decadal period (DP4) and 0.43 mm/year during LP in pre monsoon /summer season in Zone IIIB. It indicates that not only mean annual rainfall is decreasing in long term but shifting of rainfall from monsoon and post monsoon season towards pre monsoon season has been also occurred. Zone I and Zone IIIA, show decreasing trend of rainfall in all the seasons during (LP), which may be reduce the water

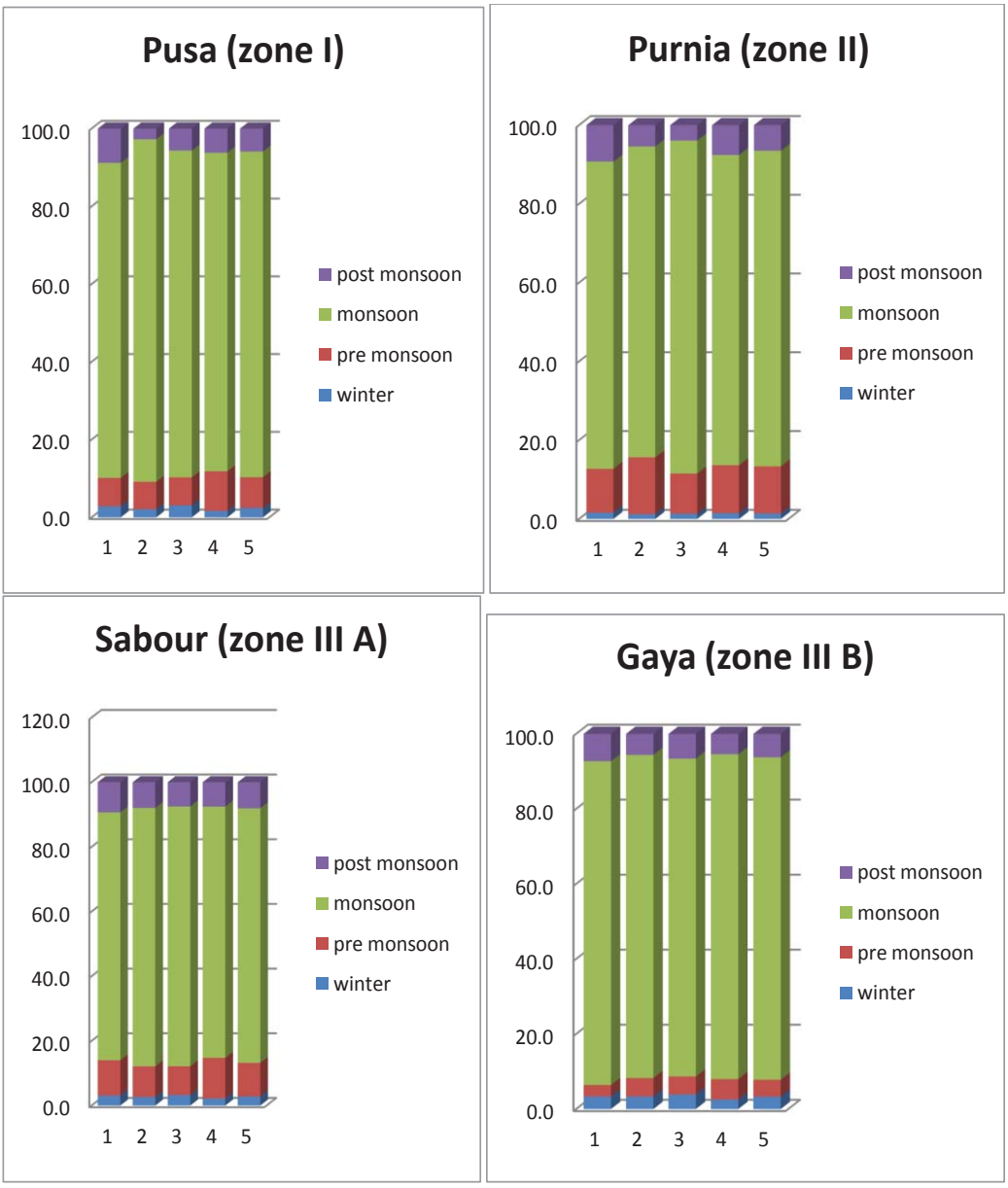

Figure 1. Contribution of different seasons in different periods (1, 2, 3, 4, 5) in different zones of Bihar (1: 1971-80; 2: 1981-90; **3**:1991-2000; 4:2001-10; 5:1971-2010).

availability in the area. In recent decadal period (DP4), all the zones show decreasing trend of monsoon and post monsoon rainfall except Zone II, which shows increasing trend of rainfall in monsoon season. Since rice crop is the important *kharif* crop in this region, the decreasing trend of rainfall in monsoon may delay/affect the transplanting/vegetative phase of the crop, and assured irrigation is very much needed to tackle the moisture stress situation. Decreasing trend of rainfall in post monsoon season may also delay the sowing of wheat crop which is important *rabi* crop in the region due to moisture stress condition.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Brunetti M, Buffoni L, Maugeri M, Nanni T (2000a). Precipitation intensity trends in northern Italy. Int. J. Climatol. 20:1017-1031. http://www.adsabs.harvard.edu/abs/2000IJCli.20.1017B

Brunetti M, Buffoni L, Maugeri M, Nanni T (2000b). Trends of minimum and maximum daily temperatures in Italy from 1865 to 1996. Theoret. Appl. Climatol. 66:49-60.

Dutta S, Patel NK, Srivastava SK (2001). District wise yield models of

rice in Bihar based on water requirement and meteorological data. J. Indian Soc. Remote Sens. 29(3):175-182. http://www.springer.com/article/10.1007%2FBF02989929

Kothawale DR, Revadekar JV, Rupa KK (2010). Recent trends in pre-monsoon daily temperature extremes over. Indian J. Earth Sci. 119(1):51-65. http://www.ias.ac.in/jess/feb2010/d9jess82.pdf

Kothyari, U.C. and Singh, V.P. (1998). Rainfall and temperature trend in India. Hydrol. Proc. 10(3):357-372. http://www.onlinelibrary.wiley.com/.../(SICI)1099-1085(199603)10:3%3C357

Luo Y, Liu S, Fu S, Liu J, Wang G, Zhou G (2008). Trends of precipitation in Beijing river basin, Guangdong province, China. Hydrol. Proc. 22:2377-2386. http://www.onlinelibrary.wiley.com/doi/10.1002/hyp.6801/abstract

Patrick SW, David LO, David JS, Singh V (2014). Heterogenous demand for drought-tolerant rice: evidence from Bihar, India. World Dev. 64:125-139. http://www.sciencedirect.com/science/article/pii/s0305750x14001387

Sadhukhan I, Lohar D, PaL DK (2000). Pre-monsoon season rainfall variability over Gangetic West Bengal and its neighborhood, India. Int. J. Climatol. 20(12):1485-1493. http://www.onlinelibrary.wiley.com/.../1097-088(200010)20:12%3C1485

Serrano, Mateos VL, Garcia JA (1999). Trend analysis of monthly precipitation over Iberian Peninsula for the period 1921-1995. Phys. Chem. Earth 24:85-90.
http://www.sciencedirect.com/science/article/pii/S1464190998000161

Sneyers R (1990). On the statistical Analysis of series of observation. Geneva. WMO Tech. Note P. 143. http://www.cabdirect.org/abstracts/19912451385

Subhash N, Sikka AK, Ram Mohan HS (2010). An investigation into observational characteristics of rainfall and temperature in Central Northeast India-a historical perspective 1889-2008. Theoret. Appl. Climatol. DOI 10.1007/s00704-010-0299-2. http://dyuthi.cusat.ac.in/xmlui/purl/2014

Subhash N, Singh SS, Priya N (2011). Extreme rainfall indices and its impact on rice productivity- A case study over sub-humid climatic evironment. Agric. Water Manage. 98(9):1373-1387. http://www.researchgate.net/publication/227411437

Subhash N, Singh SS, Priya N (2013). Observed variability and trends in extreme temperature indices and rice-wheat productivity over two districts of Bihar, India-a case study. Theoret. Appl. Climatol. 111:235-250. http://www.springer.com/article/10.1007%2Fs00704-012-0665-3

Valipour M (2012). Critical areas of Iran for agriculture water management according to the annual rainfall. Eur. J. Sci. Res. 84(4):600-608. http://www.researchgate.net/publication/264081411

Valipour M (2014). Future of the area equipped for irrigation. Arch. Agron. Soil Sci. 60(12):1641-1660. http://www.tanfonline.com/doi/full/10.1080/03650340.2014.905675

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Causality relationship between agricultural exports and agriculture's share of gross domestic product in South Africa: A case of avocado, apple, mango and orange from 1994 to 2011

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The study analysed causality between agricultural exports and its share of gross domestic product in South Africa from 1994 to 2011. Apple, avocado, mango and orange exports in tonnes were used to Granger analyse agricultural exports versa agricultural GDP contribution. The results of the Granger causality test showed a unidirectional causality between exports and GDP. Policies and programmes can help farmers with employees wage to enter the export markets which are ineffectual. Policies can be aimed at redress, such as the Employment Equity Act; which is size dependent on other sectors outside agriculture which discourage growth and export participation.

Key words: Agricultural economic growth, agricultural exports, agricultural trade policies, export-led growth, Granger Causality test.

INTRODUCTION

According to Ukpolo (1998) the notable relationship between exports and growth in developing countries has attracted exhibiting interest because of its policy implications. The establishment of the agricultural sector by the marketing of Agricultural Products Act of 1996 has placed South Africa among the world's exporters of agro-food products not limited to wine, fresh fruit and sugar. South Africa is also an important trader of agricultural exports in Africa and competes for international market with those exports destined for EU and US markets. The debate on the relationship between agricultural export and agricultural Gross Domestic Product (AgGDP) has exhibited considerable interest in the field of development economics due to the nature of the contribution of the agricultural sector. Several empirical studies were conducted to assess the role of exports towards the economic growth of developing countries from various aspects. While the true measure of these nation's development needs to be expressed through improvements in the standard of living , their economic

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growth plays a significant part in this process by providing increased per capita income, increased revenue for government sponsored social services, leading to export led-growth.

Many researchers (Haleem et al., 2005; Stiglitz, 2007; Shirazi and Manap, 2004; Raza et al., 2012; Jatuporn et al., 2011) believe that agriculture can salvage the declining economy under unstable global economic conditions. Avocado, apple, mango and orange production in South Africa over the decade has shown good growth trends. In South Africa recently, empirical studies carried out (Dlamini and Fraser, 2010; Rangasamy, 2009; Pearson et al., 2010) to appraise the impact of export growth in comparison to economic growth, comparatively yet little has been done to analyse the impact of a single or few produce within the agricultural sector. The issue of how South Africa's agricultural sector can greatly contribute to economic growth is one of the fundamental economic questions which need proper considerations. An export-led growth hypothesis, which states that agricultural exports and other exports in general are keys to promoting economic growth, provides one of the answers to these fundamental questions. According to Abou-Stait (2005), an export-led growth strategy aims to provide producers with incentives to export their produce through various governmental policies.

Chambers (1984) showed that the restriction on the openness of the economy depresses the agricultural sector, which later affects its trade, agricultural prices relative to non-agricultural prices and income. The South African agricultural industry has become less dependent on state support and internationally more competitive, although many sectors within the industry experienced a difficult period of adjustment and distress relating to segmented level of farming groups. The country's key and rising agricultural exports generally face relatively low levels of border protection, in part, due to bilateral and general tariff concessions to South Africa following the marketing of the Agricultural Products Act of 1996. However, these preferences do not exclude the country from the seasonal elevation of tariff barriers, export quotas and the implicit constraints of the entry prices built into the European Union (EU) regime for fresh fruits. This needs utmost attention since issues of seasonal elevation of tariffs affects South African's possibility of exporting fruits from provinces which have similar harvesting seasons to those in Europe and competing countries.

On average, South African avocado, apple, mango and orange production, in both commercial and subsistence sectors, has experienced increases on a yearly basis. This growth in production results in surplus quantities in the market. Drawn from a neo classical economic notion, the direct link between agricultural exports and its share of GDP can contribute to the export-led economic growth. This export-led growth can create profit allowing the agricultural economy to balance its finances, surpassing the debts and lowering returns which are challenges in South Africa's agricultural economy. The increased agricultural exports growth can trigger more avocado, apple, mango and orange production, which would create more exports opportunities. Farmers producing avocado, apple, mango and orange for exports purposes can receive export tariff subsidies and better access to the local and international markets. Exports of avocado, apple, mango and orange from South Africa to the African continent have been declining during the past three years, moving from 866 tons in 2007 to 396 tons in 2009. As a result, avocado, apple, mango and orange exports to the Americans have been consistent over the last decade, remaining below 100 tons for most of the decade and only peaking to 160 tons in 2001 (DAFF, 2011).

Avocado, apple, mango and orange exports are chosen because their productions have a higher value adding processing potential and are scattered around the republic. These agricultural produce must be clustered based on their comparative advantage and exports potential. The argument concerning the role of the exportation of these fruits as one of the main determinants of economic growth is not new. Haleem et al. (2005) investigated export supply response of citrus and mangoes in Pakistan. The study reviewed performance of citrus and mango exports for the years 1975 - 2004. The fluctuating performance of citrus and mango exports can be attributed to highly fluctuating domestic production, inconsistent export policies, currency devaluation, export duties, non-competitiveness of exports and uncertain situation in the international markets (Ghafoor et al., 2010).

Agricultural exports can play a significant role in analysing the impact of agriculture's share of GDP in South Africa. This can lead to the change in the quantity of produce exported to overseas market hence it can contest an economic decision within the local market for those products. Over the years the world agricultural exports and South African agricultural exports grew per annum. This is due to the export oriented agricultural sector and an instant demand of agricultural produce due to climate change and higher competition which improved the quality produced. The contribution of agriculture's share of GDP in South Africa has been declining while the aggregated agricultural exports are increasing.

The figures show the exports of agricultural products considered for this study. In comparison from the figures, tonnes of mango and avocado exports were lagging behind those of apple and orange exports. The tonnes of avocadoes and mangoes remained at a value less than 100 000 tonnes and fluctuated throughout compared to tonnes of apple and oranges in Figure 1, a factor which economists' debate on based on the fair competition that these produce face in the global market. The favourite climatic conditions that favours both apple and orange production in the country and its value chain analysis that

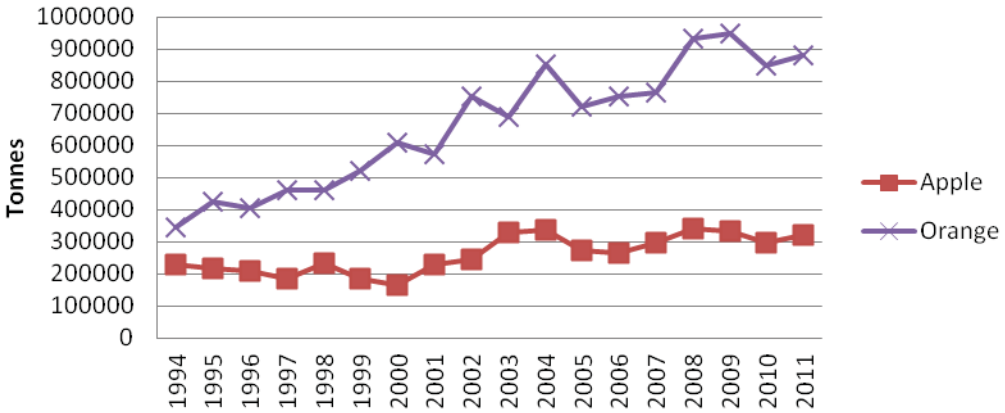

Figure 1. Apple and orange exports from 1994 to 2011 in South Africa.

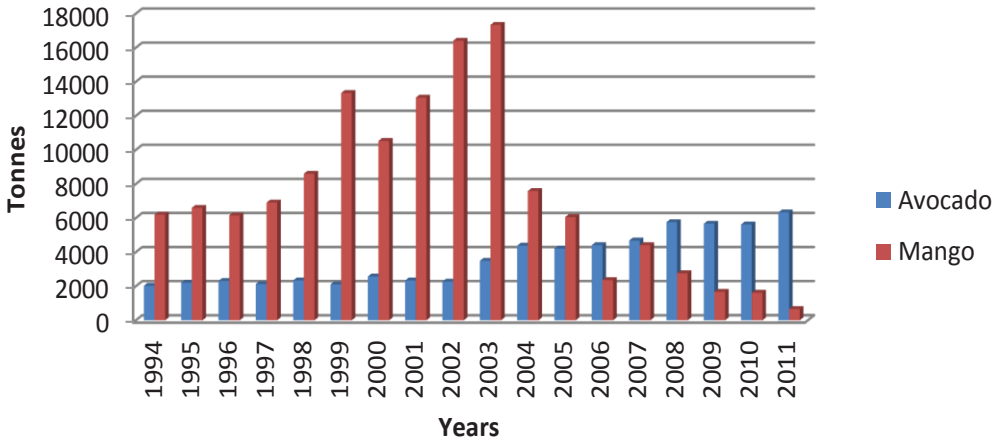

Figure 2. Avocado and mango exports from 1994 to 2011 in South Africa.

help process them contribute to this higher volume of exports. Throughout in Figure 1, the tonnes of oranges exported were far higher than that for apple and other produce in Figure 2, which shows that other produce may be improved if they can be given the necessary support.

The study analysed the causality between agricultural exports and its share of Gross Domestic Product in South Africa. Apple, avocado, mango and orange exports were used to Granger analyse agricultural exports and agricultural GDP contribution percentages.

RESEARCH METHODOLOGY

Study area and sampling procedure

The study covers the entire South Africa and used secondary time series data that was obtained from National Department of Agriculture, Fishery and Forestry Statistical Directorate. The study covered a sample size of 17 years (1994-2011) of avocado, apple, mango and orange exports in South Africa and the agriculture's share of GDP for the same period.

Analytical technique

The Granger causality test was used for empirical analysis. The export-led hypothesis was specified by a bivariate linear model. The model is described below:

Granger causality test

According to Konya (2004) the concept of Granger causality is centred on the idea that a cause come before its effect. In the case of two variable namely X and Y, X is said to Granger-cause Y, if the current value of Y (yt) is conditional on the past values of *X* (*x*t-1, *xt*-2,..., *x*0) and thus the history of *X* is likely to help predict Y. Granger causality test is a better approach to a correlation analysis as it is more efficient than other methods such as Johansson co-integration analysis. Unlike Johansen co-integration analysis which is able to estimate whether the long-run equilibrium exists between two variables, the Granger causality test helps determine the direction of causation. The test however, does not imply causation between correlated variables in any significant way as the name would imply.

Furthermore the Granger test seeks to find out whether the current value of variable *y* – *yt* can be explained by past values of

Table 1. Unit root test for agricultural exports

Parameters		t-statistics	Probabilities
ADF Test Statistic	1.468174	1% Critical value*	-2.7275
		5% Critical value	-1.9642
		10% Critical value	-1.6269

*MacKinnon critical values for rejection of hypothesis of a unit root.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
EXPORTS(-1)	0.100402	0.068385	1.468174	0.1642
D(EXPORTS(-1))	-0.330970	0.285063	-1.161041	0.2650
R-squared	0.051093	Mean dependent var.		18268.75
Adjusted R-squared	-0.016686	S.D. dependent var.		53585.57
S.E. of regression	54030.79	Akaike info criterion		24.74896
Sum squared resid	4.09E+10	Schwarz criterion		24.84554
Log likelihood	-195.9917	Durbin-Watson stat		2.119193

*represent significance at 1%, respectively.

another variable can give more insight. In that way, the variable *y is* said to be "Granger caused" by *x* if *x* helps predict *y*, which is determined by an F-test (Gilmore and McManus, 2002; Granger, 1969). The most common way to test the causal relationship between two variables is the Granger causality proposed by Granger (1969). The test involves estimating the following simple Vector Auto Regressions (VAR):

$$X_t = \sum_{i=1}^{n} \alpha_i Y_{t-i} + \sum_{j=1}^{n} \beta_j X_{t-j} + \mu_{1t} \quad (1)$$

$$Y_t = \sum_{i=1}^{m} \lambda_i Y_{t-i} + \sum_{j=1}^{m} \delta_j X_{t-j} + \mu_{2t} \quad (2)$$

Where it is assumed that the disturbances μ_{1t} and μ_{2t} are uncorrelated. Equation (1) represents that variable Y is decided by lagged variable Y and Y, so does Equation (2) except that its dependent variable is Y instead of X. It should be noted though that the term Granger causality is somewhat of a misnomer since finding "causality" does not mean that movements in one variable causes a movement in the other, but rather causality implies a chronological ordering of movements of the series (Brooks, 2002).

Agricultural exports equation

$$\log AGEXP_t = \alpha + \sum_{i=1}^{k} \varphi_i \log AGEXP_{t-i} + \sum_{i=1}^{l} \beta_i \log AGGDP_{t-i} + \mu_t$$

Agriculture's share of GDP equation

$$\log AGGDP_t = \beta + \sum_{i=1}^{k} y_i \log AGGDP_{t-i} + \sum_{i=1}^{l} \alpha_i \log AGEXP_{t-i} + \mu_t$$

Where, AGEXP represent avocado, apple, mango and orange exports and AGGDP represent agriculture's share of GDP.

Unit root tests agricultural exports and agriculture's share of GDP

The constant and coefficient of EXPORTS are significant; t ratios are less than 2 in absolute values and P-values is less than t ratios. Here the P-value gives the probability that the hypothesis (unit root test of EXPORTS) is not true. It is conventional to reject the hypothesis if the P-value is less than 0.05. The ADF statistic value is 1.468174 and associated one-sided probability value is 0.1642. The constant and the coefficient of GDP are significant, t ratios are less than 2 in absolute values and P-values are less than t ratios. Here the P-value gives the probability that the hypothesis (unit root test in GDP) is not true. It is conventional to reject the hypothesis if the P-value is less than 0.05. The more the ADF statistic test negative, the stronger the rejection of the hypothesis that there is a unit roots at some level of confidence. The ADF statistic value was negative at 1.361641 and above the associated one-sided probability value of 0.1948. This implies that 1% increase in agricultural exports would results in a 19.4% contribution on the share of GDP. ADF was lagged at 3 to minimise bias and avoid suffering the power of the model, which happens when the lag value is too small or large respectively (Tables 1 to 3).

RESULTS AND DISCUSSION

Pairwise Granger Causality Test

From the observation we reject the null hypothesis that agricultural exports does not granger cause agricultural share of GDP because the probability that agricultural exports does not granger cause agriculture's share of GDP was significant at 5%. This probability is less at 3% which helps us reject the hypothesis based on its findings. We accept the null hypothesis that agriculture's share of GDP does not cause agricultural exports with the probability value higher at 20.82%. Based on this observation we accept the null hypothesis that agriculture's share of GDP does not granger cause agricultural exports. Therefore, it is known that if hypothesis H^1_0 is not rejected but Hypothesis H^2_0 is rejected, their linear causality runs unidirectional from Y_1 to X_1.

Conclusion

The study attempted to analyse empirically the causality between agricultural exports and its share on GDP over a period of 1994 to 2011. The result derived from the Granger causality test played an important role in complementing agricultural exports in South Africa. In conclusion, the study outlined a unidirectional causality from agricultural exports to agriculture's share of GDP. Gross Domestic Product in the agricultural sector matters in the direction of exports in the agricultural scope of the republic. Thus, an increase in agricultural exports is expected to yield an increase in its share of the GDP.

