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Full Length Research Paper

Impact of DroughtTEGO® hybrid maize variety on agricultural productivity and poverty alleviation in Kenya

George Marechera[1], Ibrahim Macharia[2*], Grace Muinga[1], Stephen Mugo[3], Ruth Rotich[1], Ruth Khasaya Oniang'o[4], James Karanja[5], Caleb Obunyali[1] and Sylvester O. Oikeh[1]

[1]African Agricultural Technology Foundation (AATF), P. O. Box 30709-00100, Nairobi, Kenya.
[2]Department of Agricultural Economics, Kenyatta University, P. O. Box 43844, 00100, Nairobi, Kenya.
[3]International Maize and Wheat Improvement Center (CIMMYT), P. O. Box 30677, Nairobi, 00100, Kenya.
[4]Rural Outreach Program (ROP) Africa 9 Planets Apartments, Block S6 Kabarnet Gardens, Off Kabarnet Road P. O. Box 29086-00625 Nairobi, Kenya.
[5]Kenya Agricultural and Livestock Research Organization (KALRO), P. O. Box 57811, Nairobi, 00200, Kenya.

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Impact of DroughtTEGO® maize hybrids on agricultural productivity and poverty reduction among small-scale maize farmers were analyzed using 642 households in Kenya. The Water Efficient Maize for Africa (WEMA) project coordinated by the African Agricultural Technology Foundation (AATF) developed the varieties. While on-farm production output and farmers' testimonies indicate significantly high productivity over other varieties, a rigorous assessment of impacts at household level is missing. Direct comparison of maize income, total household income and poverty indices shows significant differences between adopters and non-adopters. However, since the observed estimates can be due to differences in both observable and non-observable characteristics between adopters and non-adopters, we cannot have any causal interpretation. This study, therefore, utilized the counterfactual outcome framework based on propensity score methods (PSM) to control for such differences. The results of PSM showed that adoption of DroughtTEGO® maize varieties led to significant increase in maize income by 82%, total income by 75%, and reduced the depth of poverty by 46-point margins. The study recommends formulation and implementation of appropriate policies to improve the adoption of DroughtTEGO® hybrid maize varieties across the country.

Key words: DroughtTEGO® hybrid, poverty reduction, impact assessment, maize, Kenya.

INTRODUCTION

Maize (*Zea mays* L.) is considered an essential food crop and is grown by small-scale farmers for both home

*Corresponding author. E-mail: macharia.ibrahim@ku.ac.ke.

consumption and local markets in Kenya. The main maize producing basket includes Bungoma, Trans Nzoia, Nakuru, Narok and Uasin Gishu counties. Other areas that grow maize include Kakamega, Vihiga, Busia, Siaya, Homa Bay, Migori, Kisumu, Nyeri, Meru, Embu, Machakos, Kitui, Tana River, Murang'a, Bomet and Isiolo counties. The consumption curve of maize in Kenya is moving upwards, as there was about 2.3 times increase in maize consumption by 2016 over 2005 (FAO, 2016). The growing trend in maize consumption is partly explained by rapid population growth estimated at 2.6% per annum, an indication that the country needs to take robust measures to increase maize productivity. However, such measures cannot be taken unless farmers use high yielding and stress tolerant varieties that have positive impact on productivity. There are many maize hybrid varieties grown in Kenya – the Kenya Plant Health Inspectorate Service (KEPHIS) lists about 338 maize varieties grown in Kenya by 2017 (Kephis, 2017).

The Water Efficient Maize for Africa (WEMA) project in partnership with CIMMYT, Monsanto and five National Agricultural Research Systems for Kenya, Uganda, Tanzania, Mozambique and South Africa, developed drought tolerant maize hybrids that were tested and released in Kenya.

The overall goal of the project was to enhance maize productivity by protecting against drought effects for improved livelihoods of particularly resource-limited smallholder farmers. A total of 60 hybrids were released in Kenya for commercialization. The hybrids were branded and commercialized as DroughtTEGO® maize hybrid varieties. Examples of these hybrids include WE1101, WE2101, WE2104, WE2109, WE3101, WE3102, WE3104, WE3105 and WE3106 (Oikeh et al., 2014; Edge et al., 2018). On-farm production output and farmers' testimonies showed significant yield advantages with an average yield of about 4.5 t/ha within three years of commercialization of the varieties when compared with local varieties that yield about 2.8 t/ha (Situma, 2018). An assessment of impacts of adoption of the hybrids at household level has not been established. Thus, this study aims to understand the extent to which DroughtTEGO® adoption contributes to maize productivity and poverty reduction.

Generally, the decision to adopt any agricultural technology is a function of the net benefits that the farmer expects to gain; and studying how small-scale farmers can improve their livelihoods is a central issue of economic development in developing countries like Kenya. Adoption of agricultural technologies can reduce poverty through direct and indirect effects. The renowned direct effects of technology adoption include productivity gains and per unit cost reductions. These two translate into increase in incomes that subsequently lead to poverty reduction. Indirectly the technologies can reduce poverty through reduced food prices and growth of related non-farm sectors that benefit through availability of raw materials.

Some studies in countries in Asia and Latin America have estimated that the use of improved seeds can increase yields and farmers' income (de Janvry and Sadoulet, 2001; Evenson and Gollin, 2003; Doss, 2006; Matuschke and Qaim, 2009). However, these kinds of studies are relatively few in Africa (Kassie et al., 2011). However, some studies have shown contradicting information on the effects of technology adoption. For example, Hossain et al. (2006) found that adoption of rice varieties that are high yielding has a positive effect on the richer households, but a negative effect on the poor households. Others observed that the adoption of high yielding maize varieties increased the crop incomes of adopters moderately (Bourdillon et al., 2002). Howard et al. (2003) also, found non-significant difference in income between farmers using improved maize seeds and traditional seeds after payment of the input loans acquired through Sasakawa-Global project in Mozambique. The disagreement of these findings clearly justifies the need for further research on this topic in Africa.

The generated information will guide governments on policy on adoption of technologies and donor community on supporting promotion and dissemination of such technologies. The present study, therefore, is the first attempt to quantify the benefits of adoption of DroughtTEGO® on maize income, household income and livelihoods improvement.

METHODOLOGY

Surveys and data

The data for this analysis came from 642 maize farmers in Kenya. A multi-stage, clustered, randomized sampling procedure was used. Although maize is grown in most parts of Kenya, this study focused on four project regions namely: Western Kenya, South Rift, Central Highlands, Upper Eastern and Lower Eastern (Figure 1), where DroughtTEGO® commercialization activities were implemented. Partly due to logistical and statistical considerations, the decision was taken to interview proportionate maize farmers in each of the five focus regions, giving 642 maize farmers. The number of farmers interviewed in each region was determined by the maize production statistics in the area and the population. Within the regions, one to two counties were selected randomly (Table 1) for the study.

Probability Proportional to Size (PPS) sampling technique using the number of counties per region as strata was applied to arrive at sample size per region. Within each identified county, a sub-county was randomly sampled. At the regional level, farmers were sampled from sub-counties with significant maize production based on figures from the statistical unit of the Ministry of Agriculture, Livestock and Fisheries (MoALF) and AATF. In some instances, due to unavailability of sampling frames, the households were randomly sampled through random transect walks. At the sub-county level, one administrative location was selected purposively, and villages selected with the help of AATF field staff and county

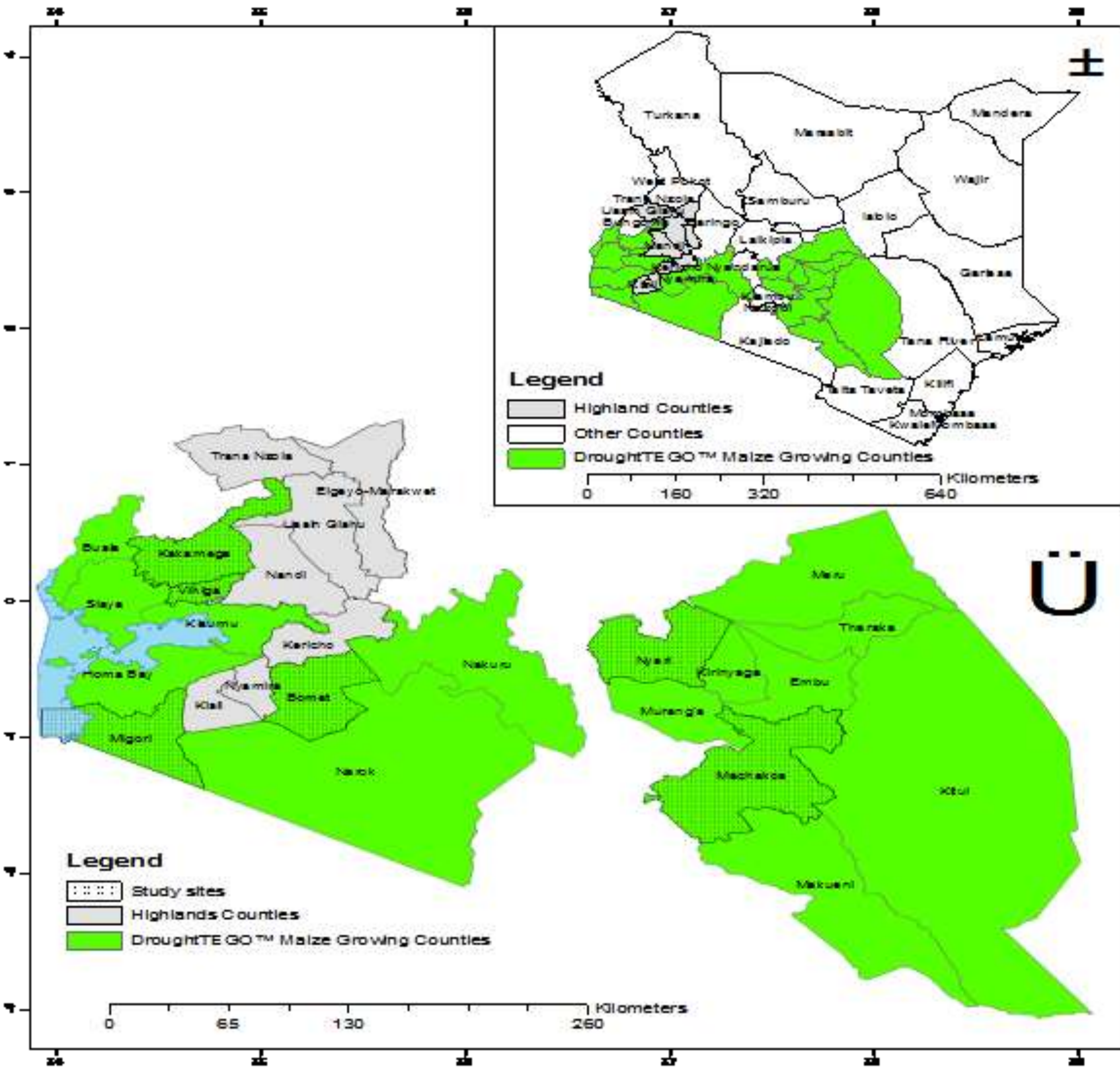


Figure 1. Map showing the DroughtTEGO® growing counties and the study area sites.
Source: This study (2017).

officials. To enhance data validity and reliability, intensively trained enumerators using a questionnaire developed by the researcher interviewed farmers. The interviews were conducted in January 2017. To maintain uniformity, data from all regions were transmitted to a host server where they were checked daily. The study utilized the Open Data Kit (ODK) whereby data was collected on a mobile device and transmitted to an aggregation server. The household-level data collected included gender, age and education level of farmer, household size, and membership to a farmers' organization. Additional information collected was accessibility to extension services, and knowledge of varieties planted by each farmer. Farm-level variables collected included size of the farm, crops grown, soil quality, distance of irrigation water source, type of maize seeds used by farmers, access to information on DroughtTEGO® maize seeds, methods of technology transfer; and advantages and drawbacks of using DroughtTEGO® maize seeds, food consumption and food security; and perceptions of changes in farm productivity and income.

Global Positioning System (GPS) was used to capture the precise location/coordinates of the sampled households and hence digitally mapped all the households/villages visited in the survey. Key stakeholders consulted included county officials, MoALF staff, AATF field staff, farmers hosting maize demonstration sites and agro-dealers.

Conceptual framework

The basic question in impact assessment is whether observed differences in maize income, total household income and poverty levels between adopters and non-adopters could be attributed to the use of DroughtTEGO® maize hybrid seeds. This situation cannot be directly observed at household level, but it is possible to approximate it by constructing an appropriate counterfactual. This

Table 1. Regional distribution of DroughtTEGO® adoption by farmers in four regions in Kenya

Region	Counties	Sampling sub-counties	Sample size based on county proportion
South Rift	Bomet	Bomet	102
Western	Vihiga	Sabatia	75
	Migori	Rongo	135
	Kakamega	Kakamega	60
Central Lower Eastern	Nyeri	Mukurweini	170
	Machakos	Kangundo	100

Source: This study (2017).

study addresses this issue of counterfactual using propensity score methods (PSM). The basic concept behind the PSM is to match observable characteristics of both adopters and non-adopters according to the estimated propensity score (Köhler et al., 2016). The prominent features of the PSM are the ability to create conditions of randomized experiment designs to evaluate a causal effect as in a controlled experiment. The idea is to compare individuals who, based on observables, have a very similar probability of receiving treatment (similar propensity score), but one of them received treatment and the other did not, i.e. PSM constructs comparison groups by matching every individual household observation of adopters with an observation household with similar characteristics from the group of non-adopters.

The PSM have several useful features: no baseline data are required. It ensures comparison of the outcome variables between adopters and non-adopters that have overlapping or similar observable characteristics as predicted by propensity scores (Dehejia and Wahba, 2002). It takes covariates to be independent of the use of the technologies under consideration when comparing sample of the population of households with similar characteristics allowing causal interpretation of the results. Unlike the Heckman and instrumental variable (IV analytical frameworks), PSM does not require either distributional, parametric or linearity assumptions because the model assumes that the conditions set in matching the observable characteristics eliminate sample selection bias (Heckman and Navarro-Lozano, 2004). Again, the PSM approach has added advantage as compared to commonly used impact assessment methods that suffer from what is referred to either as overt, hidden biases or non-compliance.

Overt bias occurs due to differences in observable characteristics between adopters and non-adopters not caused by technology adoption. Hidden bias, on the other hand, occurs due to unobservable characteristics that are inherent. Non-compliance, also referred to as endogeneity in econometrics, arises because the adoption of a variety is a farmer choice and we cannot assign treatments randomly.

Analytical model

Let $P_i = 1$ denote a dummy variable such that the i^{th} household adopts DroughtTEGO® seeds and $P_i = 0$ otherwise. Similarly let Y_{1i} *and* Y_{2i} denote potential observed outcomes (maize income, total household income, and poverty indices) for adopter and non-adopter units, respectively. Therefore, $\Delta = Y_{1i} - Y_{2i}$ is the impact of the technology on the i^{th} household, called treatment effect.

However, because we only observe $Y_i = P_i Y_{1i} + (1 - P_i) Y_{2i}$ rather than Y_{1i} *and* Y_{2i} for the same household, it is apparent that we cannot compute the treatment effect for every individual. Thus, the primary treatment effect of interest is given by:

$$\pi = E(Y_{1i} - Y_{2i} / P_i = 1) \tag{1}$$

This is commonly referred to as the average effect of the treatment on the treated (ATT). Following Rosenbaum and Rubin (1983), the propensity score (PS) can be estimated as:

$$PS(X) = PS(Y_i = 1 / X) \tag{2}$$

Where X is a vector of pre-treatment covariates, which include variables that affect both adoption and outcomes variables. These variables are listed in Table 2 as dependent and independent variables.

The ATT can then be estimated as:

$$\begin{aligned} \pi &= E(Y_{1i} - Y_{2i} / P_i = 1) \\ &= E\left[E(Y_{1i} - Y_{2i} / P_i = 1, PS(X))\right] \\ &= E\left[E(Y_{1i} / P_i = 1, PS(X)) - E(Y_{2i} / P_i = 0, PS(X))\right] \end{aligned} \tag{3}$$

According to Smith and Todd (2005), matching should be conducted on variables that influence both treatment assignment and outcomes and should not be affected by the treatment. Hence, the independent variables used in our case are as the ones used in the adoption models. In general, a larger set of variables is preferred to reduce the effects of unobservable variables. These variables are used to find a suitable counterfactual group, that is, given the outcome variable for household who uses the improved technology, the model allows a comparison with the same outcome variable for household that did not use the technology but has very similar characteristics (independent variable). A probit model was applied however; in principle, any discrete choice model can be used.

Several matching methods can be utilized to match adopters with non-adopters with similar propensity scores. These matching methods include Nearest Neighbor Matching (NNM), Caliper and Radius Matching (CRM), Kernel-Based Matching (KBM), Local Linear Matching (LLM), spline matching and Mahalanobis distance matching estimators. The basic idea is to numerically search for closest "neighbors" of adopters that have a propensity score that is very close to the propensity score of the non-adopters and vice-versa. The most commonly applied matching estimators are NNM, CRM and KBM methods. In our case, NNM and CRM are utilized.

Table 2. Variables description for DroughtTEGO® varieties adoption studies.

Variable	Units	Definition
Treatment variable		
ADOPT	Dummy	1, if household adopted any DroughtTEGO® varieties; 0, otherwise
Outcome variable		
MAINCOME	$USD/kg	Total maize income per kg of seed used
TOINCOME	$USD	Total household annual gross income
HEADCOUNT	Number	1, if household per capita income is below poverty line; 0, otherwise
POVERTYGAP	$USD	Difference from/to the poverty line
Independent variables		
Demographic characteristics		
AGE	Year	Age of household head (years)
AGESQ	Year	Age of household head squared (years)
EDUCATION0	Dummy	1, Household head with no formal education; 0, otherwise
EDUCATION1	Dummy	Household head with primary education; 0, otherwise
EDUCATION2	Dummy	Household head with secondary education; 0, otherwise
EDUCATION3	Dummy	Household head with > secondary education; 0, otherwise
GENDER	Dummy	1, if the household head is male; 0, otherwise
HHSIZE	Number	Number of family members living in the household in adult equivalent (count)
FARMWORKER	Number	Number of adults working in the farm (count)
DRATIO	Number	Dependency ratio (proportion over 64 and under 18years of age (%)
Access to information		
EXTENSION	Dummy	1, if main source of information is government extension; 0, otherwise
FARMER	Dummy	1, if main source of information is another farmer; 0, otherwise
DEMOS	Dummy	1, if main source of information demonstration and field trials; 0, otherwise
RADIO	Dummy	1, if main source of information is radio; 0, otherwise
Asset endowment		
FARMSIZE		Farm size (ha)
Other variables		
RECORD	Dummy	1, if the household keeps farm records; 0, otherwise
WOMEN	Dummy	1, if women control household resources; 0, otherwise
FOODSEC	Rate	Rating of food security in the last 1 years
PRICE	Dummy	1, if farmer perceives the DroughtTEGO® seed to be expensive; 0, otherwise
County dummies		
Bomet	Dummy	1, if the farmer is in Bomet; 0, otherwise
Vihiga	Dummy	1, if the farmer is in Vihiga; 0, otherwise
Migori	Dummy	1, if the farmer is in Migori; 0, otherwise
Kakamega	Dummy	1, if the farmer is in Kakamega; 0, otherwise
Nyeri	Dummy	1, if the farmer is in Nyeri; 0, otherwise
Machakos	Dummy	1, if the farmer is in Machakos; 0, otherwise

Source: Survey results (2017).

Nearest neighbor, matching method matches adopters with non-adopter with the nearest propensity scores. However, NNM faces the risk of bad matches, particularly if the closest neighbor is far away. To overcome this problem one can use the second alternative matching algorithm called CRM matching. Caliper and radius matching use a tolerance level on the maximum propensity score distance (caliper) to avoid the risk of bad matches. Essentially, all matching methods should give the same or similar results, but in practice one must consider trade-offs in terms of bias and efficiency with each method.

Variables

The dependent variable is a dummy variable that take value one (1) if household planted any DroughtTEGO® varieties and the value zero (0) if none was planted. The outcome variables of interest in this study are maize income (MAINCOME), total household income

(TOINCOME) and poverty indicators.

Maize income per kilogram of maize seed planted (MAINCOME) is taken to be a proxy for agricultural productivity. This is because most of the farmers in the study regions plant several crops in one plot (intercropping) making it complex and hard to quantify area allocated for maize production. Farmers intercrop maize with other crops such as beans, pigeon pea, groundnuts, cowpeas, sweet potatoes, soybeans, nappier grass, among others. Maize income was calculated as total maize revenue minus variable costs divided by amount of seed planted (maize income in $USD/kg).

Total household income (TOINCOME) was calculated as the value of all household production arising from both crop and animal production, minus variable costs and off farm income. The Foster-Greer-Thorbecke poverty index (FGT) is used in the analysis of the headcount poverty index (HEADCOUNT) and the poverty gap (POVERTYGAP). The below FGT poverty formula was utilized:

$$P_{\alpha} = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{z-y_i}{z}\right]^{\alpha} \quad P_{\alpha} = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{z-y_i}{z}\right]^{c} \tag{4}$$

Where, n is the number of households in the sampled population, z refers to the poverty line, y is the per capita income for the i^{th} person. α is the poverty aversion parameter, α ≥ 0 which takes values 0, 1 and 2 for poverty incidence, poverty depth and poverty severity, respectively. When α = 0, Pα gives the incidence of poverty (HEADCOUNT) or the proportion of people that are poor. When α = 1, then Pα gives the depth of poverty (POVERTYGAP) that is, the difference between per capita income per day to the poverty line. When α = 2, P α is a measure of severity of poverty and reflects the degree of inequality among the poor.

A dummy variable which takes the values 0 or 1 (denoting whether the individual/household income lies below the poverty line or not (that is, ‘poor’ = 1 and 0 otherwise) is used in the analysis. Due to none existence of poverty line income in Kenya, international standard of US$ 1.25/ capita/ day is used as a poverty line benchmark (World Bank, 2017). The per capita household income is calculated as the sum of total income divided by the number of household members.

Based on previous hypotheses from the literature, the independent variables utilized to find a suitable comparison group includes age of the household head and its square (AGE, AGESQ), education (EDUCATION), gender of the household head (GENDER), and dependency ratio (DRATIO). Labor availability is included by considering both available family labor (HHSIZE) and number of adult members working in the farm (FARMWORKER). Access to information on improved technologies is captured through contacts with extension officers (EXTENSION), other farmers as main source of information (FARMER), demonstrations (DEMOS), and RADIO variables. Lack of access to cash or credit can significantly limit the adoption of improved technologies hence asset endowment was included through total land size (FARMSIZE). Other variables included were record keeping (RECORD), food security in the last two years (FOODSEC), women control of the household resources (WOMEN), perception of seed prices (PRICE) and county dummies.

Before estimation, all the above variables were cross- checked for the commonly known econometric problems such as multi-collinearity done through the simple correlation matrix and variance inflation factor (VIF). VIF were by far less than 10, indicating that correlation between explanatory variables could not affect the results. An absolute value close to one means that strong correlation exists. VIF value of greater than 10 is an indication of potential serious multicollinearity (Ringle et al., 2015). Similarly, for endogeneity checks none of the independent variables was suspected to be explained within the equation it was utilized.

To ensure the robustness of the estimated average effect, the sensitivity of the estimates to hidden bias was conducted using the Rosenbaum bounds test. Plausibility of the covariates was also assessed by re-estimating the propensity score on the matched sample, for adopters and matched non-adopters and pseudo-R^2 was then compared to that of before and after matching. Again, the distribution of the estimated propensity scores before and after the matching was plotted for visual assessment. Differential adoption by county was also assessed to account for perceived heterogeneous impacts at county level.

RESULTS AND DISCUSSION

Descriptive statistics

Average maize net income was computed at 49.96 $USD/ 90kg (Ksh 4,996/ kg), where the adopters had 82% significantly higher income than the non-adopters (Table 3). Again, the comparison between adopters and non-adopters on total household income also showed that adopters reported statistically higher net income (21%) as compared to their counterpart.

Based on the poverty line, the average poverty headcount was 0.83, implying that 83% of the households in the study area lived in dire poverty. Non-adopters were relatively poorer than the average, with poverty headcount higher by 1% point, thus adopters were less poor than the non-adopters were. A closer look at the data showed extremely high poverty rate in Migori (94%), while the lowest poverty rate was observed in Nyeri (70%).

Results further indicate that 26% of the maize farmers adopted 1–6 DroughtTEGO® maize varieties. However, after accounting for the non-exposure bias arising from the farmers who were not aware of these varieties, the adoption rate rose to about 42%.

Significant difference at 1% was found between DroughtTEGO® adopters and non-adopters regarding age, indicating that adopters are relatively older than their non-adopters by 4%. This finding suggests that DroughtTEGO® adoption was positively correlated with age. Older farmers are more likely to use improved technologies when age is taken as a proxy for experience. In this case, it is assumed that with age farmers get more experience with new technologies and are likely to adopt the new technologies more efficiently. However, there is a certain age beyond which, farmers’ ability to take risk and engagement to unknown technologies and innovations tend to decrease. Age of the household head in other studies does not show a consistent pattern in this regard on technology adoption (Rogers, 2003).

Quite interesting was the insignificant difference between adopter and non-adopter regarding levels of education, suggesting that DroughtTEGO® adoption was uncorrelated with education. Some studies have shown that education is highly associated with timing of adoption rather than with the technology adoption itself (Weir and Knight, 2000).

Table 3. Characteristics of DroughtTEGO® varieties adopters and non-adopters, summary statistics before matching in Kenya.

Variable	Full sample n = 642		Non-adopters n = 476		Adopters n = 166		Difference
	Mean	S. E	Mean	S. E	Mean	S. E	
Outcome							
MAINCOME	49.96	3.84	38.08	3.88	69.29	7.45	31.11***
TOINCOME	680.33	45.22	641.43	45.61	773.61	107.85	133.25**
HEADCOUNT	0.82	0.02	0.83	0.02	0.82	0.03	0.02
POVERTYGAP	-0.28	0.05	-0.29	-0.05	-0.26	-0.13	-0.03
Independent							
AGE	49.40	0.55	48.89	0.66	50.88	0.98	-2.00*
AGESQ	2,634.42	56.56	2,594.82	67.67	2,747.71	100.89	-152.89
EDUCATION0	0.08	0.01	0.08	0.01	0.06	0.02	0.02
EDUCATION2	0.47	0.02	0.45	0.02	0.51	0.04	-0.05
EDUCATION2	0.34	0.02	0.34	0.02	0.33	0.04	0.01
EDUCATION3	0.11	0.01	0.12	0.10	0.02	0.02	0.02
GENDER	0.83	0.01	0.82	0.02	0.87	0.03	-0.06*
HHSIZE	5.96	0.23	5.67	0.25	6.79	0.29	-2.22**
FARMWORKER	2.28	0.06	2.23	0.06	2.72	0.23	-0.58***
DRATIO	42.45	2.02	42.93	2.23	42.06	2.83	2.86
EXTENSION	1.00	0.00	1.00	0.00	1.00	0.00	
FARMER	0.39	0.02	0.43	0.02	0.27	0.02	0.17***
DEMOS	0.11	0.01	0.09	0.01	0.18	0.01	-0.09***
RADIO	0.05	0.01	0.04	0.01	0.08	0.02	-0.04*
FARMSIZE	2.28	0.09	2.26	0.11	2.35	0.19	-0.09
RECORD	0.11	0.01	0.09	0.01	0.17	0.03	-0.09***
WOMEN	0.59	0.02	0.59	0.02	0.60	0.04	-0.01
FOODSEC	1.75	0.04	1.58	0.04	2.22	0.07	-0.63***
PRICE	0.06	0.01	0.05	0.01	0.08	0.02	0.04*
Bomet	0.16	0.01	0.18	0.02	0.10	0.02	0.08***
Vihiga	0.12	0.01	0.08	0.01	0.23	0.03	-0.15***
Migori	0.21	0.02	0.22	0.02	0.19	0.03	0.03
Kakamega	0.09	0.01	0.04	0.01	0.23	0.03	-0.19***
Nyeri	0.26	0.02	0.28	0.02	0.22	0.03	0.06*
Machakos	0.16	0.01	0.20	0.02	0.04	0.01	-0.16***

SE - robust standard errors, statistically significant at the 0.01 (***), 0.05 (**), 0.10 (*) level of probability (t-test are used for differences in means).
Source: This study (2017).

The data also indicated that there were significant differences in terms of gender, with about 87% of the adopters being male headed households as compared to 82% of the non-adopters. It is generally, acknowledged that male-headed households have more likelihood of getting information about new developments and are more likely to take on risky businesses as compared to their female-headed counterparts.

As expected, adopters had a significantly higher active family labor force than the non-adopters as indicated by the family size (20% higher) and number of adults who work in the farm (27% higher). This may imply timeliness in activities such as planting, weeding and harvesting, which are normally done at times of peak demands. Additionally, it could imply that the higher the number of persons per household, the more numbers of mouths to feed and the more likelihood to adopt new techniques likes the use of drought tolerant varieties to guarantee better production.

Similarly, adopters also extensively kept records (17%) as compared to non-adopters (9%). In general, record keeping of production activities enables a farmer to increase profits through better farm planning and early identification of problems in the production chain. We

Table 4. Probit estimates of the propensity score matching for DroughtTEGO® varieties adoption studies.

Variable	CRM matching		NNM matching	S.E.
	Estimated coefficients	S.E.	Estimated coefficients	
AGE	0.00	0.01	0.00	0.01
EDUCATION1	0.55	0.41	0.55	0.41
EDUCATION2	-0.01	0.38	-0.01	0.38
GENDER	0.23	0.41	0.23	0.41
HHSIZE	-0.01	0.05	-0.01	0.05
FARMWORKER	0.30	0.11***	0.30	0.11***
DRATIO	0.01	0.01**	0.01	0.01**
EXTENSION	-1.18	0.50*	-1.18	0.50*
FARMER	-0.65	0.36*	-0.65	0.36*
DEMOS	-0.34	0.42	-0.34	0.42
RADIO	0.20	0.48	0.20	0.48
FARMSIZE	0.01	0.08	0.01	0.08
RECORD	0.02	0.34	0.02	0.34
WOMEN	0.14	0.28	0.14	0.28
FOODSEC	0.21	0.80	0.21	0.80
PRICE	0.13	0.61	0.13	0.61
BOMET	-1.63	0.52***	-1.63	0.52***
VIHIGA	-0.09	0.40	-0.09	0.40
MIGORI	-1.17	0.40***	-1.17	0.40***
NYERI	-0.68	0.41*	-0.68	0.41*
Constant	-1.65	1.17	-1.65	1.17
Summary statistics				
McFadden R^2	0.22		0.22	
Model chi-square	41.80 ***		41.80 ***	
Log likelihood ratio	-75.54		-75.54	

SE - robust standard errors, statistically significant at the 0.01 (***), 0.05 (**), 0.10 (*) level of probability (t-test are used for differences in means).
Source: This study (2017).

observed significant differences in the source of information; particularly those who accessed through neighboring farmers' demo sites and radio were higher amongst adopters than the non-adopters were. Information about a new technology is a prerequisite for adoption. Information generally improves understanding, reduces the uncertainty about new technologies, and can change individual's perception from subjective to objective assessment.

We uncovered no significance difference in farm size between the adopters and non-adopters; suggesting that adoption of DroughtTEGO® is not dependent on farm size. However, this contrasts with the findings of Diagne and Demont (2007) who reported a significant difference between technology adopters and non-adopters in terms of farm size. It is important to note that the current study targeted small-scale farmers, the majority of whom have small land holdings (2.28 acres on average). For this reason, one should not expect highly significant differences in land size between adopters and non-adopters.

However, it is essentially important to remember that these comparisons of mean differences may not be the result of technology adoption, but instead may be due to other factors, such as differences in household characteristics, which may confound the impact of the technologies on the said outcome variables (Macharia et al., 2013). Additionally, because adoption is endogenous, that is a factor in a causal model or causal system whose value is determined by the states of other variables in the system contrasted with an exogenous variable, no causal interpretation could be done at this point. Therefore, further analysis was conducted (Table 3).

Propensity scores estimations

The results of the propensity score matching are reported in Table 4. As indicated earlier, the propensity scores procedure only serve as a framework for balancing the observed distribution of covariates across the treated and the untreated groups. In general, the results are consistent with our expectations and the models fit the data reasonably well. The models also have good explanatory powers (Table 4).

Among the covariates, number of people working on the farm, dependency ratio, government extensions and other farmers being the main source of information of new seeds, among others, were statistically associated with propensity to adopt DroughtTEGO® maize hybrid seed. In contrast, important variables, such as age of household head, dummy for level of education, and farm size were not related to DroughtTEGO® hybrid maize adoption. The distribution of the propensity scores and the region of common support were plotted; most of the treatment households are on the right side, while most of untreated (control) households are on the left side of the distribution (Figure 2). In general, the graph shows that there was substantial overlap and similarity among the adopters and non-adopters. Thus, the common support condition imposed satisfies the balancing property.

Table 5 reports results from covariate balance testing before and after matching procedure. It is important to note that the probability values of the likelihood ratio tests failed to reject the joint significance of covariates before matching. However, after matching it is rejected, an indication that the specification of the propensity score estimation process was successful. The pseudo-R^2 also dropped significantly from 23% before matching to about 10-12% after matching, suggesting that the matching procedure was successful in terms of balancing the distribution of covariates between the adopters and non-adopters (Sianesi, 2004).

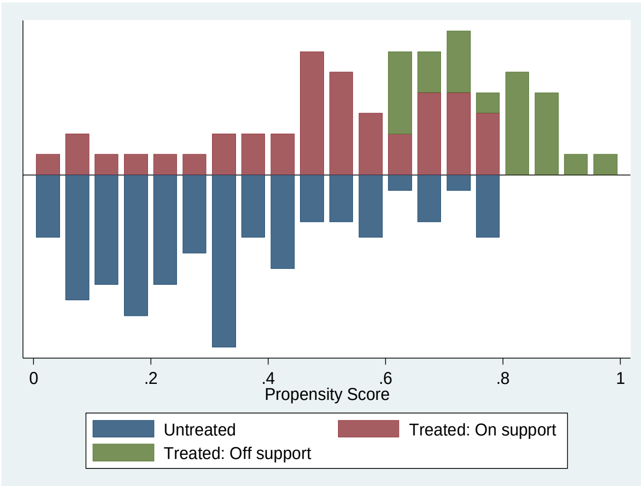
Impact of DroughtTEGO® hybrid using AVERAGE ADOPTION EﬀECT

Evidence from findings reveals that different matching algorithms produce different quantitative results, but the qualitative findings were similar (Table 6). The results indicate that the use of DroughtTEGO® hybrids significantly increased maize income, total household income by 75-82% and reduced poverty gap from 0.54 $USD (Ksh 54) to 0.8 $USD (KSh 80). The nearest neighbor based matching technique gives the highest maize income differentials of 49%, whereas the radius-based matching gives the lowest value (39%). Similarly, adoption increases total income by about 45% and reduces the depth of poverty by about 51 point using radius estimators. Deeper analysis indicates high and positive correlation between maize income and total household income (0.54) supporting the idea of poverty reduction. However, it is important to note that though the adoption of DroughtTEGO® hybrid reduces the depth of poverty, it hardly helps them in the short-term, within three years of adoption, to move beyond the poverty line as no statistically significant effect could be observed on poverty head count.

The above findings are consistent and in tandem with reported studies of impact of modern crop varieties on household welfare. For example, studies by Hossain et al. (2006) and Mendola (2007) in Bangladesh, Janaiah et al. (2006) in India and Wu et al. (2010) in China all indicated that the adoption of improved crop varieties had a significant negative impact on poverty status. Study by Becerril and Abdulai (2010) found significant increase in per capita expenditure and reduced poverty by improved maize adopters in Mexico. Kijima et al. (2008) also showed that NERICA rice adoption reduces poverty, without decline in income distribution, in Uganda. Tiwari et al. (2010) found that maize varietal interventions in Nepal increased food availability with greater benefits going to poor farmers compared to their rich counterparts. To get more understanding of the impact of DroughtTEGO® use on diﬀerent groups of adopters, we also examined the diﬀerential impact of adoption based on county. The analysis is based on matched samples obtained from nearest neighbor matching estimators. These results showed that some opposite effects were observed among counties, which were not visible in the overall sample average. The effects on maize incomes were higher for the DroughtTEGO® hybrid users across the counties, except in Bomet and not statistically different in the case of Machakos. In terms of total income, only Nyeri and Kakamega showed significant gains while adopters seemed to get similar income in other counties. With respect to poverty reduction, the picture is clear in that it seemed adopters were above poverty line except in Vihiga, hence the overall non-significant effect of adoption on head count was linked to this county.

Farmers perception of change in the household's food security

During the survey, attention was paid to the perception of change in the household's food security over the three years of technology commercialization. Overall, a larger number of households reported improved rather than worsened food security (Figure 3). DroughtTEGO® adopters had a higher proportion (54%) of households indicating that their food security had improved over the last three years, as compared to their non-adopters (22%). Similarly, the percentage of households that reported worsened food security was higher for non-adopters (63%) and the difference was statistically significant at p value of 0.005. The above results were well backed-up by the maize income, which was 81% higher for adopters compared to non-adopters (Table 6). These positive results could be due to the adoption of the



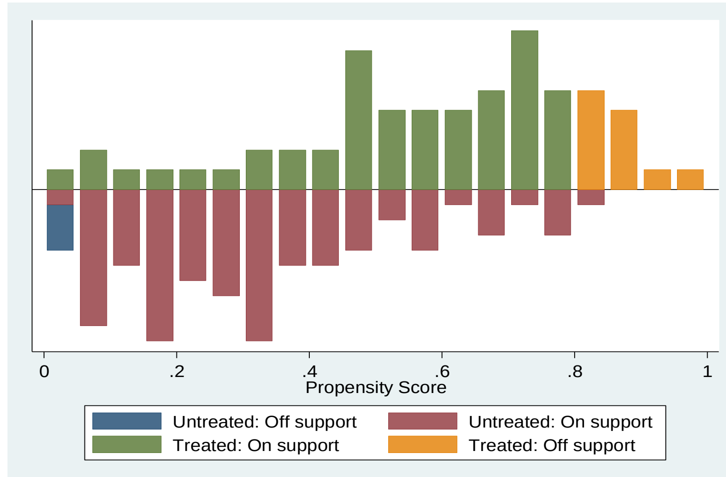


Figure 2. Propensity score distribution and common support for CRM and NNM propensity score estimation[1] respectively.
Source: This study (2017).

Table 5. Matching quality indicators before and after matching for DroughtTEGO® varieties adoption studies in Kenya.

Matching algorithm	Pseudo R^2		LR X^2(p – value)	
	Before matching	After matching	Before matching	After matching
CRM	0.23	0.10	45.05 (p = 00)***	11.53 (p = 0.93)
NNM	0.22	0.12	41.80 (p = 00)***	15.98 (p = 0.72)

SE - Robust standard errors, statistically significant at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability (t-test are used for differences in means).
Source: This study (2017).

Table 6. Maize income, total household income and incidence of poverty after matching.

Method	Outcome	Measurement	Adopters	Non- adopters	Difference=average treatment effect on the treated (ATT)
CRM	MAINCOME	$USD	79.76	48.57	31.19**
	TOINCOME	$USD	912.97	504.83	408.14*
	HEADCOUNT	%	0.85	0.92	-0.07
	POVERTYGAP	$USD	-0.04	-0.56	0.51*
NNM	MAINCOME	$USD	79.47	39.42	40.05**
	TOINCOME	$USD	889.04	524.45	364.59*
	HEADCOUNT	%	0.86	0.92	-0.06
	POVERTYGAP	$USD	-0.12	-0.52	0.40*
AVERAGE	MAINCOME	$USD	79.62	43.99	35.62**
	TOINCOME	$USD	901.00	514.64	386.36*
	HEADCOUNT	%	0.86	0.92	-0.07
	POVERTYGAP	$USD	-0.08	-0.54	0.46*

SE - robust standard errors, statistically significant at the 0.01 (***), 0.05 (**), 0.10 (*) level of probability (t-test are used for differences in means).
Source: This study (2017).

[1] Treated on support indicates the individuals in the adoption group who find a suitable match, whereas treated off support indicates the individuals in the adoption group who did not find a suitable match and Untreated indicates non-adopters.

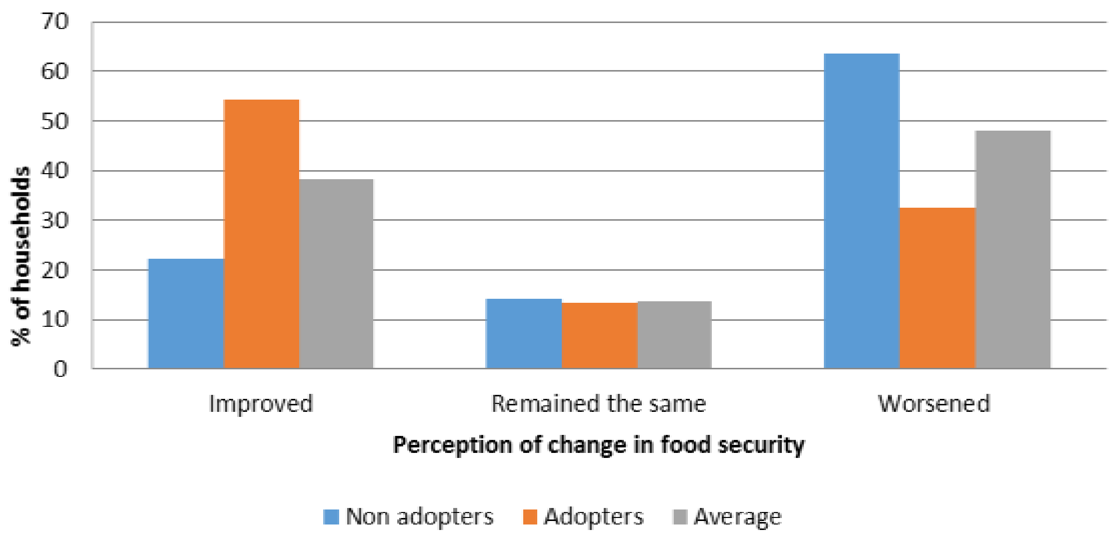


Figure 3. Perception of change in food security over the previous three years.
Source: This study (2017).

drought tolerant maize seed under promotion, supporting the widely held view that adoption of technologies is crucial to food security and poverty alleviation in rural areas of developing countries. In most African settings, a household is considered food secure if it has enough of the popular staple food.

CONCLUSION AND POLICY IMPLICATIONS

Our findings demonstrate a direct causal link on total household income, maize income and poverty status from adoption of DroughtTEGO® maize varieties in rural Kenya. The PSM techniques used in the analysis allowed us to construct an adequate counterfactual for the comparison of farmers according to their adoption status. The causal impact estimation from PSM showed, among other things, that the use of DroughtTEGO® seeds had the potential to increase maize income by 81%, total household income by 75% and reduce the depth of poverty by 46-point margins. Nevertheless, the magnitude of this effect was not yet enough to lift these farmers' above the poverty line in the short-term of three years, hence no change in poverty headcount was observed. Notable findings differentiated by County showed that maize income gains were more pronounced in Vihiga, but it hardly helped them to overcome the poverty line due to large household sizes.

These findings suggest that the use of DroughtTEGO® might have a role in improving household wellbeing through the increase of agricultural income and consequently ability to escape poverty. The study recommends the formulation and implementation of appropriate policies that could improve the adoption of DroughtTEGO® hybrid maize varieties. Further analysis with panel data captured over several years will also be useful to measure the actual change in poverty levels that could be attributed to DroughtTEGO® varieties adoption.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effect of pesticides on Exopolysaccharide (EPS) production, antibiotic sensitivity and phosphate solubilization by Rhizobial isolates from *Sesbania bispinosa* in Bangladesh

Tania Sultana, Anowara Begum and Humaira Akhter*

Department of Microbiology, University of Dhaka, Dhaka-1000, Bangladesh.

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***Rhizobium spp*. retains a symbiotic relationship with leguminous plants including *Sesbania bispinosa* by fixing N_2 through nodule formation. Several researches suggest that Exopolysaccharides (EPSs) are required for nodule formation. Rhizobial growth parameters as well as the EPS production are affected by the presence of pesticides. The present investigation was performed using three different pesticides which were Imitaf 20SL (Insecticide), Tafgor 40EC (Insecticide) and Tilt 250EC (Fungicide). Production of EPS was exceptionally increasing with the escalating concentrations of pesticides. The effects of pesticides were also observed on the antibiotic resistance of these organisms. Some gained resistance against Kanamycin while some got more sensitive than before. Detection of *nod*C gene and *nif*H gene ensured the fact that they are the residents of rhizobia bacteria. This study uncovers the fact that extensive use of pesticides may cause an unfavourable environment for survival of rhizobia and a decrease in EPS production resulting in poor N_2 fixation and thus affecting the whole agricultural economy of a country.**

Key words: Pesticides, Rhizobia, exopolysaccharide, symbiosis, *Sesbania bispinosa*, antibiotics.

INTRODUCTION

Sesbania is a well-known plant in Bangladesh for its varied uses and a member of the 'Fabaceae' family (Sarwar et al., 2017). Most of the species of this genus can nodulate in a symbiotic manner and take part in the nitrogen fixation process. Among them, *Sesbania bispinosa* (locally known as 'Dhaincha') can grow at a fast rate in the swampy and saline environment compared to other legumes, possessing high ability to fix a large amount of N_2 greater yield (Ladha et al., 1988; Ventura and Watanabe, 1993). Since Bangladesh is a

*Corresponding author. E-mail: humaira@du.ac.bd.

ABBREVIATIONS: EPS, Exopolysaccharide; **SL,** soluble liquid; **EC,** emulsifiable concentrate; **nod,** nodulation; **nif,** nitrogen fixation.

riverine country and has suitable weather to grow dhaincha, farmers have been cultivating it for a long time to increase the organic content of the soil (Sarwar et al., 2017). In addition to being used as green manure, dhaincha can be used as food for animals, a raw material for pulp production, wood for fuel (Shahjalal and Topps, 2000; Sarkar et al., 2017). So in the context of Bangladesh’s climate, dhaincha has become more important to farmers to get its versatile advantages.

In case of *Sesbania bispinosa* and rhizobial symbiotic relationship, a variety of rhizobia induces nodulation represented by the genera such as *Rhizobium, Sinorhizobium, Agrobacterium, Mesorhizobium* and *Bradyrhizobium* (Dreyfus et al., 1988; Ribeiro and Burkert, 2016). When rhizobia invade root cells of the host plant, they form nodules where they fix atmospheric nitrogen (Lepek and D’Antuono, 2005). The rhizobia legume symbiosis starts with the secretion of flavonoids (chemical attractant for rhizobia) which are excreted by the host plant root cells (Brencic and Winans, 2005). While rhizobia start synthesizing and secreting Nod factors, the root cells of the host plant initiate root curling. After trapping into the curled root hairs, rhizobia begin invading these nodules through EPS production (Philip-Hollingsworth et al., 1989; González et al., 1996; Mukherjee et al., 2011). So, EPSs are thought to play a crucial role in the invasion process. Mutants lacking the ability to produce EPSs are unable to invade the root nodules although they could induce nodule formation (González et al., 1996; Janczarek et al., 2014).

Generally, exopolysaccharides impart mucoid appearance to bacterial colonies grown on laboratory agar media (Nwodo et al., 2012). Exopolysaccharides are high molecular weight polymers which are made up of homopolysaccharides or heteropolysaccharides units. The composition of EPSs produced by rhizobial strains includes glucose, galactose, mannose, rhamnose, glucuronic acid and galacturonic acid (Gupta and Diwan, 2017).

It has been observed that EPS production and the whole symbiotic relationship gets disturbed by the harmful influence of pesticides (Ahemad and Khan, 2013). Pesticides keep the plants safe by controlling pests and preventing diseases caused by the pests but in some cases, they cause great damage to the surrounding microflora, plant growth and other factors (Gupta et al., 2014). So the present study focuses on the impact of pesticides on rhizobia especially on their EPS production along with other factors.

MATERIALS AND METHODS

Sample collection

Root samples from *S. bispinosa* were collected from different regions of Bangladesh. The samples contained both nodules and rhizospheric soil. These were further processed for isolating rhizobial strains and tagged as R1 to R44. Forty-two isolates (except R33 and R34) were studied for further biochemical tests.

Isolation and identification of rhizobia

At first, the nodules were washed thoroughly and separated from the roots by using sterile forceps. The undamaged nodules were submerged in 95% ethanol (5-10 seconds) to break the surface tension. Then, they were transferred to 3% H_2O_2 and allowed to soak for 2-3 min. After that, the nodules were rinsed in 5 to 6 changes of sterile distilled water so that there was no trace of H2O2 solution. Finally, these sterilized nodules were crushed down with a sterile glass rod with the addition of drops of sterile water. From this suspension, one loop full of suspension was inoculated on pre-sterilized Yeast Extract Mannitol Agar (YEMA) and then incubated at 28±2°C for 18 to 24 h.

Biochemical characterization

Different types of biochemical tests were performed to identify the rhizobial isolates. These tests include growth on CR-YMA agar meaning yeast extract mannitol agar with Congo red (Kneen and La Rue, 1983), starch hydrolysis test (de Oliveira et al., 2007; Bhattacharya et al., 2013), catalase and oxidase test, citrate utilization test (Simmons, 1926), MIU (Motility, Indole And Urease) test, phosphate solubilisation test (Pikovskaya, 1948), ammonia production test (Cappuccino and Sherman, 1992) and fluorescing capability test under UV light.

***nod*C and *nif*H gene amplification**

Amplification of nodC and nifH genes was done in PCR tubes each containing 2.5 µL of extracted DNA (template DNA) and 10 µL Master Mix solution. The reagents used to prepare the master mix were 7.5 µL DEPC treated water, 1.0 µL 6X PCR buffer with 20 mM MgCl2 , 0.2 µL 10 mM dNTP mixture, 0.625 µL forward primer (10 mM), 0.625 µL reverse primer (10 mM) and 0.05 U Taq Polymerase. The primers used for nodC were forward 5’- CGT TTT ACG GCA AGG GCG GTA TCG GCA -3’ and reverse 5’- TCC TCC AGC TCC TCC ATG GTG ATC GG -3’ whereas for nifH gene the primers were forward 5’- GCC ATA GTG GCA ACC GTC GT -3’ and reverse 5’- TCA CTC GCC GCT GCA AGT C -3’ (Nahar et al., 2017).

EPS production and extraction

For EPS production, the isolates were inoculated into LB broth (with or without pesticides) and incubated at 30°C for seven days. EPS extraction steps begin with transferring 1 mL of previously incubated broth culture into a 1.5 mL Eppendorf tube. Then, the tube was centrifuged at 14000×g for 10 min. After centrifugation, cell-free culture filtrate (supernatant) was transferred to a fresh test tube or falcon tube of 15 mL. Three volumes of ice-cold acetone or 96% alcohol were added to one unit volume of cell-free culture filtrate for precipitating the polysaccharides and stored at 4°C for overnight. The following day, the precipitate formed at the bottom of the tube was collected and washed 3 times alternately with distilled water and then with acetone. Finally, the dissolved solution was filtered via the filter paper (0.22 µm pore sized membrane filter paper) and allowed to dry overnight at room temperature (Mukherjee et al., 2011). The filter paper was weighed the next day and the weight of the EPS was estimated.

Estimation of extracted exopolysaccharide by spectrophotometry

The dissolved polysaccharide solution was used for the estimation

Table 1. Different concentrations of pesticides.

Pesticide	Concentration (%)			
Tafgor 40EC	0.3	0.4	0.5	-
Tilt 250EC	-	-	0.5	1.0
Imitaf 20SL	-	-	0.5	1.0

of EPS by Phenol Sulphuric Acid method following Agrawal et al. (2015). To the reaction mixture in a test tube containing 1 mL of EPS solution and 1 mL of aqueous phenol, 5 mL of conc. H2SO4 was added. After vigorous shaking, the tubes were allowed to stand for 10 min in the dark. Then, the tubes were placed in a water bath at room temperature for 15 min. After that, absorbance was measured at 490 nm. The effects of different pesticides were evaluated on the following:

1. **Rhizobial growth:** Three different pesticides named Tafgor 40EC (manufacturer- Rallis India Limited, India; marketing company- Auto Crop Care Limited, Bangladesh), Tilt 250EC (manufacturer- Syngenta Crop Protection AG, Switzerland; marketing company- Syngenta Bangladesh Limited) and Imitaf 20SL (manufacturer- Rallis India Limited, India; marketing company- Auto Crop Care Limited, Bangladesh) were used at varying concentrations as shown in Table 1 (Ahemad and Khan, 2011).
2. **EPS production:** For evaluating the impact of pesticides at different concentrations, some representative isolates were selected based on their EPS production (Ahemad and Khan, 2011).
3. **Antibiotic sensitivity:** Bacterial suspensions (of the isolates) were prepared in Muller-Hinton broth and the turbidity was adjusted (0.5 McFarland standard) after incubation. The isolates were inoculated in Muller-Hinton Agar medium which was previously prepared with an addition of pesticide. Inhibition zone was measured in millimeter after an incubation of 24 h (Sarker et al., 2014). In this study, four antibiotics were used. These were Chloramphenicol (C), Sulfamethoxazole-trimethoprim (W), Neomycin (N) and Kanamycin (K).
4. **Phosphate solubilisation:** A modified medium, NBRIP medium (National Botanical Research Institute's Phosphate growth medium) was used to screen the solubilization efficiency (Nautiyal, 1999) with and without pesticides.

RESULTS AND DISCUSSION

Morphological characteristics

Among 42 isolates, most of them were found to be gummy and sticky, whereas only a few showed the opposite (dry colonies). Almost all of them were circular shaped except a few.