There are three direct implications for policy that can arise out of this export potential. Firstly, policies and programmes that can be planned to help farmers with employees wage to help enter the export market are ineffectual, since these farms are struggling to finance production in South Africa, which in the long-run affect agricultural exports. Secondly, creating more exporters requires creating a larger pool of potential exporters of the requisite size. This means supporting the entry of emerging farmers but also encouraging the expansion of existing exporting farmers. Encouraging new investment (particularly foreign investment) requires competitive returns and guarantees of the security of this investment. These competitive returns should result from, for example, particular market characteristics (access to the Southern African region), competitive labour costs, or tax breaks. Encouraging existing farms to grow requires addressing issues that farmers cite as constraints, such as policy uncertainty, labour regulations, infrastructure investment and anticompetitive behaviour. Thirdly, policies aimed at redress, such as the Employment Equity Act, which is size dependent may discourage growth, increase costs and discourage export participation.

Conflict of Interest

The authors have not declared any conflict of interests.

REFERENCES

Abou-Stait R (2005). Are exports the engine of economic growth? An application of co-integration and causality analysis for Egypt, 1977 – 2003. Economic Research Working Paper Series. Tunis: African Development Bank.

Brooks C (2002). Introductory econometrics for finance. Cambridge University Press. Chambers RG (1984) Agricultural and financial market interdependence in the short run, Am. J. Agric. Econ. 66:12-24.

Chambers RG (1984). Agricultural and financial market interdependence in the short run. Am. J. Agric. Econ. 66(1):12-24.

DAFF (Department: Agriculture, Forestry and Fisheries) (2001). DAFF annual report 2011/12. http://www.daff.gov.za/doaDev/topMenu/AnnualReports/2011_12/AR 2012.pdf

Dlamini TS, Fraser G (2010). Economics of meat production from the springbuck in the eastern cape karoo. Contributed Paper presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa.

Department of Agriculture, Fishery and Forestry (2011). Abstract of Agriculture Statistics. Pretoria. Dlamini TS, Fraser GCG (2010). Foreign Direct Investment in the agriculture sector of South Africa: Do GDP and Exports determine locational inflows. J. Econ. Economet. 34:57-68.

Ghafoor A, Mustafa K, Zafar I, Mushtaq K (2010). Determinants of mango exports from Pakistan. J. Agric. Res. 48:1-177.

Gilmore CG, Mcmanus GM (2002). International portfolio diversification: US and Central European equity markets. Emer. Mark. Rev. 3:69-83 http://dx.doi.org/10.1016/S1566-0141(01)00031-0

Granger CWJ (1969). Investigating Causal Relations by Econometric Models and Cross-spectral Methods. Econometry 37:424-438. http://dx.doi.org/10.2307/1912791

Haleem U, Mushtag K, Abbas A, Sheikh AD (2005). Estimation of Export Supply Function for Citrus Fruit in Pakistan. Pak. Develop. Rev. 44:659-672.

Jatuporn C, Chien LH, Sukprasert P, Thaipakdee S (2011). Does a Long-Run Relationship exist between Agriculture and Economic growth in Thailand. Int. J. Econ. Fin. 3:123-135.

Konya (2004). Unit-Root, Cointegration and Granger Causality Test Results for Export and Growth in OECD Countries. Int. J. Appl. Econ. Quant. Stud. 1:67-94.

Pearson J, Viviers W, Cuyvers L, Naude WV (2010). Identifying export opportunities for South Africa in the Southern engines: A DSM approach. Int. Bus. Rev. 19:345-359. http://dx.doi.org/10.1016/j.ibusrev.2010.01.003

Rangasamy L (2009). Exports and economic growth: The case of South Afr. J. Int. Develop. 21:603-617. http://dx.doi.org/10.1002/jid.1501

Raza SA, Ali Y, Mehboob F (2012). Role of Agriculture in Economic Growth of Pakistan. Int. Res. J. Fin. Econ.83:1450-2887.

Shirazi NS, Manap TAA (2004). Export and Economic Growth Nexus: The case of Pakistan. Pak. Develop. Rev. 43:563-581.

Stiglitz JE (2007). Making Globalization Work for Developing Countries, W.W Norton & Company, Inc.

Ukpolo V (1998). Exports and economic growth in South Africa: Evidence from Cointegration and Granger-Causality tests. Afr. Econ. Bus. Rev. 1:1-5.

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Full Length Research Paper

Assessing the effect of farmers' practices on the severity of groundnut rosette virus disease in Uganda

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Groundnut rosette virus disease is the most destructive disease of groundnut in Sub-Saharan Africa, Uganda inclusive. Over the past years, a wide range of management options for this disease have been developed and recommended for farmers in Uganda. Relevant efforts have also been made by researchers in disseminating improved technologies to farmers in several parts of the country. However, questions on the extent to which farmers are currently utilizing these technologies and their effectiveness in controlling the disease in their fields remain unanswered. This study aimed at assessing the effect of farmers' practices on the severity patterns of groundnut rosette virus disease in Uganda. A survey was conducted within five agro-ecological zones in Uganda to obtain information on the various practices farmers employ in the management of the crop and disease in their fields using a structured questionnaire. Disease severity was scored in each farmer's field. Farmers were found to be employing a range of practices in groundnut production, including: early sowing, intercropping, use of improved groundnut genotypes, crop rotation; and uprooting and burning diseased plants among others. However, only two management practices: early sowing and use of improved varieties were found to significantly ($P<0.05$) reduce rosette severity in groundnut fields. Special consideration should therefore be given to these two GRVD management strategies while developing and promoting management packages for this disease.

Key words: Groundnut, rosette, incidence, severity, farmers, management.

INTRODUCTION

The groundnut (*Arachis hypogaea* L.), also known as peanut, is the second most important food legume in Uganda after beans (*Phaseolus vulgaris* L.) (UBOS, 2013; Okello et al., 2014). It is a very popular crop, especially in the eastern and northern regions of the country where it has become part of the peoples' culture (Mahmoud et al., 1991). Its production however, has been constrained by numerous factors including pests and diseases, unreliable rains with recurrent droughts, poor agronomic practices, low access to high yielding cultivars and low levels of input use (Mahmoud et al., 1991; Adipala et al., 1998; Okello et al., 2013). This situation has led to extremely low yields at farmer level averaged at 0.8 tons per hectare of dried pods which is in

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contrast to yields as high as 2.5 to3.0 tons per hectare reported at research stations within Uganda and other countries with developed agriculture (ICRISAT, 1986; Busolo-Bulafu, 2004; Okello et al., 2014).

Groundnut rosette virus disease (GRVD) is the most destructive disease of groundnut in Uganda. Over the past years, a wide range of management options for GRVD have been developed and recommended for farmers in the Uganda (NARO, 2001; Adipala et al., 2001; Okello et al., 2013, Okello et al., 2014). These include the use of improved varieties, chemical control, and cropping practices that delay the onset and spread of GRVD such as early sowing, maintaining a dense uniform stand of groundnuts, close spacing (45×15 and 30×10 cm) and removal of wild hosts. Relevant efforts have also been made by researchers from the National Groundnut Improvement Programme- at National Semi-Arid Resources Research Institute (NaSARRI) Serere and Makerere University in disseminating these research technologies to farmers in several parts of the country (Adipala et al., 2002; Okello et al., 2014). However, questions on the extent to which farmers are currently utilizing these technologies and their effectiveness in GRVD control in their fields remain unanswered. Thresh (2003) emphasized that much detailed research and a thorough knowledge of farming practices is required before an effective integrated virus disease management programme can be developed and promoted because virus spread within a given crop is facilitated by some cropping practices and impeded by others. This study aimed at investigating the current practices being employed by farmers in GRVD management and to what extent they are influencing disease severity.

MATERIALS AND METHODS

Study area

A survey was conducted in 2012 that covered 5 major groundnut producing agro-ecological zones (AEZ) of Uganda including the Lake Victoria Crescent, Kyoga Plains, South Western Farmlands, North Eastern Savannah Grasslands and the North Western Savannah Grasslands. In each zone the districts, sub counties and parishes were selected purposively based on production levels, giving preference to those which produced more groundnuts. Farmers that participated in the study were randomly selected with the help of field assistants based in the respective areas. Farmers' fields were monitored over a period of two weeks and the level of GRVD severity was visually assessed in each field and recorded. This was done when the groundnut crop in farmers' fields were between the stage of pod filling and physiological maturity.

Data collection and analyses

A structured questionnaire was developed and used to obtain information on the current management practices employed by farmers in groundnut production. In each farm, 10 plants were randomly selected. Severity of GRVD was scored using a scale of 1 to 9 based on the intensity of disease attack according to the scale:
1-3 = Low severity (mild rosette/less than ¼ of entire groundnut plant stunted).
4-6 = Moderate severity (moderate rosette/between ¼ and ¾ of plant stunted).
7-9 = High severity (severe rosette symptoms /more than ¾ of plant stunted).

The average severity score for each field was then computed. Data on farmers' management practices and severity for each field were entered and analyzed using the Statistical Package for Social Scientists, 15th edition (SPSS Inc., 2006). Regression analysis was carried out to establish the relationship between the management practices employed by farmers and GRVD severity. Linear regression was run with disease severity as the dependent variable and the management practices as the independent variables. Descriptive statistics such as frequencies and percentages were obtained for all continuous variables. Graphs and charts were also generated from the data using an excel program (Microsoft Office, 2007).

RESULTS

General characteristics of respondent farms and practices used

Of the 105 farmers interviewed during this study, 44 (42%) were male and 61 (58%) were female. Farmers planted groundnuts on an average acreage of 0.58 acres, with the majority (81.6%) operating on acreages less than 0.5 acre. A very small percentage of farmers (1.8%) planted groundnuts on land exceeding 1 acre. The most dominant ploughing method used by groundnut farmers was the hand hoe (94%) whereas fewer farmers used tractors (7%) or oxen (4%) in their fields.

Farmers in all the five agro-ecological zones visited used a wide range of plant spacings, ranging from 40 × 20 cm to 75 × 50 cm. However the majority (52%) of groundnut farmers did not use any particular spacing. Most of the farmers purchased their seeds from either the local market, input suppliers or from fellow farmers (48.6%) while 35.2% used seed they had saved from the previous harvest. Some farmers (16.2%) obtained improved seed from either NARO or the NAADS sub-county offices in the surrounding area (Figure 1).

With regard to cropping system, 65% farmers intercropped groundnut with other crops including: Maize (42%), cassava (27%), perennials (21%) and legumes (7%) (Figure 2). Minor crops (3%) not indicated in the chart but found intercropped with groundnuts included: vegetables, sorghum, okra, potato, simsim and millet.

Groundnut varieties being grown by farmers included the Serenut series, specifically Serenut 1, 2, 3 and 4 (34%). The main local varieties grown by farmers included: Red beauty (21%) and Erudurudu (16%); others included Igola, Etesot, Egoromoit, Kabonge and Omgwere (Figure 3).

Improved varieties (mainly of the Serenut series) were mainly grown in the Kyoga plains (Pallisa and Kumi districts) and the North Eastern (Lira district) and North Western (Arua district) savannah grasslands. Farmers in the Lake Victoria Crescent (Jinja and Kayunga districts)

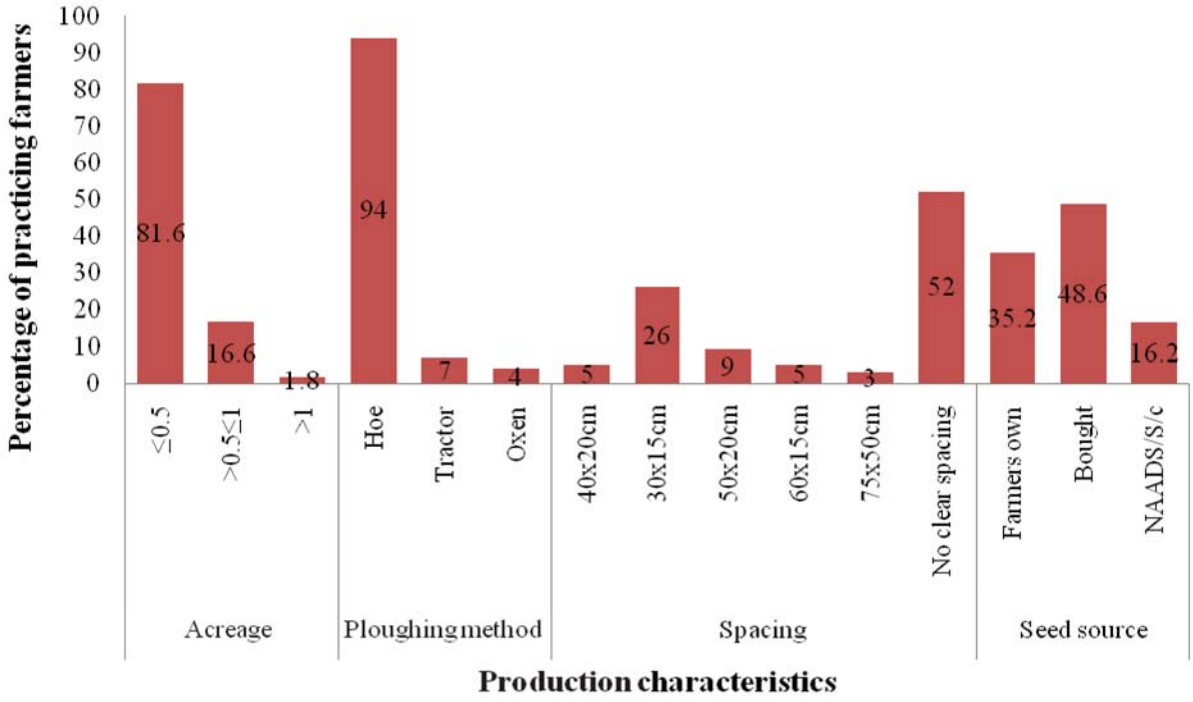

Figure 1. Groundnut production characteristics of farmers' fields visited during survey.

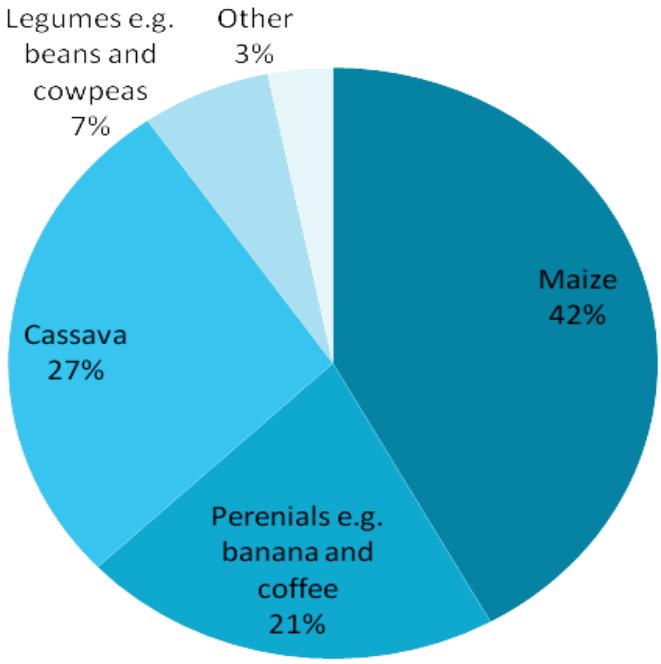

Figure 2. Major groundnut intercrops observed in the study.

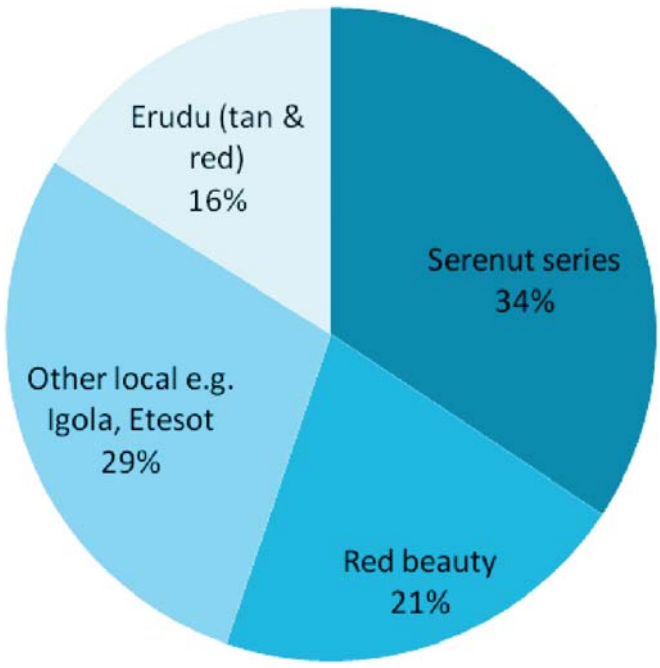

Figure 3. Major groundnut varieties planted by farmers in Uganda.

and South Western Farmlands (Mbarara district) were primarily planted local varieties (Figure 4). Different plant times were used by farmers; at the time of the survey groundnut was at different levels of physiological maturity with most (58.1%) of the crop at flowering stage, 23.8% had attained harvest maturity and 18.1% were in the pegging and pod filling stage (between flowering and maturity).

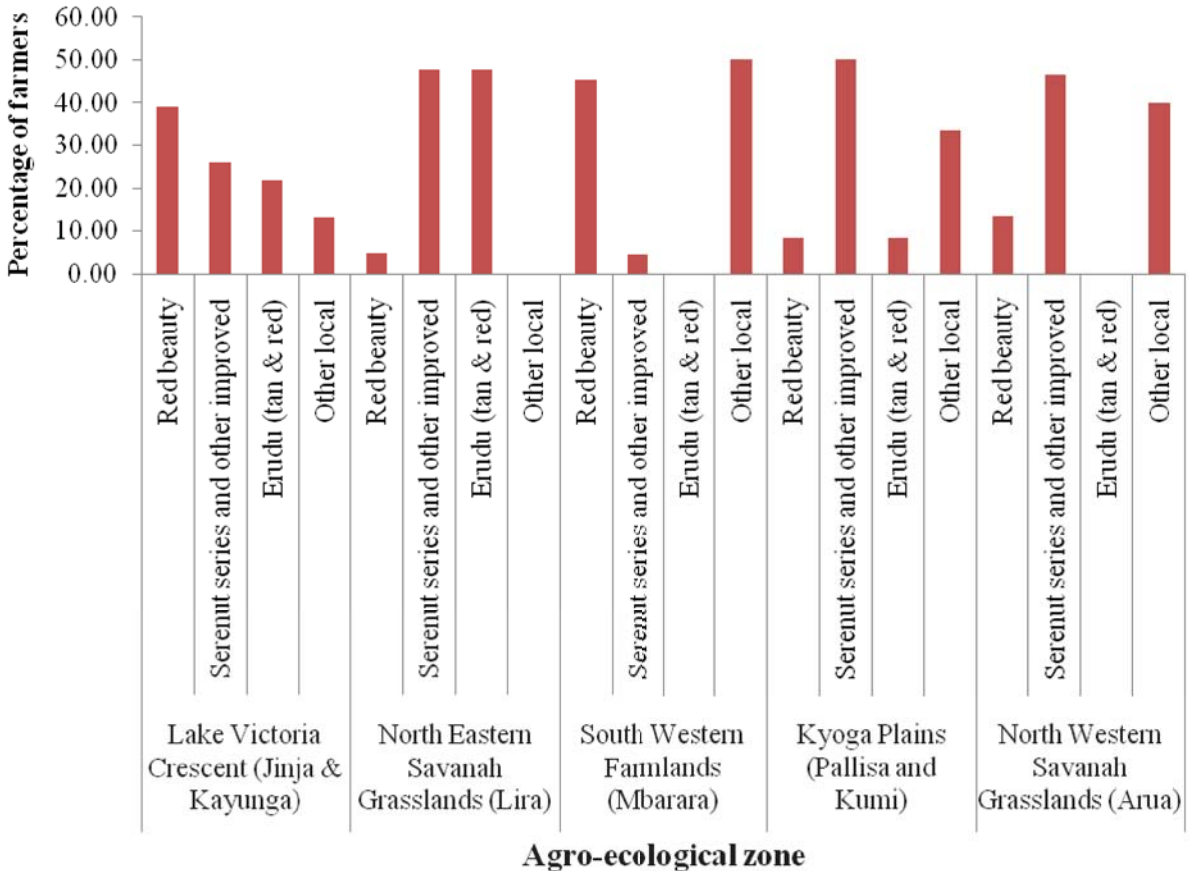

Figure 4. Groundnut varieties grown in the different agro-ecological zones.

Trends of GRVD severity within five agro-ecological zones of Uganda

Results of the survey revealed that 41% of the fields visited had moderate levels of GRVD severity whereas 52.4% exhibited low levels of disease severity. Only 6.7% of the fields visited were severely affected by GRVD. Among the fields that were severely affected by GRVD, 50% were from the Lake Victoria Crescent agro-ecological zone, 25% from the Kyoga plains and only a few from the North Western Savannah grasslands (8.3%), North Eastern savannah grasslands (8.3%) and South Western Farmlands (8.3%) (Figure 5).

Management practices employed by farmers in groundnut production

Farmers employed a range of practices in groundnut production which included: early planting, use of improved varieties, intercropping, pesticide application, crop rotation, uprooting and burning diseased plants and fallowing among others (Table 1). Among the recommended GRVD management practices, early sowing was the most common and was being practiced by 80% of the farmers, the majority of whom were women (Figure 6). Pesticide application was the least employed, with only 7.6% of farmers interviewed implementing it. Improved varieties such as the Serenut series were being used by 35.2% of the farmers interviewed while 64.8% of farmers planted local varieties such as Etesot, Egoromoit and Kabonge.

Forty percent of the farmers practiced crop rotation in their fields while 31.4% reported that they carry out fallowing in their gardens. Among the farmers interviewed, 34.3% reported that they uproot and burn diseased plants, especially during the time of weeding. A larger number (59%) of farmers weeded their gardens twice during the growing season while 37.1% weed only once during the season and 3.8% carried out hand weeding three times during the growing season. Other practices that were rarely practiced by farmers included fertilizer application (8.6%), mulching (2.9%) and herbicide use (1.9%).