Growth on CR-YMA medium

Rhizobia growing on Yeast Extract Mannitol Agar with Congo Red produce white colonies and absorb the dye weakly. But the others (for example Agrobacterium) take up the dye strongly and form pink or orange or red-colored colonies. Here, the dye (Congo Red) actually bound with the polysaccharide portion of the rhizobial capsule (Kneen and La Rue, 1983).

Starch hydrolysis test

The starch hydrolysis test result showed that if the isolate breaks down the starch then it makes a clear zone around their colonies after adding iodine solution. This type of clear zone indicates that the isolates were capable of using starch as their sole carbon source according to Bhattacharya et al. (2013); 47.62% isolates were found to be positive for starch hydrolysis that indicates the presence of starch hydrolysing enzymes.

Oxidase, catalase and MIU test

In the oxidase test, a large portion of these isolates displayed negative results where the opposite scene was observed in catalase test results. 95.24% isolates showed positive results for catalase test by forming bubbles as reported by Shahzad et al. (2012) where 7.14% of isolates showed positive results for the oxidase test. In case of MIU test, all of the isolates were indole positive; 59.52% were motile and the rest were non-motile. The urease test result showed that about 64% isolates were able to utilize urea and break it down into ammonia, resulting in a color change while the rest of them remained yellow.

Ammonia production test

Ammonia production by these bacteria helps to influence plant growth indirectly (Geetha et al., 2014). A positive result for ammonia production exhibits yellow to brownish-yellow color (Cappuccino and Sherman, 1992). A red (sometimes brown) precipitate is an indication of the presence of ammonia because this ammonia forms an insoluble precipitate while it reacts with Nessler's reagent. The intensity of the color gradually increases with the increment of ammonia produced. 80.95% of isolates displayed blue color indicative of positive citrate utilization test as they utilize citrate as their carbon source (Gachande and Khansole, 2011).

Detection of ***nod*****C and *****nif*****H gene**

Amplification of nod genes has also been reported by earlier workers and these genes have a role in nodule formation by several species of rhizobia (Haukka et al., 1998). In this experiment, most of the isolates showed nodC 500 bp sized amplicons. Along with nodC, nifH gene (amplicon size 781 bp) was also found in most of them.

Effect of pesticides on rhizobial growth

As most of the organisms could not grow at 1% concentration of Tafgor 40EC, so the organisms were incubated to grow at 0.5% of Tafgor 40EC. The isolate R2 seemed to produce a higher amount of EPS as shown in Figures 6 and 7. To ensure how Tafgor 40EC affects the isolates, three different concentrations of Tafgor 40EC (0.3, 0.4 and 0.5%) were applied to the isolates. These three concentrations increased EPS production successively (Figure 8), but, there is another exception in R5 isolate where at 0.4% Tafgor 40EC the EPS production lowered than with 0.3% Tafgor 40EC.

Figure 9 describes that EPS production may increase or decrease when the organisms come into contact with pesticides. Here, R37 spiked up to its EPS production from its normal production when they were exposed to Tilt 250EC compared to Imitaf 20SL. But the opposite thing happened to R35 and R36 where they gradually decreased their EPS production. The comparison among sugar contents of EPS with three different pesticides shows how different pesticide contributes to different amounts of EPS production (Figure 10).

Effect of pesticides on EPS production

At first, the amount of extracted EPS of the isolates (in the absence of pesticides) was estimated and recorded. Data for some isolates have been highlighted in Table 2. Five isolates (R31, R32, R35, R36 and R37) were chosen for observing the impact of pesticides at different concentrations. But isolate R37 did not grow in the presence of Imitaf 1%. So another group of R2, R3, R4 and R5 was selected for Imitaf treatment (Figures 4 and 5).

Interestingly, the amount of EPSs secreted by these isolates increased (in certain cases decreased) as the concentrations of pesticides increased. In Figure 1, variations in EPS production by the isolates were shown where some gave a higher yield of EPS and some did a lower. The neutral carbohydrate content was evaluated by spectrophotometry method (as the EPS contains higher portions of neutral sugars in proportion to other chemicals). So, a standard curve of glucose was prepared to find out an approximate content of sugars in carbohydrates in EPS.

Figure 2 depicts that the higher concentration of Tilt 250EC (1% Tilt 250EC) increased EPS production in R37. R31 and R36 also tend to raise their EPS production (shown by the upward arrow keys) in response to the elevated concentration of Tilt 250EC when their carbohydrate contents were measured (Figure 3).

The same condition was observed in 0.5% Imitaf 20SL and 1% Imitaf 20SL (Figures 4 and 5). A similar case was reported by Ahemad and Khan (2011) where *Rhizobium* secreted EPS in higher amount when they were exposed to the pesticide-stressed environment. The exact reason behind this unusual behaviour is unknown. But, it is thought that EPSs provide protection to soil bacteria against environmental stresses; hence, it is possible that rhizobia secreted more EPSs under pesticide-stress to shield themselves against these chemicals in proportion to the pesticide-concentrations (Ahemad and Khan, 2011).

As most of the organisms could not grow at 1% concentration of Tafgor 40EC, so the organisms were incubated to grow at 0.5% of Tafgor 40EC. The isolate R2 seemed to produce a higher amount of EPS as shown in Figures 6 and 7. To ensure how Tafgor 40EC affects the isolates, three different concentrations of Tafgor 40EC (0.3, 0.4 and 0.5%) were applied to the isolates. These three concentrations increased EPS production successively (Figure 8), but, there is another exception in R5 isolate where at 0.4% Tafgor 40EC the EPS production lowered than with 0.3% Tafgor 40EC.

Figure 9 describes that EPS production may increase or decrease when the organisms come into contact with pesticides. Here, R37 spiked up to its EPS production from its normal production when they were exposed to Tilt 250EC compared to Imitaf 20SL. But the opposite thing happened to R35 and R36 where they gradually decreased their EPS production. The comparison among sugar contents of EPS with three different pesticides shows how different pesticide contributes to different amounts of EPS production (Figure 10).

Phosphate solubilisation test

As some isolates could not utilize the inorganic phosphate properly using Pikovskya's medium, a modified medium (NBRIP) was used to screen them efficiently. This time, they produced a clear halo zone around their colonies. Some of the isolates showed higher phosphate solubilisation efficiency in the presence of pesticide than the normal condition (without pesticides), while some remained the same as they were before.

Antibiotic sensitivity test

In response to pesticide, how the isolates act in antibiotic sensitivity test are summarized in the chart (Table 3). In this chart, R31 which were sensitive to Kanamycin (without pesticide) became resistant (highlighted part) in

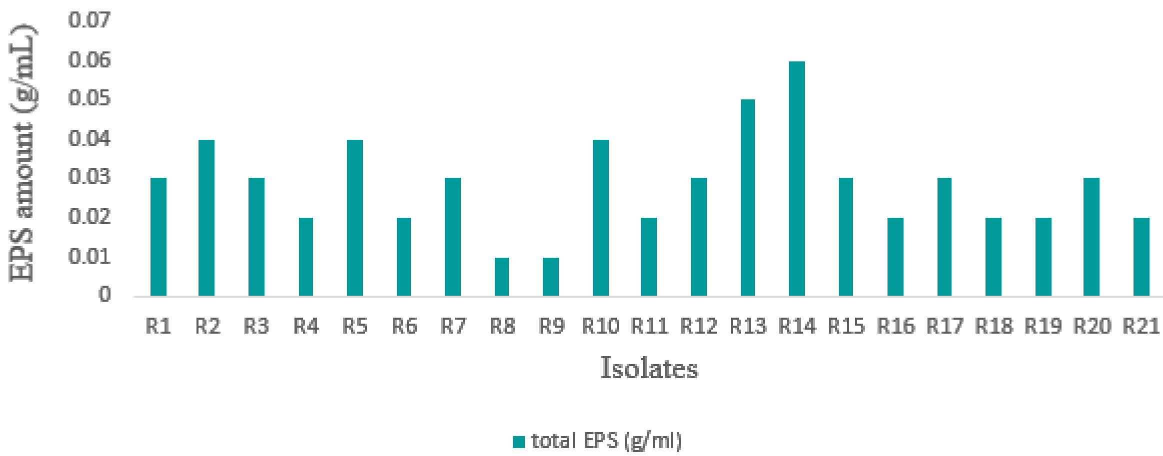

Figure 1. An illustration of different isolates producing different amounts of EPS. Data of some isolates (R1 to R21) have been presented here in the absence of pesticides.

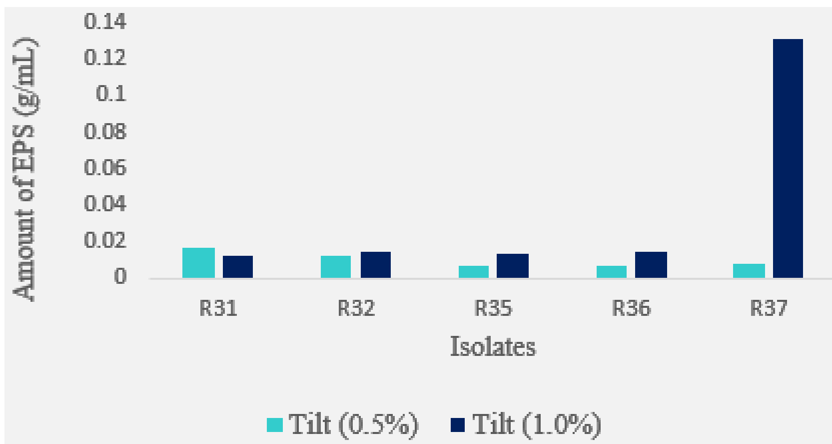

Figure 2. Effect of Tilt 250EC at two different concentrations on EPS production.

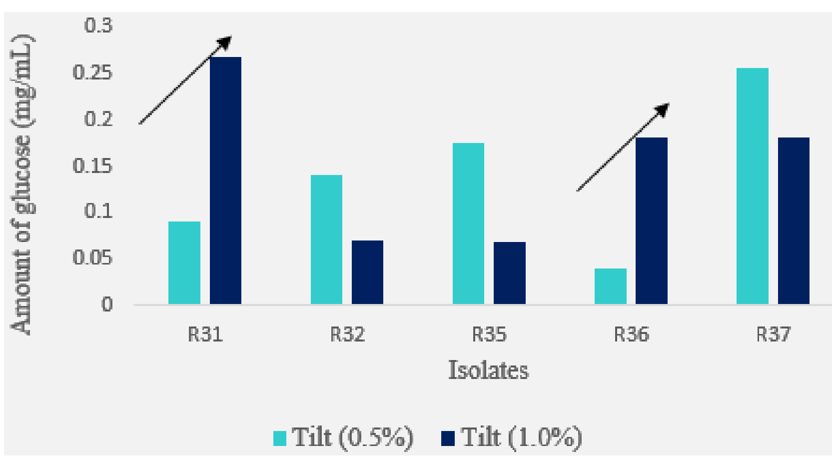

Figure 3. Effect of Tilt 250EC on EPS production (sugar content of EPS). The arrow indicates how the EPS production of R31 and R36 escalated in higher concentration of Tilt (1%). But R32, R35 and R37 showed the opposite.

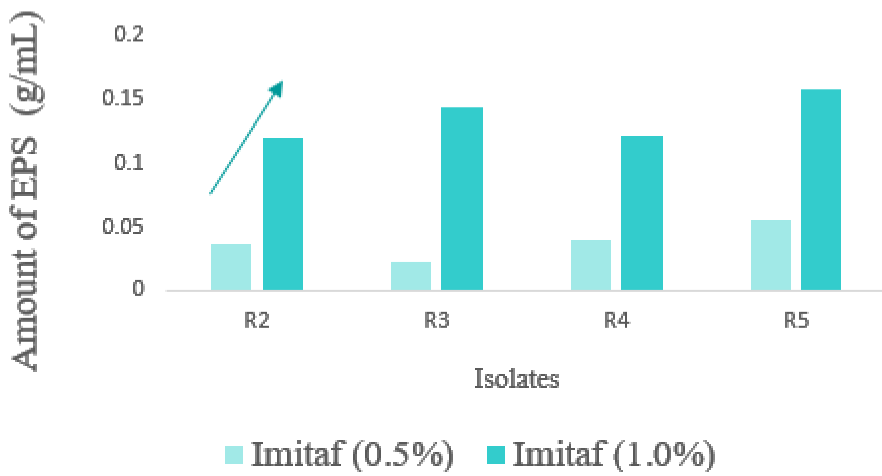

Figure 4. Effect of Imitaf 20SL on EPS production. The isolates produced a higher amount of EPS at 1% Imitaf than 0.5% Imitaf.

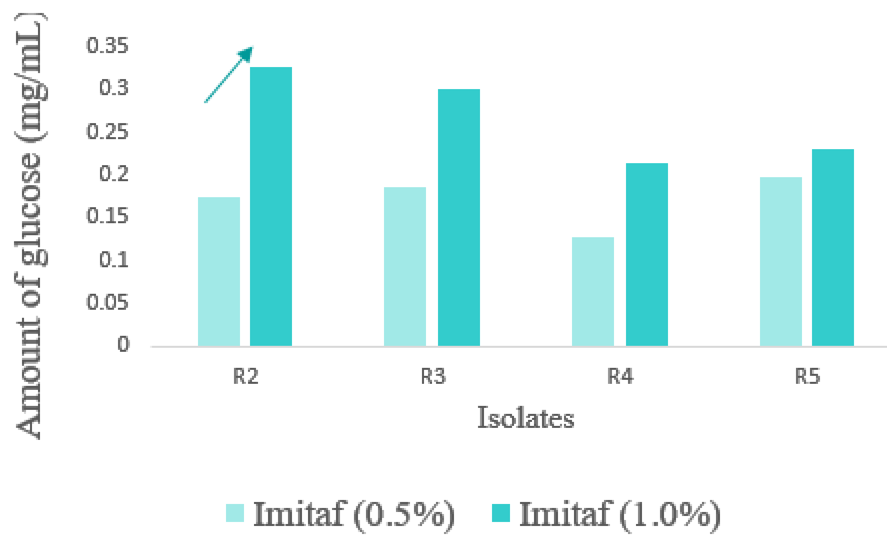

Figure 5. Effect of Imitaf 20SL on EPS (carbohydrate content). The sugar content of EPS increased in the presence of higher concentration of Imitaf (1%) than the lower one (0.5% Imitaf).

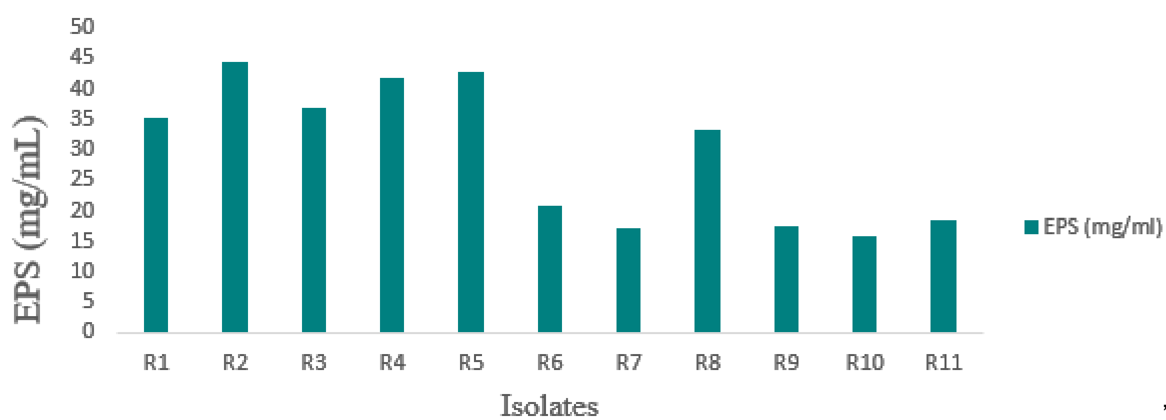

Figure 6. EPS production under the effect of Tafgor 40EC (0.5%) by different isolates.

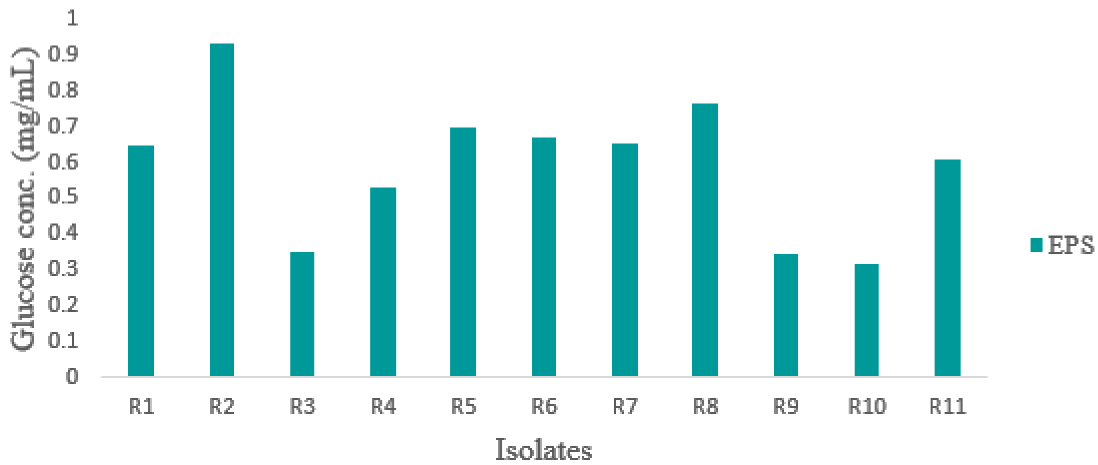

Figure 7. Sugar content in the extracted EPS at 0.5% Tafgor 40EC.

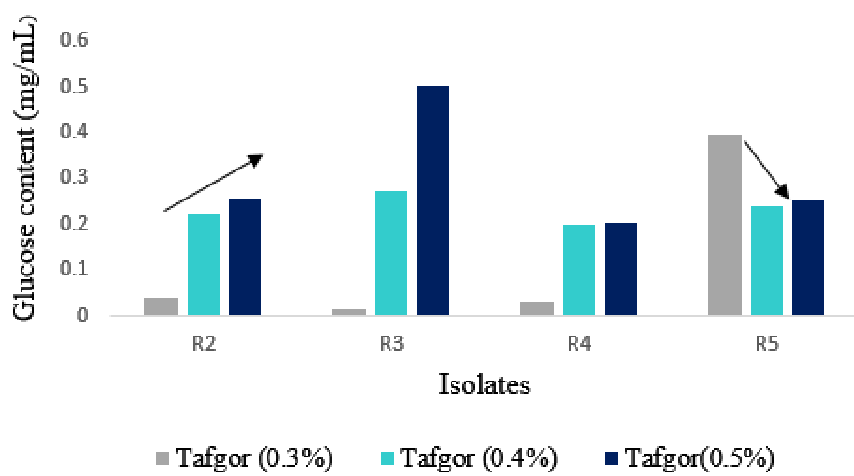

Figure 8. Variation in EPS production at different concentrations of Tafgor 40EC. At three different concentrations of Tafgor (0.3, 0.4 and 0.5%), R2 and R3 raised their EPS production. In case of R5, at 0.4% Tafgor, the EPS production lowered than 0.3% Tafgor.

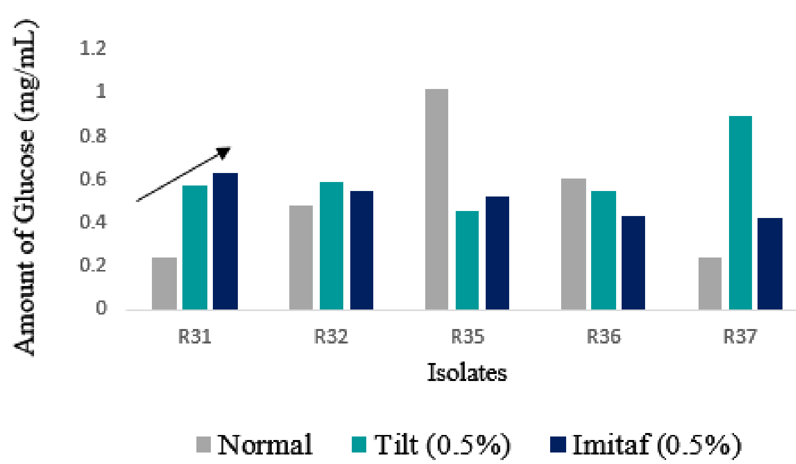

Figure 9. EPS production under normal conditions and in the presence of pesticides.

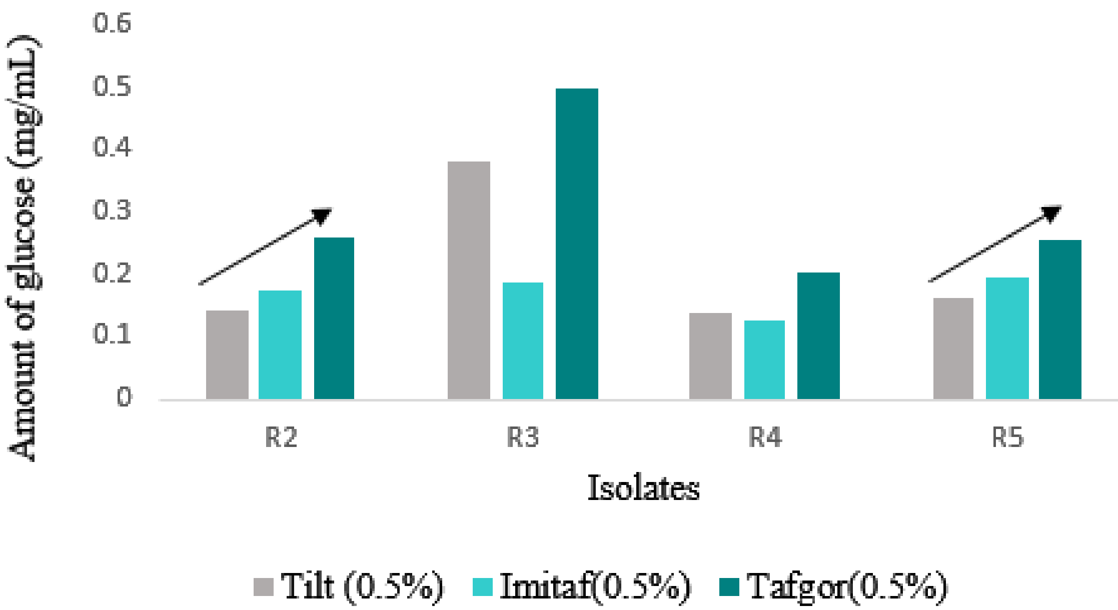

Figure 10. Comparison of EPS production under three different pesticides.

Table 2. Weight of the extracted EPS of some of the isolates (without pesticides).

Isolate	Weight of the filter paper (after extraction) (g)	Weight of the filter paper (before extraction) (g)	Weight of EPS (g/mL)
R21	0.8354	0.8143	0.0211
R22	0.8789	0.8543	0.0246
R23	0.8228	0.8014	0.0214
R24	0.8639	0.8413	0.0226
R25	0.8815	0.8582	0.0233
R26	0.8581	0.8369	0.0212

the presence of 1% Tilt 250EC. Here, the isolate R35 was sensitive to Kanamycin (in the presence of 0.5% Imitaf) but it became resistant to Kanamycin in the presence of 1% Tilt. Additionally, there was an upgrade from 'sensitive' to 'resistant' to Kanamycin exerted by R37 when it was exposed to Tilt 0.5% to Tilt 1%, respectively. So, based on the results from sensitivity to antibiotics, it could be said that the isolates developed resistance because of these stressed conditions and thus switched from sensitive to resistant, gradually.

Conclusion

EPS production varies greatly upon the type and concentration of the pesticide. Continuous delivery of these pesticides in the soil might not give a profitable output in case of growth of rhizobia and other distinguishing characteristics like EPS production, antibiotic susceptibility and phosphate solubilisation. The isolates may be further tested to observe antimicrobial activity and the impact of pesticides on other characteristics like siderophore production. So considering all the impacts of pesticides, awareness about the usage of pesticides must be raised to preserve both the environment and living organisms.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests.

ACKNOWLEDGEMENTS

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Table 3. Antibiotic sensitivity under different concentrations of pesticides.

Antibiotics	Chloramphenicol (C)	Sulfamethoxazole trimethoprim (W)	Neomycin (N)	Kanamycin (K)
R31	S	S	R	S
Imitaf (0.5%)	S	S	I	S
Imitaf (1.0%)	I	I	I	I
Tilt (0.5%)	S	S	I	I
Tilt (1.0%)	I	I	R	R
R32	S	S	R	I
Imitaf (0.5%)	S	S	I	S
Imitaf (1.0%)	S	I	I	R
Tilt (0.5%)	S	I	I	I
Tilt (1.0%)	S	S	R	R
R35	S	S	R	I
Imitaf (0.5%)	S	S	R	S
Imitaf (1.0%)	S	I	I	I
Tilt (0.5%)	I	I	R	I
Tilt (1.0%)	I	I	R	R
R36	S	S	I	R
Imitaf (0.5%)	S	S	R	S
Imitaf (1.0%)	I	I	I	I
Tilt (0.5%)	S	S	R	I
Tilt (1.0%)	I	I	R	R
R37	S	S	I	I
Imitaf (0.5%)	S	S	I	I
Imitaf (1.0%)	-	-	-	-
Tilt (0.5%)	S	S	I	S
Tilt (1.0%)	I	I	R	R

S, Sensitive; R, Resistant ; I, Intermediate.

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Disparities and influential factors to men's and women's involvement in freshwater aquaculture in Madagascar

Miarisoa Razafindrabe, Hiroaki Sugino, Hiroe Ishihara and Nobuyuki Yagi*

Graduate School of Agricultural and Life Sciences, the University of Tokyo, Tokyo, Japan.

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This research identifies the factors determining the individual decision to get involved in the aquaculture sector for both men and women through a case study in Madagascar. A rich body of scholarly literature shows that women play an important contribution in the aquaculture sector, particularly in South Asia and Africa. The literature shows that multiple factors, such as lack of access to assets and gender norms, hinder women's full participation. Data were collected through observations, interviews, and questionnaires in the northwestern part of Madagascar, where a Japan International Cooperation Agency (JICA) project was carried out to promote aquaculture. To reveal the difference between men's and women's involvement, the quantitative data on involvement variables were analyzed by the Mann-Whitney U test (U'), while hierarchical cluster analysis and random forest analysis were used to determine the factors influencing the involvement of men and women. This study confirms that men have higher involvement in aquaculture than women do. It suggests that decision-making power and gender norms prevalent in this region are the most influential factors that establish both men's and women's engagement in aquaculture.

Key words: Aquaculture, gender, involvement, roles, norms, factors, Madagascar.

INTRODUCTION

Aquaculture is the fastest-growing sector in the global economy. It contributes to poverty alleviation by improving the income and securing food (Subasinghe et al., 2009; Food and Agriculture Organization of the United Nations (FAO), 2005, Philips et al., 2016). Despite the increase in fish demand in Africa (Thurstan and Roberts, 2014), the productivity of this sector remains low (Subasinghe et al., 2009; Veliu et al., 2009; Food and Agriculture Organization of the United Nations (FAO), 2005; Philips et al., 2016; Chan et al., 2019). Likewise, Madagascar, a southeastern African island, has an underdeveloped aquaculture, in freshwater in particular.