Relationship between farmers' management practices, gender and GRVD severity

The ANOVA for regression analysis of farmers

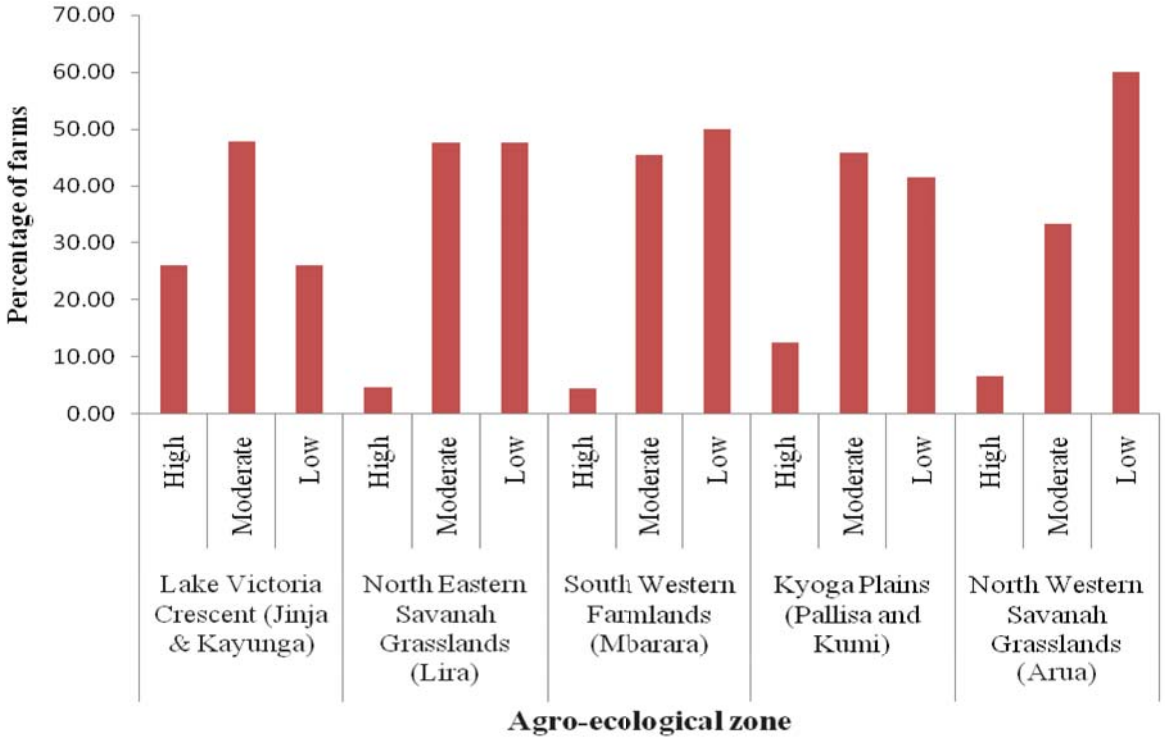

Figure 5. GRVD severity trends within five agro-ecological zones.

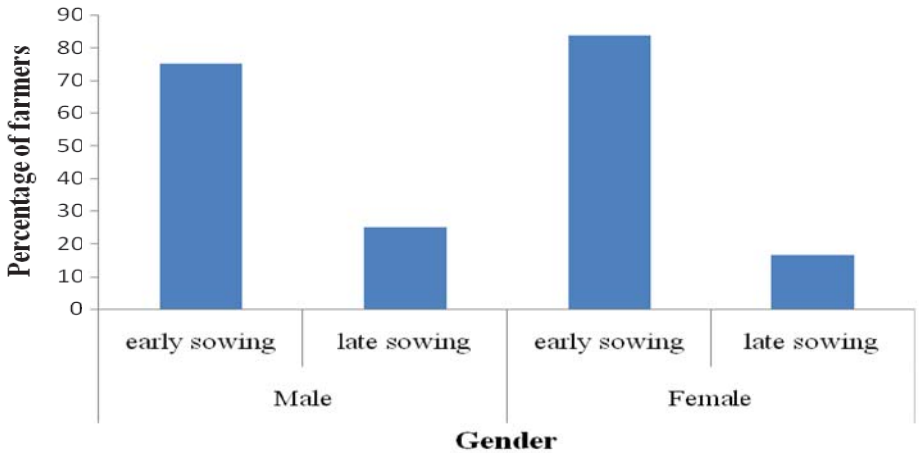

Figure 6. Planting times for female and male farmers obtained during the survey.

management practices, their gender and GRVD severity revealed that management practices and gender significantly (P≤0.05) affected GRVD severity. The model obtained from linear regression revealed that planting date, variety planted and gender were the only variables that significantly (P≤0.05) affected GRVD severity in farmer fields. Variables which were found to have no significant effect on disease severity (P≤0.05) included: crop rotation, uprooting and burning diseased plants, pesticide application, fertilizer application, mulching, number of times the crop is weeded and fallowing among others (Table 2). A summary of the model is expressed in the following regression equation:

GRVD severity = 3.7 - 0.3 gender + 0.3 planting date - 0.6 variety planted

The equation implies that, holding all other factors constant, GRVD severity is lower for female managed gardens compared to male managed gardens. In

Table 1. Management practices currently employed by groundnut farmers in Uganda.

Management practices		No. of practicing farmers	Marginal percentage (%)
Variety planted	Improved	37	35.2
	Local	68	64.8
Weeding regime	Once	39	37.1
	Twice	62	59.0
	Thrice	4	3.80
Intercropping	Yes	68	65.0
	No	37	35.0
Pesticide application	Yes	8	7.60
	No	97	92.4
Fertilizer application	Yes	9	8.60
	No	96	91.4
Crop rotation	Yes	42	40.0
	No	63	0.0
Uproot and burn diseased plants	Yes	36	34.3
	No	69	65.7
Fallowing fields	Yes	33	31.4
	No	72	68.6
Planting date	Early planting	84	80.0
	Late planting	21	20.0
Other (e.g. mulching, herbicide use)	Yes	5	4.80
	No	100	95.2
Total		**105**	**100**

particular, the GRVD severity in female managed gardens is lower by 34.99% ([($e^{0.3}$) - 1]*100) in comparison to male managed fields. A delay in planting (late planting) increases GRVD severity by 34.99% ([($e^{0.3}$) - 1]*100) compared to early planting. GRVD severity is 82.2% ([($e^{0.6}$) - 1]*100) higher in local varieties compared to improved varieties.

DISCUSSION

This study was aimed at assessing the effect of farmers' management practices on the severity of GRVD in Uganda. Farmers were found to be utilizing a range of management practices. However, these practices influenced GRVD severity in different ways and to different degrees. Results revealed that it was planting date (early planting vs. late planting) and variety planted (improved vs. local) which significantly ($P<0.05$) affected GRVD severity. Farmers who planted their groundnuts during the earlier part of the season had significantly ($P<0.05$) less GRVD affecting their groundnut crop compared to those who planted late. The same was also true for farmers who used improved varieties in comparison to those who planted local varieties. Improved varieties (Serenut series) have host plant groundnut rosette resistance (Okello et al., 2014). Earlier research (Farrell, 1976a) reported that farmers seldom practice early sowing of groundnuts since they prefer sowing their main staple food crops first. The results of this study, however, are divergent from this report. Out of all the farmers interviewed, 80% reported that they had planted their groundnuts at the start of the rainy season and the lesser 20% planted later along the season. It possible that over the years, some farmers may have realized through experience that late sown crops end up more severely affected by GRVD and has therefore chosen early sowing as one of the practices for disease management. Different researchers have reported that GRVD incidence is generally low when groundnuts are planted early in the season compared to the late sown crop (Farrel, 1976b; Subrahmanyam and Hildebrand,

Table 2. Regression results for the relationship between farmer management practices, gender and GRVD severity.

Regression model[a]	Coefficients	Std. Error	t-value	p-value
(Constant)	0.715	3.725	5.210	0.000
Gender	0.108	-0.284	-2.619	*0.010
Planting date	0.142	0.294	2.067	*0.042
Variety planted	0.113	-0.621	-5.491	*0.000
Weeding regime	0.098	0.010	0.104	0.918
Fertilizer application	0.188	0.243	1.293	0.199
Pesticide application	0.200	-0.050	-0.250	0.803
Herbicide application	0.398	-0.372	-0.935	0.352
Crop rotation	0.110	-0.068	-0.614	0.541
Uproot and burn	0.113	0.116	1.025	0.308
Fallowing	0.124	-0.114	-0.919	0.360
Mulching	0.318	-0.346	-1.085	0.281

[a]Dependent variable: disease severity in field; *Significance at 5% level.

1994; Naidu et al., 1999; Adipala et al., 2001; Okello et al., 2014). The early sown crops cover the ground before the aphids' main period of flight activity and largely escape infection because aphids prefer younger crops and often alight preferentially on widely spaced plants. The results of this study are in line with these findings; late planting was found to lead to an increase of 34.9% in GRVD severity compared to early planted crops in farmers' fields. Furthermore, experiments conducted on integrated management of groundnuts by researchers at the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) (Subrahmanyam et al., 2000) as well revealed that using early sowing and improved genotypes in combination while planting at optimum plant population, exhibited the best performance of groundnuts under high disease situations. The results of this study, which show that use of improved varieties and early sowing are the two major practices that can significantly reduce GRVD severity in farmers' fields are consistent with their reports.

Gender, a variable that is not one of the management practices, was also found to affect GRVD severity significantly ($P<0.05$), with female managed fields having less disease severity compared to male managed ones. This is probably because a greater percentage of women were found to be engaged in early planting compared to the men. Earlier reports have indicated that groundnut in Sub Saharan Africa and Uganda inclusive, are primarily produced by small holder farmers, the majority of whom are women (Naidu et al., 1999, VECO, 2011; Okello et al., 2014). This was confirmed in this study where the majority (81.6%) of groundnut farmers were found operating on acreages less than 0.5 acres and with a greater percentage being women (58%). This is also in line with reports that females make up approximately 75% of agricultural employment in Uganda (EPRC, 2009).

This study demonstrated that management practices such as intercropping, planting at close spacing, pesticide application and rouging did not significantly reduce the incidence and severity of GRVD in farmers' fields. Intercropping groundnut with crops such as beans) and sorghum has previously been reported to be effective in reducing GRVD incidence (Farrell, 1976; Alegbejo, 1997). It is possible that intercropping was not found to reduce GRVD severity in farmers' fields because beans share aphids with groundnuts hence more GRVD. More still, farmers were practicing it in a haphazard manner, with no clear spacing which is in contrast to intercropping experiments in which recommended spacings were used. According to the survey results, 65% of the farmers were engaged in intercropping groundnuts with other crops such as maize and cassava. This is supported by reports by Okello et al. (2010), which indicated that the groundnut crop in Uganda is mainly grown as an intercrop with maize and cassava. Intercropping together with varietal mixtures are now recognized by agronomists and other researchers as forms of crop diversity that are important in providing farmers with some degree of resilience and stability that contribute to reliable yields and avoids total crop failure (Smithsone and Lenne, 1996). Planting groundnut at close spacings (45×15 and 30×10 cm), has also been reported to lead to reduction of GRVD levels. During the survey, the closest spacings that farmers were found to be using were 40×20 cm (5% of the farmers) and 30×15 cm (26%), which differs from the recommended. The recommended spacing is that of national average pooled from major groundnut growing areas. Spacing has strong relation to the fertility of the land and the intercrop regiment. This could explain why they were not realizing any significant reduction in GRVD severity in their fields.

The use of pesticides for management of GRVD, though recommended, is associated with several

challenges. One is the fact that the relationships between viruses and their vectors are complex and a decrease in vector populations does not necessarily achieve a corresponding decrease in virus spread (Thresh, 2003). Improper use of pesticides has also been reported to alter the delicate balance between aphids and their natural enemies, possibly resulting into the development of insecticide resistant biotypes (Naidu et al., 1999). More still, financial constraints also limit the use of pesticides by small holder farmers. Thresh (2003), reported that it is inappropriate to promote the use of pesticides on subsistence crops whose value is seldom sufficient to cover the cost of treatment. In this study, only 7.6% of the farmers mentioned that they applied pesticides (Dimethoate) for aphid control at some point during crop growth. Financial limitations among the groundnut farmers, most of who cultivate on less than an acre of land, could have contributed to the lesser usage of this technique in GRVD management. In this study, results revealed that pesticide usage was not significantly reducing GRVD in the fields of farmers practicing this control technique. This could also be attributed to financial constraints since it has been reported that even farmers who opt for chemical control at times find it difficult to treat their crops throughout their entire vulnerable growth periods (Thresh, 2003). This could lead to unscheduled pesticide applications which may not be effective in GRVD control in the long run.

Roguing (uprooting of diseased plants) was being practiced by about 34% of the farmers. However, this approach has been reported to be most effective against viruses that do not spread quickly or far in any considerable amount (Putter, 1980), which is not the case for GRVD. Roguing has also been reported to be unpopular with some farmers who may not be prepared to allocate the time and effort required to inspect crops and identify and remove diseased plants or others who are reluctant to remove any diseased plants that may contribute some little yield (Thresh, 2003). This, to some extent, explains why this practice may not have significantly contributed to reduction in GRVD severity.

The highest levels of GRVD severity during the survey were recorded in the Lake Victoria Crescent agro-ecological Zone (LVCZ), confirming past reports that identified this location as one of the hotspots of the disease (Okello et al., 2010, 2014). Approximately 50% of the most severely affected fields were found to be located in this zone. Results of the survey revealed that improved varieties for instance Serenut 1, 2, 3 and 4, were majorly being grown in the northern and eastern areas of Uganda, with farmers in the LVCZ utilizing less of these varieties. Farmers within this zone mainly grew local varieties for instance Red Beauty, which are more susceptible to GRVD.

The high levels of GRVD in Jinja could therefore be partially attributed to the low utilization of improved varieties within the region compared to the Northern and Eastern regions of Uganda. It has recently been reported that farmers in Eastern Uganda are more likely to acquire information regarding research outputs from external sources as compared to those in Busoga region where Jinja district is located (Thuo et al., 2014). The existence of a known hotspot for rosette in this zone, Nakabango, compounded with the use of landraces could exacerbate GRVD severity in the area.

CONCLUSION AND RECOMMENDATIONS

This study was aimed at evaluating the influence of farmers' management practices on the severity of GRVD. It was observed that farmers were utilizing a number of management strategies for the disease. However, only two major practices significantly reduced GRVD severity in their fields: early sowing (planting at the onset of the rains) and the use of improved varieties. Farmers' practices are therefore important factors influencing GRVD severity in groundnut fields. This information contributes to our understanding as to which practices farmers are currently employing in groundnut production in Uganda, to which extent they are being utilized and which particular ones are contributing significantly to the reduction of GRVD severity.

While promoting GRVD management packages, special attention should be given to the use of improved varieties and early sowing since they were found to be more effective in controlling GRVD in farmers' fields. Government agencies such as the National Agricultural Advisory Services (NAADS) and non-governmental organizations, which provide inputs to farmers and conduct trainings for farmer groups should emphasize the use of an integrated approach mainly based on the two cropping practices rather than a single practice such that farmers can exploit their synergistic interactions, thereby increasing the potential for GRVD management. Researchers on the other hand should continue to focus on developing improved varieties that have high levels of resistance to GRVD.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Adipala E, Karungi J, Bashasha B, Mugisha J, Asekenye CE, Iceduna C, Odeke V, Ekemu R, Kayiira M, Kagino F, Erbaugh M (2002). Dissemination and adoption of an integrated pest management package for groundnut production in Eastern Uganda. In: IPM/ CRSP annual report, 2001-2002.

Adipala E, Kyamanywa S, Epieru G, Mukankusi C, Warren H, Wilson H, Erbaugh M (2001). Integrated Management of Groundnut Insect Pests and Diseases.In; IPMCRSP annual report, 2000-2001.

Adipala E, Warren HL, Epieru G, Takan JP, Kyamanywa S, Wilson H (1998). Comparative performance of cv. Igola 1 and other local groundnut cultivars for the control of Rosette disease.Pages In: Proceedings of the third IPM-CRSP Symposium. May 15th – 18th, 1998, Virginia U.S.A. pp. 87-92.

Alegbejo MD (1997). Survey of the effect ofintercropping of groundnut with cereals onthe incidence of groundnut rosette virus disease in Northern Nigeria. Int. Arach. Newsletter. 17:39-40.

Busolo-Bulafu C (2004). Development of groundnut rosette and vector resistant varieties. Uganda J. Agric. Sci. 9(1):574-578.

EPRC (Economic Policy Research Centre) (2009). Gender and productivity. Analytical Report.URL:www.eprc.or.ug/pdf_files/policybrief12_gender.pdf. Accessed on 15/05/2013.

Farrell JAK (1976a). Effects of groundnut sowing date and plant spacing on rosette virus disease in Malawi. Bulletin of Entomological Research 66:159-171.http://dx.doi.org/10.1017/S000748530000657X

Farrell JAK (1976b). Effects of inter sowing with beans on the spread of groundnut rosette virus by Aphis craccivora Koch (Hemiptera, Aphididae) in Malawi.Bull. Entomol. Res. 66:331-333 http://dx.doi.org/10.1017/S0007485300006726

ICRISAT (International Crops Research Institute for the Semi Arid Tropics). 1986. Annual Report. Groundnuts. P. 215.

Mahmoud MA, Osman AK, Nalyongo PW, Wakjira A, David C (1991). Peanut in East Africa: 1981-1990. In: Peanut, A Global Perspective: Proc. Intl. Workshop, 22-29 Nov, Patancheru, India pp. 89-95.

Naidu RA, Kimmins FM, Deom CM, Subrahmanyam P, Chiyembekeza AJ, Van der Merwe PJA (1999). Groundnut rosette: a virus disease affecting groundnut production in sub-Saharan Africa. Plant Dis. 83:700-709. http://dx.doi.org/10.1094/PDIS.1999.83.8.700

NARO (National Agricultural Research Organization) (2001). Groundnuts In: Agriculture in Uganda, Volume II, Crops pp. 87-96.

NaSARRI (National Semi Arid Resources Research Institute). 2011. NaSARRI Annual Report 2010-2011, unpublished.

Okello DK, Akello BL, Tukamuhabwa P, Odong TL, Adriko J, Ochwo-Ssemakula M, Deom CM (2014). Groundnut Rosette Disease Symptoms types distribution and management of the disease in Uganda. Afr. J. Plant Sci. 8(3):153-163. http://dx.doi.org/10.5897/AJPS2014.1164

Okello DK, Monyo E, Deom CM, Ininda J, Oloka HK (2013). Groundnuts production guide for Uganda: Recommended practices for farmers. National Agricultural Research Organisation, Entebbe. ISBN: 978-9970-401-06-2

Okello DK., Biruma, M. and Deom, CM 2010. Overview of groundnuts research in Uganda: Past, present and future. Afr. J. Biotechnol. 9(39):6448-6459.

Putter CAJ (1980). The management of epidemic levels of endemic disease under tropical subsistence farming conditions. In: Comparative Epidemiology: a tool for better disease management Wageningen, Netherlands pp. 93-103.

Smithson JB, Lenne JM (1996). Varietal mixtures: A viable strategy for sustainable agriculture. Ann. Appl. Biol. 128:127-158. http://dx.doi.org/10.1111/j.1744-7348.1996.tb07096.x

SPSS (Statistical Package for Social Scientists) (2006). SPSS 15.0 Command Syntax Reference 2006, SPSS Inc., Chicago Ill.

Subrahmanyam P, Hildebrand GL (1994). Integrated disease management: an important component in sustaining groundnut production in the SADC Region. In: Sustainable Groundnut Production in Southern and Eastern Africa: Proceedings of a Workshop, 5-7 July 1994. Mbabane, Swaziland.

Subrahmanyam P, Van Der Merwe PJA, Chiyembekeza AJ, Chandra S (2000). Integrated management of groundnut rosette disease. African Crop Sci. J. 10(1):99-110. http://dx.doi.org/10.4314/acsj.v10i1.27560

Thresh JM (2003). Control of plant virus diseases in sub-Saharan Africa: the possibility and feasibility of an integrated approach. Afr. Crop Sci. J. 11(3):199-223.

Thuo M, Bell AB, Bravo-Ureta BE, Lachaud MA, Okello DK, Nasambu OE, Kidula NL, Deom CM, Puppala N (2014). Effects of social network factors on information acquisition and adoption of improved groundnut varieties: the case of Uganda and Kenya. Agric. Hum. Values P. 12. http://dx.doi.org/10.1080/1389224X.2012.757244

VECO (2011). VECO East Africa Annual report 2011. URL: www.veco-ngo.org/sites/www.veco-ngo.org/.../veco_ea_ar_2011.pdfAccessedon21/03/2013.

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Review

Allelopathy in weed management: A critical review

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Allelopathy is defined as both beneficial and deleterious biochemical interaction between plant and weeds, and / or plants and microorganisms through the production of chemical compounds that escape into the environment and subsequently influence the growth and development of neighboring plants. Allelochemicals are present in all types of tissues and are released into the rhizosphere by a variety of mechanism, including decomposition of residues, volatilization and root exudation. Allelochemical its structure and mode of action are different and may offer a potential for future development of herbicide. This paper describes the variety of weeds and crop species that exihibit aallelopathic interface either with crop or weeds.

Key words: Allelopathy, allelochemicals, agriculture, crop, weed.

INTRODUCTION

The capability of some plant species to affect surrounding plants has been well documented since antiquity. The earliest writings on this topic are attributed to Theophrastus (*ca*. 300 B.C), a successor of Aristotle who noticed the harmful effects of cabbage on a vine and suggested that such effects were caused by "odours" from the cabbage plants (Willis, 1985). This phenomenon is known as allelopathy (from the Greek *allelon* = of each other, *pathós* = to suffer). The term was coined in 1937 by German plant physiologist Hans Molisch to define "the harmful effect of one plant upon another". Currently, a more complete definition includes the positive and negative effects of chemical compounds produced mainly from the secondary metabolism of plants, micro-organisms, viruses and fungi that have an influence upon the growth and development of agricultural and biological ecosystems (excluding mammals) (Kruse et al., 2000; Olofsdotter et al., 2002; Weston, 2005).

Although allelopathy has been observed for over 200 years and the phenomenon reports as early as 300BC document that many crop plants inhibited the growth of other plants and destroyed its field weeds (Rice, 1984). In 1974, after the publication of first book of allelopathy by Elory L. Rice the phenomenon got a new attention in science community, who later reinforced this definition of allelopathy (Olofsdotter et al., 2002). The effects of one plant to another plant may be either both stimulatory and inhibitory that depends on the concentration of the released compounds (Bhowmik and Inderjit, 2003). From a practical point of view, such effects are achieved due to the release of active biomolecules, commonly called "allelochemicals", into the environment by the "allelopathic" plants (Kruse et al., 2000; Bertin et al., 2003). Chemicals, at lower concentration that inhibit the

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growth of some species where at higher concentration that may be stimulate the growth of different species (Ahmed et al., 2007). Allelochemicals may be involved in plant-plant, plant insect or plant-herbivore chemical communication (Weir et al., 2004) as well as micro-organism-derived allelochemicals that may be involved in microbe-microbe or microbe-plant interactions (e.g., colonisation process of a new environment) (Singh et al., 2003).

The occurrence of natural allelopathic activity in crops has important positive and negative implications for cropping systems. The application of the allelopathic properties of some crops has been suggested for weed management due to the possibility of reducing the application of expensive, pollutant synthetic herbicides (Belz, 2007; Kruse et al., 2000). On the other hand, agricultural practices such as crop rotation, use of green manure, minimal tillage, covering crop, etc., require previous knowledge on the part of farmers regarding the allelopathic interactions that can occur between the plant species involved. Changes in the distribution pattern of crops, difficulties in replanting crops and fruit trees in orchards or low yield could be an indication of negative allelopathic activity (Chon et al., 2006; Kruse et al., 2000). When a given species produces and releases allelochemicals that can cause damage to a different plant species, this phenomenon is called *heterotoxicity,* whereas, when its own germination and development is affected, this allelopathic effect is called *autotoxicity* (Chon et al., 2006; Kruse et al., 2000).

Autotoxicity is thought to be the result of natural selection, in which an older plant avoids competing with younger individuals for resources (light, water, nutrients, etc.) by maintaining them at a certain distance. Thus, in harsh natural habitats, it is possible to see somewhat uniform spatial patterns within populations, such as in desert plant populations, in which plants tend to be evenly spaced. From the agronomic point of view, the interest in autotoxicity resides in the possible problems for reseeding or overseeding crops (Chon et al., 2006). Autotoxicity has been studied in members of the Cucurbitaceae family, revealing considerable genetic variations, mainly in cucumber, watermelon and melon. Benzoic and cinnamic acid are among the allelochemicals exudated from the roots of these plants (Ding et al., 2007). The authors cited suggest that there is a specific recognition of these allelochemicals. The addition of cinnamic acid, an autotoxin exudated by cucumber roots, to a nutritive solution was found to cause oxidative stress followed by the death of cucumber root tissues, but did not cause the same damage to the roots of *Cucurbita ficifolia* Bouché, which is a member of the same family. A number of important crops have recognised allelopathic activity that can be either greater or lesser depending on the cultivar, climatic conditions, soil fertility, water availability and competing weeds.