A wide body of literature has examined the significant contribution of women in aquaculture, particularly in Asia, Latin America, the Caribbean and Africa (Kusakabe, 2003; Food and Agriculture Organization of the United Nations (FAO), 2016, 2018) through their active involvement in the post-production nodes in the

*Corresponding author. E-mail: yagi@fs.a.u-tokyo.ac.jp.

aquaculture value chain (Food and Agriculture Organization of the United Nations (FAO), 2016).

Despite their significant engagement, women particularly have more challenges compared to their male counterparts. The concept of gender is suggested to explain differences, hierarchies and divisions within society, between men and women (West et al., 2007). Gender is a globally used concept suggested to explain the expected roles assigned to men and women. Studies reveal the difference in involvement between men and women is primarily caused by the gender division of labor (Browne, 2002; Lambeth et al., 2002; Demmke, 2006). Evidence suggests that gender norms are the most important factors of the involvement in aquaculture especially women (Morgan et al., 2015).

There are a few studies on gender in aquaculture in Africa. In Madagascar, gender is gradually being integrated but not in the Fisheries and Aquaculture sector yet. Studies on gender in aquaculture are particularly scarce in the country. Aquaculture is generally considered as a male-dominated sector in Madagascar (Institut National de la Statistique (INSTAT), 2011). This research aims to reveal the enabling factors and obstacles that the females face when they aim to be involved in aquaculture by focusing on the gender norms in Madagascar.

METHODOLOGY

Study site

This study focuses on the three districts of the Boeny region located at the Northwest coast of Madagascar. The three districts comprises Marovoay, Ambato-boeny, and Mahajanga II. They were beneficiaries of a project on freshwater aquaculture development between 2011 and 2014 funded by a private entity named Japan International Cooperation Agency (JICA). Aquaculture is a secondary source of income in the region. Its productivity is comparatively less than marine aquaculture and fisheries. As of January 2014, 195 fish farmers, mainly men, were estimated.

Sampling and data collection

Firstly, field observations were conducted during the project implementation (2011-2014). Then in October 2016, qualitative and quantitative data were collected. By a snowball sampling method (Goodman, 1961), 31 men and 21 women from aquaculture households were interviewed. Respondents were asked about their demographic information, their involvement level, the factors of their involvement and their perceptions on gender norms on roles.

Data analysis

A general description was generated through the results of the qualitative data. R software version 3.4.4 was the tool used for quantitative analysis. To reveal the difference in involvement between men and women, Mann-Whitney U test (*U'*) was conducted since the data was non-paired and non-parametric. The *p-value* was deemed at 0.05. After running the cluster analysis, random forest analysis (RFA) (Breiman, 2001) was independently operated to determine the most influential variables of involvement. RFA, one of the machine learning techniques, is a method to generate a classifying model with certain number of groups, and it has the advantage of accuracy even for small-sized data. The most important variables to involvement were generated by the calculations of the Mean Decrease Gini (MDG) (Calle et al., 2011), the mean minimal depth and the p-value of each dependent variable. A variable is important when simultaneously presenting a high value of MDG, a low value of mean minimal depth and a *p-value* less than 0.01. At last, the negative/positive influence of the most important variables was reflected in the clusters.

RESULTS AND DISCUSSION

Characteristics of the respondents

Table 1 summarizes the characteristics of the respondents. Only one female respondent was a widow. Most of the women were having an elementary education and a higher rate of illiteracy (14.3%). Rice cultivation was found the main livelihood activity of the respondents. About 38% of women had house chores as their main job. Only six male respondents have aquaculture as their main income-generating livelihood. The sample of this study revealed that 83.9% of men and 47.6% of women attended training provided by the JICA project.

Difference in involvement in aquaculture

Men presented a significant involvement compared to women. Table 2 shows that men were more active in land preparation, pond management, feeding fish, harvest work, fish marketing, and decision-making roles. Women have no considerable involvement but partly involved. Moreover, the qualitative study adds the wider involvement of men such as working as trainers for other farmers or as teachers for students. These men were in close collaboration with the local extension staff and the JICA project. As aquaculture is a family business, women and children both partially play a supporting role as helpers or assistants to men. Women only become fully involved when their husbands are absent from home. Two male interviewees described how they were involved in aquaculture as follows:

My wife works as a teacher in an elementary school in Mahajanga II. She is also taking care of our children. We do not live together and she does not know anything either involved in this business at all. I am in charge of all livelihood activities of the house including aquaculture and rice cultivation (*Male interviewee in Ambato-boeny district, October 2016).*

I work every day for our farm ponds and I mainly decide on everything about their management. I also decide on agriculture but sometimes my wife has her opinions. My mother attended training from the project; however, my wife only supports me when I have worked elsewhere (Male interviewee in Mahajanga II, October 2016).

Table 1. Characteristics of the men and women respondents in aquaculture in the three districts.

Indicator	Variable	Men (%) *n=31*	Women (%) *n=21*
Age (years)	15-24	6.5	9.5
	25-34	6.5	14.3
	35-44	41.9	23.8
	45-54	22.6	28.6
	55-64	16.1	14.3
	65-74	6.5	9.5
Aquaculture household category	Seed producers	35.5	33.3
	Grow-out fish farmers	64.5	66.7
District	Ambato-boeny	32.3	28.6
	Marovoay	35.5	38.1
	Mahajanga II	32.3	33.3
Marital status	Single	6.5	9.5
	Married	93.5	85.7
	Widow	0.0	4.8
Education attainment	Elementary	22.6	42.9
	Middle school	29.0	23.8
	High school	29.0	19.0
	University	9.7	0.0
	No education	9.7	14.3
Land ownership	Man	77.4	47.6
	Woman	6.5	23.8
	Parents in law	22.6	28.6
	Others	0.0	9.5
Main job	Agriculture	58.1	33.3
	Farming	16.1	9.5
	Aquaculture	19.4	4.8
	Shop	0.0	19.1
	Milling rice	3.2	0.0
	Household chores	0.0	38.1
	Others	25.8	14.3
Source of knowledge in aquaculture	Previous Japanese project	83.9	47.6
	Spouse	3.2	42.9
	Others	12.9	9.5

Men remain the dominant actor in the aquaculture business in the study site. In numerous cases in Asia and Africa, both men and women are involved in aquaculture (Kumar Barman, 2001; Thomas-Slayter and Sodikoff, 2001). In contrast of the finding of this study, women are active particularly in processing and marketing in Asia and West Africa (Brugere et al., 2001a; Kumar Barman, 2001; Veliu et al., 2009; Weeratunge et al., 2010; Allison, 2011; Food and Agriculture Organization of the United Nations (FAO), 2016). This may be because the aquaculture is yet being developed in the case of the Boeny region. The substitute role of women when their husbands are engaged in other businesses, such as rice cultivation, is often cited in the literature (Kumar Barman, 2001).

Factors of involvement

The cluster analysis suggested four clusters based on the

Table 2. The difference between men and women's involvement in aquaculture.

Parameter	Scale of involvement n=52 (m=31, f=21)		1	2	3	4	5	Mann-Whitney U value (*p-value*)	
Land preparation	Men	n	3	3	1	7	17	0.00	*
		%	9.68	9.68	3.23	22.58	54.84		
	Women	n	10	4	0	3	4		
		%	47.62	19.05	0.00	14.29	19.05		
Pond management	Men	n	2	0	2	5	22	0.00	*
		%	6.45	0.00	6.45	16.13	70.97		
	Women	n	5	6	1	6	3		
		%	23.81	28.57	4.76	28.57	14.29		
Feed preparation	Men	n	6	2	0	3	20	0.05	
		%	19.35	6.45	0.00	9.68	64.52		
	Women	n	4	0	2	10	5		
		%	19.05	0.00	9.52	47.62	23.81		
Cooking for hired workers	Men	n	29	0	1	0	1	0.16	
		%	93.55	0.00	3.23	0.00	3.23		
	Women	n	17	0	2	0	2		
		%	80.95	0.00	9.52	0.00	9.52		
Fish feeding	Men	n	3	3	2	4	19	0.01	*
		%	9.68	9.68	6.45	12.90	61.29		
	Women	n	4	2	2	9	4		
		%	19.05	9.52	9.52	42.86	19.05		
Harvest	Men	n	1	0	3	7	20	0.00	*
		%	3.23	0.00	9.68	22.58	64.52		
	Women	n	5	2	2	8	4		
		%	23.81	9.52	9.52	38.10	19.05		
Marketing	Men	n	5	3	1	5	17	0.00	*
		%	16.13	9.68	3.23	16.13	54.84		
	Women	n	10	3	1	2	5		
		%	47.62	14.29	4.76	9.52	23.81		
Frequency of working hours	Men	n	2	4	0	4	21	0.34	
		%	6.45	12.90	0.00	12.90	67.74		
	Women	n	0	3	2	4	11		
		%	0.00	14.29	9.52	19.05	52.38		
Decision-making role	Men	n	0	2	3	4	22	0.00	*
		%	0.00	6.45	9.68	12.90	70.97		
	Women	n	2	5	2	8	3		
		%	9.52	23.81	9.52	38.10	14.29		

*Significance level at *p-value*<0.05.

involvement variables. Two clusters were focused on here: Cluster 1 as a male dominant group with high involvement and, cluster 4 composed by mainly women with the lowest involvement.

Figure 1 shows the most influential variables. Ten of them were highlighted such as "type of mother", "type of jobs", "knowledge", "decision-making" power, the perception of "fish farming", "University" education, "Mahajanga II", "women work", "experience in aquaculture", and the "support" of the JICA project. The

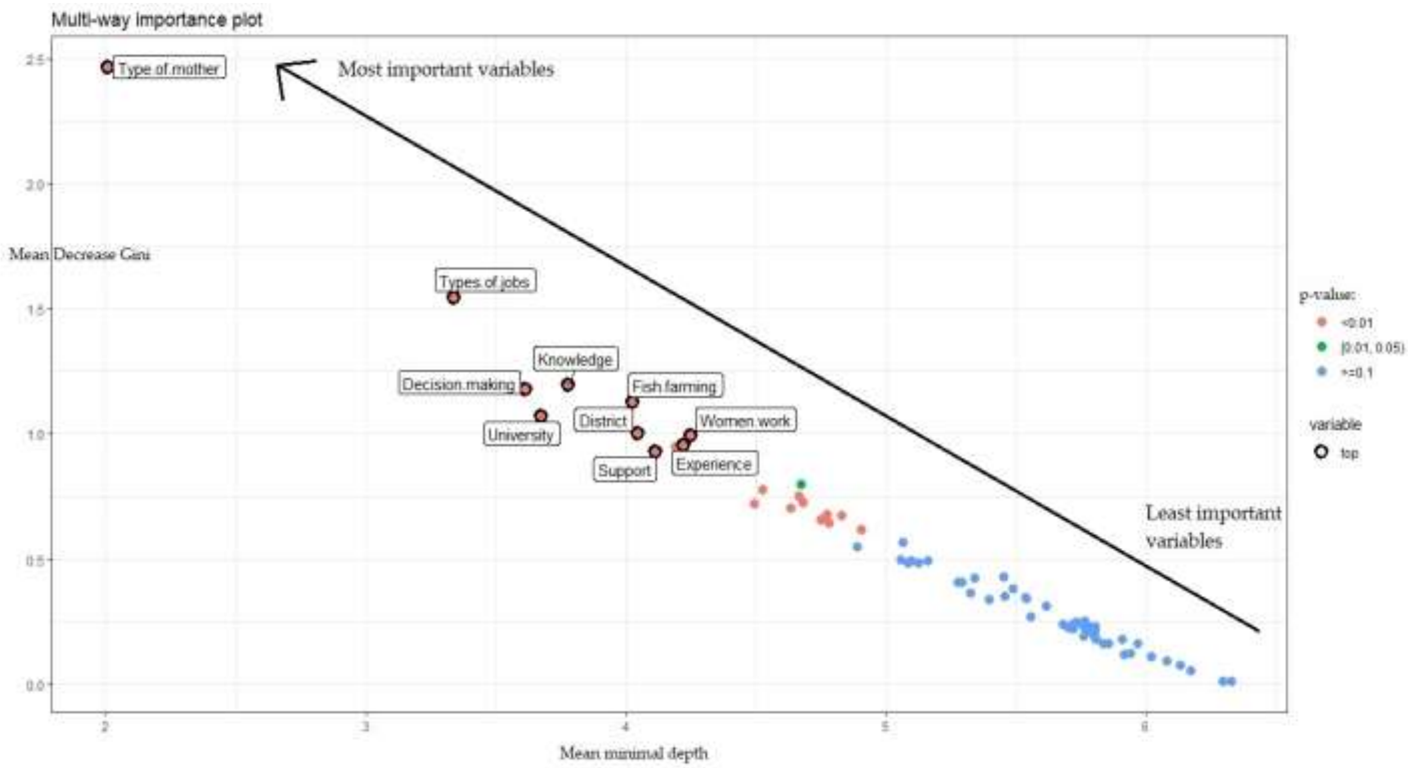

Figure 1. The measure of the influence of variables to involvement in aquaculture (x-axis as mean minimal depth, y-axis as Mean Decrease Gini (MDG) and z-axis as *p-value*). Dots represent the dependent variables. The arrow illustrates the level of importance of the variables from least to most important. The most important variables are located at the top left side of the figure (red dots with black outlined). They simultaneously showed a low mean minimal depth value, a high MDG value and a p-value <0.01. In contrast, at the right lower side of the figure, the least important variables were presenting a low MDG value, a high mean minimal depth and a *p-value* >0.01.

variables on "type of mother", "type of job" and "women work" are about gender norms on roles.

Further analysis indicated that these important variables have different influence in clusters 1 and 4 (Table 3). Findings show that home duties and paid jobs are ideal characteristics of a mother. However, the typical jobs for men and women in the community negatively influence the involvement of women in aquaculture (cluster 4). Low-involved women were negatively influenced by their experience in aquaculture. Fish farming as a less time-consuming activity negatively influenced the involvement in both clusters. In contrast, the knowledge, the university degree, the district of Mahajanga II and the decision-making power at home present a positive influence on their involvement. Respondents in cluster 1 are surprisingly less influenced by the support from the JICA project. Besides, the qualitative result reveals monetary and non-monetary factors for both men and women. They consider aquaculture not just as means to gain additional income but also as a dream, love, hobby, for peace of mind, and for relaxation. In addition, men were also interested in improving the fish consumption of the household. They were very motivated by the support of the JICA project, and have technical knowledge through trainings.

This study confirms that involvement is associated with gender norms. The perceptions of the norms of differentiation of men and women's works and duties might explain the low involvement of the women. A strong relationship between norms and involvement has been reported in the literature. The normative roles of women importantly impede their involvement in aquaculture (Jahan et al., 2010; Samina et al., 2010) and in Nigeria (Fapohunda, 2005).

Fish-related activities in general, including the aquaculture, might be perceived as a male activity in the district because marine fisheries, which is a prosperous sector in Mahajanga II, is a male dominated industry (Boeny, 2016). The reason is why this specific district, aquaculture might be perceived as a male activity.

Unlike men, the lack of knowledge can lead to a low involvement for women. This finding corroborates with previous findings. Several works showed that restricted access to assets, particularly the lack of access to knowledge and training, constrains women's involvement (Kumar Barman, 2001; Veliu et al., 2009; Weeratunge et al., 2012; Ndanga et al., 2013). These restrictions are commanded by the norms, which also affect women's

Table 3. Importance of the ten most influential variables (negative or positive influence) in the high involvement cluster (cluster 1) and the low involvement cluster (cluster 4).

Variable	Detail	Cluster 1	Cluster 4
Type of mother	A mother who stays at home and raises children is not the only ideal type of mother	+	+
Types of jobs	Women should enter into jobs traditionally held by men, those of pilot, engineer, taxi driver, and chef, diplomat, and mathematician	+	-
Women work	Women should work even if they are not in need	-	-
Fish farming	Fish farming is a less time-consuming activity than other major source of income	-	-
Knowledge	I have enough technical knowledge in aquaculture	+	+
Experience	I have enough experience in aquaculture	+	-
University	University education attainment	+	+
Support	I was supported, technically and/or financially, by the JICA project	-	+
Mahajanga II	The district of Mahajanga II	+	+
Decision- making	I have high decision-making power at home	+	+

mobility and responsibilities at home (Kusakabe, 2003; Seguino, 2007; Kantor et al., 2015; Morgan et al., 2015).

Education, mainly the university degree, significantly influences involvement. However, it is important to note that most of farmers in rural Madagascar only have an elementary education background. This result may be consistent with other authors' findings. The level of education affects the adoption of technologies in agricultural livelihoods (Osei-Adu et al., 2015). At this stage of aquaculture development in the study area, technical knowledge might be a more important factor than education.

Decision-making power as an important variable to involvement also matches those observed in earlier studies. For instance, in Bangladesh, men dominate the cage culture business by their decision-making power (Brugere et al., 2001b). Women are generally not privileged to decide. The lack of access to knowledge may affect women's decision-making power in Northeast Thailand (Kusakabe, 2003). However, as Morgan et al. (2016) suggested that decision-making power was not a constraint upon female household heads (Morgan et al., 2016) including widows.

Men expected money from aquaculture, whereas women expected poverty alleviation and food security for the household (Locke et al., 2017). The JICA project was initiated to improve the income of these farmers' households through aquaculture (PATIMA, 2011). As most of the farmers are men, they were encouraged on the monetary benefit of aquaculture. The non-monetary factors to involvement in aquaculture were not found in the literature. However, these types of factors might be related to the influence of norms. Norms may orient men to be involved in monetary activities (in agriculture) whereas women in non-monetary ones (in house care). Income from men might be more important (Viviana, 1989). These findings may help us to understand that the income-oriented business such as aquaculture may restrict women to be involved.

CONCLUSION AND RECOMMENDATIONS

The ten important variables influencing the involvement of men and women in this study were related to gender norms. Therefore, it was concluded that gender norms affect their involvement in aquaculture. The current norms allow both rural men and women in Madagascar to be involved in the aquaculture; however, they also determine the appropriate roles of men and women. The new finding on the non-monetary factor was also linked to its probable relationship to gender norms. Findings of this study are suggested to be useful for aquaculture development strategies and planning in Africa and in other islands. As both men and women are actors in development, both could contribute to aquaculture development, ultimately for sustaining their incomes and fish protein food. Suggestions can focus on the inclusion of women in training, introducing homestead technologies particularly for women and finding markets. To deepen the knowledge on the difference and inequality between men and women, social relations as an important feature of the structure of gender norms (West et al., 2007) warrant a particular study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Entomocidal activity of some plant extracts against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae)

Suleiman M.*, Sani I., Yusuf A. M. and Abdullahi B. K.

Department of Biology, Faculty of Natural and Applied Sciences, Umaru Musa Yar'adua University, Katsina, Nigeria.

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Entomocidal activity of ethanolic leaf extracts of four plant species namely *Euphorbia balsamifera* Aiton, *Lawsonia inermis* L., *Mitracarpus hirtus* (L.) DC. and *Senna obtusifolia* L. were evaluated in order to assess their protectant ability to stored sorghum against *Sitophilus zeamais* Motsch. The botanicals were applied to 20 g of sorghum grains at the rate of 25, 50 and 100 mgml^{-1}, while no extracts was added to the control. Percentage repellency was recorded at 24 h after exposure (HAE) while adult mortalities of the weevils were obtained at 3 days after treatment (DAT). Adult emergence and grain perforations were recorded at 49 and 84 DAT, respectively. Repellency levels of the botanicals against *S. zeamais* ranged from 87.05 ± 0.45 to 100.00 ± 0.00%. Also, the ethanolic extracts resulted in high adult mortalities of the weevils in the treated sorghum grains. No adult emergence was recorded in grains treated with the botanical extracts. Highest (10.00 ± 2.04%) grain perforations among the treatments were observed in 25 mgml^{-1} of *S. obtusifolia*, while 2.50 ± 1.25% was the least in the highest concentration of *E. balsamifera*. Findings of the study have revealed that the selected botanicals could serve as stored sorghum protectants against *S. zeamais* infestations.

Key words: Adult mortality, adult emergence, grain perforations, plant extracts, repellency levels, *Sitophilus zeamais*.

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is an important cereal crop grown worldwide for food and animal feed purposes (Dahlberg et al., 2011). Sorghum belongs to the grass family Gramineae and one of the most important cereal crops grown in the tropics and sub-tropics (Mofokeng, 2016). The crop is mostly cultivated in semi-arid tropics where water is scarce and drought is frequent (ICRISAT, 2015).

Insect pests are a key constraint to effective production and utilization of cereal crops in sub-Saharan Africa (SSA), and post-harvest losses resulting from insect remain a huge challenge (Tefera et al., 2010; Midega et al., 2016). Insect infestations to stored products are one of the major agricultural development problems in the tropics which results in substantial waste of farm produce and hence considerable loss to the economy (Adejumo and Raji, 2007; Abbas et al., 2014; Sori, 2014). Insect pests damage to stored grains results in reduction of

*Corresponding author. E-mail: mohammed.suleiman@umyu.edu.ng.

quantity as well as quality deterioration of stored cereals like sorghum, maize, wheat and rice (Okonkwo, 1998).

Sitophilus zeamais is the most devastating storage pest of maize, causing serious management problem facing agriculture in developing countries (Abulude et al., 2007). The grain damage caused by *S. zeamais* to cereal crops prompted researchers to investigate more on controlling strategies of the weevils in maize and wheat (Rugumamu, 2012; Khaliq et al., 2014; Cosmas et al., 2018). Although most of the researchers investigated the level of damages caused by *S. zeamais* to stored maize, some have found it necessary to involve stored sorghum considering its position as the second cereal crop in Africa which is also infested and damaged by the maize weevil (Goftishu and Belete, 2014; Suleiman, 2014; Suleiman and Rugumamu, 2017; Suleiman et al., 2018a). Despite effective pest control both on farm fields and storage provided by synthetic insecticides, there is growing concern about the potential hazards to the ecosystem (Midega et al., 2016; Cosmas et al., 2018). Hill (1997) among others had earlier emphasized that, to reduce the hazards associated with chemical application in stored cereals, Integrated Pest Management (IPM) approach, involving all the suitable techniques and methods in maintaining pest population below economic injury level (EIL) is necessary.

To complement IPM strategies, botanicals have been used for many years by small scale farmers in many parts of Africa to protect stored products from insect infestations (Tesema et al., 2015). Plant materials have been applied to a commodity, usually at a rate of 1 to 5% (w/w) to protect stored grains from insect pest infestations (Dales, 1996). Laboratory and field evaluations of some botanical products in Africa indicate their effectiveness against insect pests of stored products (Ajayi, 2013; Rugumamu, 2014, 2015; Ojo and Omoloye, 2016; Suleiman et al., 2018b).

In view of the promising effects of some botanicals against insect pests of stored products, *Euphorbia balsamifera* Aiton, *Lawsonia inermis* L., *Mitracarpus hirtus* (L.) DC and *Senna obtusifolia* L. were selected for this study due to their local availability, and reported efficacies of some of them against other insect pests such as *Callosobruchus maculatus* F. and *Trogoderma granarium* Everts (Al-Moajel, 2004; Chudasama et al., 2015). This study was therefore aimed at evaluating effect of ethanolic extracts of the aforementioned botanicals on the control of *S. zeamais* infesting stored sorghum grains.

MATERIALS AND METHODS

Rearing of *S. zeamais*

Fifty pairs of *S. zeamais* were obtained from infested grain stores and then introduced into each of 500 ml rearing bottles containing 250 g of the disinfested sorghum grains which served as parent stock. The bottles were covered with muslin cloth and kept in the incubator for oviposition at 30°C and 70% R.H. for 14 days, after which the parents were removed. The bottles were maintained in the incubator under the same condition for adult emergence. Progeny of 1-7 days old were sieved and used for the laboratory experiments.

Preparation of the botanical extracts

Sufficient amount of fresh leaves of *E. balsamifera*, *L. inermis, M. hirtus* and *S. obtusifolia* was collected and rinsed with distilled water to remove any dust and unwanted particles. They were then shade-dried at room temperature. The dried leaves were ground into powder using a laboratory blender and sieved using a laboratory sieve with mesh size of 80 microns.

Method of Khaliq et al. (2014) was followed for extraction of the botanicals. One hundred grams of each of the plant powders was dissolved in 400 ml of ethanol in conical flasks. Mouths of the conical flasks were properly corked and kept in a refrigerator for 48 h. The extract was separated using muslin cloth and filtered with Whatman No.1 filter papers using vacuum pump. The filtrate was separately concentrated by evaporating excess solvents using rotary evaporator with rotary speed of 3 to 6 rpm for 8 h. The aliquot was poured into crucibles and placed on water bath to evaporate the remaining excess solvents. The resulting extracts were air-dried and stored in refrigerator at 4°C.

Determination of repellency levels of ethanolic extracts against *S. zeamais*

Each of the four botanicals was diluted to three different concentrations of 25, 50 and 100 mgml^{-1} each of ethanol. Two milliliters of each of the extracts was mixed with 20 g of sorghum grains in bottle A and allowed to completely air-dried. Another 20 g of the grains without any botanical extract was placed in bottle C serving as a control. Ten adult *S. zeamais* were introduced in bottle B from where their direction of movement to either bottle A or C was observed at 32 ± 2^{o}C and 65 ± 10% R.H. The number of weevils moving from (B) to either (A) or (C) was recorded at 24 h after exposure (HAE). Percentage repellency was calculated according to the methods of Sakuma and Funkami (1985) using the following formula:

$$\mathrm{PR} = \left[1 - \frac{\mathrm{NT}}{\mathrm{NT} + \mathrm{NC}}\right] \mathrm{X}\ 100$$

Where: PR = Percentage Repellency.
NT = Number of insects in the chemical-treated test chamber.
NC = Number of insects in the control test chamber.

Assessment of adult mortality of *S. zeamais* in sorghum treated with ethanolic leaf extracts

Method of de Oliveira et al. (2012) was adopted to assess per cent adult mortality of *S. zeamais* in sorghum grains treated with different leaf extracts of the test plants. Crude extracts were diluted with ethanol to make different concentrations of 25, 50 and 100 mgml^{-1} as previously described. Twenty grams of sorghum grains were weighed and placed in treatment bottles (250 ml). The grains were impregnated with 2 ml of the diluted extracts at the three concentrations, while the control contained the grains only. The grain mass was mixed thoroughly with the aid of glass rod and air-dried for 4 h. Five pairs of adult weevils were introduced into the bottles containing the treated grains, and covered with muslin cloth secured by rubber bands. All treatments were arranged in a completely randomized design (CRD) in the incubator with four

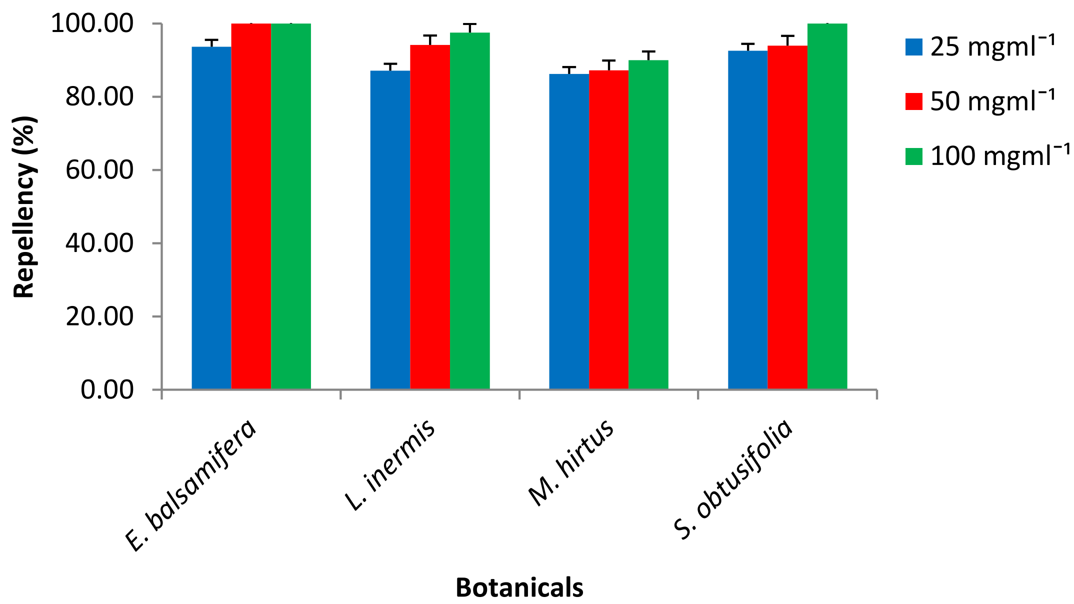

Figure 1. Mean percentage repellency of ethanolic extracts of different botanicals applied at different concentrations against *S. zeamais* at 24 HAE.

replicates. The set-ups were inspected daily and dead weevils in each treatment were removed and recorded daily for three days (when the first total mortality was achieved).

Data were recorded, organized, analyzed and presented as mortalities of *S. zeamais* within 3 DAT. Weevils in untreated containers were allowed to remain in the grains until they reached 14 days for oviposition before they were removed leaving the grains only until F_1 emerged. Percent adult mortality was assessed as number of dead weevils divided by total number of weevils per each bottle, multiplied by one hundred.

Examination of adult emergence of *S. zeamais*

Grains were inspected daily after removal of the earlier introduced individuals for adult emergence of the weevils. The emerging progenies (F_1) from each bottle were removed daily, counted and recorded for 49 days (84 days after infestation) after which observations stopped to avoid overlapping of generations. Inhibition rate (IR) in adult emergence was calculated using the following formula (Tapondju et al., 2002):

$$\mathrm{IR} = \frac{C_n - T_n}{C_n} \times 100$$

Where:
IR = Inhibition rate (%)
C_n = Number of insects that emerged in the control; and
T_n = Number of insects that emerged in the treated grains.

Assessment of grain perforations in treated sorghum infested by *S. zeamais*

To assess grains perforations made by *S. zeamais*, 20 grains from the extract treatments were sampled and examined after 49 days of emergence of F_1. Percent grain perforations were assessed as follows:

$$\%\ \text{Grain Perforations} = \left(\frac{\text{Number of Perforated Grains}}{\text{Total Number of Grains Sampled}}\right) \times 100$$

Data analysis

GraphPad Prism (version 7.03) was the statistical package used to analyze all the data obtained from this study. Shapiro-Wilk normality test was used for normality test of the data. Two-way ANOVA was employed for level of significance in percent repellencies of the extracts against *S. zeamais*, adult mortality and percent grain perforations. Significantly different means were separated by using Bonferroni's multiple comparisons test at 5% level of significance.

RESULTS

Repellency of ethanolic botanical extracts against *S. zeamais*

E. balsamifera had the highest repellency which ranged from 93.65 ± 3.72% to 100.00 ± 0.00%, while *M. hirtus* had the least (87.22 ± 2.42 to 90.00 ± 4.08%) at 24 HAE (Figure 1). Percentage repellencies of *L. inermis* varied between 87.05 ± 0.45 and 97.50 ± 2.50%. The repellency of *S. obtusifolia* at 25, 50 and 100 mgml^{-1} was 92.50 ± 2.50, 93.93 ± 3.61 and 100.00 ± 0.00%, respectively at 24 HAE (Figure 1).

The varying concentrations of ethanolic extracts showed different degrees of repellency against the maize weevils within 24 h of exposure. At 25 mgml^{-1}, *E. balsamifera* had the highest repellency, followed by *S. obtusifolia*, *L. inermis* and finally *M. hirtus*. At 50 mgml^{-1}

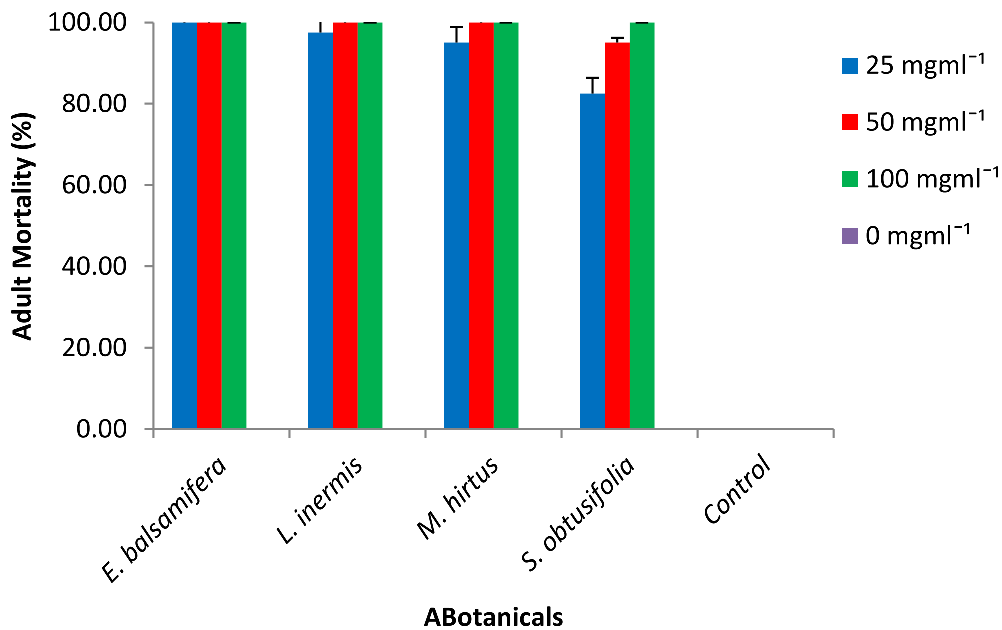

Figure 2. Mean percentage adult mortality of *S. zeamais* in sorghum grains treated with ethanolic extracts of different botanicals applied at different concentrations within 3 DAT.

of the botanical extracts, the decreasing order of their repellent action was *E. balsamifera* > *L. inermis* > *S. obtusifolia* > *M. hirtus*. At 100 mgml^{-1}, the percentage repellency was in the order *E. balsamifera* > *S. obtusifolia* > *L. inermis* > *M. hirtus*. There was no significant interaction between the ethanolic extracts and concentrations on the repellency levels ($F_{(6,36)}$ = 0.6139; p = 0.7176). It however, showed that the repellency was significantly different among both the botanical types ($F_{(3,36)}$ = 8.513; p = 0.0002) and the varying concentrations ($F_{(2,36)}$ = 7.553; p = 0.0018) within 24 h.

Adult mortality of *S. zeamais* in sorghum grains treated with ethanolic leaf extracts

Ethanolic extracts of the selected botanicals applied at different concentrations of 25, 50 and 100 mgml^{-1} exhibited varying percentage mortalities of *S. zeamais* within 3 DAT. Treating the grains with *E. balsamifera* resulted in total (100.00 ± 0.00%) adult mortality of the weevils at all the three concentrations within 3 DAT (Figure 2). This was followed by treatments with *L. inermis* and *M. hirtus* where 97.50 ± 2.50 and 95.00 ± 2.89% were respectively recorded at 25 mgml^{-1}, while 100.00 ± 0.00% of the weevils died at both 50 and 100 mgml^{-1}. The adult mortalities recorded in grains treated with *S. obtusifolia* ranged from 82.50 ± 2.50 to 100.00 ± 0.00%. None of the weevils died in untreated grains at the end of 3 DAT (Figure 2). There was a significant difference in adult mortality of *S. zeamais* among the botanicals ($F_{(4,45)}$ = 2947; p = 0.0001).

Emergence of adult *S. zeamais* in sorghum grains treated with ethanolic leaf extracts

There was no emergence of adult *S. zeamais* in sorghum grains treated with ethanolic extracts of the selected botanicals. However, the mean number of emerged weevils in untreated grains was 156.80 ± 5.41. Therefore, ethanolic extracts of all the botanicals at the three concentrations of 25, 50 and 100 mgml^{-1} resulted in total (100%) inhibition rate in adult emergence of *S. zeamais* in sorghum grains.

Grain perforations in sorghum treated with ethanolic leaf extracts

Highest grain perforations (7.50 ± 1.44 to 10.00 ± 2.04%) in sorghum grains were obtained in *S. obtusifolia* treatments, while the least (2.50 ± 1.44 to 5.20 ± 0.00%) were in sorghum treated with *E. balsamifera*. Grain perforations in sorghum treated with *L. inermis* and *M. hirtus* ranged from 3.75 ± 1.25 to 6.25 ± 1.25% and 5.00 ± 2.04 to 8.75 ± 1.25%, respectively, but 66.25 ± 3.15% of the grains ere perforated in untreated samples. The grain perforations in the different treatments appeared to be in the following order: Control > *S. obtusifolia* > *M. hirtus* > *L. inermis* > *E. balsamifera* and 25 > 50 > 100 mgml^{-1} in terms of concentration (Figure 3). There was a highly significant difference (F (4, 45) = 588.30, p < 0.0001) in grain perforations among the treatments. Further, there was no significant difference in grain

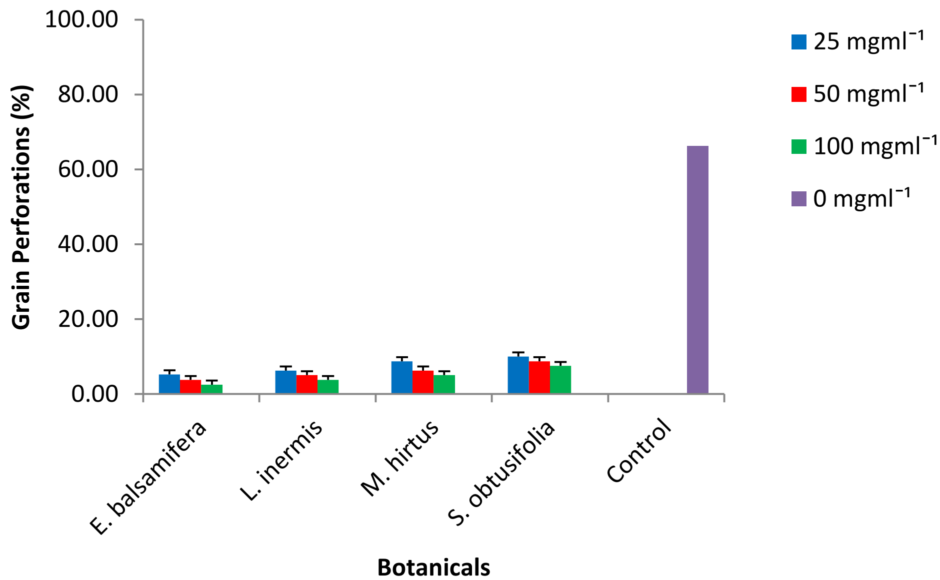

Figure 3. Mean grain perforations in sorghum grains treated with ethanolic extracts of different botanicals applied at different concentrations infested by *S. zeamais*.

perforations among the varying concentrations (F (2, 45) = 1.71, p = 0.1924).

DISCUSSION

Repellency of the botanicals against *S. zeamais*

All the botanicals, *E. balsamifera, L. inermis, M. hirtus* and *S. obtusifolia*, tested in this study have repellent potentiality against adult *S. zeamais* infesting sorghum. The present investigation has shown that the repellency of ethanolic extracts of the test botanicals against *S. zeamais* within 24 h was encouraging. The high repellent activity of ethanolic extract of *E. balsamifera* concurs with Idris et al. (2014) and Suleiman et al. (2018a) who recorded > 90.90% repellency of ethanolic and methanolic extracts of *E. balsamifera* against *Anopheles gambiae* and *S. zeamais*, respectively.

Similarly, the repellency potential of ethanolic extracts of *L. inermis* is in line with Datti and Idris (2013) that the extracts were highly repellent against mosquitoes. Application of the extract at 12.50% concentration on a marked area of forearm repelled 83.90% of *Anopheles gambiae*.

Findings of Akinbuluma et al. (2015) revealed the repellent effects of ethanolic extracts of *Capsicum frutescens* and *Dennettia tripetala* on *S. zeamais* where the botanicals repelled 91.68 and 89.58% of the weevils, respectively. These outcomes concur with Vigilianco *et al.* (2008) who earlier reported that ethanolic extracts of *Solanum argentinum* Bitter and Lillo repelled 55.0% of *S. oryzae*.

It is interesting to note that all the botanicals were found to demonstrate repellent activities against adult *S. zeamais* in sorghum grains. This shows that the plant materials could probably reduce *S. zeamais* infestations to sorghum by repelling the insect from the grains. The study revealed that *E. balsamifera* and *L. inermis* exhibited greater repellency against the weevils than the rest. The repellent activities of the selected botanicals could be attributed to the presence of +non-host volatile odour components of plants with insects' repellent activities (Kuhns et al., 2016). Active ingredients such as alkaloids, flavonoids, saponins, phenolics and tannins, have been identified in some plant species and suggested to confuse the olfactory receptors so that the insects could not smell the host (Effiom et al., 2012). Further, Adesina et al. (2016) reported that secondary metabolites present in *Bridelia micrantha*, *Chasmanthera dependens* and *Vernonia cinerea* were responsible for repelling *Dysdercus superstitious* (Herrich Schaffer).

Effect of the botanicals on adult mortality of *S. zeamais*

This study has revealed that leaves of *E. balsamifera*, *L. inermis*, *M. hirtus* and *S. obtusifolia* caused significant mortalities of adult *S. zeamais*. Ethanolic extracts of the selected botanicals were found to be highly effective by resulting in total mortality of adults of *S. zeamais* in sorghum grains at all concentrations of *E. balsamifera* and higher rates of *L. inermis*, *M. hirtus* and *S. obtusifolia*. The efficacy of the test botanicals concurs with earlier findings that ethanolic extracts of some plant species caused significant adult mortality of maize weevils (Ajayi, 2013; Ibrahim et al., 2016). Also, findings of Ibrahim et al. (2016) showed that application of ethanolic leaf extract of *C. odorata* at 10 ml per 50 g maize caused 14.00% adult mortality of *S. zeamais* at 7 DAT. Findings of this study showed that the mortality of adult *S. zeamais* was directly proportional to the post treatment period agreeing with Ajayi (2013) and Ibrahim et al. (2016).

All the selected botanicals were effective against the weevil even at lower concentrations. This was possible because plant species contain secondary metabolites which are huge store of compounds such as the steroids, phenolic compounds, tannins, terpenoids, flavonoids, alkaloids, saponins and glycosides with wide range of biological activity reported to have great impact on insecticidal activities (Biswas et al., 2016; Hikal et al., 2017). The characteristic smell of the study botanicals might have also contributed to their insecticidal activity by repelling the insects away from the grains (Suleiman et al., 2018a). Ethanolic leaf extracts of *E. balsamifera*, *L. inermis*, *M. hirtus* and *S. obtusifolia* were generally found toxic to adult *S. zeamais* and suppressed their survival in sorghum grains by causing considerably high mortality.

Effect of the botanicals on adult emergence of *S. zeamais*

Ethanolic extracts of the test botanicals exhibited total inhibition in adult emergence of *S. zeamais* in treated sorghum grains as there was no adult emergence recorded. Application of plant powders to reduce adult emergence of *S. zeamais* was previously reported (Rivera et al., 2014; Oni and Ogungbite, 2015).

The total inhibition rate in adult emergence of the weevils in grains treated with ethanolic leaf extracts of the test botanicals at varying concentrations recorded in this study agrees with Ileke (2014) who reported a complete inhibition of adult emergence of *S. zeamais* when exposed to aqueous extracts of *A. boonei*. The suppression activity in adult emergence of *L. inermis* was also recorded against *C. maculatus* (Suleiman and Suleiman, 2014; Chudasama et al., 2015). It is found out that the botanicals might be lethal to the eggs deposited and as such led to inhibition in adult emergence of the weevils in the treated grains, concurring with Chudasama et al. (2015) that poisonous substances present in the extracts may enter into the egg through chorion and suppressed further embryonic development.

Influence of ethanolic extracts in reducing grain perforations in of stored sorghum infested by *S. zeamais*

The effectiveness of *E. balsamifera* and *L. inermis* in reducing grain perforations of sorghum by *S. zeamais* corroborates with Suleiman and Suleiman (2014) who reported that application of leaf powders of the botanicals at 1.0 g / 20 g cowpea reduced perforations caused by *C. maculatus* from 18.33% in the control to 1.67%. Other botanicals were tested for their effectiveness in reducing grain perforations caused by *S. zeamais*. The weevil did not cause any grain perforation in stored wheat treated with powders of *A. indica* and *A. boonei* at 2.5, 5.0, 12.5 and 25.0% (Ileke and Oni, 2011). Similarly, no grains were perforated by *S. zeamais* 45 days after infestation when treated with 2.0 g *Corymbia citrodora* per 30 g of maize (Longe, 2016).

The significant reduction in grain perforations by the selected botanicals in this study could be due to total inhibition in emergence of the adult weevils in ethanolic extracts, since most of the perforations occurred as a result of emergence holes made by the insects. In addition to this, the secondary metabolites present in the botanicals might serve as antifeedants, and therefore the weevils found the treated grains unpalatable, hence reduction in perforations. This is supported by Dales (1996) and Rajashekar et al. (2012) that secondary compounds can affect insects by causing rapid death and acting as antifeedants, among others.

Conclusion

Findings have revealed that ethanolic extracts of *E. balsamifera, L. inermis, M. hirtus* and *S. obtusifolia* are repellents against *S. zeamais* in stored sorghum. The botanicals were found to be toxic to adult *S. zeamais*. The extracts were highly effective as adult emergence inhibition agents against *S. zeamais*. All the botanicals reduced grain perforations in sorghum at all the concentrations. The repellent activity, adult mortality effects, inhibition in adult emergence and reduction in grain perforations of the extracts indicated that the botanicals could be used as protectants of stored sorghum against *S. zeamais*, thereby contributing to IPM strategies. However, further investigations on their toxicity on mammals and other insect pests are hereby recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Influence of mineral nutrition on plant development and chemical composition of volatile oils *of Porophyllum ruderale* (Jacq.) Cass subspecies

Rodrigues D. S., Leporini N., Raggi L., Zara K. R. and Young M. C. M.

Instituto de Botânica de SP. Av. Miguel Estefano, 3671, São Paulo-SP. 04301-012, Brazil.

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The objective of this study was to find out the influence of soil nutrition on the composition of volatile oils of *Porophyllum ruderale* subsp. *macrocephalum* and *Porophyllum ruderale* subsp. *ruderale.* The seedlings were transplanted into pots containing sand as substrate. Every seven days, different Hoagland solutions were applied: Complete solution and solution lacking, respectively nitrogen, phosphorus, potassium, calcium, magnesium, sulfur and a control. The experiment was done in a randomized block with eight treatments and five replicates. For biometrics, height, leaf area and dry mass of shoots were analyzed. The average was compared by Tukey test (5%) probability. Aerial parts were collected and oil was extracted by hydrodistillation in Clevenger apparatus for 4 h. The major components of *P. ruderale* subsp. *ruderale* were trans-β-ocimene monoterpene, limonene and hydrocarbon undecene. As for the *P. ruderale* subsp. *macrocephalum,* the major component was monoterpene limonene and undecene hydrocarbon. The results of biometric analyses in this work showed that the two species have different growth. Treatments without nitrogen, phosphorus and the control had the lowest average and increased undecene content in the two subspecies. The chemical composition of volatile oils nutrition did not interfere significantly in their composition. Monoterpene limonene was the highest in *macrocephalum* subspecies.

Key words: Brazilian medicinal plants, fertilizers.

INTRODUCTION

Brazil is a country with a rich genetic diversity in both flora and fauna. In its flora, there have been cataloged more than 55,000 species of an estimated total of 350,000 to 550,000 species. The increased genetic diversity and chemical diversity allow the use of plants as invaluable source of bioactive compounds for the development of new drugs (Gottlieb et al., 1996). Plants produce a wide variety of organic compounds that are

*Corresponding author. E-mail: dsrodrigues@ibot.sp.gov.br.

economically important, such as alkaloids, resins, tannins, volatile oils, among others (Croteau et al., 2000). The growing demand for medicinal plants constitutes a concern for conservation. Because extraction threatens more native species (Ioris et al., 1999), a more detailed study is needed on native vegetation for the recovery of species of medicinal value (Dias, 2000).

According to Di Stasi et al. (2002), among the plant species of therapeutic interest, the Asteraceae family can be considered as one of the most important. This is because the large number of plants belonging to it, such as *Baccharis trimera* (gorse) and *Achillea millefolium* ("novalgina") in addition to arnicas, guacos and bidens, are popularly used as drugs. Most of these species are native to Brazil, while several others have acclimatized and can be found throughout Brazilian territory, which have been incorporated in traditional medicine.

Porophyllum ruderale (Jacq.) Cass., popularly known as arnica is a ruderal herb used in folk medicine for healing, as haemostatic (Goleniowski et al., 2006), antitinflamatória (Lima et al., 2010) and for combating leishmaniasis (Takahashi et al., 2011). There are two subspecies of *Porophyllum* used for the same purpose: *P. ruderale* subsp. *ruderale* and *P. ruderale* subsp. *macrocephalum*. The two subspecies have the same common name and share some morphological characters, such as herbaceous and similar inflorescences, attributted to the misuse of species. The chemical composition of the volatile oil of the two subspecies is different. The major compounds in *P. ruderale* subsp. *ruderale* are monoterpenes trans-β-ocimene, α-pinene and limonene, while in *P. ruderale* subsp. *macrocephalum*, there are monoterpenes limonene and β-pinene (Raggi et al., 2010). There are few works done on the subspecies, *ruderale* and *macrocephalum*. Some authors have reported the presence of β-phellandrene (Fonseca et al., 2006), sabinene (Loayza et al., 1999), limonene and 7-tetradecene (Guillet et al., 1998) as major compounds in the chemical composition of the volatile oil of *P. ruderale*.

According to Martins et al. (1995), of all the factors that can interfere with the active principles of plants, nutrition is one of those that require more attention, as excess or deficient nutrients can be directly correlated to changes in the production of active substances. Evaluating the influence of mineral nutrition on yield and volatile oil composition of *Ocimum basilicum* (basil), *Coriandrum sativum* (coriander), *Anethum graveolens* L. (dill), and *Mentha piperita* L. (Mint) and Hornok (1983) reported the occurrence of variations based on the four levels of NPK used. With increased phosphorus level, there was an increase in the volatile oil content of mint and basil and low volatile oil content of biomass and dill. High nitrogen levels increased the essential oil of mint and basil, but reduced the percentage of menthol and linalool. Also in relation to nitrogen levels, the authors observed an increase in the production of green biomass of dill and cilantro, but not seeds.

The species of the genus Porophyllum are widely used in folk medicine of South and Central America. However, there are phytotechnical works related to soil nutrition and the chemical composition of the volatile oils of species *P. ruderale* subsp*. macrocephalum* and *P. ruderale* subsp. *ruderale.* The objective of this project was, consequently, to study the effect nutrition management on plant development and production of volatile oils of arnica's subspecies.

This work aimed to evaluate the management of mineral nutrition for plant growth, yield and chemical composition of the volatile oils of *P. ruderale* subsp. *ruderale* (Jacq.) Cass. and *P. ruderale* (Jacq.) Cass. subsp. *macrocephalum* (DC.) R. R. Johnson.

MATERIALS AND METHODS

Seedlings of *P. ruderale* subsp. *ruderale* and *P. ruderale* subsp. *macrocephalum* were obtained from seeds and grown in a greenhouse at the Experimental Field of Ornamental Plants Research Center, São Paulo Botanic Institute.

The seeds used were obtained from mother plants of PEFI (State Park Ipiranga Font) and sown in polystyrene trays with 128 cells, using Tropstrato HT Hortaliças® as substrate. After the appearance of four pairs of permanent leaves, the seedlings were transplanted into plastic pots of 10.5L, using sand as substrate and placed in a greenhouse equipped with microsprinkler irrigation system, in the Experimental Field Ornamental Plants. The pots were fertilized once a week with 50 ml of nutrient solutions of Hoagland and Arnon (1950), under different managements: complete solution, solution without nitrogen (-N^{3-}), solution without phosphorus (-P^{5+}), solution without potassium (-K^{+}), solution without magnesium (-Mg^{2+}), solution without calcium (-Ca^{2+}), solution without sulfur (-S^{2-}), and a control with 50 mL distilled water. The experiment was done in a randomized block design with eight treatments for each species, five replications and four vessels.

The height of both subspecies was taken with a measuring tape in centimetre from the soil surface to the highest part of the plant. The first measurement was done 30 days after transplanting, while the other was done every 20 days until the end of the experiment (130 days) after treatments application. To obtain dry mass, three individuals from each treatment were weighed on an analytical balance, placed in paper bags and oven-dried at 45°C for 15 days. The leaf area was determined in a meter Model LI-3100C expressed in square decimetres. Leaf area is defined as the average of the areas of all the leaf blades of the three subjects per treatment (Benincasa, 2003).

All data collected were submitted to Tukey test at 5% significance using the SISVAR program (Ferreira, 2002).

For extraction and identification of volatile oil, plant materials were collected at 130 days after treatment application, in the morning. The plant materials were stored in transparent bags and kept in a freezer at -22°C for later extraction in the Center for Research in Physiology and Biochemistry, São Paulo Botanic Institute. The shoots were subjected to extraction to obtain volatile oil in a continuous process by hydrodistillation using Clevenger apparatus. They were adapted to a round bottom flask of 6000 mL, for 4 h in three replicates for each treatment. After this period, the volatile oil was removed from the apparatus and stored in an

Erlenmeyer. For the complete removal of the volatile oil, solvent pentane was added. Anhydrous sodium sulfate was used to remove any water present in the volatile oil. The volatile oil containing pentane was transferred to a vial with cap. With the aid of rotatory evaporator at room temperature, pentane was completely removed leaving only the pure volatile oil. The oil mass was determined with the aid of an analytical balance. The oils were stored in cardboard box in a freezer at -22°C for further identification of its constituents. The yield of each oil was calculated from the fresh mass (Santos et al., 2004; Pino et al., 2006; Kelen and Tepe, 2008).