The current worldwide demand for cheaper, more environmentally-friendly weed management technologies has motivated a number of studies on the allelopathic interaction between crops and weeds (Dudai et al., 1999; Om et al., 2002). Agricultural practices such as reseeding, overseeding, cover crops and crop rotation must take into account the allelopathic activity of the crops involved, at the risk of obtaining low yields (Chon et al., 2006; Oueslati, 2003). Allelopathic plants may also be considered a potential source of new molecules with herbicidal action for the chemical industry, the necessity of which is due to the emergence of resistant weeds to older synthetic molecules (Bhowmik and Inderjit, 2003; Duke et al., 2000; Einhellig, 1996; Kruse et al., 2000). Another potential application is in the development of genetically modified crops that can be used as allelopathic plants (Duke, 2003; Duke et al., 2001; Taiz and Zeiger, 2006). From an ecological perspective allelopathy may play an important role in the process of biological invasion. It has been observed that some exotic invaders succeed in obtaining high densities in the invaded ranges, but exhibit low densities in their native ranges. To try to explain this phenomenon, the “novel weapons” theory was proposed, which holds that some exotic plants release into the new invaded ecosystem a set of biochemical compounds with inhibitory effects on local plant and soil microbes, but with relative inefficacy against their natural neighbourhood that had been adapted over time (Callaway and Ridenour, 2004; Vivanco et al., 2004). Seen as the Achilles’ heel in the beginning of allelopathic research due to the lack of chemical evidence to corroborate this phenomenon, currently the isolation and identification of allelochemicals is well established.

Modern techniques and equipment are available and an increasing number of bioactive molecules are isolated and identified every year from crops, weeds and forest trees. A number of chemical separation methods combined with spectroscopic techniques, such as multinuclear/ multidimensional nuclear magnetic resonance (NMR), have proven useful for isolating, quantifying and identifying known or new molecules with potential allelopathic activity (D’Abrosca et al., 2001). Bioassays using target species with an isolated substance or mixture of substances at increasing concentrations are carried out to confirm their allelopathic activities. A large number of biological molecules throughout diverse chemical groups can exhibit allelopathic activity. It is notorious that in their majority allelochemicals are products of secondary metabolism, with a few exceptions of primary metabolism. However, even with this diversity, these metabolites have basically four precursors: acetyl coenzyme A, shikimic acid, mevalonic acid and deoxyxylulose phosphate. Based on these precursors, secondary metabolites can be grouped into three main chemical classes: terpenoids, N-containing compounds and phenolic compounds. There is some consensus that a simple compound in a field

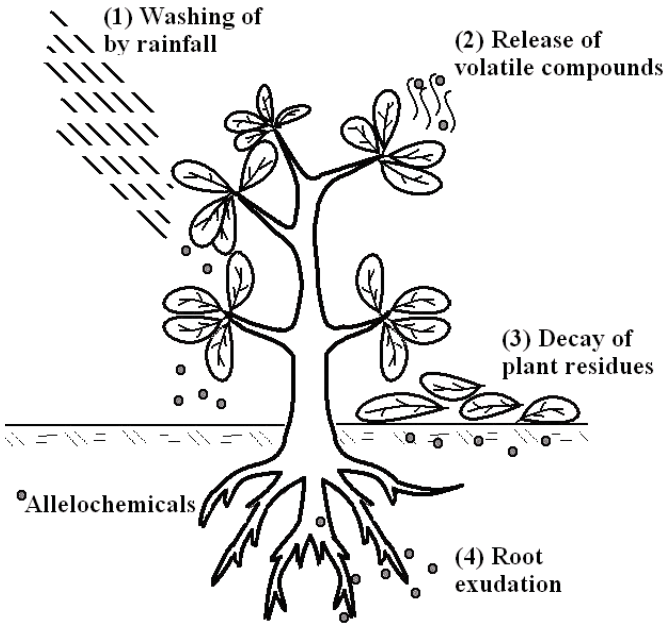

Figure 1. Possible pathways for release of allelochemicals into the environment.

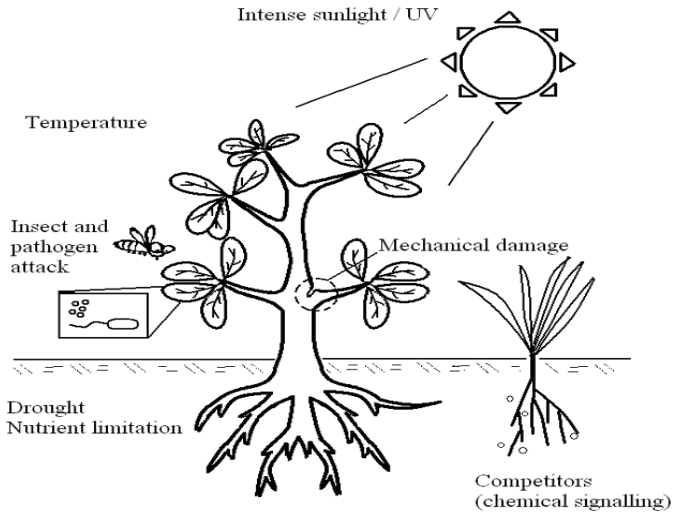

Figure 2. Induction of allelochemical production by biotic and abiotic factors.

situation may not be enough to affect the growth of the receiving plant and it is likely that different allelochemicals act additively or synergistically to inhibit growth (Belz, 2007; Kruse et al., 2000; Tabaglio et al., 2008). The present literature review covers aspects of the current knowledge on the allelopathic interaction between crops and weeds. Examples of crops and weeds with recognized allelopathic activity and their importance for weed management are presented.

RELEASING ALLELOPATHIC COMPOUNDS INTO THE ENVIRONMENT

Allelochemicals can be found in different concentrations in several parts of plants (leaves, stems, roots, rhizomes, seeds, flowers and even pollen) (Bertin et al., 2003; Gatti et al., 2004; Kruse et al., 2000) and their pathway of release into the environment varies among species. The following are known pathways: (1) Exudation and deposition on the leaf surface with subsequent washing off by rainfall; (2) Exudation of volatile compounds from living green parts of the plant; (3) Decay of plant residues (e.g., litterfall or dead roots); and (4) Root exudation (Chon et al., 2006; Olofsdotter et al., 2002) (Figure 1). Different types of abiotic and biotic stress can alter the production and release of allelochemicals during the vital cycle of plants. Drought, irradiation, temperature, nutrient limitation, competitors, disease and damage from insects have been pointed out as factors that can cause an increased release of allelochemicals from allelopathic plants (Figure 2) (Cseke and Kaufman, 2006; Einhellig, 1996)

Studying the effects of varietal and seasonal variations in the expression of autotoxicity of field-harvested barley on germination and seedling growth under laboratory conditions, Oueslati et al. (2005) found barley autotoxicity to be enhanced under severe drought conditions. Ben-Hammouda et al. (2001) observed that the inhibitory effects of barley extracts can oscillate depending on the plant part and growth plant stage. Furness et al. (2008) found that Houndstongue (*Cynoglossum officinale* L.) plants grown with increasing degrees of ultraviolet-B radiation increased their allelopathic influence on some forage grasses. Debris from *Helianthus annuus* L. plants grown under nutrient deficiency was found to be more effective at depressing *Amaranthus retroflexus* L. germination than debris from control plants (Hall et al., 1982). Volatiles from *Ageratum conyzoides* L. plants under nutrientdeficient conditions or in competition with *Bidens pilosa* L. were found to increase their allelopathic effects on the peanut (*Arachis hypogaea* L.), redroot amaranth (*A. retroflexus*), cucumber (*Cucumis sativus* L.) and ryegrass (*Lolium multiflorum* Lam.) (Kong et al., 2002). Mwaja et al. (1995), evaluating the effects of three fertility regimes (low, medium or high) *Sorghum* sp. after exposure to water-soluble root leachates from *Abutilon theophrasti* Medik., thereby suggesting that chemical-mediated crop/weed interactions may include biochemical signalling for the induction of plant defence against weeds.

FATE OF ALLELOCHEMICALS IN SOIL

Once released into the soil by the donor plant, allelochemicals enter a complex plant-soil system in which diverse factors affect their availability, and

consequently their effective influence on target plants (Kruse et al., 2000). Processes such as those mentioned above are responsible for the addition of allelochemicals to the system, for which the amount added depends on donor plant biomass and density, and phenologic stage as well as the concentration and solubility of specific allelochemicals (Seigler, 1996; Weidenhamer, 1996). On the other hand, leaching, physiochemical processes, microbial breakdown and uptake by plants are factors that can reduce the soil concentration of allelochemicals (Inderjit, 2001; Inderjit et al., 2001; Vidal and Bauman, 1997). Weidenhamer (1996) argues that, similar to herbicides, allelochemicals can be made unavailable due to their binding to organic matter and clays in the soil. Studying the degradation of catechin, a supposed allelochemical exuded by *Centaurea maculosa* Lam., and phenolic acid cosolutes in a sandy loam and silt loam soil. Tharayil et al. (2008) found that oxidation and sorption are the primary factors involved in the disappearance of these allelochemicals. Soil texture can also have a direct influence on the leaching of allelochemicals. Studying the influence of soil texture on the flow of alfalfa extracts in columns, Jennings and Nelson (1998) found that allelopathic chemicals moved through the Sarpy fine sandy loam (mixed, mesic Typic Udipsamments) soil faster than through the Carlow silty clay loam (fine, smectitic, mesic Vertic Endoaquulls). Soil microbes take up the compounds released from plants and degrade them through the action of extra-cellular and intercellular microbial enzymes for their own energy-building processes. Such microbiological transformations can either detoxify the soil of these compounds or produce other more phytotoxic allelochemicals (Bhinu et al., 2006). A typical example is the occurrence of AZOB (2,2 - oxo-1,1 -azobenzene), an azoperoxide – in non-sterilised soils after addition of BOA (benzoxazolin-2(3H)-one) or DIBOA (2,4-dihydroxy-2H-1,4-benzoxazin-3(4H)-one), which are hydroxamic acids with allelopathic properties produced by rye residues (Nair et al., 1990). These allelochemicals are found almost exclusively in Gramineae (Frey et al., 1997).

Physiochemical degradation of plant residues (e.g., oxidation) can also detoxify or produce additional allelochemicals (Weidenhamer, 1996). Sorgoleone (2-hydroxy-5-methoxy-3- [(8 Z,11 Z)-8,11,14-pentadecatriene]-p-hydroquinone), a potent PSII inhibitor produced from *Sorghum* plants – is apparently exuded as a reduced inactive form and, after its secretion, is oxidised into an active benzoquinone (Dayan et al., 2003). However, the studies of Czarnota et al. (2001) on the soil persistence of sorgoleone suggest that the soil microflora have a minimal role in sorgoleone degradation. Weston and Czarnota (2001), studying the soil persistence of sorgoleone, verified that its recovery from an artificially impregnated soil declined during a period of 42 days, being detectable even after 7 weeks. Contradictory results were found by Gimsing et al. (2009) when studying the mineralisation of sorgoleone in four soils (two from North America and two from Denmark). These authors verified a complete degradation into CO_2 in all soils tested, and the mineralisation kinetics indicated that microorganisms in American soils use sorgoleone as a source of energy.

Rice

Chung et al. (2003) described the effect of allelopathic potential of rice (*Oryza sativa* L.) residues against *Echinochloa crusgalli* P. Beauv. var. *oryzi-cola* Ohwi (barnyardgrass), an associated weed of paddy. It was found that average inhibition by the variety Duchungjong on *Echinochloa crusgalli* was 77.7% higher than other 113 tested varieties. Early and late maturing varieties showed less inhibitory effect of 50.2 and 56.1% respectively and intermediate rice varieties with 59.3% inhibition, although the difference between the intermediate and late-maturing groups was not significant. Microscope studies revealed that allelopathic rice cultivars seem to inhibit secondary growth in barnyard grass roots besides reducing root elongation (Figure 1) (Olofsdotter et al., 2002). Numerous phytotoxins such as cytokinins, diterpenoids, fatty acids, flavones, glucopyranosides, indoles, momilactones (A and B), oryzalexins, phenols, phenolic acids, resorcinols and stigmastanols have been identified as growth inhibitors in rice. However, the actual modes of action of these compounds as well as other potential rice phytotoxins in nature are not well understood (Khanh et al., 2007).

More than ten phytotoxic compounds from several chemical classes (e.g., fatty acids, benzoxazinoids, indoles, phenolic acids, phenylalkanoic acids and terpenoids) have been identified in rice extracts and exudates, as listed by Belz (2007). Momilactone B diterpenoid (3,20-epoxy- 3α-hydroxy-9β-primara-7,15-dien-16,6β-olide) has been suggested as an important allelochemical for weed suppression (Kato-Noguchi and Ino, 2005), as have a flavone (5,7,4'-trihydroxy-3', 5'-dimethoxyflavone) and cyclohexenone (3- isopropyl-5-acetoxycyclohexene-2-one-1) (Kong et al., 2004). Moreover, momilactone A and B may be involved in physiological defence strategies in the rice rhizosphere, preventing competition from neighbouring plant roots (Kato-Noguchi et al., 2008)

According to the authors cited above, at low concentrations, these three compounds can inhibit the growth of the weeds *Echinochloa crus-galli* (L.) Beauv. and *Cyperus difformis* L., which are associated with rice. The mixture of these compounds exhibited stronger inhibitory activity than the individual compounds. Furthermore, allelopathic rice can detect the presence of other plants and modify microorganisms in the soil through the release of allelochemicals. A study on the

interaction of allelochemicals fromrice roots with micro-organisms in the soil found that some micro-organisms either increase or decrease in number depending on the type of allelochemicals released, suggesting that allelopathic rice could modify the microbial community (Gu et al., 2008). Testing three rice cultivars (one non-allelopathic and two allelopathic) under hydroponic conditions, Kim et al. (2005) concluded that the allelopathic activity of rice was species-specific and depended on the source and concentration. Antifungal activity has also been found in rice allelochemicals.

Wheat (*Triticum aestivum* L.)

Considered the second most produced food among the cereal crops, wheat is another member of the Triticeae tribe and has allelopathic potential for the management of weeds, pests and diseases. Its allelopathic activity is due to the release of a broad set of allelochemicals, including phenolic acids (p-hydroxybenzoic, vanillic, p-coumaric, syringic and ferulic acids), hydroxamic acids and short-chain fatty acids. Both wheat residue allelopathy and wheat seedling allelopathy can be used for managing weeds, including resistant biotypes. Wheat varieties differ in allelopathic potential againstweeds, indicating that the selection of allelopathic varieties may be a useful strategy in integrated weed management (Wu et al., 2001). Oueslati (2003) evaluated the allelopathic effects of diluted extracts from the roots, leaves and stems of two varieties (Karim and Om rabii) of durum wheat (*Triticum durum* L.) on germination rate and radicle length of one barley (*Hordeum vulgare* L. cultivarManel) and one bread wheat (*T. aestivum* cultivar Ariana). The leaf extract was more effective at depressing radicle length in both crops. Based on the results, the author suggests that durum wheat heterotoxicity could be depressive to crops in a sequence. Krogh et al. (2006) incorporated wheat and rye sprouts into the soil in order to follow the fate of the allelochemicals. In the wheat experiments, the authors report 6-methoxybenzoxazolin-2-one (MBOA) as the main compound; 2-hydroxy-7-methoxy-1,4- benzoxazin-3-one (HMBOA) and 2-hydroxy-1,4-benzoxazin- 3-one (HBOA) were detected as well and no phenoxazinones were detected. Macías et al. (2004a), analysing the fate of benzoxazinoids in two soils cultivated with two wheat varieties, verified that DIMBOA degraded rapidly, yielding MBOA in both studied soils at different doses and that MBOA, an intermediate in the degradation pathway from DIMBOA to 2- amino-7-methoxy-3Hphenoxazin-3-one (AMPO), was more resistant toward biodegradation. Recently the European Commission funded the FATEALLCHEM project, a multi-country ecological effort that aims at an environmental and human risk assessment of exploiting the allelopathic properties of winter wheat in conventional and organic farming, and developing a framework for future assessments of other allelopathic crops (Duke et al., 2007). Oueslati (2003) examined the allelopathic effect of diluted extracts of roots, leaves and stems of two durum wheat varieties viz., Karim and Om rabii on barley (variety Manel) and bread wheat (variety Ariana).

Buckwheat

Buckwheat (*Fagopyrum* spp.) is not only an important crop in many countries, but is also useful for soil improvement and reduction of pests and weeds (Xuan and Tsuzuki, 2004). The allelopathic potential of buckwheat species follows the order: Perennial> tartary>annual (Tsuzuki et al., 1975). In upland fields, buckwheat (cv. Hruszowska) markedly suppressed growth of quack grass (*Agropyron repens* L.) (Golisz et al., 2002). In another trial, buckwheat, weed alone, and buckwheat–weed incorporation were established (Tominaga and Uezu, 1995). Among 13 weed species found, the biomass of *Digitaria ciliaris* and *Galinsoga ciliata* was drastically reduced by buckwheat. The biomass of *E. crus-galli*, *Portulaca oleracea*, *C. album* and *Amaranthus lividus* was 32.8, 31.9, 13.1, and 10.3% of that in the weed plot respectively (Tominaga and Uezu, 1995). In paddy fields, application of buckwheat pellets at 2 tons ha^{-1} significantly reduced weed density (75-80%) and dry weight (60%). The pellets completely controlled the growth of *C. difformis*, *Dopatrium junceum*, and reduced the growth of *E. crus-galli*, *E. acicularis* and *M. vaginalis* (Xuan and Tsuzuki, 2004).

Barley (*Hordeum vulgare* L.)

Barley is an annual cereal grain that serves as a major animal feed crop, with smaller amounts used for malting and in health food. It is also known as a “smother crop”, initially due to its competitive ability for nutrients and water and later due to the release of allelochemicals (Overland, 1966). Dhima et al. (2008), investigating the phytotoxic activity of 10 winter barley varieties on barnyard grass in the laboratory, found varietal differences in the level of germination, root length and total fresh weight inhibition. Linking these results with the data obtained from a two-year field experiment, these authors suggest that the increased competitiveness of the variety Lignee 640 was possibly higher due to its phytotoxic ability. Bertholdsson (2005) suggests that for barley and wheat the early crop biomass and potential allelopathic activity are the only parameters that significantly contribute to their competitiveness. Little information has been produced in the last ten years on the identification of barley allelochemicals (Belz, 2007).

Phytotoxic phenolic compounds, including ferulic, vanillic and p-hydroxybenzoic acids, have been identified in the cold-water extract of barley straw as well as in

methanol extract from living barley roots. The allelopathic action of the alkaloids gramine (N,N-dimethyl-1H-indole-3-methanamine) and hordenine (p-[2-(dimethylamino)ethyl]phenol) has been confirmed.

Rye (*Secale cereale* L.)

Rye is a member of the wheat tribe (Triticeae), closely related to barley and wheat, and grows extensively as a grain and forage crop. Its allelopathic activity has mainly been investigated in relation to its ability to suppress weeds when used as green manure or as a cover crop (due to its massive biomass production) and root exudate release of allelochemicals (Barnes and Putnam, 1983; Kruse et al., 2000; Its known effective allelochemicals include phenolic acids [beta-phenyl-lactic acid (PLA) and beta-hydroxybutyric acid (HBA)], hydroxamic acids [2,4-dihydroxy-1,4(2H)- benzoxazin-3-one (DIBOA), 2(3H)-benzoxazolinone (BOA) and 2,2'-oxo-1,1'-azobenzene (AZOB, which is a compound formed by the microbial transformation of rye residues)]. Hence, a variety of natural products can contribute to the herbicidal activity of rye residues Kruse et al., 2000; Reberg-Horton et al., 2005). Reberg-Horton et al. (2005) identified seasonal changes in the production of allelochemicals that varied depending on the cultivar and harvesting time, with lesser production at the end of the harvest. Chlorosis was a symptom of damage from rye residues on several indicators and may be related to the effect of DIBOA and BOA on photophosphorylation and electron transport (Barnes and Putnam, 1987). Structural changes such as a delay in cell differentiation and reduction in the number of lateral roots were observed in cucumbers after exposure to DIBOA and BOA, respectively (Burgos et al., 2004). The study cited also found that the roots of seedlings cultivated in vitro in the presence of allelochemicals increased in diameter and decreased in length. Moreover, tissue changes were observed after treatment with BOA (increase in size and decrease in number of meristematic cells) and DIBOA (more numerous and smaller cortical cells).

Sorghum

Cheema (1988) reports at least nine water-soluble allelochemicals from mature sorghum plants that are phytotoxic to weeds, such as *Phalaris minor* Retz., *Chenopodium album* L., *Rumex dentatus* L. and *Convolvulus arvensis* L. However, the most studied metabolites exudated by the living roots of sorghum are a group of hydrophobic benzoquinones called sorgoleone – 2-hydroxy-5-methoxy-3-[(Z,Z)-8',11',14'-pentadecatriene]-pbenzoquinone and its 1,4-hydroquinone (Czarnota et al., 2001, 2003a). Ultrastructure analysis has revealed that the production of exudates occurs in the root hairs, deposited between the plasmalemma and cell wall. In *Sorghum*, the root hairs are glandular and can produce and release high quantities of an oil-like substance containing 80 to 95% sorgoleone (Dayan et al., 2007). Sorgoleone was revealed to be a potent inhibitor of the oxygen evolution of plants (Einhellig and Souza, 1992), with a similar effect to the so-called diurontype herbicides, such as *s*-triazines, phenylureas, triazinones, ureas, uracils and biscarbamates (Streibig et al., 1999). Nimbal et al. (1996) showed that sorgoleone was a potent competitive inhibitor of electron transport in photosystem II (PSII). However, Czarnota et al. (2001) provided conclusive evidence when these authors observed that sorgoleone required about half the amount of free energy to dock at the plastoquinone QB-binding site of PSII, compared with plastoquinone. In addition, other effects can be detected in higher plants treated with sorgoleone. Sorgoleone also inhibits hydroxyphenyl-pyruvate dioxygenase (HPPD), which disrupts the biosynthesis of carotenoids, resulting in foliar bleaching (Weir et al., 2004). Anatomical changes in the stem occur in bean (*Phaseolus vulgaris* L.) seedlings exposed to sorgoleone. This tissue undergoes changes in the cellulose wall, inhibition of cell division and an increase in the number of metaphases, the latter of which is mainly related to changes in the division of spindle fibres (Hallak et al., 1999). Currently, sorgoleone biosynthesis is nearly completely elucidated and several key enzymes have been identified and characterised (Baerson et al., 2008; Dayan et al., 2007). Netzly and Butler (1986) isolated sorgoleone {2- hydroxy- 5- methoxy- 3- [(8 'Z, ll 'Z)- 8' ,1l' ,14' -pentadecatriene]- p- benzoquinon} from hydrophobic root exudates of sorghum. Sorgoleone, the major pbenzoquinone, and three other structurally related minor p-benzoquinones together constitute 90% or more of the root exudates (Netzly et al., 1988).Cheema and Khaliq (2000) tested the allelopathic effect of sorghum to control weeds of irrigated wheat under semiarid region of Punjab (Table 1). These authors found that soil incorporation of sorghum stalks at 2, 4 and 6 Mg ha^{-1} reduced weed dry weight by 42, 48 and 56%, respectively. Sorgaab spray reduced weed dry weight by 35 to 38%. They also studied the effect of concentration and frequency of sorgaab application. They found that one, two or three sorgaab spray at 1:10 gave the same result as three sprays at 1:20 ratio at 90 DAS, although one or two sprays showed less weed suppression.