To identify the constituents, the extracted volatile oils were dissolved in acetone 1:10 (v/v) and 2 uL of each diluted sample was analyzed by gas chromatography on Agilent apparatus (6890 series) HP, coupled to spectrophotometer mass with quadrupole system (Agilent 5973 Network mass Selective Detector), and 70 eV ionization energy. The capillary column used was HP-5 MS (30 m × 0.25 mm internal diameter, 0.25 thickness) under the following conditions: gun (with flow-split split/splitless) to 250°C (split ratio 1: 20), the column of heating temperature of 40 to 240°C to 3°C min^{-1}, 240°C for 10 min using helium as carrier gas at a pressure of 80 kPa and a linear speed of 1 ml min^{-1}. The total analysis time was 78 min. Nitrogen, synthetic air and hydrogen are used as auxiliary gases in the ratio of 1:1:10, respectively. The retention index (RI) was calculated on HP-5 MS column using a homologous series of n-alkanes (C5 to C30) under the same conditions for chromatographic analysis. The identification of the compounds was made by comparing mass spectra to those registered in the library database 275.

RESULTS AND DISCUSSION

Growth of *P. ruderale* subspecies under differents nutrient solutions of Hoagland

It was observed that the growth of plants *P. ruderale* subsp. *ruderale* and *P. ruderale* subsp. *macrocephalum* was differently influenced by the different treatments.

The mean height of the subspecies *ruderale* treated with complete nutrient solution at 130 days after treatment application (DAT) was 144.8 cm; while *macrocephalum* was 126.1 cm in the same period.

The highest mean of plant height was obtained with the complete solution treatment and treatments without Ca^{2+}, Mg^{2+} and S^{2-}, respectively. Subspecies *ruderale* that had the lowest plant height mean was treated with the nutrient solution minus nitrogen ($–N^{3-}$) and the control. The means obtained with these treatments ($–N^3$ and control) signifcantly differed from the others height means.

The descending order height for *macrocephalum* subspecies was: $-Ca^{2+}$, $-Mg^{2+}$, $- S^{2-}$, complete solution, $-K^+$, $-P^{5+}$, $-N^{3-}$ and control; for subspecies *ruderale*: $-Mg^{2+}$, $-Ca^{2+}$, $-S^{2-}$, $-K^+$, complete solution, $-P^{5+}$, $-N^{3-}$ and control. Importantly for both subspecies, in $-N^{3-}$ treatment and control, the plants are not developed satisfactorily.

In this study, the two subspecies responded similarly to the treatments without nitrogen (N^{3-}) and the control; they had significantly lower growth compared to other treatments (Tables 1 and 2). According to Kerbauy (2008), nitrogen is essential for plant growth and its deficiency significantly influences the growth of the plant. Nitrogen is the mineral element required in larger quantities by plants and is the constituent of many components of the plant cell (Castro, 2007). It has a structural function in the plant and parts of many cell components such as proteins, nitrogenous bases, nucleic acids, enzymes, co-enzymes, vitamins and pigments. It, also, participates in processes such as ion absorption, photosynthesis, respiration, cell multiplication and differentiation (Malavolta, 2006). Its deficiency rapidly inhibits plant growth (Taiz and Zeiger, 2004).

At 130 days, the height mean of plants treated with the nutrient solutions $-Ca^{2+}$ and $-Mg^{2+}$ were not statistically different from each other and were similar to the one of the plants which received full Hoagland nutrient solution. This showed that the absence of this nutrient did not negatively affect the development of *macrocephalum* subspecies (Tables 2 and 3).

Although many studies conducted showed that the absence of calcium and magnesium dramatically affects the development of plant, their absence effect differed in the subspecies *Porophyllum* since in both species the absence of these nutrients did not affect their growth.

The application of nutrient solution minus P did not negatively affect the height, dry mass and leaf area of *P. ruderale* subsp. *ruderale* comparatively to the ones of the plants that received full nutrient solution of Hoagland. Phosphorus is involved in the storage and transfer of energy and nitrogen fixation; nitrogen is connected to the rapid development of roots, accelerated fruit ripening, increased fruiting as carbohydrate content, oils, fats and proteins (Malavolta, 2006).

According to Malavolta (2006), nitrogen is required for flowering. Without this nutrient, the emission of flowers will be retarted. This is because the limitation of nutrient reduces the assimilation of CO_2 through photosynthesis, and after a variable period it ends up decreasing biomass production, photosynthesis and stomatal conductance (Fujita et al., 2003).

Phosphorus has fundamental function in the life of plants. As part of compounds, it is rich in energy like adenosine triphosphate (ATP) (Malavolta, 1985), and through this energy, seeds germinates, plant performs photosynthesis, absorbs actively soil nutrients and synthesizes various organic compounds (Naiff, 2007). Phosphorus is also involved in essential functions of cellular metabolism, which acts in the synthesis of metabolites and complex molecules such as DNA, RNA and phospholipids, in the electron transport chain, redox reactions promoting the regulation of the rate of several enzymatic reactions and metabolic processes, such as respiration and photosynthesis (Alves et al., 1996).

As also noted with *ruderale* subspecies, the indicative biometric variables of *macrocephalum* subspecies growth were also significantly affected by nitrogen omission.

Symptoms of deficiency or excess of a mineral element

Table 1. Mean values of dry matter of shoot and leaf area of *Porophyllum ruderale* subsp. *ruderale* at 130 days after treatment application.

Parameter	Nutrient solutions							
	Full	$-N^{3-}$	$-P^{5+}$	$-K^{+}$	$-Ca^{2+}$	$-Mg^{2+}$	$-S^{2-}$	Control
Height (cm)	158.4^{a}	99.0^{b}	147.8^{a}	165.6^{a}	168.2^{a}	173.4^{a}	168.4^{a}	78.6^{b}
Fresh mass (g)	217.5	68.6	158.7	229.0	220.7	251.4	198.5	45.6
Dry mass (g)	14.4^{a}	3.6^{b}	10.9^{a}	14.8^{a}	12.8^{a}	13.7^{a}	12.9^{a}	2.8^{b}
Leaf area (dm^2/plant)	46.25^{a}	8.43^{c}	33.74^{ab}	44.31^{ab}	29.17^{b}	36.52^{ab}	31.66^{ab}	3.57^{c}

Means followed by the same letter in the same lines do not differ significantly by Tukey test at 5% probability.

Table 2. Mean values of dry matter of shoot and leaf area of *Porophyllum ruderale* subsp. *macrocephalum* at 130 days after treatment application.

Parameter	Treatments							
	Full	$-N^{3-}$	$-P^{5+}$	$-K^{+}$	$-Ca^{2+}$	$-Mg^{2+}$	$-S^{2-}$	Control
Height (cm)	151.8^{ab}	58.4^{c}	134.0^{b}	139.4^{ab}	164.4^{a}	160.8^{a}	157.2^{ab}	44.2^{c}
Fresh mass (g)	168.3	58.1	221.1	179.6	209.6	239.8	191.5	27.7
Dry mass (g)	6.8^{a}	0.7c	3.9^{b}	7.3^{a}	6.3^{ab}	7.4^{a}	7.6^{a}	0.1^{c}
Leaf area (dm^2/plant)	12.23^{a}	2.23^{bc}	8.53^{ab}	10.68^{a}	11.40^{a}	14.50^{a}	9.37^{ab}	0.98^{c}

Means followed by the same letter on the lines do not differ significantly by Tukey test at 5% probability.

are similar in all plant species (Leal and Prado, 2008). According to Pozza et al. (2001), nutrients perform specific functions in plant metabolism, not only in influencing its growth, but also its production. Thus, a nutrient in abnormal levels can damage production causing a nutritional stress (Deon, 2007). The dry matter production data of shoot and leaf area of the subspecies *Porophyllum* are shown in Table 2.

Analyzing the variables, for the shoot dry matter production was differently affected by the treatments. The plants treated with the nutrient solution minus nitrogen and the control had significantly lower shoot dry matter of 3.6 and 2.8 g, respectively. As well, the leaf area was differently influenced by the treatments: the control had the lowest mean of 3.57 dm^2 per plant and the highest mean of 46.25 dm^2 per plant was obtained with the complete nutrient solution.

Table 3 shows the height mean values of shoot dry matter and leaf area of the subspecies *macrocephalum*. Significant differences were observed between the treatments: the treatments without potassium ($-K^{+}$), calcium ($-Ca^{2+}$) and magnesium ($-Mg^{2+}$) and the complete nutrient solution had the highest mean leaf area.

Chemical composition of the essential oils of the aerial parts of *P. ruderale* subsp. *ruderale* as influenced by different nutrient solution of Hoagland

The chemical composition of volatile oils of *P. ruderale* subsp. *ruderale* is presented in Table 3. Twenty-two compounds were identified out of thirty compounds. The yield of volatile oil was 0.07% for treatments with complete Hoagland solution and without sulfur ($-S^{2-}$); 0.06% for treatments without phosphorus ($-P^{5+}$), potassium ($-K^{+}$), magnesium ($-Mg^{2+}$) and calcium ($-Ca^{2+}$); 0.03% for the control treatment and 0.02% for treatment without nitrogen ($-N^{3-}$). Monoterpenes were the predominant constituents, ranging from 48.5% (treatment $-N^{3-}$) to 95.7% ($-Ca^{2+}$ treatment). The other major compounds were trans-β-ocimene, limonene and hydrocarbon. The different nutrient solution handlings also influenced the chemical composition of the volatile oils except limonene; even the treatments with a greater influence negative ($-N^{3-}$ and control) remained constant at about 20% of the total chemical composition. The major compound was trans-β-ocimene, accounting for about 62%, on average, of the total chemical composition of the volatile oil of subspecies *ruderale* for almost all treatments except N in which it was 22.2%. The content of the hydrocarbon undecene was greater about eight times in the N treatment (18.9%) and six times in the control treatment (13.7%), relative to the treatment with addition of the complete Hoagland solution.

The presence of sesquiterpenes was also higher in the treatment without nitrogen. The hydrocarbon of undecene was also observed by Raggi et al. (2012) who compared the chemical composition of volatile oils of green material collected at 270 days and aging plant collected at 300 days. Undecene increased by about 10 times in plants of

Table 3. Chemical composition of the essential oils of the aerial parts of *P. ruderale* subsp. *ruderale* grown under different managements of nutrient solution.

Compound	Retention time	Kovats index	Peak area (%)							
			Full	$-N^{3-}$	$-P^{5+}$	$-K^{+}$	$-Mg^{2+}$	$-Ca^{2+}$	$-S^{2-}$	Control
Pentanone	6.39	822	0.8	1.8	1.0	0.7	0.8	0.8	0.9	0.8
α-Pineno	9.87	931	0.6		-	0.4	0.2	0.2	0.2	
Sabinene	11.61	971	0.9	-	0.6	0.8	0.8	0.8	0.8	-
β-Pineno	11.79	975	7.9	3.2	6.5	7.3	7.6	7.4	6.8	3.9
Myrcene	12.42	988	0.1	-	-	-	-	-	-	-
Limonene	14.28	1029	20.5	21.3	24.0	20.8	21.0	20.4	20.7	17.4
Cis-β-Ocimene	14.62	1036	1.0	-	0.9	1.0	1.0	0.9	0.9	0.8
Trans-β-Ocimene	15.13	1046	62.9	22.2	59.0	62.5	64.3	65.1	62.9	58.6
Undecene	17.28	1087	2.2	18.9	3.7	2.5	2.4	2.5	3.0	13.7
Decanol	22.71	1199	-	1.0	-	-	-	-	-	-
NI	22.80	1201	0.5	2.8	1.1	0.8	0.5	0.4	0.8	-
NI	25.57	1264	-	2.2	1.0	0.2	-	-	0.2	-
Silfineno	28.88	1338	-	0.6	-	-	-	-	-	-
NI	30.47	1374	-	1.7	0.5	-	-	-	-	-
α-Isocomeno	30.72	1379	-	0.9	-	-	-	-	-	-
β-Isocomeno	31.66	1399	-	0.8	-	-	-	-	-	-
β-Cariofileno	32.04	1408	0.5	2.0	-	0.4	-	-	0.4	1.2
NI	33.94	1449	-	1.4	-	-	-	-	-	-
NI	34.15	1453	-	0.6	-	-	-	-	-	-
NI	34.25	1455	-	0.3	-	-	-	-	-	-
Germacrene-D	34.60	1462	0.5	-	-	0.6	0.2	-	0.4	-
Biciclogermacrene	35.19	1474	0.4	-	-	0.6	0.5	0.5	0.5	1.1
NI	36.88	1512	-	1.6	0.3	-	-	-	-	-
NI	37.64	1536	-	1.9	-	-	-	-	-	0.7
NI	37.91	1544		1.2	-	-	-	-	-	-
NI	38.16	1551	-	0.3	-	-	-	-	-	-
Spathulenol	38.39	1558	1.2	5.1	1.5	1.3	1.0	0.9	1.4	0.6
Caryophyllene oxide	38.58	1564	-	1.3	-	-	-	-	-	-
NI	38.70	1568	-	0.3	-	-	-	-	-	-
Phthalate *	48.64	1774	-	0.8	-	-	-	-	-	-
Hexadecanoic acid	52.19	1957	-	3.6	-	-	-	-	-	1.3
Linoleic acid	57.34	2106	-	1.0	-	-	-	-	-	-
Linoleate ethyl	57.50	2108	-	1.2	-	-	-	-	-	-
Total	-	-	99.5	85.8	97.1	99.0	99.6	99.6	98.9	99.3
Monoterpenes	-	-	94.6	48.5	92.0	93.5	95.6	95.7	93.2	81.5

Table 3. Contd.

Sesquiterpenes	-	-	2.6	10.7	1.5	3.0	1.6	1.4	2.7	2.8
Outhers	-	-	2.2	26.6	3.7	2.5	2.4	2.5	3.0	15.0
Yield (%)	-	-	0.07±0.01	0.02	0.06±0.01	0.06±0.01	0.06±0.00	0.06±0.00	0.07±0.02	0.03

NI: Not identified; *Poisoning; Full: complete solution; -N^{3}-: solution with no nitrogen; -P^{5+}: solution with no phosphorus; -K^{+}: solution with no potassium; -Mg^{2+}: magnesium absence solution; -Ca^{2+}: solution absence of calcium; -S^{2-}: solution with no sulfur; Control: treatment with no nutrient solution. Amounts related to the average of three extractions except –N^{3-} and control. Income calculated based on the fresh weight + standard deviation.

300 days old relative to the green material. Though, there are no studies on the hydrocarbon of undecene in different plant growth stages.

For the biometric analysis, treatments that led to nutritional deficiency in the chemical composition of volatile oils were -N^{3-} and control.

Chemical composition of the essential oils of the aerial parts of *P. ruderale* subsp. *macrocephalum* as influenced by different nutrient solution of Hoagland

The yield of volatile oil of *macrocephalum* subspecies was lower compared to that of *ruderal*e. For -K^{+} and -Ca^{2+} treatments, the yield was 0.04%; for complete and -S^{2-}, -Mg^{2+} treatments, the yield was 0.03% and for phosphorus, the yield was 0.02%. In -N^{3-} and control treatments, there was no much oil yield due to the small amount of oil obtained. As noted in the biometric analysis, -N^{3-}, -P^{5+} and control treatments did not produce sufficient biomass to conduct the volatile oil extraction in three repetitions, as the other treatments.

The chemical composition of volatile oils of *macrocephalum* subspecies is described in Table 4. Of the twenty compounds, thirteen were identified. Monoterpene limonene was the major constituent in almost all treatments except control, whose main component was undecene hydrocarbon (29%). The other treatments showed, on average, 15% of hydrocarbon. -Mg^{2+} treatment found to have the highest percentage of limonene (70.5 %) and the lowest content of this constituent was found in the control treatment (27.4%). Treatments without potassium and sulfur had the highest percentages of myrcene (18.2 and 18.4%, respectively), compared to the same constituent in the other treatments on average, 8%, except the control treatment containing only 2.6%. The sesquiterpenes content was higher in the control (12.4%) compared to other treatments, 2.7% on average.

The chemical composition of volatile oil of *Porophylum* is well reported in the literature. However, little is said about the studied subspecies. The levels of the major constituents were very different. Rondón et al. (2008), working with *P. ruderale* collected in Venezuela, identified a mixture of limonene and β-phellandrene as the main components of the chemical composition of volatile oils. For plants collected in Bolivia, the main constituent was sabinene (Loayaza et al., 1999). Fonseca et al. (2006) identified β-phellandrene monoterpene in plants collected in Minas Gerais. In Ceará, Neto et al. (1994) said the major compound was limonene (74%).

Many articles report that geographical and climatic variations are responsible for the variation in the chemical composition of volatile oils. However, besides these, there is also correct identification of the material to be studied and the quality of tillage. Raggi et al. (2014), working with both species, concluded that the major components in subspecies *macrocephalum* and *ruderale* were limonene and E-β-ocimene, respectively. They noted that the difference in the two species is not caused by climate, but by genetic issues.

Monoterpene limonene present mainly in subspecies *macrocephalum* has different biological activities such as antimicrobial and anti-inflammatory. These activities are related to its medicinal use (Souza et al., 2003; Lorenzi and Matos, 2008).

Conclusion

Both species did not have proper growth development with nitrogen deficiency, phosphorus and control. The chemical composition of volatile oils nutrition did not interefere significantly in their composition. Monoterpene limonene was the highest in *macrocephalum* subspecies,

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

Table 4. Chemical composition of the essential oils of the aerial parts of P. ruderale subs. macrocephalum grown under different managements.

Compound	Retention time	Kovats index	Peak area (%)							
			Full	$-N^{3-}$	$-P^{5+}$	$-K^{+}$	$-Mg^{2+}$	$-Ca^{2+}$	$-S^{2-}$	Control
Pentanone	6.39	822	0.7	1.1	0.8	0.9	0.7	0.8	0.6	1.1
Sabinene	11.61	971	0.5	0.8	0.9	0.3	1.1	0.8	0.8	-
Beta Pinene	11.80	975	0.6		0.8	1.3	0.7	0.6	1.5	-
Myrcene	12.42	988	8.8	8.9	6.9	18.2	7.7	8.2	18.4	2.6
Limonene	14.27	1028	58.0	68.3	64.8	54.8	70.5	66.5	54.1	27.4
Trans Beta Ocineme	15.09	1046	3.7	4.4	3.2	3.7	4.0	3.8	3.9	2.4
Undecene	17.28	1087	17.2	14.0	18.6	15.2	12.1	15.0	16.3	29.0
Decano	22.72	1199	0.2	-	-	0.2	-	-	0.2	1.2
NI	30.43	1373	02	-	-	-	-	-	-	1.2
Alfa Isocomeno	30.71	1379	2.0	1.1	1.3	1.4	1.0	1.2	1.4	5.7
Beta Isocomeno	31.66	1399	1.1	-	0.7	0.6	0.5	0.7	0.7	3.1
Beta Caryophyllene	32.05	1408	0.3	-	-	-	-	-	-	1.3
Germacrene-D	34.60	1462	1.3	-	0.7	0.7	0.6	0.7	0.7	2.3
NI	36.11	1492	0.5	-	-	1.1	-	1.2	-	2.3
NI	48.64	1774	-	-	-	-	-	-	-	1.4
NI	49.79	1790	-	-	-	-	-	-	-	1.2
Hexadecanoic Acid	52.18	1957	1.3	-	-	0.3	-	-	-	-
NI	62.65	1882	0.7	1.4	1.4	1.4	1.2	0.5	1.5	-
NI	62.70	2156	2.5	-	-	-	-	-	-	13.6
NI	65.93	2184	0.5	-	-	-	-	-	-	4.2
Total	-	-	95.6	98.6	98.7	97.5	98.8	98.3	98.5	76.1
Monoterpenes	-	-	72.3	83.5	77.4	79.2	84.5	80.7	79.3	33.6
Sesquiterpenes	-	-	4.6	1.1	2.7	2.6	2.1	2.6	2.8	12.4
Outhers	-	-	18.7	14.0	18.6	15.7	12.1	15.0	16.4	30.1
Yeld (%)	-	-	0.03±0.01	*	0.02	0.04±0.01	0.03±0.01	0.04±0.00	0.03±0.00	*

NI: Not identified; Full: complete solution; $-N^{3}$: solution with no nitrogen; $-P^{5+}$: solution with no phosphorus; K^{+}: potassium absence solution; $-Mg^{2+}$: absence of magnesium solution; $-Ca^{2+}$: solution absence of calcium; $-S^{2-}$: solution with no sulfur; Control: treatment with no nutrient solution. Values referring to the average of three extractions except $–N^{3-}$, $-P^{5+}$ and witness. Income calculated based on the fresh weight + standard deviation.

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Transforming smallholder agriculture through cooperatives for improving households' food security at OR Tambo District Municipality, South Africa

Cishe B. E.* **and Shisanya S. O.**

Research Department, Faculty of Educational Sciences, Walter Sisulu University, Mthatha, South Africa.

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Agriculture is a primary source of food, employment and income in rural households. Agricultural cooperatives have been regarded as possible vehicles in achieving these objectives. Small holder farming in the OR Tambo District Municipality has marginally been performed in contributing to households' food security. Research indicates that there are many factors affecting agricultural cooperative development and agriculture productivity that are unique. This study investigated the role of agricultural cooperatives in transforming small holder agriculture and household food security in OR Tambo District municipality. A questionnaire and focus group discussions were used in data collection. Comparison of means and construction of themes were used in data analysis. The findings showed that agricultural cooperative members had very little understanding of the cooperative principles. They experienced low commodity prices and lacked the knowledge and capital to deal with food insecurity. They employed a variety of coping strategies to deal with these challenges. Most households were in the moderately to mildly food insecure categories. Transforming small holder agriculture in OR Tambo District Municipality will require building members' capacity on cooperative principles and agricultural production processes for improved households' food security.

Key words: Co-operatives, climate, agriculture, food security, copping strategies.

INTRODUCTION

Cooperatives have been promoted world over with the aim of enabling small producers to tap into mainstream economic activities. A co-operative is an autonomous association of persons united voluntarily to meet their common economic, social and cultural needs and aspirations through a jointly owned and democratically controlled enterprise. The United Nations recognizes the contribution cooperatives can make in contributing to the global development goals including productive employment, eradicating poverty, enhancing social integration and especially promoting the advancement of women. Whereas the development potential of co-operatives is in principle not different from the one of other types of enterprises, the double nature of co-operatives (members are at the same time owners and users of their co-operatives) makes them more

*Corresponding author. E-mail: ecishe@wsu.ac.za.

appropriate for specific population groups, geographical areas, sectors or situations. Hence, co-operatives possess an inherent special potential for socio-economic development. Cooperatives function as an economic unit to promote their members by rendering services, rather than to maximize profits. Cooperative businesses stabilize communities because they are community-based business anchors; and distribute, recycle, and multiply local expertise and capital within a community. They pool limited resources to achieve a critical mass. They enable their owners to generate income, and jobs, and accumulate assets; provide affordable, quality goods and services; and develop human and social capital, as well as economic independence (Nembhard, 2014). Agricultural cooperatives have the potential of helping small-holder farmers aggregate their surplus output, pool both tangible and intangible resources, generate economies of scale and scope in marketing (Markelova and Mwangi, 2009). OR Tambo District Municipality is a generally rural district where agriculture still plays an important role in households' food security.

Working with cooperatives in Malawi, Lecoutere (2017) showed that being a member of an agricultural cooperative had a significantly positive impact on economic wellbeing, knowledge and adoption of agronomic practices, especially among women. In the rural context, cooperatives are appreciated for their role in combining business enterprises with a concern for communal welfare with indirect benefits of improving socio-economic status of communities through improved incomes (Majurin, 2012). Further, agricultural cooperatives can simplify marketing and value addition by directly bypassing intermediaries and lowering horizontal and vertical coordination costs (Shiferaw et al., 2009).

According to Develtere et al. (2008), approximately one in seven Africans now belong to a cooperative, with countries such as Senegal, Rwanda, and Egypt possessing membership rates of over ten percent. These 'contemporary' cooperatives have been reported to benefit smallholders economically by reducing transaction costs, increasing market access, and improving bargaining power (Bernard and Taffesse, 2012). Work done by Thamaga-Chitja et al. (2011) showed that agricultural cooperatives do experience challenges ranging from internal factors that included low capabilities of the cooperative to mobilise and utilise their limited resources, low capabilities for management of institutional arrangements and external factors that included lack of external support such as finding, education and extension services. They further showed that apart from the small land holding limiting farmers' expansion to meet the high produce demand, the land tenure system legally prohibited the farmers from using the land as collateral for obtaining loans from funding institutions. Therefore, there was serious under capitalisation issues within the cooperatives leading to the aforesaid ineffectiveness.

LITERATURE REVIEW

In South Africa before 1994, there existed well-established agricultural cooperatives, predominantly white that received a lot of support from the apartheid government (Phillips, 2003:17; DTI, 2004: 6). They were backed by ready access to finance through the Land Bank, and with effective control of the market boards that regulated prices.

Post 1994, the South African Government acknowledges that development of cooperatives is a significant and advisable means for mitigating poverty and unemployment. The Cooperatives Development Policy for South Africa which forms the basis for the Cooperative Act 14, 2005 (establishment and development of cooperatives) was adopted in 2004 (DTI, 2004: 1). The South Africa Government's approach to co-operative development is one of creating an enabling environment for cooperatives to thrive (Department of Trade and Industries ((DTI), 2004)). The 2012–2022 *Integrated Strategy on the Development and Promotion of Cooperatives* is aimed at promoting co-operatives, in order to unleash their potential to create and develop income-generating activities and decent, sustainable employment. The strategy aims to reduce poverty, develop human resource capacities and knowledge; strengthen competitiveness and sustainability; increase savings and investment; improve social and economic well-being; and contribute to sustainable human development. As a result, cooperatives have been receiving increased financial and other support from development and government agencies to facilitate agricultural system innovation and poverty alleviation (Johnson and Shaw, 2014).

Most cooperatives in South Africa are currently black controlled, are young "emerging cooperatives" which, in the government's view, warrant intense support intervention in order to attain medium and long-term sustainability and success (DTI, 2009: 1; Ortmann and King, 2007: 40). The South African Government has in the recent past promoted and supported cooperatives presuming that cooperative form of ownership benefits the whole community in a collective manner rather than developing an individual. Investment in cooperatives would result in 'decent work opportunities', 'sustainable livelihoods', 'increased agricultural production and productive land-use' and 'financially viable entities that can implement employment-intensive production schemes' (Zuma 2009).This paper aims to gain a better understanding of the contribution of smallholder agricultural cooperatives in OR Tambo District to members' household food security and to identify institutional and governance constraints affecting their performance.

MATERIALS AND METHODS

Our population of interest were households who are involved in agricultural cooperatives in O. R. Tambo District Municipality. A total of 405 households from all the five local municipalities participated in the study: King Sabata Dalidyebo (67), Nyandeni (62), Ingquza Hill (135), Mhlontlo (79), and Port St. Johns (62). Convenience sampling (A type of nonprobability sampling) was employed in the study where we started carrying out interviews with the first households researchers were guided to by a community guide. This was then followed by snowball sampling where existing participants were used to recruit the next participants until there were no more qualifying households to be interviewed.