Black mustard (*Brassica nigra* L.)

Brassica spp. contains high amounts of glucosinolates (Fenwick et al., 1983). According to Petersen et al. (2001) Isothiocyanates were strong suppressants of germination on tested species-spiny sowthistle (*Sonchus asper* L. Hill), scentless mayweed (*Matricaria inodora* L.), smooth pigweed (*Amaranthus hybridus* L.), barnyard

Table 1. Effect of various weed control methods on density and dry weight of weeds.

Treatment	Weed density (Number of plants per m^{-2})	Weed dry weight (g m^{-2})
Control	63.7[aa]	19.6[a]
Sorghum stalks (soil incorporation) at 2 Mg ha^{-1}	50.9[b](20.2[b])	11.3[bcd](42.0)
Sorghum stalks (soil incorporation) at 4 Mg ha^{-1}	45.0[c](29.2)	10.0[cd]e(48.0)
Sorghum stalks (soil incorporation) at 6 Mg ha^{-1}	37.7[d](40.8)	8.6e(56.0)
Sorgaab spray (1:20) 30 DAS	50.0[b](21.6)	12.6[b](35.4)
Sorgaab spray (1:20) 30 and 60 DAS	49.0[bc](23.1)	12.0[bc](38.7)
Chlorotoluron CMCPA AND 2.50 kg ha^{-1}	11.6e(81.8)	2.3f(88.0)
Hand weeding	32.6[d](48.9)	6.6[dc](51.0)
LSD (0.05)	4.9	2.12

[a] Means with different letters in a column differed significantly (5% level); [b] In parenthesis % decrease compared with control; DAS, days after sowing; Major weed flora of the experimental field: *Fumaria indica, Phalaris minor* Retz., *Rumex dentatus* L. and *Chenopodium album* L. Source: Cheema and Khaliq (2000)

Table 2. Influence of various concentrations of different aqueous extracts made from *Brassica nigra* L. plant parts on the germination of *Avena fatua* L. seeds.

Extracting plant part	Germination by extract concentration (g kg^{-1})					LSD (0.05)
	4	8	12	16	20	
Leaf	73	70	62	55	43	3.0
Stem	90	86	82	77	71	4.0
Flower	80	75	69	65	61	4.0
Root	85	80	75	69	65	3.2
Mixture	76	71	65	59	48	2.3
Control			98			
LSD (0.05)	3.0	3.0	2.8	4.0	3.0	

Leaf, stem, root extracts obtained from vegetative parts; flower extract obtained from reproductive parts. The mixing equal parts from Leaf, stem, flower root extracts prepared from the mixture. Source: Turk and Tawaha (2003).

grass (*Echinochloa crusgalli* L. Beauv.), blackgrass (*Alopecurus myosuroides* Huds.) and wheat (*Triticum aestivum* L.). Turk and Tawaha (2003) studied the allelopathic effect of black mustard (*Brassica nigra* L.) on germination and seedling growth of wild oat (*Avena fatua* L.). Allelopathic effect of extracts of different plant parts like leaf, stem, flower and root of black mustard was experimented. These authors found that germination and radicle length were affected by extract solutions and the inhibitory effect on germination increased with increasing concentration of extract solution of the fresh plant parts (Table 2). They also observed that the protease enzyme activity was suppressed causing reduced water uptake, which led to poor seed germination of wild oat. They found that residue incorporation affected the germination, plant height and dry matter accumulation per plant and the effect was greater for both root and shoot incorporation than only root incorporation.

Legumes

Allelopathic effect of aqueous extracts of perennial legume *Pueraria thunbergiana* leaves on the germination and growth of lettuce was reported by Fujii (1994). Noguchi (2002) reported that xanthoxins may be responsible for the allelopathic effect of this plant. Kato-Noguchi (2003) isolated pisatin (32.7 nmol g^{-1} fresh weight) from methanol extract of pea shoots and showed its inhibitory effect on the root and hypocotyl growth of cress at concentrations greater than 10 mM, and those of lettuce at concentrations greater than 30 mM. Akemo et al. (2000) used mulch of dead pea plants to control weeds with an aim to utilize its allelopathic potentiality in place of man-made chemicals. They found that growth of several weeds was affected. Caamal-Maldonado et al. (2001) examined the toxic effect of four legumes velvetbean (*Mucuna deeringiana* (Bort) Merr.), jackbean (*Canavalia ensiformis* (L.) DC.), jumbiebean (*Leucaena leucocephala* (Lam.) de Wit), and wild tamarind (*Lysiloma latisiliquum* (L.) Benth.) on growth of three weeds viz., barnyardgrass (*Echinochloa crusgalli* L. P. Beauv.), alegría and amaranth (*Amaranthus hypochondriacus* L.). The aqueous leachates (1%) of all four legumes exhibited strong phytotoxic effect on the radical growth of the weeds.

Sunflower

The sunflower is an annual oleaginous plant native to the Americas that also has allelopathic activity against weeds (Bogatek et al., 2006). Its use as a natural herbicide for some broadleaf weeds has been suggested (Anjum and Bajwa, 2007a, b). In this species several substances with allelopathic properties such as phenolic compounds, diterpenes and triterpenes have been isolated and chemically characterised (Macías et al., 2004b). Om et al. (2002) found that the use of sunflowers as green manure promoted a reduction in the population of *Phalaris minor* Retz., by 42 and 100% under field and laboratory conditions, respectively.

Trees

A member of the Juglandaceae family, the black walnut (*Juglans nigra* L.) is one of the oldest known examples of allelopathic activity among woody species. The members of this family produce *juglone* (5-hydroxy-1,4-napthoquinone), which is a potent allelochemical that can inhibit the growth of a large number of plants at concentrations as low as 1 µM. Sensitive plants include both herbaceous and woody species (e.g., tomato, potato, apple, cucumber, watermelon, alfalfa, wheat and corn) that can exhibit wilting, browning of vascular tissues, necrosis and eventually death when cultivated close to established black walnut trees (Bertin et al., 2003; Willis, 2000). An elegant series of studies were carried out by von Kiparski et al. (2007), to verify the occurrence and fate of juglone in Alley soils under black walnut trees (juglone's release, accumulation and decline in greenhouse pot and laboratory sorption/degradation studies). These authors found that juglone is both microbially and abiotically degraded, and is particularly short-lived in soils supporting microbial activity. *Leucaena leucocephala* (Lam.) de Wit is a tree used for revegetation, soil and water conservation, and animal improvement in India. It contains mimosine, a toxic, non-proteinamino acid in its leaves and foliage that exhibits allelopathic activity (Xuan et al., 2006). Studying the allelopathic potential of aqueous extracts from the aerial part of *L. leucocephala* on the weeds *Desmodium purpureum* Hook. and Arn., *B. pilosa* and *Amaranthus hybridus* L., Pires *et al.* (2001) found that *B. pilosa* and *A. hybridus* were the most sensitive species to the extract in the bioassays. The same authors found a correlation between mimosine and extract concentrations, and suggest this allelochemical as possibly responsible for the effects on weed germination and development. *Eucalyptus* is another interesting genus with evidence of allelopathic activity. Studies conducted by May and Ash (1990) mimicking the typical daily rainfall rates upon quantities of foliage, leaf litter and bark litter as well as root leachates, soil leaching and volatiles from leaves on the germination of *Lolium* and growth of *Lolium, Lemna, Eucalyptus* and *Acacia* concluded that the allelopathic activity of the *Eucalyptus* genus is probably the cause of understorey suppression, especially in drier climates. Babu and Kandasamy (1997), investigating the effects of fresh and dried leaf leachates of *Eucalyptus globulus* Labill. on *Cyperus rotundus* L. and *Cynodon dactylon* L., verified significant suppression of the establishment of propagules and early growth of these two species. El-Rokiek and Eid (2009), evaluating the effects of aqueous extracts of *E. citriodora* Hook. on *Avenua fatua* and associated grassy weeds, found that the inhibitory effects on weeds were correlated with accumulation of the internal contents of total phenols. Investigating the allelopathic potential of leaf powder and ethanolic extracts from 15 arboreal species found in the exclusive Brazilian biome known as the *cerrado*, Silva et al. (2006) found that at least four species had an inhibitory effect: *Ouratea spectabilis* (Mart.) Spreng., *Pouteria ramiflora* (Mart.) Radlk., *Qualea grandiflora* Mart. and *Stryphnodendron adstringens* (Mart.) Coville. Among these species, *S. adstringens* was selected for detailed phytochemical and biological studies, in which four active fractions (one in ethyl acetate and three in chloroform) exhibited positive reactions to terpenoids. Evaluating the allelopathic activity of aqueous leaf extracts from four native Brazilian species [*Erythroxylum argentinum*O. E. Schulz, *Luehea divaricata* Mart., *Myrsine guianensis* (Aubl.) Kuntze and *Ocotea puberula* (Rich.) Nees], Maraschin-Silva and Aqüila (2006) detected a slight alteration in lettuce germination by the *E. argentinum* and *L. divaricata* extracts, while all the species inhibited the growth of the target plant.

Allelopathic potentiality of weeds

Many weeds are now achieving importance as an agent of weed control for having special types of allelochemicals. These allelochemicals are capable of suppressing germination and growth of several other weeds, some of which are herbicide resistant.

Congress grass (*Parthenium hysterophorus* L.)

Parthenium hysterophorus L. is an obnoxious weed of present day, which is creating problem by its huge proliferation in any place. It exerts negative effects on agriculture, animal husbandry, ecology and the environment (Kohli and Rani, 1994). The allelopathic effect of this weed is mainly due to the presence of parthenin, a sesquiterpene lactone of pseudoguanolide nature in various parts of the plant (Kanchan and Jayachandra, 1980b; Kohli et al., 1993; de la Fuente et al., 2000), having greatest concentration in the leaves followed by inflorescence, fruits, roots and stems (Kanchan, 1975). Parthenin is known to have specific inhibitory effects on root and shoot growth of *Crotalaria mucronata* L., *Cassia tora* L., *Oscimum basilicum* L.,

Table 3. Allelopathic effect of different weeds on germination and growth of *Phalaris minor*.

Treatment		Germination of *P. minor* (%)	% inhibition over control	Length of plumule	Length of radicle
Weeds					
1	*C. arvense*	34.33(34.66)	47.85	2.25(1.78)	2.75(2.03)
2	*A. arvensis*	59.16(50.53)	10.13	3.78(2.17)	4.03(2.25)
3	*C. album*	0.00(0.57)	100.0	0.00(1.00)	0.00(1.00)
4	*R. acetosella*	59.67(50.69)	9.36	3.58(2.12)	3.82(2.18)
5	*L. aphaca*	40.83(39.22)	37.98	3.95(2.22)	4.11(2.25)
6	*M. denticulata*	0.00(0.57)	100.0	0.00(1.00)	0.00(1.00)
7	*M. indica*	0.00(0.57)	100.0	0.00(1.00)	0.00(1.00)
8	*V. hirsuta*	9.00(12.87)	86.33	0.80(1.28)	1.27(1.43)
9	*C. arvensis*	0.0(0.57)	100.0	0.00(1.00)	0.00(1.00)
10	*C. didymus*	68.00(55.73)	-3.30	4.12(2.23)	4.90(2.72)
11	*C. dactylon*	71.00(57.76)	-7.85	3.90(2.20)	4.60(2.37)
12	Control	65.83(54.38)	-	3.73(2.17)	4.97(2.40)
CD at 5%		(4.59)	-	(0.13)	(0.12)
Extract concentration					
1:4		30.19(26.94)		2.17(1.67)	2.48(1.76)
1:8		37.78(32.74)		2.18 (1.69)	2.60(1.79)
CD at 5%		(1.87)		(NS)	(NS)

Oscimum americanum L. and barley (*Hordeum vulgare* L.) (Khosla and Sobti. 1979, 1981). Various phenolic compounds identified in *Parthenium* (caffeic, vanillic, ferulic, chlorogenic and anisic acid) (Kanchan, 1975; Kanchan and Jayachandra, 1980a, b) may be responsible for growth reduction of test crops in amended soils. There was a 30-40% reduction in yield of crop plants when grown on soil containing dried root and leaf material of *Parthenium*. Parthenin enters the soil through the decomposing leaf litter (Kanchan and Jayachandra, 1976).

Chenopodiacea species

Jefferson and Pennacchio (2003) tested the allelopathic potentiality of the aqueous and methanol extracts of the leaves of four Chenopodiacea species viz., *Atriplex bunburyana* F. Muell., *Atriplex codonocarpa* Paul G. Wilson., *Maireana georgei* (Diels) Paul G. Wilson and *Enchylaena tomentosa* R. Br. at 0.006, 0.06, 0.63, 1.55, 3.12, 6.25 g l^{-1} and 0.025, 0.25, 2.5, 6.25, 12.5, 25 g l^{-1} respectively, for allelopathy on lettuce seeds as well as on the chenopod species themselves. They found that germination of lettuce seed was inhibited at concentrations ranging from 3.12 and 6.26 g l^{-1}. The root and shoot growth of lettuce was also inhibited. These authors also observed the inhibitory effect of the extracts of the leaves of *Atriplex bunburyana* and *Atriplex codonocarpa* on the seed of the chenopods, *Enchylaena tomentosa* and *Maireana georgei*. However, *A. codonocarpa* was not, in contrast, affected by extracts derived from the leaves of *E. tomentosa* and *M. georgei*. At the same time all four species were susceptible to allelopathy by extracts isolated from leaves of their own respective species. These results indicated that allelopathy could be considered as a possible mechanism controlling the timing of chenopod germination and seedling establishment.

Canary grass (*Phalaris minor* Retz.)

Om et al. (2002) listed the allelopathic effect of different weeds on *Phalaris minor* (Table 3). It is clear from the data that the allelopathic potentiality is in the following order: C*henopodium album* L.< *Medicago denticulate* L.< *Melilotus indica* L.< *Convolvulus arvensis* L. (inhibiting 100% germination over control) < *Vicia hirsute* L. (inhibited 86.33% germination) < *Cirsium arvense* L. (47.85% inhibition) < *Lathyrus aphaca* L. (37.98%) < *Rumex acetosella* L. (9.36%). Two weeds, that is, one grassy (*Cynodon dactylon* L.) and one broad leaf (*Coronopus* didymus L.) had stimulating effect by 7.85 and 3.30% increase in germination. The length of radicle and plumule was affected in the similar order as that of germination. Higher concentration of weed extract (1:4) had more inhibiting effect by about 20 to that of lower concentration (1:8) (Table 3).

Russian knapweed (*Acroptilon repens* L.)

A. repens is a widely distributed and problematic weed of

the western US (Maddox et al., 1985). Stevens (1986) found that the roots of *A. repens* inhibited the root growth of many plants including some weed species also such as *Lactuca sativa*, *Medicago sativa*, *Echinochloa crusgalli* and *Panicum miliaceum* by 30% at concentrations comparable to those found in the soil surrounding *A. repens* plants.

The germination of *Agropyron smithii* and *Bromus marginatus* was inhibited by aqueous leaf extracts of *A. repens* at high levels, however, according to Beck and Hanson (1989), germination was induced by lower concentrations.

Morning glory (*Ipomoea tricolor* Cav.)

Similarly, some species of *Ipomoea* are used as green manures and as a weed controller in some tropical regions of Mexico. In sugarcane (*Saccharum officinarum* L.) fields of the state of Morelos, Mexico, farmers promote *Ipomoea tricolor* (Cav.) growth before sugarcane cultivation. The allelopathic potential of *Ipomoea* was described by Anaya et al. (1990). Pereda-Miranda et al. (1993) identified Tricolorin A as the major phytogrowth inhibitor from the resin glycoside mixture of the plants.

Croton bonplandianum

Sisodia and Siddiqui (2010) conducted a study to investigate the allelopathic effects of *Croton bonplandianum* weed on seed germination and seedling growth of crop plants (*Triticum aestivum* L., *Brassica oleracea* var. botrytis L. and *Brassica rapa* L.) and weed plants (*Melilotus alba* Medik., *Vicia sativa* L. and *Medicago hispida* Gaertn). Aqueous extracts of root, stem and leaf of Croton at 0.5, 1.0, 2.0 and 4.0% concentrations were applied to find out their effect on seed germination and seedling growth of test plants under laboratory conditions. The root, stem and leaf extracts had no effect on seed germination. The stem extracts had a stimulatory effect on the shoot length at all concentration levels, as against an inhibitory effect of leaf extracts.

Among the different parts, leaves were the most allelopathic and stems were least allelopathic. The inhibition effect was found to increase with increasing concentrations of different aqueous extracts (Sisodia and Siddiqui, 2008, 2009). Stem extracts at low concentration generally promoted root length but leaf and root extracts inhibited root length and dry weight. Root length, shoot length of weed species decreased progressively when plants were exposed to increasing concentration (0.5, 1, 2 and 4%). It was also found that with increasing concentrations of aqueous extracts of different parts of *C. bonplandianum,* the osmotic potential and phenolic content increased while pH does not have any major change.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Ahmed R, Uddin MB, Khan ASA, Mukul SA, Hossain MK (2007). Allelopathic effects of *Lantana camera* on germination and growth behavoiur of some agricultural crops in Bangladesh, J. For. Res. 18(4):301-304.

Akemo MC, Regnier EE, Bennett MA (2000). Weed suppression in spring-sown rye (Secale cereale)-pea (*Pisum sativum*) cover crop mixes. Weed Technol. 14:545–549.

Anjum T, Bajwa R (2007a) Field appraisal of herbicide potential of sunflower leaf extract against *Rumex dentatus*, Field Crops Res. 100:139–142.

Anjum T, Bajwa R (2007b). The effect of sunflower leaf extracts on *Chenopodium album* in wheat fields in Pakistan, Crop Prot. 26:1390–1394.

Babu RC, Kandasamy OS (1997). Allelopathic effect of *Eucalyptus globulus* Labill. on *Cyperus rotundus* L. and *Cynodon dactylon* L. Pers, J. Agron. Crop Sci. 179:123–126.

Baerson SR, Dayan FE, Rimando AM, Nanayakkara NPD, Liu CJ, Schöder J, Fishbein M, Pan Z, Kagan IA, Pratt LH, Cordonnier- Pratt MM, Duke SO (2008). A functional genomics investigation of allelochemical biosynthesis in *Sorghum bicolor* root hairs, J. Biol. Chem. 283:3231–3247.

Barnes JP, Putnam AR (1983). Rye residues contribute to weed suppression in no-tillage cropping systems. J. Chem. Ecol. 9:1045–1057.

Belz RG (2007). Allelopathy in crop/weed interactions - an update. Pest Manage. Sci. 63:308–326.

Ben-Hammouda M, Ghorbal H, Kremer RJ, Oueslati O (2001). Allelopathic effects of barley extracts on germination and seedlings growth of bread and durum wheats. Agronomie 21:65–71.

Bertholdsson NO (2005). Early vigour and allelopathy - two useful traits for enhanced barley and wheat competitiveness against weeds. Weed Res. 45:94–102.

Bertin C, Yang X, Weston LA (2003). The role of root exudates and allelochemicals in the rhizosphere. Plant Soil 256:67–83.

Bhinu VS, Narasimhan K, Swarup S (2006). Plant natural products in the rhizosphere, in: Cseke L.J., Kirakosyan A., Kaufman P.B., Warber S., Duke J.A., Brielmann H. (Eds.), Natural products from plants. CRC Press, Boca Raton, FL. pp. 143–164.

Bhowmik PC, Inderjit (2003). Challenges and opportunities in implementing allelopathy for natural weed management. Crop Prot. 22:661–671.

Bogatek R, Gniazdowska A, Zakrzewska W, Orac K, Gawronski SW (2006). Allelopathic effects of sunflower extracts on mustard seed germination and seedling growth. Biol. Plant 50:156–158.

Burgos NR, Talbert RE, Kim KS, Kuk YI (2004). Growth inhibition and root ultrastruture of Cucumber seedlings exposed to allelochemicals from rye (*Secale cereale*). J. Chem. Ecol. 30:671–689.

Callaway RM, Ridenour WM (2004). Novel weapons: invasive success and the evolution of increased competitive ability. Front. Ecol. Environ. 2:436–443.

Cheema ZA (1988). Weed control in wheat through sorghum allelochemicals, Ph.D. thesis, Agronomy Department, University of Agriculture, Faisalabad, Pakistan.

Cheema ZA, Khaliq A (2000). Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi arid region of Punjab, Agric. Ecosyst. Environ. 79:105-112.

Chon SU, Jennings JA, Nelson CJ (2006). Alfalfa (*Medicago sativa* L.) autotoxicity: Current status. Allelopathy J. 18:57–80.

Chung IM, Kim KH, Ahn JK, Lee SB, Kim SH, Hahn SJ (2003). Comparison of Allelopathic Potential of Rice Leaves, Straw, and Hull Extracts on Barnyardgrass. Agron. J. 95:1063-1070.

Cseke LJ, Kaufman PB (2006). Regulation of metabolite synthesis in plants. Nat. Prod. Plants pp. 101-141.

Czarnota MA, Paul RN, Dayan FE, Nimbal CI, Weston LA (2001).