The study employed a mixed method where quantitative research was employed in assessing magnitude and frequencies of constructs while qualitative methods were used in exploring meaning and understanding of constructs (Tashakkori and Creswell, 2007). Primary data were collected using a household survey and focus group discussions. Semi-structured interviews were conducted with key informants involved in cooperatives including traditional leadership, development organizations, and government. Data were analysed using SPSS.

RESULTS

Main household livelihood strategy

Table 1 shows that across all the five local municipalities, majority of the respondents depend more on grants for their livelihood (54.8-75.9%). Cooperatives formed second largest main livelihood strategy (38.7-45.2%). It was expected that households' involvement in agricultural cooperatives would complement and promote individual household agricultural practices, which was not the case. From our focus group discussions, fencing of individual household land for agriculture was their greatest limitation due to the cost involved. Further, they indicated that water for irrigation was not easy to come by at their individual household gardens. This makes agricultural cooperatives a lesser livelihood strategy and that there are a number of barriers that are limiting performance of cooperatives.

Households' exposure to agricultural information

Households received agricultural information that was useful to their agricultural production processes (Table 2). The results show that there are households who have never received any information based on agricultural production. Port St. Johns leads this category of households with 45.2%. However, the majority had received information of agricultural production in the past one month, followed by households who received information in the past one year. Critical information like weather reports of local conditions was lacking due to lack of appropriate information gathering infrastructure. Limited agricultural information negatively affected agricultural productivity of cooperatives in form of lack of innovative and new methods of doing agricultural business.

Cooperative land ownership

Cooperative members were asked the type of ownership of the land on which the cooperative was operating (Table 3). Generally, across the district, cooperatives were utilising members' land for their cooperative activities with substantial numbers using communal land for the cooperative activities (31.3 - 54.1%). It was indicated that the nature of land ownership does not allow for cooperatives to undertake structural developments e.g. irrigation systems because cooperatives do not own the land on which they operate.

Cooperative agricultural activities

Cooperatives were involved in a variety of agricultural projects (Table 4). The two prevalent occupations were vegetable and maize and other cereals production. Members indicated that there was market for the vegetables and cereals and that their productions costs were relatively low. One thing that bothered them was theft on their crops while in the fields. This was a problem since they had to limit their cropping fields to those that were close to their households limiting their ability to expand.

Households' food security

Households were categorised into food security categories using the Household Food Insecurity Access Scale (HFIAS) (Table 5). Most households across the district are in the category of moderately food insecure. This is followed by fewer households that are mildly food insecure. We have very few outliers across the district that is food secure and severely food insecure. Household food security is predominantly affected by external incomes including salaries, remittances, grants and pensions. These sources of income are not stable and hence the instability in household food security.

Conclusion

The results show that overall, households did not use the proposed copping strategies more frequently. Copping strategies that were used more as compared to the others included; eating less preferred and less expensive food, increasing short term food availability, borrowing food from friends and relatives, purchasing food on credit and limiting portion size at meal time. Extreme copping strategies like consuming seed stock and skipping entire day without eating were seldom used.

Type of land ownership by agricultural cooperatives

Table 1. Main Household livelihood strategy.

Main livelihood strategy	Local Municipalities				
	King Sabata Dalidyebo	Nyandeni	Ingquza Hill	Mhlontlo	Ports st Johns
Cooperative	26 (39.4%)	25 (40.3%)	61 (45.2%)	31 (39.2%)	24 (38.7%)
Employment	9 (13.6%)	6 (9.7%)	8 (5.9%)	8 (10.1%)	8 (12.7%)
Grant	50 (75.8%)	34 (54.8%)	100 (74.1%)	60 (75.9%)	43 (69.4%)
Trade/Business	1 (1.5%)	3 (4.8%)	4 (3.0%)	1 (1.3%)	1 (1.6%)
Labour/ Wages	2 (3.0%)	2 (3.2%)	6 (4.4%)	3 (3.8%)	2 (3.2%)
Household farming	7 (10.6%)	5 (8.1%)	11 (8.1%)	8 (10.1%)	5 (8.1%)
Service	0 (0.0%)	1 (1.6%)	0 (0.0%)	1 (1.3%)	0 (0.0%)

Source: Author’s computation from field survey (2018).

Table 2. Frequency of access to agricultural information.

Frequency of access to agricultural information	Local Municipalities				
	King Sabata Dalidyebo	Nyandeni	Ingquza Hill	Mhlontlo	Port st. Johns
Everyday	1 (1.5%)	1 (1.6%)	-	1 (1.3%)	-
In the past one week	5 (7.5%)	8 (12.9%)	24 (17.8%)	1 (1.3%)	6 (9.7%)
In the past one month	27 (40.3%)	22 (35.5%)	32 (23.7%)	19 (24.1%)	19 (30.6%)
In the past one year	18 (26.9%)	21 (33.9%)	53 (39.3%)	43 (54.4%)	9 (14.5%)
never	15 (22.4%)	10 (16.1%)	26 (19.3%)	15 (19%)	28 (45.2%)

Source: Author’s computation from field survey (2018).

Table 3. Type of cooperative land ownership.

Type of land ownership	Local Municipalities				
	King Sabata Dalidyebo	Nyandeni	Ingquza Hill	Mhlontlo	Port st. Johns
Communal	17 (25.0%)	22 (35.5%)	34 (24.1%)	25 (31.3%)	17 (27.9%)
Coop members’ land	32 (47.1%)	22 (35.5%)	68 (48.2%)	25 (31.3%)	33 (54.1%)
Lease agreement	2 (2.9%)	4 (6.5%)	4 (2.8%)	5 (6.3%)	10 (16.4%)
Permission to Occupy	16 (23.5%)	14 (22.6%)	34 (24.1%)	25 (31.3%)	1 (1.6%)
Non-specific	1 (1.5%)	0 (0%)	1 (0.7%)	0 (0%)	0 (0%)

Source: Author’s computation from field survey (2018).

Table 4. Agricultural activity of cooperatives.

Agricultural activities of cooperatives	Local Municipality				
	King Sabata Dalidyebo	Nyandeni	Ingquza Hill	Mhlontlo	Port st. Johns
Poultry keeping	17 (25.4%)	6 (9.7%)	33 (24.4%)	11 (13.9%)	5 (8.1%)
Livestock keeping	11 (16.4%)	5 (8.1%)	10 (7.4%)	9 (11.4%)	2 (3.2%)
Vegetable production	42 (62.7)	43 (69.4%)	109 (80.7%)	40 (50.6%)	47 (75.8%)
Maize and other cereals	44 (65.7%)	27 (43.5%)	48 (35.6%)	47 (59.5%)	26 (41.9%)
Fruit production	5 (7.5%)	9 (14.5%)	37 (27.4%)	5 (6.3%)	1 (1.6%)
Fish production	1 (1.5%)	10 (16.1%)	1 (0.7%)	4 (5.1%)	1 (1.6%)
Bee keeping	0 (0.0%)	10 (16.1%)	1 (0.7%)	4 (5.1%)	0 (0.0%)
Wool production	6 (9.0%)	4 (6.5%)	5 (3.7%)	1 (1.3%)	0 (0.0%)
Mixed farming	3 (4.5%)	4 (6.5%)	2 (1.5%)	4 (5.1%)	1 (1.6%)

Source: Author’s computation from field survey (2018).

Table 5. Household food security categories.

Food security categories	Local Municipality				
	King Sabata Dalidyebo	Nyandeni	Ingquza Hill	Mhlontlo	Ports st Johns
Food secure	9 (13.4%)	7 (11.3%)	17 (12.6%)	17 (21.5%)	5 (8.1%)
Mildly Food Insecure	16 (23.9%)	10 (16.1%)	23 (17.0%)	19 (24.1%)	7 (11.3%)
Moderately Food Insecure	36 (53.7%)	37 (59.7%)	85 (63.0%)	35 (44.3%)	42 (67%)
Severely Food Insecure	6 (9.0%)	8 (12.9%)	10 (7.4%)	8 (10.1%)	8 (12.9%)
Total	**67 (100%)**	**62 (100%)**	**135 (100%)**	**79 (100%)**	**62 (100%)**

Source: Author's computation from field survey (2018).

has profound effect on the level of agricultural productivity. There is need for government to consider land ownership options that will promote investment in agriculture. Limited markets confined agricultural cooperatives vegetable and maize production. Programmes that promote value addition will go a long way in opening avenues for diversified agricultural production. O R Tambo District Municipality should work on a strengthened and effective agricultural extension programme that can be able to reach the agricultural cooperatives for improved agricultural production and food secure households. This will call for collaboration of all relevant departments and development partners who are working in the community development sectors.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Dynamics of weed biomass on yield and yield component stability of maize under various weed management strategies

Adewale B. Daniel* and Badmus A. Adesile

Department of Crop Science and Horticulture, Federal University Oye-Ekiti, Ikole-Ekiti Campus, Ekiti State, Nigeria.

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Weed is a very significant enemy of crop production. Its density, diversity and the interaction complexes on the yield and yield component of maize cv "Quality protein" were investigated in the present study. The experiment was laid out in randomized complete block design (RCBD) containing five weed management strategies and a weedy check as treatments in 2015 and 2016. Data were collected on weed density, yield and yield components of maize for the two years. For the years and the treatments, a mixed model factorial in RCBD was employed for the analysis of variance of the data. Significant ($P \leq 0.05$) variation exists among the two years; the six treatments and their interaction for the grain yield and its components. The use of Pendimenthalin (330 EC) at 3.0 kg a.i.ha^{-1} supported the highest grain yield (2.4 tons ha^{-1}); hoe weeding and mulching was next with significantly ($P \leq 0.05$) lower grain yield of 2.2 tons ha^{-1}. The weedy check had the lowest grain yield of 1.2 tons/ha. An average yield loss of 42% was obtained by comparing the weed control methods with each of the weedy check. By Shukla variance estimate, maize-soybean intercrop gave the most stable grain yield for the two years. Year 2016 significantly ($P \leq 0.05$) favoured grain yield, its components and weed density. The proportion of weed categories in the study was: Broadleaves (52.38%), grasses (33.33%) and sedges (14.28%). Broad leaves and grasses density measured at interval displayed a significant linear trend. The sixth week after planting was most critical for grain yield determination in the tested maize cultivar.

Key words: Weed management strategies, maize, grain yield, interaction complexes.

INTRODUCTION

The productive potentials of crops are hindered by a number of factors, one of which is weed interference. Weeds compete with corn and other crops for resources such as light, nutrients, space and moisture that influence its morphology and phenology, reduce the yield, lower value of soil and land, make harvesting difficult, mar the quality of harvested products, increase the cost of production, reduce the returns on productions, etc. (Vernon and Parker, 1983; Perry et al., 1983; Knezevic et al., 1994; Kremer, 2004). According to Randall (2016), only 9,855 of the 40,874 referenced weeds listed in the database have scores indicating their level of risk in

*Corresponding author. E-mail: d.adewale@gmail.com. E-mail: +234 803 9228 085.

agricultural production. Among those whose presence constitutes risks to crop production in West African fields are: 263 species belonging to 38 plant families in the category of broad-leaved, grasses and sedges according to Chikoye and Ekelemo (2001).

The perpetual low maize productivity of 2.2 ton/ha from smallholder farmers' fields whose output accounts for more than 90% of the total production in the sub Saharan Africa has been of great concern. Chikoye et al. (2005) had indicted weed infestation to be the most supreme biotic factors that are responsible for low maize grain yield and reported the highest loss potential of about 37%, compared to 18, 16 and 2% loss potentials from animal pests, fungal and bacterial pathogens and viruses, respectively. Corn-weed competitive interaction is usually very severe during the early growing period which is characterized by slow rate of plant growth. Weed species, densities, and their interactions influence corn yield loss (Scholes et al., 1995; Fausey et al., 1997) through competition. Therefore, to realize the yield potential of corn, weed management is indispensable (Mitchell et al., 2014) especially during the critical periods.

Different weed control methods have been utilized to manage weeds; mechanical and chemical methods are more frequently used than any other methods (Tesfay et al., 2015). Meanwhile, none of the two methods has satisfactorily provided season long effect on weed control when used alone (Badmus et al., 2006; Lagoke et al., 2014). Reasons for the poor success from the use of either of the two methods have been documented by Adigun et al. (1992) and Chikoye et al. (2002). Moreover, weed management strategies vary in their suppressive potential. The growing of two or more crop species simultaneously in the same field during a growing season is a common practice to prevent total crop losses, an investigation of its possible role in weed control is rare (Takim, 2012; Amujoyegbe et al., 2012). Similarly, the art of covering the soil around the crop with dried plant residues is another eco-friendly cultural operation which is not popular in maize production. We deemed it meaningful in the present investigation to assess the potentiality of intercropping and mulching along with mechanical and chemical weed control methods.

Maize (*Zea mays* L.) is a member of the family Poaceae and one of the most important cereal crops used as staple food for man, feed for livestock and essential raw material in confectionaries, pharmaceuticals and agro allied industries (Adigun and Lagoke, 1999; IITA, 2012). Its cultivation is globally wide and occupies a very vital position in global food security and economy. All the Nigerian agro-ecologies support the cultivation and production of maize; this makes her a very relevant producer in Africa. Maize production is wide spread in Ekiti State (Southwestern Nigeria) with average annual growth rate of 2.33% (World Data Atlas, 2018).

The reports of Tesfay et al. (2015) had identified grasses, broadleaved and sedges to be the major weed categories in maize plots. Owing to the awareness that functional interactive complexes exist among different weed species and soil characteristics, climate, cultural practices and different weed control methods (Kremer, 2004), a kin look at the prospective roles of different weed categories on yield and yield components of corn in Ikole-Ekiti, Southwestern Nigeria was thought worthwhile to assess the relative scoring of the negative potentials of the different weed types. Due to the differences in environmental factors accompanying different years, weed development dynamics and complexes of crop-weed type interactions, the present study therefore seek to: assess population of different weed categories in maize plot and understand their impacts on the yield and yield component of maize in Ikole-Ekiti, Ekiti State, Nigeria.

MATERIALS AND METHODS

Two years field trials were conducted in the late wet seasons of 2015 and 2016 to evaluate weed density, their biomass production and their influence on kernel yield and yield component of maize at the Teaching and Research Farm of the Federal University Oye-Ekiti, Ikole-Ekiti Campus (7° 48'N and 5° 29'E) Ekiti State, Nigeria. In the two years trials, the land was ploughed and later harrowed after two weeks. The experiment, containing six weed management strategies as treatments (Table 1) was laid out in a randomized complete block design (RCBD) of three replications. The test crop was a hybrid maize variety "quality protein".

For the treatments involving maize-legume intercropping, cowpea (cv. Oloyin, ART 98/SW1) and soybean (cv. TGX 1740) obtained from the Institute of Agricultural Research and Training (IAR & T), Ibadan, Nigeria were used. Seeds of maize were planted at 0.75 m × 0.5 m while the seeds of cowpea and soybean were planted at 0.75 × 0.30 m and 0.75 × 0.05 m, respectively. In each of the two intercropping cases, maize and cowpea or soybean lied side by side along rows on the flat. Planting was done on the same day. At germination, thinning was done to two plants stand^{-1} for each crop. NPK (15:15:15) fertilizer and urea were applied as side dressing for maize at 3 and 6 WAP at the rate of 120 and 60 kg ha^{-1}, respectively.

Data on weed characters such as species composition, level of occurrence and dry matter production (g) were recorded using plants from the two central rows of each plot based on 0.5 m^2 quadrat capture at 6, 9 and 12 WAP. Weed species within the quadrant area were separated into broadleaves, grasses and sedges and later identified following the weed species guide by Akobundu et al. (2016). Weed samples were oven-dried to a constant weight at 60°C for 48 h to obtain the dry matter production. Data collected on maize at harvest included: net plot yield (g), 100 seed weight, weight of ten cobs (g), grain yield of ten cobs (g), total grain yield (kgha^{-1}) and shelling percentage which was estimated as the proportional percentage of the kernel to the whole cob.

For the data analysis, the two years data for the six treatments were treated as a factorial in RCBD. Data collected on weed density, grain yield and yield components were subjected to analysis of variance (ANOVA) using SAS version 9.4 (SAS, 2011). Significance by comparison of the means of the levels of each main effects was tested using least significant difference (LSD) at P = 0.05. The significant year by treatment interaction component from the ANOVA for grain yield and yield related traits was further partitioned for stability test using the Shukla variance estimate

Table 1. Description of the six weed management strategies.

S/N	Treatment codes	Description
1	T1	Maize-Cowpea inter-rows intercrop followed by one supplementary hoe weeding at 6 WAP
2	T2	Maize-Soybean inter-rows intercrop followed by one supplementary hoe weeding at 6 WAP
3	T3	Mulching with grass straw (*Digitaria ciliaris* [Retz.]) Koel at 5 tons ha^{-1} followed by hoe weeding at 6 WAP
4	T4	Pendimenthalin (330 EC) at 3.0 kg a.i / ha followed by hoe weeding at 6 WAP
5	T5	Two hoe weedings at 3 and 6 WAP
6	T6	Weedy check (negative) control.

WAP: Weeks after planting.

Table 2. Common weed species found in the experimental plots of maize and their level occurrence.

S/N	Weed species	Family	Level of occurrence	
	Broadleaves		**2015**	**2016**
1	*Amaranthus spinosus* (Linn.)	Amaranthaceae	***	**
2	*Biden pilosa* L.	Asteraceae	***	***
3	*Cassia hirsuta* (L.)	Leguminosae	*	**
4	*Cassia obtusifolia* (L.)	Leguminosae	**	-
5	*Corchorus olitorius* (L.)	Tiliaceae	***	-
6	*Euphorbia heterophylla* (L.)	Euphorbiaceae	*	**
7	*Fleurya aestuans* [Linn] ex Miq.	Urticaceae	***	*
8	*Physalis angulata* (Linn.)	Solanaceae	**	-
9	*Solanum nigrum* (L.)	Solanaceae	-	*
10	*Solanum torvum* (SwartzL.)	Solanaceae	**	-
11	*Spigelia anthelmia* (Linn.)	Loganiaceae	***	*
	Grasses			
12	*Andropogon tectorum* schum & Thonn	Poaceae	-	***
13	*Commelina bengalensis* (L.)	Commelinaceae	*	**
14	*Commelina nodiflora* (L.)	Commelinaceae	***	*
15	*Digitaria abyssnica* (A, Rich) Stapf	Poaceae	**	**
16	*Eleusine indica* (L.) Gaertn	Poaceae	-	*
17	*Panicum maximum* (Jacq.)	Poaceae	***	****
18	*Setaria longista* (P. Beauv.)	Poaceae		
	Sedges			
19	*Cyperus esculentus* (Linn.)	Cyperaceae		
20	*Cyperus rotundus* (Linn.)	Cyperaceae		
21	*Mariscus alternifolius* (Vahl.)	Cyperaceae		

(Shukla, 1972). Weed population responses for broadleaves, grasses and sedges for the three periods of measurements (that is, at 6, 9 and 12 weeks after planting (WAP) were investigated for the six weed management strategies by trend analysis. Furthermore, for each of the three different periods of sampling the weed type populations, the means of a pair of the six weed management strategies were compared for significance testing by LSD (0.05). The relationship between the different weed populations and the grain yield and yield components was investigated by Pearson correlation.

RESULTS AND DISCUSSION

From Table 2, the occurrence of three categories of weed species in the experimental unit at Ikole-Ekiti, Nigeria was in the percentage of: 52.38% (Broadleaves), 33.33% (Grasses) and 14.28% (Sedges). The percentages of occurrence of the three categories in the present study differed from what Tesfay et al. (2014) obtained; they reported 72.7% broadleaved weeds, 9.09% grasses and18.19% sedges weeds in their experiment with maize at West Showa, Ethiopia. It is clear from their studies and ours that the broadleaves weeds usually predominate in cultivated maize field. The variation for the second and third place in the present study and theirs by grasses or sedges could be due to the variation in the environment.

The analysis of variance result (Table 3) revealed highly

Table 3. The variance components of the different sources of variation for grain yield and yield components of the studied maize variety.

Sources of variation	Df	Mean squares					
		100Swt	Wt10cobs	Gy_10_Cobs	NPY	GY/ha	%Shelling
Rep	3	263.95	31.29	0.00091	1896.47	2.90	263.9495
Years	1	319.01***	210.99***	0.23***	12984.36***	27.02**	319.01***
Treatments	5	668.76***	1438.36***	0.43***	19592.67***	19.09***	668.76***
Years×Treatments	5	76.89***	80.21***	0.008***	709.03***	5.57***	76.89***
Error	33	5.95	4.21	0.0001	21.91	0.17	5.92

Table 4. Mean performances of maize for each of the two years under the six weed management strategies and proportion of losses in performance of each treatment compared to the check.

Years	100Swt	Wt10cobs	Gy_10_Cobs	NPY	Grain yield/ha	%Shelling
2015	13.56[b]	616.21[b]	482.91[b]	0.788[b]	1720.07[b]	77.55[a]
2016	14.49[a]	667.81[a]	524.76[a]	0.923[a]	2049.02[a]	76.05[b]
Treatments						
T1	13.92[b]	590.32[c]	460.17[d]	0.72[c]	1603.25[c]	78.84[c]
T2	13.82[b]	569.48[c]	457.51[d]	0.71[c]	1595.16[c]	77.78[c]
T3	14.49[a]	691.69[b]	582.06[c]	1.01[b]	2248.03[b]	82.34[b]
T4	14.38[a]	705.62[b]	595.94[b]	1.03[b]	2284.44[b]	84.43[a]
T5	14.56[a]	764.30[a]	648.11[a]	1.13[a]	2400.98[a]	84.84[a]
T6 (Check)	12.97[c]	530.64[d]	279.23e	0.53[d]	1175.40[d]	52.56[d]
Proportion (%) of losses compared to the check						
T5 - T6	10.92	30.57	56.92	53.1	51.04	38.05
T4 - T6	9.81	24.8	53.14	48.54	48.55	37.75
T3 - T6	10.49	23.28	52.03	47.52	47.71	36.17
T2 - T6	6.55	7.32	63.85	33.96	35.71	47.98
T1 - T6	6.82	10.11	39.32	26.39	26.69	33.33
Average	8.88	20.12	49.12	42.39	41.99	35.62

Means with the same letter are not significantly different and mean comparison is along each column.

significant ($P \leq 0.01$) variations for the two main effects (years and weed management strategies) for the yield and yield components and the three different weed type population densities. However, some of the traits equally exhibited significant year by weed management interaction. For the six grain yield characters, performance was much and significantly ($P \leq 0.05$) higher in 2016 for all the characters except shelling percentage (Table 4). In the present result, 2016 greatly supported grain yield, its determinants and the densities of the three weed categories compared to 2015. This seems to approve that two environments does not display the same characteristics and thus affect the same biological phenomenon differently. Environmental factors such as moisture availability and daily temperature which differ from year to year play a key role in influencing the performance of specific crop genotypes under different weed type regime in a particular season (Mwendwa et al., 2016). An Australian wheat-weed competition evaluation trial by Mwendwa et al. (2016) equally indicted the environment (location and year) as a very prominent factor which influences wheat competitive traits, grain yield and suppressive capability of weed management strategies.

T5 (a treatment involving weeding twice with hoe at 3 and 6WAP) most significantly ($P \leq 0.05$) supported the five grain yield attributes including grain yield (Table 4). Treatments 4 and then 3 supported the yield parameters in succession behind treatment 5. The weed management strategy check (with no weeding), that is, T6, provided the least support to the six grain yield parameters (Table 4). Weeding with hoe provides an immediate zero maize-weed competition; the same situation enhances optimum utilization of available moisture and nutrients resources by the crop. Hoe weeding at the 3rd and 6th weeks after seedling emergence in the present study coincided with

Table 5. Stability estimates of the interaction of the six treatments and two years.

Treatment	Wgt100	Wt10cobs_g	Yld_Kg_ha	Shelling	Gy_10_Cob	NPY
1	0.061	0.651	0.882	-0.378	-1.281	0.345
2	-0.038	-0.208	-0.136	-0.288	1.052	-0.053
3	-0.037	-0.025	-0.924	-0.253	-5.768	-0.164
4	0.029	-0.454	-0.485	-0.181	-6.021	0.049
5	-0.036	-0.473	0.663	-0.368	-5.988	-0.186
6	-0.026	0.033	-1.021	1.090	11.936	-0.249

NPY: Net plot yield, Gy: grain yield, Yld_Kg_ha: grain yield in Kilogram per hectare, Wgt100: 100 seed weight, Wt10cobs_g: weight of seeds from 10 cobs in grammes. Interpretation is based on absolute values and dimension is not relevant. Higher values of the variance estimate imply low stability. Source: Shukla (1972).

the critical period of maize vulnerability to yield loss (that is, weeks one to eight) as identified by Perry et al. (1983), Vernon and Parker (1983) and Jhala et al. (2014). In the present result, it was equally noted that keeping maize from weed competition within this period especially at the 6th week significantly and positively enhanced grain yield and its components.

The support of treatments four (herbicide usage) and five (mechanical method) for grain yield and its component and weed suppression was relatively the same in this study; although chemical control method distinguishes itself in the suppressive pattern for the three weed categories. However, the evolution of herbicide resistant weed biotypes has always been the problem from the continuous use of registered herbicide. Heap (2016), cited in Mwendwa et al. (2016) reported that weeds have evolved resistance to 22 of the 25 known herbicide modes of action and to 160 different herbicides globally. Therefore, the incorporation of other strategies with sole herbicides usage could help to reduce the trend of evolution of resistance of weeds to herbicides.

The performance of the yield and yield related characters in Table 4 by the maize cultivar, “Quality protein” under intercrop conditions (that is, T1 and T2) was not different, however, both significantly ($P \leq 0.05$) outperformed the check. In the comparison of each of the five treatments with the check in Table 4, the highest (56.92%) proportion of loses was between T5 and T6, followed by the percentage loss between T4 and T6, then T3 and T6, T2 and T6 and lastly T1 and T6. However, for grain yield of ten cobs and shelling percentage, the highest percentage loss was between T2 and T6 (Table 4). With the aggregate mean loss of 42% in this study from the comparison of each treatment to the check, it is imperative that control of weeds in the fields of maize is very essential to be able to obtain good harvest.

No significant difference was observed in the weed type population between the use of either cowpea or soybean as companion crop with maize in this study. This seems to suggest that the two may have related smothering activity for the three weed categories in the maize field. However, loses in the grain yield and its component was least in the comparison between the check with maize-cowpea intercrop. The wider intra-row space between maize and cowpea in the intercrop seems most relevant to explain for the limited compensatory loss. Mitchell et al. (2014) had suggested that closer row planting patterns could lead to more effective weed management in corn and hence increased reduction of grain yield loss. Although mulching and hand hoeing are two cultural methods, however, their efficacy for weed control distinctly differs in all the stages of the crop growth.