Mode of action, localization of production, chemical nature, and activity of sorgoleone: A potent PSII inhibitor in *Sorghum* spp. Root exudates. Weed Technol. 15:813–825.
Czarnota MA, Paul RN, Weston LA, Duke SO (2003a). Anatomy of sorgoleone-secreting root hairs of Sorghum species. Int. J. Plant Sci. 164:861–866.
Czarnota MA, Rimando AM,Weston LA (2003b). Evaluation of seven sorghum (Sorghum sp.) accessions, J. Chem. Ecol. 29:2073–2083.
D'Abrosca B, DellaGreca M, Fiorentino A, Monaco P, Previtera L, Simonet AM, Zarrelli A (2001). Potential allelochemicals from *Sambucus nigra.* Phytochemistry 58:1073–1081.
Dayan FE, Kagan IA, Rimando AM (2003). Elucidation of the biosynthetic pathway of the allelochemical sorgoleone using retrobiosynthetic NMR analysis. J. Biol. Chem. 278:28607–28611.
Dayan FE, Watson SB, Nanayakkara NPD (2007). Biosynthesis of lipid resorcinols and benzoquinones in isolated secretory plant root hairs. J. Exp. Bot. 58:3263–3272.
De la Fuente JR, Uriburu ML, Burton G, Sosa VE (2000). Sesquiterpene lactone variability in *Parthenium hysterophorus* L. Phytochemistry 55:769–772.
Dhima K, Vasilakoglou I, Lithourgidi A, Mecolari E, Keco R, Agolli XH, Eleftherohorinos I (2008). Phytotoxicity of 10 winter barley varieties and their competitive ability against common poppy and ivy-leaved speedwell. Exp. Agric. 4:385–397.
Ding J, Sun Y, Xiao CL, Shi K, Zhou YH, Yu JQ (2007). Physiological basis of different allelopathic reactions of cucumber and figleaf gourd plants to cinnamic acid. J. Exp. Bot. 58:3765-3773.
Dudai N, Poljakoff-Mayber A, Mayer AM, Putievsky E, Lerner HR (1999). Essential oils as allelochemicals and their potential use as bioherbicides. J. Chem. Ecol. 25:1079–1089.
Duke JA, Brielmann H (Eds.), Natural products from plants, CRC Press, Boca Raton, FL. pp. 101–141.
Duke SO (2003). Weeding with transgenes, Trends Biotechnol. 21:192–195.
Duke SO, Baerson SR, Rimando AM, Pan Z, Dayan FE, Belz RG (2007). Biocontrol of weeds with allelopathy: Conventional and transgenic approaches, in: Vurro M., Gressel J. (Eds.), Novel biotechnologies for biocontrol agent enhancement and management, Springer. Netherlands pp. 75–85.
Duke SO, Romagni JG, Dayan FE (2000). Natural products as sources for new mechanisms of herbicidal action. Crop Prot. 19:583–589.
Duke SO, Scheffler BE, Dayan FE, Weston LA, Ota E (2001). Strategies for using transgenes to produce allelopathic crops. Weed Technol. 15:826–834.
Einhellig FA (1996). Interactions involving allelopathy in cropping systems, Agron. J. 88:886 893.
Einhellig FA, Souza IF (1992). Phytotoxicity of sorgoleone found in grain sorghum root exudates. J. Chem. Ecol. 18:1–11.
El-Rokiek KG, Eid RA (2009). Allelopathic effects of *Eucalyptus citriodora* on amaryllis and associated grassy weed. Planta Daninha 27:887–899.
Fenwick GR, Heaney, RK, Mullin, WJ, (1983). Glucosinolates and their breakdown products in food and food plants. Crit. Rev. Food Sci. Nutr. 18:123–301.
Frey M, Chomet P, Glawischnig E, Stettner C, Grün S, Winklmair A, Wolfgang E, Bacher A, Meeley RB, Briggs SP, Simcox K, Gierl A (1997). Analysis of a chemical plant defense mechanism in grasses. Science 277: 696–699.
Fujii Y (1994). Screening of allelopathic candidates by new specific discrimination, and assessment methods for allelopathy, and the identification of l-dopa as the allelopathic substance from the most promising velvetbean (*Mucuna pruriens*). Bull. Natl. Inst. Agro-Environ. Sci. 10:115–218.
Furness NH, Adomas B, Dai Q, Li S, Upadhyaya MK (2008). Allelopathic influence of Houndstongue (*Cynoglossum officinale*) and its modification by UV-B radiation. Weed Technol. 22:101-107.
Gatti AB, Perez SC, Lima MIS (2004). Atividade alelopática de extratos aquosos de *Aristolochia esperanzae* O. Kuntze na germinação e no crescimento de *Lactuca sativa* L. e *Raphanus sativus* L.. Acta Bot. Bras. 18:459–472.
Gimsing AL, Blæum J, Dayan FE, Locke MA, Sejero LH, Jacobsen CS (2009). Mineralization of the allelochemical sorgoleone in soil. Chemosphere 76:1041–1047.
Golisz A, Ciarka D, Gawronski SW (2002). Allelopathy activity of buckwheat –Fagopyrum esculentum Moench. In: Fujii Y, Hidarate S, Araya H, eds. Proceedings III World Congress on Allelopathy, Sato Printing Company Limited, Tsukuba City, Ibaraki, Japan. P. 161.
Gu Y, Wang P, Kong CH (2008). Effects of rice allelochemicals on the microbial community of flooded paddy soil, Allelopathy J. 22:299-309.
Hall AB, Blum U, Fites RC (1982). Stress modification of allelopathy of *Helianthus annuus* L. debris on seed germination. Am. J. Bot. 69:776–783.
Hallak AMG, Davide LC, Gavilanes ML, Souza IF (1999). Efeito de exsudatos de raiz de sorgo (*Sorghum bicolor* L.) sobre características anatômicas do caule do feijoeiro (*Phaseolus vulgaris* L.). Ciênc. Agrotec. 23:317–322.
Inderjit (2001). Soil:environmental effects on allelochemical activity, Agron. J. 93:79–84.
Inderjit, Kaur M, Foy CL (2001). On the significance of field studies in allelopathy. Weed Technol. 15:792–797.
Jefferson LV, Pennacchio M (2003). Allelopathic effects of foliage extracts from four Chenopodiaceae species on seed germination. J. Arid Environ. 55:275–285.
Jennings JA, Nelson CJ (1998). Influence of soil texture on Alfalfa autotoxicity. Agron. J. 90:54–58.
Jennings JA, Nelson CJ (2002). Zone of autotoxic influence around established alfalfa plants. Agron. J. 94:1104–1111.
Kanchan SD (1975). Growth inhibitors from *Parthenium hysterophorus* Linn. Curr. Sci. 44:358–359.
Kanchan SD, Jayachandra D (1980a). Allelopathic effects of *Parthenium hysterophorus* L. II. Leaching of inhibitors from aerial vegetative parts. Pl. Soil 55:61–66.
Kanchan SD, Jayachandra D (1980b). Allelopathic effects of *Parthenium hysterophorus* L. IV. Identification of inhibitors. Plant Soil 55:67–75.
Kanchan SD, Jayachandra D (1976). *Parthenium* weed problem and its chemical control. Paper presented at seminar on Parthenium-A positive Danger. UAS, Bangalore, India.
Kato-Noguchi H, Ino T (2005). Possible involvement of momilactone B in rice allelopathy, J. Plant Physiol. 162:718–721.
Kato-Noguchi H, Ino T, Ota K (2008). Secretion of momilactone A from rice roots to the rhizosphere. J. Plant Physiol. 165:691–696.
Kato-Noguchi H, Salam MA, Kobayashi T (2009). A quick seeding test for allelopathic potential of Bangladesh rice cultivars. Plant Prod. Sci. 12:47–49.
Khanh TD, Xuan TD, Chung MI (2007). Rice allelopathy and the possibility for weed management. Ann. Appl. Biol. 151:325-339.
Khosla SN, Sobti SN (1979). Parthenin-A national health hazard, its control and utility-a review. Pesticides 13:21-27.
Khosla SN, Sobti SN (1981). Parthenin-A promising root inhibitor from *Parthenium hysterophorus* L. Indian J. For. 4:56-60.
Kim SY, Madrid AV, Park ST, Yang SJ, Olofsdotter M (2005). Evaluation of rice allelopathy in hydroponics. Weed Res. 45:74-79.
Kohli RK, Rani D (1994). *Parthenium hysterophorus* L. - A review. Res. Bull. (Sci.) Pb. Univ. 44:105-149.
Kohli RK, Rani D, Verma RC (1993). A mathematical model to predict tissue response to parthenin - An allelochemical. Biol. Plant 35:567–576.
Kong C, Hu F, Xu X (2002). Allelopathic potential and chemical constituints of volatiles from *Ageratum conyzoides* under stress. J. Chem. Ecol. 28:1173-1182.
Kong C, Liang W, Xu X, Hu F, Wang P, Jiang Y (2004). Release and activity of allelochemicals from allelopathic rice seedlings. J. Agric. Food Chem. 52:2861–2865.
Krogh SS, Mensz SJM, Nielsen ST, Mortensen AG, Christophersen C, Fomsgaard IS (2006). Fate of Benzoxazinone allelochemicals in soil after incorporation of wheat and rye sprouts. J. Agric. Food Chem. 54:1064–1074.
Kruse M, Strandberg M, Strandberg B (2000). Ecological effects of allelopathic plants. A review, Department of Terrestrial Ecology, Silkeborg, Denmark, Rep. P. 315.
Macías FA, Oliveros-Bastidas A, Marín D, Castellano D, Simonet AM, Molinillo JMG (2004a). Degradation studies on Benzoxazinoids. Soil degradation dynamics of 2,4-Dihydroxy- 7-methoxy-(2H)-1,4-

benzoxazin-3(4H)-one (DIMBOA) and its degradation products, phytotoxic allelochemicals from Gramineae. J. Agric. Food Chem. 52:6402–6413.
Macías FA, Molinillo JMG, Chinchilla D, Galindo JCG (2004b). Heliannanes - A structure-activity relationship (SAR) study, in: Macías FA, Galindo J.C.G., Molinillo J.M.G., Cuttler H.G. (Eds.),
Maddox DM, Mayfield A, Poritz NH (1985). Distribution of yellow starthistle (*Centaurea solstitialis*) and Russian knapweed (*Centaurea repens*). Weed Sci. 33:315–327.
Maraschin-Silva F, Aqüila MEA (2006). Contribuição ao estudo do potencial alelopático de espécies nativas. Rev. Árvore 30:547–555.
Mwaja VN, Masiunas JB, Weston LA (1995). Effect of fertility on biomass, phytotoxicity, and allelochemical content of cereal rye. J. Chem. Ecol. 21:81–96.
Nair MG, Whiteneck CJ, Putnam AR (1990). 2,2'-oxo-1,1'- azobenzene, a microbially transformed allelochemical from 2,3- benzoxazolinone, J. Chem. Ecol. 16:353–364.
Netzly D, Riopel JL, Ejeta G, Butler LG (1988). Germination stimulants of witchweed (*Striga asiatica*) from hydrophobic root exudates of sorghum (Sorghum bicolor). Weed Sci. 36:441-446.
Netzly DH, Butler LG (1986). Roots of sorghum exude hydrophobic droplets containing biologically active components. Crop Sci. 26:775-778.
Nimbal CI, Pedersen JF, Yerkes CN, Weston LA, Weller SC (1996). Phytotoxicity and distribution of sorgoleone in grain sorghum germplasm. J. Agric. Food Chem. 44:1343–1347.
Olofsdotter M, Jensen LB, Courtois B (2002). Improving crop competitive ability using allelopathy - An example from rice. Plant Breed. 121:1–9.
Om H, Dhiman SD, Kumar S, Kumar H (2002). Allelopathic response of Phalaris minor to crop and weed plants in rice–wheat system. Crop Protect. 21:699–705.
Oueslati O (2003). Allelopathy in two durum wheat (*Triticum durum* L.) varieties. Agric. Ecosyst. Environ. 96:161–163.
Oueslati O, Ben-Hammouda M, Ghorbal MH, Guezzah M, Kremer RJ (2005). Barley autotoxicity as influenced by varietal and seasonal variation. J. Agron. Crop Sci. 191:249–254.
Overland L (1966). The role of allelopathic substances in the "smother crop" barley. Am. J. Bot. 53:423–432.
Petersen J, Belz R, Walker F, Hurle K (2001). Weed Suppression by Release of Isothiocyanates from Turnip-Rape Mulch. Agron. J. 93:37-43.
Pires NM, Prates HT, Pereira Filho IA, Oliveira Jr RS, Faria TCL (2001). Atividade alelopática da leucena sobre espécies de plantas daninhas. Sci. Agric. 58:61–65.
Reberg-Horton SC, Burton JD, Daneower DA, Ma G, Monks DW, Murphy JP, Ranells NN, Williamson JD, Creamer NG (2005). Changes over time in the allelochemical content of ten cultivars of rye (*Secale cereale* L.). J. Chem. Ecol. 31:179–193.
Rice EL (1984). Allelopathy."2nd Ed. Academic press, Newyork.pp.421.
Seigler DS (1996). Chemistry and mechanisms of allelopathic interactions. Agron. J. 88:876–885.
Silva GB, Martim L, Silva CL, Young MCM, Ladeira AM (2006). Potencial alelopático de espécies arbóreas nativas do Cerrado. Hoehnea 33:331–338.
Singh HP, Batish DR, Kohli RK (2003). Allelopathic interactions and allelochemicals: New possibilities for sustainable weed management. Crit. Rev. Plant Sci. 22:239–311.
Sisodia S, Siddiqui MB (2008). Allelopathic effect of Lantana camara on *Bidens pilosa.* Vegtos 20:29-32.
Sisodia S, Siddiqui MB (2010). Allelopathic effect by aqueous extracts of different parts of *Croton bonplandianum* Baill. on some crop and weed plants. J. Agric. Ext. Rural Dev. 2:22-28.
Sisodia S, Siddiqui MB (2009). Allelopathic potential of rhizosphere soil of Croton bonplandianum on growth and establishment of some crop and weed plants. Afr. J. Agric. Res. 4:461-467.
Stevens KL (1986). Allelopathic polyacetylenes from *Centaurea repens* (Russian knapweed). J. Chem. Ecol. 12:1205–1211.
Streibig JD, Dayan FE, Rimando AM, Duke SO (1999). Joint action of natural and synthetic photosystem II inhibitors. Pestic. Sci. 55:137–146.
Tabaglio V, Gavazzi C, Schulz M, Marocco A (2008). Alternative weed control using the allelopathic effect of natural benzoxazinoids from rye mulch. Agron. Sustain. Dev. 28:397–401.
Taiz L, Zeiger E (2006). Plant Physiology, 4th ed., Sinauer Associates, Inc., Massachusetts.
Tharayil N, Bhowmik PC, Xing B (2008). Bioavailability of allelochemicals as affected by companion compounds in soil matrices. J. Agric. Food Chem. 56:3706-3713.
Tominaga T, Uezu T (1995). Weed suppression by buckwheat. In: T.Matano, and A. Ujihara (eds), Current Advances in Buckwheat Research, Shinshu University Press, Asahi Matsumoto, Japan pp. 693-697.
Tsuzuki EA, Katsuki SS, Danjo T (1975). The growth inhibitors contained in buckwheat plants. II. The effects of water and organic solvent extracts on the growth of rice seedling. Rep. Kyushu Branch Crop Sci. Soc. Japan 42:83-84.
Turk MA, Tawaha AM (2003). Allelopathic effect of black mustard (*Brassica nigra* L.) on germination and growth of wild oat (*Avena fatua* L.). Crop Prot. 22:673–677.
Vidal RA, Bauman TT (1997). Fate of allelochemicals in the soil. Ciênc. Rural 27:351–357.
Vivanco JM, Bais HP, Stermitz FR, Thelen GC, Callaway RM (2004). Biogeographical variation in community response to root allelochemistry: novel weapons and exotic invasion. Ecol. Lett. 7: 285–292.
Von Kiparski GR, Lee LS, Gillespie AR (2007). Occurrence and fate of the phytotoxin Juglone in Alley soils under Black Walnut trees. J. Environ. Qual. 36:709–717.
Weidenhamer JD (1996). Distinguishing resource competition and chemical interference: Overcoming the methodological impasse. Agron. J. 8: 866–875.
Weir TL, Park SW, Vivanco JM (2004). Biochemical and physiological mechanisms mediated by allelochemicals. Curr. Opin. Plant Biol. 7:472–479.
Weston LA, Czarnota MA (2001). Activity and persistence of sorgoleone, a long-chain hydroquinone produced by sorghum bicolor. J. Crop Prod. 4:363–377.
Weston LA (2005). History and current trends in the use of allelopathy for weed Management. Allelopathy J. 13:529-534.
Willis RJ (1985). The historical bases of the concept of allelopathy. J. Hist. Biol. 18:71–102.
Willis RJ (2000). Juglans spp., juglone and allelopathy. Allelopathy J. 17:1–55.
Wu H, Pratley J, Lemerle D, Haig T (2001). Allelopathy in wheat (*Triticum aestivum*), Ann. Appl. Biol. 139:1–9.
Oueslati O (2003). Allelopathy in two durum wheat (*Triticum durum* L.) varieties, Agric. Ecosyst. Environ. 96:161–163.
Xuan TD, Elzaawely AA, Deba F, Fukuta TS (2006). Mimosine in Leucaena as a potent bio-herbicide, Agron. Sustain. Dev. 26:89–97.
Xuan TD, Tsuzuki E (2004). Allelopathic plants: Buckwheat. Allelopathy J. 13: 137-148.

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Full Length Research Paper

Comparative study on some egg quality traits of exotic chickens in different production systems in East Shewa, Ethiopia

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A total of 227 eggs were collected during summer 2013 from Isa Brown (IB), Bovan Brown (BB) and Potchefstroom Koekoek (PK) chickens for comparative study of internal and external egg quality traits under intensive and village production systems in East Shewa, Ethiopia. The data collected was analyzed using SPSS and significant differences in egg quality traits were compared using post hoc multiple comparisons. Average egg weight, Haugh Unit, shell thickness, yolk colour, albumen weight, yolk percent and yolk to albumin ratio of IB showed a significant difference ($p<0.05$) under intensive and village production systems. BB showed a statistical significant difference ($p<0.05$) for egg weight, yolk height, albumen height, yolk colour, Haugh Unit, shell thickness, yolk percent and albumen percent under intensive and village production systems. Further, average yolk height, yolk weight, yolk color, yolk percent and yolk to albumen ratio of PK revealed a significant difference under village and intensive production systems. The study revealed that even though the differences were observed in egg quality traits under intensive and extensive system, eggs produced from village were also found to be good quality.

Key words: Egg quality traits, exotic chicken, intensive and village production system.

INTRODUCTION

Worldwide, 80% of the total chicken populations are found in village poultry production system (Alabi et al., 2006), indicating the importance of village chicken production for the development rural economy. In Ethiopia, total poultry population at country level is estimated to be 50.38 million and with regard to breed, 96.9, 0.54 and 2.56% were reported to be indigenous, hybrid and exotic chickens, respectively (CSA, 2013). From the total population of chicken, 99% are raised under the traditional backyard system of management, while 1% is under intensive management system (Solomon, 2007). The poultry sector can be characterized into village or backyard, small scale and large scale commercial poultry production system (Dawit et al., 2008).

Embryo development is dependent on the egg quality traits such as egg weight, yolk and albumen weights, genetic line and age of the hen (Onagbesan et al., 2007), besides egg weight is one of the important phenotypic traits that influence egg quality and reproductive fitness of

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the chicken (Islam et al., 2001; Farooq et al., 2001). Eggshell thickness is an important trait for hatchability; in which hatchable egg thickness lies between 0.33 and 0.35 mm and few eggs with a shell thickness less than 0.27 mm will hatch (Khan et al., 2004). In addition, marketability of eggs entirely depends on eggshell thickness and strength, as poor eggshell quality results in millions of dollars of loss in USA (Roland, 1988). Even though, it is subjective and varies from country to country, yolk color remains to be key a factor for consumer acceptability (Okeudo et al., 2003). Further, the egg is probably the food item most frequently involved in outbreaks of foodborne infections with *Salmonella species* as ethiological agent (Gast et al., 2005; Gantois et al., 2009). Several factors affect penetration of the egg by *Salmonella species,* but the common factors includes the quality of eggshell, albumen and yolk (Messens et al., 2004).

With the aim of improving poultry productivity exotic chickens such as Isa Brown (IB), Bovan Brown (BB) and Potchefstroom Koekoek (PK) were distributed to smallholder farmers in Ada'a and Lume districts of East Shewa Zone, Ethiopia (Tadesse et al., 2013). In the layer reference for more than 30 years everywhere in the world, IB is the most efficient layer in the poultry industry producing many high quality eggs and adapts itself to all climates and environments (ISA, 2010). The PK was bred from crosses between the Black Australorp and the White Leghorn in South Africa and is one of the most promising breeds. It is also second to White Leghorn, Fayoumi in terms of hen-housed egg production per hen and hatchability, respectively (Grobbelaar et al., 2010).

Despite the benefits of quality eggs, common surveys and previous research works conducted by Tadelle et al. *(*2003), Moges et al. (2010) and Mengesha et al. (2011) indicated village poultry farmers have low awareness to sort eggs for different purposes such as for hatching, marketing and home consumption purposes. Hence a considerable portion of eggs will be lost because of indiscriminate use of eggs rather than sorting eggs for different purposes. The egg quality could be affected by the production system among others. Thus, comparison between eggs from village and intensive production system would help researchers to suggest possible intervention options to improve quality of eggs in different production systems. Thus, the present study was designed with the objective to compare egg quality traits of three exotic chickens under intensive and village poultry production systems in East Shewa Zone of Oromiya, Ethiopia.

MATERIALS AND METHODS

Management of chickens

Under village production system, more than 90% of farmers provided separate housing for their chicken in Lume and Ada'a districts. Chickens scavenge feed materials such as kitchen wastes, insects, worms and agricultural leftovers. Maize and wheat were provided three times a day (morning, noon and evening) in addition to the normal scavenging by 95% farmers in both districts. Similarly, water was provided as free access by more than 96% of the farmers in both districts. Under intensive system, the housing management was based on semi-opened deep litter system, fed on commercial balanced ration and with standard feeder and watering facility in both private and government poultry farms sampled.

Egg sample collection and evaluation

From village production system, a total of 137 fresh eggs (57 from IB, 56 from BB and 24 from PK) were collected from adult laying hens from six Peasant Associations (PA's) (Momoshoki, Byobiskie and Jogogudedo) in Lume and (Denkaka, Kurkuradenbi and Godino) in Ada'a districts for egg quality evaluation. Further, under intensive production system a total of 90 freshly laid eggs from three breeds (30 from each) were collected from two privately owned farms for IB and BB and from a government owned intensive farm for PK. A total 227 eggs were collected from both production systems for evaluation of internal and external egg quality traits at Debre Zeit Agricultural Research Institute (DZARC) laboratory.

Data collection

External egg quality traits such as egg weight were measured using digital balance (g) and shell thickness (mm) using an electronic Digital Caliper (Mitutoyo, Japan). The shell thickness was measured at three different points in the equatorial shell and the calculated average of the three was taken as a trait. To determine the internal egg quality traits, eggs were broken onto a flat surface. The thick albumen height (AH) was measured at its widest part at a position half way between the yolk and the outer margin. Yolk height was measured using Tripod Micrometer (TSS, England). The yolks were carefully separated from the albumen. Albumen and yolk weight were determined by weighing with electronic sensitive balance (Sartorius, Germany) separately. The yolk colour was determined using the Roche Colour Fan (Printed in Switzerland); a standard colorimetric system ranged from 1 to 15. Individual Haugh Units (HU) were calculated from the two parameters; height of albumen (AH) and egg weight (EW) using the formula:

$$HU=100\log (AH-1.7\ EW^{0.37}+7.6)$$

Where HU=Haugh Unit, AH=Albumen height and EW=Egg weight (Haugh, 1937).

The albumen ratio (AR) and the yolk ratios (YR) were calculated as follows:

$$\text{Yolk percent}=(\text{weight of yolk/weight of whole egg})\times 100$$

$$\text{Albumen percent}=(\text{weight of albumen/weight of the whole egg})\times 100.$$

Data management and analysis

The data were entered into Microsoft Excel spreadsheet and analyzed using SPSS (Version, 17). To examine the significant differences among egg quality traits, post hoc multiple comparisons were done using means generated from one-way ANOVA.

RESULTS AND DISCUSSION

Egg weight

It is one of the important phenotypic traits that influence

Table 1. External egg quality traits of exotic chickens under different production systems in East Shewa, Ethiopia.

Traits	Management system used	Egg quality traits		
		Isa Brown, N=87 (Mean±SD)	Bovan Brown, N=86 (Mean±SD)	Koekoek, N=54 (Mean±SD)
Egg weight (g)	Intensive	64.78±3.81[a]	63.46±4.14[a]	47.79±4.43
	Village	58.92±7.16[b]	59.32±4.78[b]	47.53±4.72
Shell thickness (mm)	Intensive	0.34±0.03[a]	0.35±0.03[a]	0.29±0.03
	Village	0.31±0.05[b]	0.33±0.04[b]	0.29±0.03

[a-b] means with different superscript in the same column were differ significantly (P<0.05).

egg quality and reproductive fitness of the chicken parents (Islam et al., 2001). The analysis for average egg weight (g) revealed that (64.78, 58.9), (63.46, 59.32) and (47.79, 47.53) under intensive and village production systems for IB, BB and PK layer chickens, respectively (Table 1). Average egg weight of IB and BB under intensive system was significantly higher than under village production system ($p<0.05$), such difference is not a surprise since IB and BB are commercial strains developed for egg weight improvement (Hocking et al., 2003). However, there was no significant difference for PK under intensive and village production systems; this could indicate that PK breed could perform comparatively under village production systems, as it is also an indigenous African chicken (Grobbelaar et al., 2010).

Shell thickness

The analysis for egg shell thickness revealed that (0.34, 0.31), (0.35, 0.33) and (0.29, 0.29) mm for IB, BB and PK under intensive and village production systems, respectively (Table 1).

The average egg shell thickness of IB and BB under intensive production system was significantly higher ($p<0.05$) than under village production systems ($P<0.05$) and agreed with the reports of Tulin and Ahmet (2009) and Dorji (2013). However, the average egg shell thickness of PK did not differ significantly under intensive and village production system.

Yolk height

The analysis for yolk height (mm) revealed that (17.81, 17.35), (18.57, 18.11) and (17.59, 18.80) for IB, BB and PK under intensive and village production systems, respectively. Similar average yolk height was reported for IB under village production system by Tadesse et al. (2013). The average yolk height of BB was a significantly higher ($p<0.05$) in intensive than under village production system. However, the average yolk value of PK under village production system significantly higher ($p<0.05$) than intensive production system. In the present study, the yolk height recorded under intensive and village production was comparable to those reported in intensive system in northern Ethiopia by Niraj et al. (2014), but significantly higher than the report of Aberra et al. (2013) in different agro-ecology of Ethiopia for indigenous chickens under village production system.

Albumen height

The mean albumen heights were (6.17, 6.34), (9.51, 6.92) and (5.53, 5.54) g for IB, BB and PK under intensive and village production systems, respectively (Table 2). The mean albumen height of BB under intensive system was significantly higher under village production system ($p<0.05$). However, albumen height of IB and PK breeds did not differ significantly in intensive and village production systems. Under village production system, comparable average albumen height was reported by Tadesse et al. (2013) for IB and PK breeds in East Shewa, Ethiopia. But, the present average albumen height recorded was significantly lower than the report of Niraj et al. (2014) under intensive management in northern Ethiopia.

Yolk weight

As presented in Table 2, there was no significant statistical difference in yolk weight for IB and BB; this is in agreement with the report of Tulin and Ahmet (2009) for eggs collected under village production system. The mean yolk weight recorded in the present study was comparable to the report of Tadesse et al. (2013), but significantly lower than the report of Niraj et al. (2014) under intensive management for Rohde Island Red breed. Further, in the current study, the average yolk weight of PK recorded under village was significantly higher ($p<0.05$) than intensive production system; this might suggest the capability of PK to perform well for better yolk weight at village level (Grobbelaar et al., 2010).

Table 2. Internal egg quality traits of exotic chickens under different production systems in East Shewa, Ethiopia.

Traits	Management system used	Egg quality traits		
		Isa Brown, N=87 (Mean±SD)	Bovan Brown, N=86 (Mean±SD)	Koekoek, N=54 (Mean±SD)
Yolk height (mm)	Intensive	17.81±0.79	18.57±0.33[a]	17.59±0.89[a]
	Village	17.35±1.42	18.11±0.91[b]	17.80±0.83[b]
Albumen height (mm)	Intensive	6.17±1.08	9.51±1.37[a]	5.53±1.33
	Village	6.34±1.81	6.92±1.62[b]	5.54±1.35
Yolk weight (g)	Intensive	16.69±1.83	15.39±1.28	14.54±1.14[a]
	Village	16.14±1.89	15.97±1.77	15.94±3.50[b]
Yolk color (ranges 1-15)	Intensive	6.13±1.55[a]	6.10±1.73[a]	10.3±0.13[a]
	Village	9.78±3.19[b]	7.77±3.15[b]	10.72±1.97[b]
Albumen weight (g)	Intensive	37.23±4.37[a]	35.98±4.28	26.07±2.69
	Village	33.19±5.89[b]	34.54±5.67	25.14±2.65
Haugh Unit	Intensive	85.34±4.72[a]	87.45±6.35[a]	78.38±8.58
	Village	77.56±12.96[b]	79.26±9.90[b]	77.26±8.97
Yolk percent	Intensive	25.44±2.89[a]	24.45±2.05[a]	30.55±2.42[a]
	Village	27.79±4.26[b]	26.63±3.29[b]	33.22±4.88[b]
Albumen percent	Intensive	56.48±3.95	56.85±3.55[a]	54.66±3.04
	Village	56.28±6.21	57.05±5.23[b]	53.07±4.84
Yolk:Albumen ratio	Intensive	0.45±0.07[a]	0.43±0.06	0.56±0.07[a]
	Village	0.50±0.11[b]	0.47±0.09	0.64±0.13[b]

[a-b] means with different superscript in the same column were differ significantly (P<0.05).

Yolk color

In the present study, the yolk color of eggs collected from IB, BB and PK under village production system had a deep yellow colour (~8 to 12) than that of collected under intensive system (~6 to 10) (Table 2), indicating yolk colour is a function of feed not breeds (Demeke, 2004). Village chicken roaming near the backyard could get enough the xanthophyl (plant pigment) content of the diet consumed, which determines the yolk colour (Silversides and Scott 2006). Green grass during scavenging might be responsible for carotenoid deposits in the yolk, which improves the yolk color. Ethiopian consumers have a strong preference for eggs with deep yellow yolk colour. Very small sized eggs from the scavenging local chicken with deep yellow yolk colour fetch much higher prices compared to larger eggs of improved strains with pale yolk (Tadelle et al., 2003).

Albumen weight

Albumen weight had more closely associated with egg weight than yolk weight (Harms and Hussein, 1993).The analysis for albumen weight (g) revealed that (37.23, 33.19), (35.98, 34.54) and (26.07, 25.14) for IB, BB and PK under intensive and village production system, respectively (Table 2). In the current study, the average albumen weight of IB under intensive system was significantly higher than under village production system (P<0.05). However, albumen weight of BB and PK did not differ under intensive and village production system. The current albumen weight recorded under village and intensive system for IB and BB was higher than the report of Niraj et al. (2014) in Ethiopia and comparable with the report of Kabir et al. (2014) in Nigeria under intensive management.

Haugh Unit

The Haugh Unit (HU) is calculated from the height of the inner thick albumen and the weight of an egg and it is considered to be a typical measure of albumen quality (Haugh, 1937). In the present study, the average HU value were (85.34, 77.56), (87.45, 79.26) and (78.38, 77.26) for IB, BB and PK under intensive and village production system, respectively (Table 2). It is generally accepted that the higher the HU value, the better the quality of the eggs. Study has shown in UK that there is consumer resistant to purchase eggs which have HU's below 60 and the minimum acceptable level of 70 HU on

regular documented tests (TSS, 1999). The average HU of IB and BB under intensive production was significantly higher than that in under village production system ($p<0.05$). The average HU recorded for IB and BB in the current study was significantly higher than the report of Niraj et al. *(*2014) under intensive management for Rohde Island Red and Bovans white breeds in northern Ethiopia. The current finding disagreed with Tulin and Ahmet (2009) and Dorji (2013), who reported no significant difference in HU for eggs collected from village and intensive production systems.

Albumen and yolk percent

The results of albumen and yolk percent are presented in Table 2. The mean yolk percent were (25.44, 27.79), (24.45, 26.63) and (30.55, 33.22) for IB, BB and PK under intensive and village production systems, respectively (Table 2). In the present study, the yolk percent of IB, BB and PK under village production system was significantly higher than under intensive system ($p<0.05$) and this was in agreement with the finding of Dorji (2013). As presented in Table 2, the albumen percent were (56.48, 56.28), (56.85, 57.05) and (54.66, 53.07) for IB, BB and PK under intensive and village production systems, respectively. In the current study, the albumen percent of IB, BB, and PK did not differ significantly under intensive and village production system and this was disagreed with the comparative egg quality study of Dorji (2013) in under intensive and village production systems.

Yolk to albumen ratio

The yolk albumen ratio in the present study revealed that (0.45, 0.50), (0.43, 0.47) and (0.56, 0.64) for IB, BB and PK under intensive and village production systems, respectively (Table 2). The yolk to albumen ratio of IB and PK under village production system was a significantly higher than under intensive production system ($p<0.05$), while the yolk : albumen ratio of BB did not differ significantly. It was reported that there was a small positive relationship between egg weight and yolk albumen ratio was found (Harms and Hussein, 1993). Higher yolk to albumen ratio is an attribute to differences more in proportion of albumen than in proportion of yolk (Suk and Park, 2001). However, the yolk albumen ratio of IB in both production systems in the present study was significantly higher than the report Suk and Park (2001) and Harms and Hussein (1993) under intensive management.

Conclusion

In the current study, even though the differences were observed in egg quality traits under intensive and extensive system, eggs collected from the village were also found to be good quality, which are normally perceived as inferior quality by consumers. This could indicate the efforts of farmers to apply improved management in housing, feeding and health management provided by agricultural extension works in the study areas.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Aberra M, Worku Z, Teklegiorgis Y (2013). Assessment of the prevailing handling and quality of eggs from scavenging indigenous chickens reared in different agro-ecological zones of Ethiopia. J. Environ. Occup. Sci. 2(1):1-8. doi:10.5455/jeos.20130104091334. http://dx.doi.org/10.5455/jeos.20130104091334

Alabi RA, Esobhawan AO, Aruna MB (2006). Econometric determination of contribution of family poultry to women's in Niger – Delta, Nigeria. J. Central. Eur. Agric.7:753-760.

CSA (Central Statistical Agency) (2013). Agricultural sample survey. Report on livestock and livestock characteristics 2012/13 report. The Federal Democratic republic of Ethiopia, Private Peasant Holdings. Statistical Bulletin Addis Ababa, Ethiopia, April, 2013. P. 570.

Dawit A, Tamrat D, Stotaw F, Nzietcheung S, Roy D (2008). Overview and background paper on Ethiopia's poultry sector. Relevance for HPAI Research in Ethiopia. www.hpai-reserach net. Accessed 06 April 2014.

Demeke S (2004). Egg production performance of local and White Leghorn hens under intensive and rural household conditions in Ethiopia. Lives. Res. for Rural Dev. 16:9. Retrieved on May 29, 2012, from http://www.lrrd.org/lrrd16/2/deme1602.htm.

Dorji N (2013). Comparative study of the egg quality of Bhutanese indigenous strains reared under different production systems. Bang. J. Anim. Sci. 42(2):175-178. http://dx.doi.org/10.3329/bjas.v42i2.18507

Farooq M, Mian M, Ali M, Durranim F, Asquar A, Muqarrab A (2001). Egg traits of Fayoumi bird under subtropical conditions. Sarad. J. Agri. 17:141-145.

Gantois I, Ducatelle R, Pasmans F, Haesebrouck F, Gast R, Humphrey TJ, Van Immerseel F (2009). Mechanisms of egg contamination by Salmonella Enteritidis. FEMS Microbiol. Rev. 33:718-738. http://dx.doi.org/10.1111/j.1574-6976.2008.00161.x PMid:19207743

Gast RK, Holt PS, Murase T (2005). Penetration of *Salmonella enteritidis* and Salmonella Heidelberg into egg yolks in an in vitro contamination model. Poult. Sci. 84:621-625.http://dx.doi.org/10.1093/ps/84.4.621 PMid:15844820

Grobbelaar J, Sutherland B, Molalakgotla N (2010). Egg production potentials of certain indigenous chicken breeds from South Africa.

Anim. Genet. Resour. 46:25-32. http://dx.doi.org/10.1017/S2078633610000664
Harms RH, Hussein SM (1993). Variations in yolk: albumen ratio in hen eggs from commercial flocks. J. Appl. Poult. Res. 2:166-170. http://dx.doi.org/10.1093/japr/2.2.166
Haugh R (1937). The Haugh unit of measuring egg quality. US egg Poult. Magazine 43:552-555.
Hocking P, Bain M, Channing C, Fleming R, Wilson S (2003). Genetic variation for egg production, egg quality and bone strength in selected and traditional breeds of laying fowl. Br. Poult. Sci. 44:365-373. http://dx.doi.org/10.1080/0007166031000085535 PMid:12964619
ISA (Hendrix Company) (2010). Product performance of Isa Brown Commercial layer. http://www.isapoultry.com/en/Products/Isa/Isa%20Brown.aspx.
Islam M, Bulbul S, Seeland G, Islam A (2001). Egg quality of different chicken genotypes in summer and winter. Pak. J. Biol. Sci. 4:1411-1414. http://dx.doi.org/10.3923/pjbs.2001.1411.1414
Kabir M, Sulaiman RO, Idris RK, Abdu SB, Daudu OM, Yashim SM, Hassan MR, Adamu HY, Eche NM, Olugbemi TS, Adedibu (2014). Effects of Strain, Age and the Interrelationships between External and Internal Qualities of Eggs in Two Strains of Layer Chickens in Northern Guinea Savannah Zone of Nigeria. Iran. J. Appl. An. Sci. 4(1):179-184.
Khan M, Khatun M, Kibria A (2004). Study the quality of eggs of different genotypes of chicken under scavenging system at Bangladesh. Pak. J. Biol. Sci. 7(12):2163-2166. http://dx.doi.org/10.3923/pjbs.2004.2163.2166
Mengesha M, Tamir B, Dessie T (2011). Village Chicken Constraints and Traditional Management Practices in Jamma District, South Wollo, Ethiopia. Lives. Res. Rural Dev. 23:37. http://www.lrrd.org/lrrd23/2/meng23037.htm.
Messens W, Duboccage L, Grijspeerdt K, Heyndrickx M, Herman L (2004). Growth of Salmonella serovars in hens' egg albumen as affected by storage prior to inoculation. Food Microbiol. 21:25-32. http://dx.doi.org/10.1016/S0740-0020(03)00045-5
Moges F, Aberra M, Tadelle D (2010). Assessment of village chicken production system and evaluation of the productive and reproductive performance of local chicken ecotype in Bure district, North West Ethiopia. Afr. J. Agri. Res. 5(13):1739-1748.
Niraj K, Zinabu N, Yohanes T, Etsay K (2014). Evaluation of egg quality traits of Rhode Island Red and Bovans White under Intensive Management in Mekelle, Ethiopia. IOSR J. Agric. Vet. Sci. 7(2):71-75. http://dx.doi.org/10.9790/2380-07227175
Okeudo N, Onwuchekwa C, Okoli I (2003). Effect of oil treatment and length of storage on the internal quality, organoleptic attributes and microbial profile of chicken eggs. Trop. Anim. Prod. 6:63-70.
Onagbesan O, Bruggeman V, Desmit L, Debonne M., Witters A, Tona K, Everaert N, Decuypere E (2007). Gas exchange during storage and incubation of avian eggs: Effects on embryogenesis, hatchability, chick quality and post-hatch growth. World's Poult. Sci. J. 63:557-573. http://dx.doi.org/10.1017/S0043933907001614
Roland D (1988). Eggshell problems: Estimates of incidence and economic impact. Poult. Sci. 67:1801-1803. http://dx.doi.org/10.3382/ps.0671801
Silversides F, Scott T (2001). Effect of storage and layer age on quality of eggs from two lines of hens. Poult. Sci. 80:1240-1245. http://dx.doi.org/10.1093/ps/80.8.1240
Solomon D (2007). Comparative nutritive value and protein qualities of Atella and industrial brewers grains in poultry ration in Ethiopia. Livestock Research for rural Development. The International Journal for Research into Sustainable Developing World Agriculture. CIPAV, Cali, Colombia.
Suk YO, Park C (2001). Effect of breed and age of hens on the yolk to albumen ratio in two different genetic stocks. Poult. Sci. 80:855–858. http://dx.doi.org/10.1093/ps/80.7.855
Tadelle D, Kijora C, Peters K, (2003). Indigenous chicken ecotypes in Ethiopia: growth and feed utilization potentials. Int. J. Poult. Sci. 2:144-152. http://dx.doi.org/10.3923/ijps.2003.144.152
Tadesse D, Harpal S, Ashenafi M, Wondimeneh E, Tadelle D (2013). Study on productive performances and egg quality traits of exotic chickens under village production system in East Shewa, Ethiopia, 11 April, 2013. Afr. J. Agric. Res. 8(13):1123-1128.
TSS (Technical Services and Supplies) (1999). Technical Services and Supplies, QCD instrument Range Manual. York, England, Version 2.1- Release 27E7.
Tulin C, Ahmet K (2009). Comparison of village eggs and commercial eggs in terms of quality. J. An. Vet. Adv. 8:2542-2545.

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Full Length Research Paper

"Efficacy of mycorrhizal inoculations on seed germination and plant growth of Bambara groundnut, *Vigna subterranea* (TVsu 283)"

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This Research work was conducted to study the effects of mycorhizal fungal inoculation on seed germination and plant growth of Bambara groundnut (*Vigna subterranea*). The impacts of *Glomus mosseae*, *Aspergillus niger*, *Aspergillus fumigatus* and *Malbranchea gypsea* on some plant growth parameters were studied both in their crude and pure forms. Compared to un-inoculated plants, the fungal strains significantly increased plant growth parameters. The highest rate of germination at the 42nd day was observed in the crude fungal inoculation treatments and specifically in *A. fumigatus* crude inoculation as it increased the number of leaves, leaf length, leaf surface area, stem girth, and number of shoots by 54.2, 23.8, 49.1, 20.0 and 40.0%, respectively.

Key words: Mycorrhizal, *Vigna subterranea*, crude and pure forms, plant growth parameters.

INTRODUCTION

In most of the Sub-Sahara African countries, increased population growth leads to hunger, the main cause of malnutrition and food insecurity. This food insecurity relies on low crop productivity, limited by low soil fertility which is accelerated by low soil cation exchange capacity and organic matter, high soil acidity and/or bad cultural practices (Bado, 2002; Yao et al., 2005). All these constraints create disequilibrium between the available quantity of crops produced and the population needs on one hand, and the environment on the other, suggesting that this population is not eating or living safely (Cooke, 1998).

In an effort to enhance crop production, most of our tropical countries rely on chemical fertilizers, which have potentially revealed to be a pollutant to human life and environment (Margni et al., 2002), in addition to their high cost, as the result of lack of own available chemical fertilizer manufacturers.

The lack of food rich in proteins in the world and particularly in developing countries has urged researchers to seek for alternative source of proteins to complete their diet (Ahmed and Abdallah, 2010). Hence, the food insecurity, the environmental pollution and the soil fertility problems need to be solved if promotion of biological and sustainable agriculture is to be accomplished through measures such as improved fallow, intercropping, agroforestry or biofertilizers. Among these strategies, biofertilizers have been reported

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Plate 1. Bambara seeds (TVsu 283).

to increase yield of several crops in Cameroon (Megueni et al., 2006; Ngakou, 2007; Ngakou et al., 2007a, 2008, 2011). Unlike other crop legumes, very little is known about Mycorhiza-*Vigna subterranea* interactions.

Bambara groundnut belongs to the under-utilized grain legumes that possess high crude protein content between 22 and 37% (Adeparusi, 2001; Fasoyiro et al., 2004). It is widely grown in Nigeria and in other African countries like Ghana, Cameroon, Ivory Coast and Togo (Klu et al., 2001). Bambara groundnut is the third most important legume after groundnut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*) (Howell et al., 1994). Hence, there is a need to improve the productivity of this food security crop known to grow on low soil fertility, where it can withstand drought and low rainfall (Berchie et al., 2010).

Therefore, we hypothesize that Mycorhiza symbiosis could alleviate the host plant nutrient requirements, thus resulting to sustainable yield improvement of this valuable crop, so as to substitute chemical fertilizers.

MATERIALS AND METHODS

Site of experiment

The potted experiment was carried out beside the General Biology Laboratory of the Department of Biological Sciences, Osun State University Osogbo, Osun State (Latitude 7.5°N and Longitude 4.5°E, at 246 m elevation) for a period of 6 weeks (July - August, 2014). The culture test was carried out in the Microbiology Laboratory of the Department of Biological sciences, Osun State University Osogbo, Osun State.

Seed collection and treatments

Seeds of Bambara groundnut (*V. subterranea*) with accession number TVsu 283 (Plate 1) were collected from International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State. The seeds were treated by soaking in 0.02% sodium hypochlorite for 2 min and washed five times with sterilized distilled water (Gholami et al., 2009).

Site of crude inoculum collection

The crude inoculum of *Aspergillus niger* and *Aspergillus fumigatus* was gotten from a sample of native soil obtained from the root of *Araucaria columnaris* while that of *Malbranchea gypsea* was obtained from a sample of soil obtained from the root of *Cassia fistula* at Yidi, Oke-Baale, Osogbo, Osun State (Plate 2). The crude inoculum of *Glomus mosseae* (Plate 3) was obtained from International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State.

Soil preparation and processing

Sandy soils were randomly collected to 6 sacs each of 30 kg from Idi-Iroko Meta Area, Oke-Baale, Osogbo on 9th June, 2014. The soil was sieved to exclude stones and pebbles. The soil was characterized by its dark-brown color and semi-coarse texture. Sterilization of the soil was done by heating in an oven at 100°C. The soil was covered with foil paper to prevent contamination before use.

Seed viability of bambara seeds

Viability of the seeds was determined using a cold water sink-float test (Stuckey and Reese, 1981). Germination tests were then conducted on seeds which were viable.

Pre-germination trials on Bambara seeds

Germination paper sheets (sterile Serviette paper) were arranged in the transparent polyethylene box (10 layers). Rectangular box (170 × 110 × 50 mm) was used for the germination tests. Using a

Plate 2. Site of crude inoculums collection at Yidi, Oke – Baale Area, Osogbo.

Plate 3. Crude Inoculum of *Glomus mosseae* collected from IITA, Ibadan.

measuring cylinder, 20 ml of water was added to the box and excess water was poured off from the germination box before autoclaving. With the use of a forcep, 10 seeds were placed in the autoclaved box in 2 rows/lines. The box was closed tightly and placed near a window where there is natural light. First germination record was taken 6 days after seed setting and then every 48 hour until germination rate reached a plateau (11 days maximum). The contaminated seeds were discarded. After 9 days, the box was opened to allow full seedling development. Seedling vigor was recorded at day 11 (Oyatomi et al., 2010).

Serial dilution

Serial dilution was carried out on the crude inoculums. This was done to reduce the microbial load. One gram of soil was added into the tube containing 9mL of sterile Ringers solution to obtain 1/10 dilution (stock solution) and using a 5 ml sterile syringe, a series of 1/00, 1/1000, 1/10,000, and 1/100,000 dilutions was prepared by adding 1 ml of solution to 9 ml of sterile Ringers solution respectively. Each test tube with the Ringers solution and the crude inoculum was mixed vigorously.

Preparations of the bio-inoculants

Pour plate method was used as culture technique to get pure cultures. Using a 5 ml sterile syringe, 0.5 ml suspension from the dilutions of 10^{-2}, 10^{-4}, and 10^{-6} was transferred onto sterile Petri dishes upon which the already prepared and cool Potato Dextrose Agar (PDA) was poured. Plates were incubated at room temperature for 72 h and observed for growth. Identification of the isolates was done by colonial characterization. The colonies containing the isolates were then sub-cultured in an inoculating chamber on potato dextrose agar to get a pure culture by using the streak plate method. The fungi isolated and identified were: *A. niger, A. fumigatus* and *M. gypsea* designated An, Af and Mg respectively; while *Glomus mosseae* was designated Gm.

Fungal identification

1. With nose mask and hand gloves on, the colonies were first observed visually for the surface color and also on the reverse.
2. Few drops of Lactophenol were put on sterile microscope slide using a pipette.
3. With the use of a forcep, the isolates were placed on the slide, mixed and then covered with sterile cover slip.
4. At low magnification power of microscope (40 objective lens), detailed examinations were done according to Raper and Fennell (1965) and Gams et al. (1985).
5. The microscopic structures (such as conidia, conidiophores, phialides and the mycelia) of each fungus were observed and compared with relevant literatures as reference.

Seedling establishments

Thirty-two buckets of 10 L each were used for planting; all buckets were perforated at the bottom to allow the easy passage of water and to prevent water logging. The buckets were properly labeled for easy identification. Three sterilized seeds of Bambara were sown in each bucket filled with sandy soil; 5-7 cm deep and 10 cm apart and watered regularly. In total, there were eleven groups of thirty-two treatments, with three replications of each bio-inoculant. Three seeds each were sown into each treatment. The control was planted first to avoid contamination. The various groups are listed as follows:

Group A - Sterilized soil + Bambara seeds + crude inoculum of Gm.
Group B - Sterilized soil + Bambara seeds + crude inoculum of An.
Group C - Sterilized soil + Bambara seeds + crude inoculum of Af.
Group D - Sterilized soil + Bambara seeds + crude inoculum of Mg.
Group E - Sterilized soil + Bambara seeds + pure inoculum of Gm.
Group F - Sterilized soil + Bambara seeds + pure inoculum of An.
Group G - Sterilized soil + Bambara seeds + pure inoculum of Af.
Group H - Sterilized soil + Bambara seeds + pure inoculum of Mg.
Group I - Sterilized soil + Bambara seeds + pure inoculum of Gm, An, Af and Mg.
Group J - Sterilized soil + Bambara seeds + crude inoculum of Gm, An, Af and Mg.
Group K - Sterilized soil + Bambara seeds, with no fungi strains (Control).

Harvesting took place 6 weeks after planting. Fresh weight of seedlings were determined immediately after harvesting while dry weight was determined after oven-drying the seedlings at 80°C for 24 h.

Application of the pure and crude inoculums

Ten grams of each of the crude inoculum was mixed with the top soil in each bucket before sowing of Bambara seeds (Pathak et al., 2013). For the pure inoculations, pure cultures of the fungi were suspended in distilled Ringers solution and 10 ml of the solution was inoculated into each bucket using sterile syringe. 10 g and 10 ml each of the crude and pure inoculums respectively, were added to the treatments containing the four fungi acting in concert.

Statistical analysis

Statistical analysis of all tests was carried out using SPSS 15.0 design. Data was analyzed with analysis of variance (ANOVA) at $P<0.05$ level. Tests were conducted in triplicates and values given as mean ± standard error.

RESULTS

Growth parameters

Seed emergency

V. subterranea seeds started emerging from the soil 7 days after planting (7 DAP) in all the 5 treatments. Germination was complete in the field 12 DAP, thus 5 days after the first emergency.

Seed emergence counts

The seed emergence count was done after 7 days of planting and mycorhizal inoculation.

Net assimilation rate / moisture content

Moisture content / net assimilation rate (%) was calculated using the formula:

$$\text{Percentage moisture content} = \frac{(\text{Wet weight} - \text{Dry weight})}{\text{Wet weight}} \times 100$$

Wet and dry weights of roots and shoots

While the wet weights of shoots and roots were measured directly, dry weights were measured after cleaning, rinsing in distilled water and drying for 24 h in an oven at 70°C (Jha and Saraf, 2011). Measurements were taken in gram (g) using weighing balance.

Plant height

The plant was straightened to its fullest length and the length (cm) was measured with a ruler alongside (Harold, 1957).

Number of leaves

Only true leaves were measured and considered as the correct number of leaves (Table 1).

Mycorrhizal dependency

Mycorrhizal dependency (%) which is defined by Gerdemann (1975) as the degree to which a plant is dependent on the mycorrhizal condition to produce its maximum growth on yield at a given level of soil fertility, was measured using the formula (Ajiboye, 2009):

$$\frac{\text{Total dry weights of (Inoculated seedlings- non-inoculated seedlings)}}{\text{Total dry weight of Non-inoculated seedlings}} \times 100$$

DISCUSSION

After sowing, germination occurred 1 week later in all the treatments. This was within the range of 7 to 15 days (Swanevelder, 1998), or 7 to 10 days (Yao et al., 2005) period reported as necessary for germination of Bambara groundnut.

A recent report by Brink et al. (2006) indicated that flowering in Bambara occurs within 30 to 55 days after sowing. This observation and the findings from this research are different from those made by Ocran et al. (1998) that Bambara groundnut flowers within 43 days, while Berchie et al. (2010) revealed date to 50% flowering at between 39 and 41 DAP. The results of this research suggest that dates to 50% flowering for Bambara groundnut significantly vary with the seed variety and the growing area, because after 6 weeks of planting, the Bambara seeds (TVsu283) did not flower.

It was observed at the end of the growing period and from the results of the measured parameters (among many others) that the growth of the Bambara groundnut was more enhanced by the crude mycorrhizal inoculations. Crude *A. fumigatus* increased number of leaves by 54.2% as compared to the non-mycorrhizal treatments (Table 1). This is followed by pure *A. fumigatus* with 37.5% increase, then pure *M. gypsea* with 29.2%, crude *M. gypsea* with 25.0% increases respectively. Next is that of the pure inoculations of the four fungi having 20.8% increase. Following closely are those of the crude inoculations of the four fungi, crude *A. niger* and pure *G. mosseae* all with 12.5% increase. There was no increase in the number of leaves produced by pure *A. niger* as compared to the non-mycorrhizal treatments. Crude *G. mosseae* had a lower number of leaves than the non-mycorrhizal treatments.

A. fumigatus is more effective than the other fungal inoculums because it has been recorded that *A. fumigatus* has an early duplication cycle compared to other filamentous fungi (Michelle and Ian, 2000). Thus more strains of it are available for the Bambara seed to increase its yield and productivity.

The lower yield in the treatments with the four fungal strains is linked to the fungi acting antagonistically. The highest stem length was found in crude *A. niger* with leaf length of 1.9±0.59 cm (Table 2). Crude *A. fumigatus* and pure *A. fumigatus* had the same leaf lengths of 1.7±0.25 cm and 1.7±0.68 cm respectively. Crude *M. gypsea* and pure *A. niger* also had the same leaf lengths of 1.6±0.22 cm and 1.6±0.36 cm respectively, then pure *M. gypsea* having leaf length of 1.4±0.45 cm. The same leaf length was observed in pure *G. mosseae*, pure inoculations of the four fungi, crude inoculations of the four fungi and control with leaf lengths of 1.3±0.18, 1.3±0.15, 1.3±0.25 and 1.3±0.27 cm respectively; the least being crude *G. mosseae* with leaf lengths of 1.2±0.50 cm.

The highest total dry weight was observed in crude *A. fumigatus* with total dry weight of 2.5 ± 0.90 g, followed by pure *M. gypsea* with total dry weight of 2.1 ± 0.50 g (Table 3). Following this were those of crude *A. niger*, pure *A. niger* and pure *A. fumigatus* with total dry weights of 1.5 ± 0.75, 1.5 ± 0.91 and 1.5 ± 0.56 g respectively. Next are those of crude *M. gypsea* and pure *G. mosseae* with total dry weights of 1.4 ± 1.13 and 1.4 ± 1.15 g respectively. Following these are those of the pure and crude inoculations of the four fungi both with 1.1 ± 0.88 g as their total dry weights and crude G. mosseae having 0.7 ± 0.70 g total dry weight. The least total dry weight was found in the non-mycorrhizal inoculations with 0.5 ± 0.17 g total dry weight.

The highest total fresh weight was observed in crude *A. fumigatus* with total fresh weight of 11.1 ± 2.92 g,

Table 1. Number of leaves observed at the end of each specified day.

Treatment	Day			
	14	28	35	42
Crude *G. moseae*	5 ± 1.00	12 ± 1.58	12 ± 1.58	17 ± 1.87
Crude *A. niger*	8 ± 1.14	18 ± 1.90	21 ± 2.76	27± 2.72
Crude *A. fumigatus*	8 ± 1.14	23 ± 1.14	29 ± 2.10	37 ± 1.82
Crude *M. gypsea*	9 ± 0.00	17 ± 1.72	20 ± 1.24	30 ± 2.09
Pure *G. moseae*	5 ± 0.91	17 ± 1.97	21 ± 1.63	27 ± 2.96
Pure *A. niger*	6 ± 0.33	14 ± 1.14	24 ± 0.00	24 ± 1.63
Pure *A. fumigatus*	9 ± 0.33	16 ± 1.14	23 ± 1.14	33 ± 1.90
Pure *M. gypsea*	8 ± 0.80	18 ± 1.15	24 ± 0.00	31 ± 1.14
Pure of the 4	10 ± 1.00	17 ± 0.80	23 ± 1.24	29 ± 0.80
Crude of the 4	8 ± 1.14	16 ± 1.82	23 ± 1.41	27 ± 1.82
Control	9 ± 0.00	15 ± 0.00	18 ± 1.73	24 ± 0.00

Values are mean ± SD of three replicates.

Table 2. Stem Length (cm) observed at the end of each specified day.

Treatment	Day			
	14	28	35	42
Crude *G. moseae*	0.9 ± 0.30	0.9 ± 0.42	1.1 ± 0.44	1.5 ± 0.50
Crude *A. niger*	1.4 ± 0.88	1.8 ± 0.36	1.8 ± 0.34	1.9 ± 0.59
Crude *A. fumigatus*	1.2 ± 0.37	1.5 ± 0.37	1.7 ± 0.40	1.7 ± 0.25
Crude *M. gypsea*	1.1 ± 0.62	1.4 ± 0.51	1.5 ± 0.45	1.6 ± 0.22
Pure *G. moseae*	0.4 ± 0.10	1.0 ± 0.18	1.3 ± 0.33	1.3 ± 0.18
Pure *A. niger*	1.2 ± 0.66	1.4 ± 0.40	1.4 ± 0.15	1.6 ± 0.36
Pure *A. fumigatus*	1.0 ± 0.52	1.2 ± 0.36	1.2 ± 0.33	1.7 ± 0.68
Pure *M. gypsea*	1.1 ± 0.48	1.1 ± 0.33	1.2 ± 0.39	1.4 ± 0.45
Pure of the 4	1.0 ± 0.54	1.2 ± 0.15	1.3 ± 0.55	1.3 ± 0.15
Crude of the 4	0.8 ± 0.33	0.9 ± 0.33	1.2 ± 0.44	1.3 ± 0.25
Control	0.4 ± 0.38	1.1 ± 0.74	1.2 ± 0.45	1.3 ± 0.27

Values are mean ± SD of three replicates.

Table 3. Record of the total dry weight after 42 days of mycorrhizal inoculations.

Treatment	Total dry weight (g)
Crude *G. moseae*	0.7 ± 0.70
Crude *A. niger*	1.5 ± 0.75
Crude *A. fumigatus*	2.5 ± 0.90
Crude *M. gypsea*	1.4 ± 1.13
Pure *G. moseae*	1.4 ± 1.15
Pure *A. niger*	1.5 ± 0.91
Pure *A. fumigatus*	1.5 ± 0.56
Pure *M. gypsea*	2.1 ± 0.50
Pure of the 4	1.1 ± 0.88
Crude of the 4	1.1 ± 0.88
Control	0.5 ± 0.17

Values are mean ± SD of three replicates.

Table 4. Record of the total fresh weight after 42 days of mycorrhizal inoculations.

Treatment	Total fresh weight (g)	Net assimilation rate (%)
Crude *G. moseae*	4.9 ± 2.11	86.0
Crude *A. niger*	8.5 ± 1.83	82.4
Crude *A. fumigatus*	11.1 ± 2.92	77.5
Crude *M. gypsea*	7.8 ± 1.53	82.1
Pure *G. moseae*	6.9 ± 2.25	80.0
Pure *A. niger*	4.8 ± 2.05	69.0
Pure *A. fumigatus*	8.3 ± 1.27	82.0
Pure *M. gypsea*	9.7 ± 1.75	78.4
Pure of the 4	6.4 ± 1.35	83.0
Crude of the 4	5.9 ± 1.70	81.4
Control	4.4 ± 2.02	89.0

Values are mean ± SD of three replicates.

Table 5. Mycorrhizal dependency.

Treatment	Mycorrhizal dependency (%)
Crude *G. moseae*	40
Crude *A. niger*	200
Crude *A. fumigatus*	400
Crude *M. gypsea*	180
Pure *G. moseae*	180
Pure *A. niger*	200
Pure *A. fumigatus*	200
Pure *M. gypsea*	320
Pure of the 4	120
Crude of the 4	120
Control	0

Values are mean ± SD of three replicates.

followed by pure *M. gypsea* with total fresh weight of 9.7 ± 1.75 g (Table 4).

Following this were those of crude *A. niger*, pure *A. fumigatus* and crude *M. gypsea* with total fresh weights of 6.9 ± 2.25, 6.4 ± 1.35 and 5.9 ± 1.70 g respectively. Next are those of crude *G. mosseae* and pure *A. niger* with total fresh weights of 4.9 ± 2.11 and 4.8 ± 2.05 g, respectively. The least total fresh weight was found in the non-mycorrhizal inoculations with 4.4 ± 2.02 g total dry weight.

The highest mycorrhizal dependency was observed in crude *A. fumigatus* with 400% dependency, followed by pure *M. gypsea* with 320% dependency (Table 5). 200% mycorrhizal dependency was found in crude *A. niger*, pure *A. niger* and pure *A. fumigatus*. Crude *M. gypsea* and pure *G. mosseae* both had 180% dependency. Also, both pure and crude inoculations of the four fungi had 120% mycorrhizal dependency. The least mycorrhizal dependency of 40% was found in crude *G. mosseae.*

The Bambara seedlings were uprooted after 6 weeks of Mycorrhizal inoculation for thorough examination (Plate 4).

It can thus be said that the highest growth was found in those inoculated with crude *A. fumigatus.* This is followed by those inoculated with the crude forms of the four fungi, that is, *G. mosseae, A. niger, A. fumigatus* and *M. gypsea* acting in concert. Following this is the *A. niger* inoculated treatment and least being treatment of *G. mosseae*.

Among the pure inoculations, the highest improvement of growth was found in treatment with pure *M. gypsea* and followed closely by those of pure *A. fumigatus.* The third highest improvement was found in treatment of pure *G. mosseae*, followed by those of *A. niger* and the least being treatment of the four fungi acting in concert.

The non - mycorrhizal treatment showed the lowest growth compared to the mycorrhizal treatment, except for the crude *G. mosseae* inoculated treatment which showed lower growth than the non - mycorrhizal treatment.

The dependency of the plant on mycorrhiza ranged widely in the various treatments: the treatment with crude *A. fumigatus* showed the greatest dependency of 400%

Plate 4. Bambara shoots and roots uprooted for thorough examination.

while the least was found in the treatment with crude *G. mosseae* with dependency of 40%. Thus the poor growth and development observed in crude *G. mosseae* – inoculated seedlings can be attributed to the low mycorrhizal dependency. The mycorrhizal dependency of the treatments increased as the root weight increased. It is well known that root production seems to be an important factor in mycorrhizal dependency (Mehraverahn, 1977; Nemec, 1978). Although these results showed a correlation between root dry weight and mycorrhizal dependency, root weight alone cannot be used as a measure of mycorrhizal dependency, and thus agree with Menge et al. (1978) that such relationship ought to be viewed with caution.

The enhanced biomass of inoculated plants has been attributed to increased nutrient uptake in mycorrhizal inoculated plants (Smith and Read, 1997; Ngakou et al., 2007a, 2008).

Conclusion

In conclusion, mycorrhiza improved the plant biomass as compared to un-inoculated treatment. Biofertilizers could thus be recommended to boost the crop productivity and alleviate the long cooking properties of *V. subterranea* seeds. The overall improvement in seedling vigor through a significant increase in various physiological parameters suggests that these fungal strains have a plant-growth promoting ability on Bambara seedlings and hence could be used for seed inoculation for better establishment of seedlings. The plants with enhanced seedling vigour can assist to better plantations. Thus it can be concluded that the use of Bioinoculants or Biofertilizers in agricultural practices may assist to enhance food production.

Improvement of soil fertility and promotion of sustainable agriculture in Osun region is feasible if under-utilized crops such as Bambara groundnut (*Vigna subterranea*) could be inoculated by mycorhizal strains in the field. It is therefore recommended that the results obtained from this research work be forwarded to extension officers in the Ministry of Agriculture and Rural development to tackle problems of seed germination and seedling establishment of this legume with enormous benefits.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Adeparusi EO (2001). Effect of processing on some minerals, anti-nutrients and nutritional composition of African Yam Bean. J. Sustain. Agric. Environ. 3(1):101-108.

Ahmed GM, Abdallah AA (2010). Nutritive evaluation of Bambara groundnut (*Vigna subterranea*) pods, seeds and hull as animal feeds. J. Appl. Sci. 6:383-386.

Ajiboye AA (2009). Seed germination and seedling physiology of four multipurpose savanna tree species in Nigeria. Ph. D. Thesis. Department of Biological Sciences, Federal University of Agriculture, Abeokuta, Nigeria, P. 350.

Bado BV (2002). Role of leguminous crops on fertilization of ferruginous tropical soils in the guinea savannah zone. Ph. D. Thesis. Department of Environmental Resource Conservation, Kenyatta University, Burkina-Faso, P. 402.

Berchie JN, Sarkodie AJ, Adu-Dapaah H, Agyemang A, Addy S, Asare E, Donkor J (2010). Yield evaluation of three early maturing Bambara groundnut (*Vigna subterranea* L. Verdc). J. Agron. 9:175-179. http://dx.doi.org/10.3923/ja.2010.175.179

Brink M, Ramolemana GM, Sibuga KP (2006). Plants resources of Tropical African Cereals and Pulses, 3rd Edn. PROTA Foundation, Wageningen, Netherlands, P. 218.

Cooke RD (1998). Food Insecurity ACP Countries: Politiics and Intervention Programs of Vulnerable Groups, Report and recommendation of the seminar of CTA, 26-30 October 1998, University of Louvain, Louvain-la-Neuve, Belgium. P. 19.

Fasoyiro SB, Ajibade SR, Omole AJ, Adeniyan ON, Farinde EO (2004). Proximate, minerals and anti-nutritional factors of some underutilized grain legumes in South Western Nigeria. J. Nutr. Food Sci. 36:18-23. http://dx.doi.org/10.1108/00346650610642151

Gams W, Christensen M, Onions JP, Samson RA (1985). In: Advances in Penicillium and Aspergillus systematics, 1st Edn. Springer, New York, P. 56.

Gerdemann W (1975). Vesicular-arbuscular mycorrhizae: The development and function of root, 7th Edn. Academic Press, New York, P. 591.

Gholami A, Shahsavani S, Nezara S (2009). The Effect of Plant Growth Promoting Rhizobacteria on Germination, Seedling Growth and Yield of Maize. World Acad. Sci. Engr. Tech. 49:19-24.

Harold FH (1957). The Measurement and Value of Plant Height in the Study of Herbaceous Veget. Ecol. 38:313-320. http://dx.doi.org/10.2307/1931691

Howell JA, Eshbaugh WH, Guttman S, Rabakonandrianina E (1994). Common names given to Bambara groundnut (*Vigna subterranea*n: Fabaceae) in central Madagascar. Econ. Bot. 48:217-221.

Klu GYP, Amoatey HM, Bansa D, Kumaeja FK (2001). Cultivation and use of African yam bean (Sphenostylis stenocarpa ex A Rich) in the Volta region of Chana. Ecol. Bot. 6:74-77.

Jha KS, Saraf M (2011). Effect of Plant Growth Promoting Rhizobacteria on Seed Germination Behaviour and Seedling Vigor of Jatropha curcas. Int. J. Biotech. Biosci. 1(1):101-103.

Margni M, Rossier D, Crettag P, Jolliet O (2002). Life cycle impact assessment of pesticides on human health and ecosystem. Agric. Ecosyst. Environ. 93:279-392. http://dx.doi.org/10.1016/S0167-8809(01)00336-X

Megueni C, Ngakou A, Makalao MM, Kameni TD (2006). Relative responses of soybean (Glycine max) to soil solarization and rhizobial field inoculation at Dang Ngaoundere, Cameroon. Asian J. Plant Sci. 5:832-837. http://dx.doi.org/10.3923/ajps.2006.832.837

Mehraverahn K (1977). Mycorrhizal dependency of six citrus cultivars. Ph. D. Thesis. Department of Agriculture, University of Illinois, P. 134.

Menge JA, Johnson LV, Plattr G (1978). Mycorrhizal dependency of several citrus cultivars under three nutrient regimes. New Phyt. 81:553-559. http://dx.doi.org/10.1111/j.1469-8137.1978.tb01628.x

Michelle M, Ian T (2000). Landmarks in the early duplication cycles of *Aspergillus fumigatus* and *Aspergillus nidulans*: Polarity, germ tube emergence and septation. Microbiology 146(12):3279-3284.

Nemec S (1978). Response of six citrus rootstocks to three species of Glomus, a mycorrhizal fungus. Proc. Fla. State Hortic. Soc. 91:10-14.

Ngakou A (2007). Potentials of selected biofertilizers and a mycoinsecticides in managing Megalurothrips sjostedti and improving cowpea production in Cameroon. Ph.D. Thesis. Department of Biological Sciences, University of Ngaoundere, P.197.

Ngakou A, Nwaga D, Nebane CLN, Ntonifor NN, Tamò M, Parh IA (2007a). Arbuscular-mycorrhizal fungi, rhizobia and Metarhizium anisopliae enhance P, N, Mg, K, and Ca accumulations in fields grown cowpea. J. Plant Sci. 2:518–529.http://dx.doi.org/10.3923/jps.2007.518.529

Ngakou A, Megueni C, Makalao MM, Nwaga D, Taine J, Ndjouenkeu R (2008). Changes in the physico-chemical properties of soil and harvested soybean seeds in response to soil solarization and bradyrhizobial inoculation. Arch. Agron. Soil Sci. 54:189-202. http://dx.doi.org/10.1080/03650340701793579

Ngakou A, Moctar M, Njintang YN, Tamò M (2011). Some cowpea quality seed indicators as influenced by field application of selected biofertilizers and mycoinsecticide in three agroecological zones of Cameroon. Ann. Plant Soil Sci. 42:1277-1289.

Ocran VK, Delimini LL, Asuboah RA, Asiedu EA (1998). Seed Management. Manual for Ghana, MOFA, Accra, Ghana.

Oyatomi O, Ihenacho J, Adebowale O, Dumet D (2010). Standard Operating Procedure (SOP) for IITA seed bank P. 10.

Pathak DV, Surender S, Saini RS (2013). Impact of bio-inoculants on seed germination and plant growth of guava (*Psidium guajava*). Forest. J. Hortic. 5(10):183-185.

Raper KB, Fennell DI (1965). The genus Aspergillus, 5th Edn. Williams and Wilkins Company, Baltimore, U.S.A., P. 344.

Smith S, Read DJ (1997). Mineral Nutrition, Heavy Metal Accumulation and Water Relation of VA Mycorrhizal Plants, 3rd Edn. Academic Press, New York. P. 160.

Stuckey and Reese (1981). Seed conditioning and germination of New Jersey Tea, *Ceanothus americanus*. Ohio J. Sci. 15:226-237.

Swanevelder CJ (1998). Bambara - Food for Africa. National Department of Agriculture, Government Printer, Republic of South Africa.

Yao D, Bonny B, Zoro I (2005). Preliminary observation of the variability between some morphotypes of voandzou (*Vigna subterranea* L. verdc. Fabaceae) in Ivory coast. Biotechnol. Agron. Soc. Environ. 9:249-258.

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