Generally, within the two years of evaluations, only grain yield of ten cobs showed much higher values for the Shukla stability variance, most of the other characters had values less than a unit (Table 5). Moreover, among the six treatments for the two years, treatments 2 had the lowest Shukla variance estimate for grain yield/ha and grain yield of 10 cobs while treatment 4 had the lowest values for shelling percentage and NPY (Table 5). The most stable treatments for weight of ten cobs and 100 seed weight in this study were treatments 3 and 6, respectively because they had the lowest value each (Table 5); this makes them the most stable treatments. A long-term analysis (1996-2011) by Ferrero et al. (2017) showed that the combined effects of internal and external processes involving weed diversity were strongly associated with soybean and maize yield fluctuations. Furthermore from their work, while maize seems to be more sensitive to environmental variation, soybean seems to have stronger regulation in its production with varied environment. In the present two-year research, the least affected treatment by the variation in the year effect for maize grain yield was the intercrop programme involving maize with soybean. Weed diversity has significant association with different crop species, with reference to soybean and maize according to Ferrero et al. (2017). In our result therefore, the presence of soybean with maize may have a conditioning influence in regulating the environmental factors such that the yield from maize was stable for the two years.

Different weeds species in the classes of broadleaves, grasses and sedges can be obtained in a single

Table 6. Annual means density of the three weed categories evaluated at sixth, ninth and twelfth week after planting

6th week	Broadleaved	Grasses	Sedges
2015	51.62[b]	7.62[b]	2.50[b]
2016	53.04[a]	9. 47[a]	3.36[a]
9th week			
2015	55.55[a]	3.74[b]	2.60[b]
2016	64.60[a]	4.75[a]	3.51[a]
12th week			
2015	169.64[b]	3.51[b]	1.82[b]
2016	196. 49[a]	4.32[a]	2.31[a]

Means with the same letter are not significantly different and mean comparison is along each column.

Table 7. Trend of different weed population measured at three intervals during the growing period of the maize variety

Sources of variation	DF	Broad leaves	Grasses	Sedges
		Mean squares		
Treatments	17	5380.98**	21.45	2. 46
Weed Control Strategy (WCS)	5	3841.72**	37.32*	3.83
Intervals (In)	2	32275.55***	40.09	1.74
In-Linear	1	51270.13***	64.52*	2.24
In-Quadratic	1	13280.97**	15.65	1.23
Error	10	771.68	9.81	1.92

experimental site (Mehmeti et al., 2012); each one and their complexes differ in competitive potential to affect crop yield. From Table 6, higher weed densities were observed for broadleaves, grasses and sedges at each of the three weeks interval of measurements in 2016 compared to 2015. For the broadleaf weed type, increase in density was clearly observable from the sixth week to the twelfth week for each of the two years; the observed difference between 6 and 9th was small compare to the difference between 9 and 12th week (Table 6). For grasses in the two years, population declined from the 6 and 12th week. Sedges population at the 9th week was slightly higher than what was obtained in the 6th week, however, the recorded density for the same at the 12th week for the two years was lowest compared to the two earlier periods of population density evaluation (Table 6). Higher population of broadleaves and grasses at 6 WAP in a maize field was highly detrimental to all the grain yield components and the yield of maize. Among the three weed types, the influence of sedges was most minimal.

The six treatments and the three intervals of measuring the population density of the three weed types were investigated by trend analysis, the result is presented in Table 7. Significant ($P \leq 0.05$) differences were obtained among the six treatments in the population of broadleaves and grasses (Table 7). The two categories of weeds equally exhibited significant ($P \leq 0.05$) positive linear and quadratic (broadleaves) and negative linear (grasses) responses along the two intervals of 6 to 9th and 9 to 12th. Moreover, broadleaves weed type additionally exhibited significant quadratic response (Table 7). The expressed dynamics for increase or decrease in the weed type population with the interval of measurement were unique in this experiment: it was both linear and quadratic for broadleaves, linear for grasses but the pattern of response by sedges was not well defined. The positive linear trend exhibited by the broadleaved weed species with the intervals (6 to 9th weeks) seems to reflect the usual vigour characteristic by weed species during their vegetative and early reproductive growth stages. However, the noted negative quadratic trend for the same group within the interval of 6 to 12th weeks after planting seem to reflect the nature of the ephemerals plant species; whose vegetative, reproductive developmental stages and senescence occurs within short time. Akobundu (1987) had long

Table 8. Paired mean comparison of the six weed management strategies for the three different weed type population densities measured at three periodic weeks interval.

Parameter	B_Leaf6WAP					Grass6WAP					Sedge6WAP				
	T1	**T2**	**T3**	**T4**	**T5**	**T1**	**T2**	**T3**	**T4**	**T5**	**T1**	**T2**	**T3**	**T4**	**T5**
T2	0.57					3.71**					0.63*				
T3	17.71**	17.14**				6.40**	2.69**				1.00**	0.38*			
T4	13.72**	13.15**	3.99*			9.15**	5.44**	2.75**			0.05	0.58*	0.96**		
T5	17.71**	17.14**	0.00	3.99*		7.99**	4.28**	1.59**	1.16**		1.97**	2.60**	2.98**	2.02**	
T6	4.63*	5.20*	22.34**	18.35**	22.34**	8.91**	12.62**	15.31**	18.06**	16.90**	0.77*	1.40**	1.77**	0.82**	1.20**
LSD0.05			3.15					0.97					0.27		
	B_Leaf9WAP					**Grass9WAP**					**Sedge9WAP**				
	T1	**T2**	**T3**	**T4**	**T5**	**T1**	**T2**	**T3**	**T4**	**T5**	**T1**	**T2**	**T3**	**T4**	**T5**
T2	1.57					0.07					0.43				
T3	2.06	0.49				0.14	0.07				0.87*	0.44*			
T4	0.72	2.29	2.78			3.49**	3.42**	3.36**			3.59**	3.16**	2.72**		
T5	0.45	1.12	1.61	1.17		0.03	0.04	0.11	3.46**		0.15	0.28	0.72**	3.44**	
T6	78.58**	77.01**	76.52**	79.30**	78.13**	2.76**	2.83**	2.90**	6.26**	2.79**	4.59**	4.16**	3.72**	1.00**	4.44**
LSD0.05			4.27					0.44					0.43		
	B_Leaf12WAP					**Grass12WAP**					**Sedge12WAP**				
	T1	**T2**	**T3**	**T4**	**T5**	**T1**	**T2**	**T3**	**T4**	**T5**	**T1**	**T2**	**T3**	**T4**	**T5**
T2	1.04					0.20					0.14				
T3	23.82**	22.78**				1.14**	1.34**				0.05	0.19			
T4	19.68**	18.63**	4.15			1.79**	1.99**	0.65*			3.52**	3.66**	3.46**		
T5	23.28**	22.23**	0.55	3.60		1.60**	1.80**	0.46	0.19		1.45**	1.59**	1.39**	2.07**	
T6	99.33**	98.28**	75.50**	79.65**	76.05**	7.44**	7.64**	6.30**	5.65**	5.84**	3.03**	3.17**	2.98**	0.49*	1.58**
LSD0.05			6.20					0.59					0.24		

remarked that majority of broadleaves weeds are ephemeral in nature. The positive linear nature of the trend analysis for grasses at the interval (6 to 12th) weeks after planting seems to indict the supportive role of the perennating organs in grasses which support their continual survival after establishment.

Table 8 presents paired comparison of differences between two treatment means using LSD at P = 0.05. At the 6, 9 and 12th WAP, significant ($P \leq 0.05$) differences existed for the population of broadleaves, grasses and sedges between T6 (the check) and the other five treatments. Except for grasses and sedges population at the 6^{th} week, there were no significant differences between intercropping maize with either soybean or cowpea (Table 8). For the two cultural management practices (T3 and T5), population of sedges at 6, 9 and 12th WAP and grasses at 6 WAP differed significantly ($P \leq 0.05$). Furthermore, in Table 8, chemical weed control (T4) was significantly ($P \leq 0.05$) different from other treatments at the different stages for the three weed types except treatments (T1, T2 and T3 at 9WAP) for broadleaves category, T1 (Sedge at 6 WAP) and T3 (Broadleaves at 12 WAP). The competitive role of grasses and broadleaves at 6 and 9th WAP on maize would need to be further investigated to be able to ascertain the contributory impact of the

Table 9. Correlation between grain yield and yield components with periodical weed type densities.

Correlation	GR6	SDG6	BL9	GR9	SDG9	BL12	GR12	SDG12	WT100	Wt10cobs	Gy10Cobs	NPY	Yld/ha	Shelling
BL6	0.829*	0.124	0.558	0.546	0.221	0.287	0.301	-0.063	-0.894*	-0.963**	-0.911*	-0.971**	-0.971**	-0.714
GR6		-0.098	0.881*	0.825*	0.439	0.716	0.706	0.138	-0.952**	-0.846*	-0.960**	-0.912*	-0.923**	-0.948**
SDG6			-0.248	-0.243	-0.076	-0.337	-0.379	-0.421	0.031	-0.304	-0.081	-0.162	-0.102	0.142
BL9				0.739	0.725	0.954**	0.948**	0.485	-0.866*	-0.612	-0.831*	-0.701	-0.714	-0.977**
GR9					0.078	0.632	0.574	-0.165	-0.711	-0.590	-0.717	-0.661	-0.692	-0.781
SDG9						0.782	0.824*	0.874*	-0.530	-0.280	-0.476	-0.331	-0.317	-0.642
BL12							0.993***	0.614	-0.679	-0.357	-0.630	-0.457	-0.472	-0.869*
GR12								0.688	-0.683	-0.349	-0.625	-0.454	-0.469	-0.861*
SDG12									-0.222	0.102	-0.125	0.019	0.016	-0.349
WT100										0.910*	0.989***	0.955**	0.962**	0.948**
Wt10cobs											0.946**	0.987***	0.977***	0.763
Gy10Cobs												0.978***	0.978***	0.928**
NPY													0.997***	0.834*
Yld/ha														0.845*

BL6, BL9 and BL12: Density of broadleaves weed at 6, 9 and 12 weeks after planting (WAP); GR6, GR9 and GR12: density of grasses at 6, 9 and 12 WAP; SDG6, SDG9 and SDG12: density of sedges at 6, 9 and 12 WAP; NPY: net plot yield; Gy: grain yield, Yld/ha: grain yield in kilogram per hectare; WT100: 100 seed weight; Wt10cobs: weight of seeds from 10 cobs in gram.

two intervals on the yield of maize.

At 6 WAP, significant (P ≤ 0.05) positive correlation (r = 0.829) existed between broad-leaves and grasses (Table 9). The correlation between grass at 6 WAP with broadleaves at 9 WAP (r = 0.881) and grasses 9 WAP (r = 0.825) were both positive and significant (P ≤ 0.05). Our result strongly indicted broadleaves and grasses weeds categories to be very prominent in causing yield reduction in maize. Moreover, broadleaves and grasses at 6 WAP had very strong (r > 0.8), significant (P ≤ 0.05) but negative correlation with: 100 seed weight, weight of ten cobs, grain yield of ten cobs, net plot yield, grain yield per hectare and shelling percentage (Table 9). Broadleaves population at 9 WAP significantly (P ≤ 0.01) and positively correlated with the population of broadleaves and grasses at 12 WAP (r = 0.954 and 0.948, respectively). The association between sedges population at 9 WAP with grasses and sedges population at 12 WAP was strongly (r > 0.8) significant (P ≤ 0.05). Moreover, broadleaves population at 9 WAP significantly (P ≤ 0.05) but negatively affected 100 seed weight (r = - 0.866), grain yield of ten cobs (r = - 0.831) and shelling percentage (r = - 0.977). At 12 WAP, broadleaves and grasses population significantly (P ≤ 0.05) and negatively supported shelling percentage (Table 9). Summarily, from Table 9, the five grain yield components and the grain yield exhibited strong (r > 0.8), positive and significant (P ≤ 0.05) correlation. Our report notably corroborated that of Ferrero et al. (2017) which stated that: maize usually have highly diverse weed community which greatly affects its yield and yield components. Kremer (2004) had earlier indicted possible functional interactive complexes which exist among different weed species and maize to be responsible for maize yield reduction or losses.

Weed competition in maize plots should be avoided in order to prevent more than 50% losses in production. All the weed control strategies evaluated in this study had better performances than the control with significant positive enhancement on the grain yields of the maize cultivar. Thus either of the weed management strategies could be employed for improved maize yield not minding the initial capital or labour constraints. The resultant support from their involvement in maize production will provide a tradeoff for all initial expenses to be incurred.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Yield of different varieties of cassava (*Manihot esculenta* Crantz) in different harvest intervals

Wilfrido Meza Giménez*, Sonia Liliana Recalde Sanabria, Gustavo Daniel Vega Britez, Sixto Barreto Pérez, Derlys Salinas Cohene, José Augusto Velazquez Duarte, Victorina Barreto Pérez, Laiana Patricia Paredes Lopes and Nelson David Lesmo Duarte

Facultad de Ciencias Agrarias, Universidad Nacional de Asunción, Pedro Juan Caballero, Paraguay.

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This experiment was installed in the experimental plot of the Faculty of Agrarian Sciences, National University of Asunción Department of Amambay, Paraguay, with the objective of evaluating the yield of four varieties of cassava in three harvest intervals. The experimental design was randomized blocks, with four treatments (Seda, Pomberi, Sa'yju and Tacuara) and five repetitions. The spacing was 0.8 x 0.7 m, with a population density of 17,870 plants per hectare. Root quantity per plant, root weight per plant, amount of commercial and non-commercial root, weight of commercial and non-commercial root, yield per hectare were evaluated at eight, ten and twelve months after planting. The root number per plant was infuenced (p <0.05) by the varieties, and was higher for the variety Seda; number and weight of commercial root which did not vary (p> 0.05) depending on the varieties and harvest intervals. The root weight per plant does not present significant differences (p> 0.05) between varieties and harvest intervals. Commercial root weight and root yield were significantly (p <0.05) higher in harvest intervals performed 12 months after sowing, where the Tacuara variety showed the highest yield. Variety of table or sweet manioc Tacuara presents superior performance at 12 months after sowing. Cassava varieties tested have acceptable production parameters, and the knowledge of them as well as cutting interval may allow better use mainly by small farmers. It is recommended to evaluate the influence of planting density on the varieties and cutting interval.

Keywords: *Manihot esculenta*, agronomic behavior, cultivars, harvest index.

INTRODUCTION

Cassava is a woody, perennial shrub plant that produces tubers rich in starch, suitable for human and animal consumption (Okogbenin et al., 2013). It is the third most important source of calories in the tropics, after rice and corn, and may be responsible for a more sustainable diet of the human population, mainly for people with low income. Production of this plant is characterized by small peasant farmers worldwide, mainly in South America,

*Corresponding author. E-mail: wilfrido_meza@hotmail.com.

Table 1. Initial physical and chemical characteristics of the soil for the experiment.

Depth (cm) (cm)	pH (Water)	M.O ($dag.kg^{-1}$)	Al^{3+} ($Cmolc.dm^{-3}$)	Ca+Mg ($Cmolc.dm^{-3}$)	P ($mg.kg^{-1}$)	K ($mg.kg^{-1}$)	Text. Touch
0-20	6.30	3.0	0.0	8.00	6.00	220.7	A

Extractors: pH=Water; PyK=Mehlich^{-1}; Ca+Mg yAl_3^+=KCl 1 mol.L^{-1}; A=Clay.
Source: Soil Laboratory of the Faculty of Agricultural Sciences, Pedro Juan Caballero, Paraguay.

Africa and South-East Asia (Delaquis et al., 2018), where they are widely marketed and consumed.

Due to its phenotypic and genotypic plasticity, cassava can be cultivated in different ecological environments and in low-input systems, due to its drought tolerant attributes that make cassava attractive to low-income farmers. In cassava roots with good sensory characteristics, the firing is fast and uniform, with few fibers and reduced concentration of cyanide acids, mainly in improved varieties for human consumption. These characteristics are associated with genotype, plant age, harvest time and population density (Aguiar et al., 2010).

Preferably, cassava is harvested with a vegetative cycle that varies between eight to fourteen months. Before eight months, they are not normally harvested because they do not have the appropriate commercial diameters or standards, or after fourteen months, there is reduction of their principal sensory and culinary characteristics. However, the success of cassava cultivation can be influenced by different factors, including the incidence of diseases (Chikoti et al., 2016), planting density (Adeniyan et al., 2014), genetic variability (Adjebeng-Danquah et al., 2016) and mainly harvest time and varieties of greater adaptation to the specific región, factors that can compromise the success of the crop.

In Paraguay, cassava is one of the main areas of family farming (Carballo et al., 2010) and is one of the areas with the lowest fluctuation in terms of production area between the last two decades (Lesmo et al., 2018); thus, knowledge of the agronomic behavior of the main varieties used in the northern region of Paraguay is essential to collaborate with a more sustainable production.

The objective of the present investigation was to verify the agronomic characteristics of four varieties of cassava in three harvest intervals in the district of Pedro Juan Caballero, Paraguay.

MATERIALS AND METHODS

Study site description

The experiment was conducted in the Experimental Field of the Faculty of Agricultural Sciences, located in the Raúl Ocampos Rojas Colony (Chirigüelo) on Route V, 20 km from the city of Pedro Juan Caballero, Department of Amambay (22º39'36"S and 55º53'36"W, 485 m above sea level). The climate of the región is of the Cwa type according to the Köppen classification, temperate climate with dry winter and rainy summer. 1,050 mm of precipitation was recorded during the experiment. The type of soil where the experiment was executed is predominantly sandy loam texture, whose physical and chemical characteristics were determined through soil analysis (Table 1).

The total area of the experiment was 1.040 m^2, the useful plots corresponded to the two central rows of each block, each with 200 m^2 (40 x 5 m), a separation between blocks of 2 m and the treatments consisted of four varieties of cassava. The evaluations were carried out in three intervals, at eight, ten and twelve months after planting. The preparation of the land, previously covered by green manure, was done mechanically, by using a harrow to break the lumps and thus generate good aeration in the soil.

The sowing was carried out in September 2015 with a density of 17,870 plants per hectare as well as a separation of 80 cm between rows and 70 cm between plants. In each block, six rows 40 m long were sown, seed stakes were used from three to five yolks to ensure the outbreak, the depth was conditioned with soil moisture where in each hole a seed stake was placed at a depth that did not exceed 10 cm. Cultural care was done manually.

Statistical analysis

The experimental design used was randomized complete blocks in a 4 × 3 factorial scheme with five repetitions per treatment. With the data, the analysis of variance and the comparison of means with the 5% Tukey test was performed using the AgroEstat® software (Barbosa and Maldonado, 2015).

RESULTS AND DISCUSSION

Significant effect ($p < 0.05$) of the different varieties was verified for the variable number of roots per plant. However, there was no effect ($p > 0.05$) of the commercial root number, non-commercial root weight for varieties and harvest intervals, or significant interactions ($p > 0.05$) between varieties and harvest seasons (Table 2).

According to Shindoi et al. (2018), the number of commercial roots per plant, defines the ability of the genetic material to be sold fresh. Although, statistically there was no significant differences between the harvest intervals for the variable number of roots per plant, a greater tendency is observed (Table 2) when they are harvested at eight months after planting. In general, the total number of roots per plant and number of commercial roots observed in the present investigation was lower than those reported by Shindoi et al. (2018) in an investigation of agronomic performance of ten cultivars of cassava in the Argentine Chaco.

Table 2. Root number per plant, commercial root number per plant and non-commercial root weight per plant of four cassava varieties in three harvest intervals.

Parameter	No. of root/ plant	No. of comercial root	Non-commercial root weight (kg)
Variety (V)			
Seda	7.86[a]	4.13[a]	0.43[a]
Pomberí	5.66[c]	3.60[a]	0.25[a]
Sa'yju	6.00[bc]	3.13[a]	0.42[a]
Tacuara	7.60[ab]	4.00[a]	0.43[a]
CV (%)	16.14	12.13	23.38
p - value	0.004**	0.196[ns]	0.113[ns]
Harvest intervals (HI)			
8 months	7.25[a]	3.55[a]	0.44[a]
10 months	6.80[a]	3.00[a]	0.33[a]
12 months	6.30[a]	3.70[a]	0.37[a]
CV (%)	7.01	4.72	14.55
p - value	0.301[ns]	0.721[ns]	0.344[ns]
Variety x Harvest intervals (VxHI)	0.728[ns]	0.127[ns]	0.148[ns]

[abc]Lowercase letters in the columns differ with 5% probability; ns = not significant. CV = coefficient of variation.

Among the factors that influence commercial root production is the population density used (silver/hectare), which according to Aguiar et al. (2010), is positively correlated with low planting density, making it possible to obtain good root production per plant from six to 10 months after planting with a density of 5,000 plants/ha. However, in the present investigation, the plantation was 0.8 x 0.7 m, with a density of 17,870 plants/ha; even so, there is a tendency of greater number of roots per plant eight months after planting.

Root weight per plant does not show significant differences ($p>0.05$) depending on the variety and time of harvest; also, the root weight per plant was not influenced ($p> 0.05$) by harvest interval. The Tacuara variety presents 36,144 kg/ha and superior yield ($p <0.05$) to the other varieties. Higher ($p<0.05$) commercial root weight and yield per hectare is verified in the harvest made at 12 months after planting. There were significant interactions ($p <0.05$) between varieties and harvest time for the variables of commercial root weight and yield per hectare (Table 3).

Oliveira et al. (2015) evaluated three varieties of cassava and observed that the best time to harvest the evaluated cultivars is between 12 and 24 months after planting, where there is greater accumulation of dry matter in the roots, resulting to a larger size of starch granules in that growth cycle (Fernandes et al., 2019). Motta et al. (2012) reported that the Tacuara variety has 3.6 roots per plant and a yield of 22,319 kg/ha, lower than those observed in the present investigation, which was 7.6 root per plants and 36,144 kg/ha yield. The yield include traits of high heritability, high positive correlation with the number of leaves, crop index, root yield per plant, height of the first branch and plant height (Adjebeng-Danquah et al., 2016; Chipeta et al., 2016).

Likewise, the root length has a high positive correlation with the weight of the fresh root (Adu et al., 2018), however, the leaf área and root diameter are the main features that they contribute to genotypic variation between varieties.

Aguiar et al. (2010) show a higher production of commercial roots per plant when population density decreases (plant/ha), being higher at a density of 5,000 plants/ha for six harvest intervals (6, 8, 10, 12, 14 and 16 months). This finding by the authors is attributed to plants competition being at a lower density, less competition for nutrients, absence of restriction of luminosity, and therefore, greater development of the roots. Likewise, according to Zanetti et al. (2014), the best spacing adjustment for the productivity of cassava roots was 0.9 x 0.7 m, this being a viable option for the producer, since it can provide low cost of cuttings per planted area.

Higher population density according to Aguiar et al. (2010) results in greater total root productivity, regardless of the harvest interval, however, with lower commercial root yields, since lower planting density increases commercial root production in relation to total production. In the present investigation, it is observed that the weight of the commercial root was not influenced ($p> 0.05$) by the varieties, but significantly ($p <0.05$) by the times of harvest, being greater weight of the commercial root when harvested at 12 months. This difference is probably

Table 3. Root weight per plant (kg), commercial root weight (kg/plant) and root yield (kg/ha) of four cassava varieties in three harvest intervals.

Parameter	Root weight /plant (kg)	Commercial root weight (kg)	Yield (kg/ha)
Variety (V)			
Seda	1.76[a]	1,30[a]	22,446[d]
Pomberí	1.63[a]	1,38[a]	28,467[c]
Sa'yju	1.91[a]	1,48[a]	33,460[b]
Tacuara	2.06[a]	1,62[a]	36,144[a]
CV (%)	10.13	9,66	20.01
p - value	0.216[ns]	0,379[ns]	0.000**
Harvest intervals (HI)			
8 months	1.64[a]	1.17[b]	25,671[c]
10 months	1.87[a]	1.53[ab]	30,519[b]
12 months	2.01[a]	1.63[a]	34,197[a]
CV (%)	10.06	16.97	14.19
p - value	0.143[ns]	0.018*	0.000**
Variety x Harvest intervals (VxHI)	0.272ns	0.028*	0.000**

[abcd]Lowercase letters in the columns differ with 5% probability. ns = not significant. CV = coefficient of variation.

related to a greater assimilation of carbohydrates in the tubers when the plants are 12 months old, at the time of greatest development of the plant.

The number of tuberous roots is defined mainly in the first 120 days after planting (Lorenzi, 2003); after that period, the continuous growth of these roots is verified by the accumulation of carbohydrates. The phase in which the greatest development of the roots occurs goes from the sixth to the tenth month after planting, when the highest rate of carbohydrate translocation for the roots is observed. According to Alves (2002), during the development cycle, the cassava plant concomitantly has two main drainage of photoassimilates: the tuberous roots that are the main storage organs, and the aerial part, which consumes a large part of the sugars produced in the photosynthesis for the development of leaves and stems.

The average yield obtained (Table 3) were higher than those verified by Caballero et al. (2010). In this investigation, the Tacuara variety was the variety with the highest yield, while Romero and Caballero (2013) study on agronomic behavior of five cassava varieties revealed that the one with the highest commercial root yield is the Sa'yju variety, which at the same time, has a higher content of dry matter and starch. Likewise, the observed yield (Table 3) in the four varieties evaluated are within the parameters for table cassava varieties, similar to those observed by Tironi et al. (2015).

However, according to Chipeta et al. (2016), some cassava genotypes may present at a higher age carbohydrate accumulation, a situation not observed in the varieties evaluated (Table 3). The soil preparation has an influence on the yield, causes an increase in the resistance to the penetration of the roots in the soil, results in a greater accumulation of dry matter in the stem than in the roots, able to decrease the growth of the cassava roots (Figueiredo et al., 2017), and also influences the diameter of the roots, in the fresh and dry matter, at the beginning of the physiological and retaken rest phases of the new vegetative period, while not influencing the chronological definition of the components of production, nor the morphology of mandioca roots (Gonzales et al., 2014). These parameters may have been determinants in the differences observed for yield, in addition to the varieties evaluated.

Conclusion

The commercial root number and weight of the non-commercial root is not related to the variety and harvest intervals. Tacuara variety presents superior yield, and harvest intervals at 12 months after planting is the ideal time to obtain better yields.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Genotype×environment interaction and stability analysis of soybean genotypes for yield and yield components across two locations in Nigeria

Jandong, E. A.[1*], Uguru, M. I.[2] and Okechukwu, E. C.[2]

[1]Department of Agronomy, Taraba State University, P. M. B. 1167, Jalingo, Taraba State, Nigeria.
[2]Department of Crop Science, Faculty of Agriculture, University of Nigeria, Nsukka, Enugu State, Nigeria.

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A multilocational evaluation of 20 soybean genotypes was conducted in two distinct locations (Nsukka in Derived Savanna agro-ecology and Jalingo in northern Guinea Savanna) of Nigeria in 2015 and 2016 cropping seasons. The main objective of this study was to assess the genotype-by-environment interaction (G x E) for specific traits such as number of pods, pod weight, seed yield and yield stability. The results revealed highly significant differences among the genotypes and locations for all the traits except for seed yield. Genotype by environment interaction was not significant for all the traits except for days to 50% flowering indicating relative consistency in time of flowering among the genotypes across the locations and year. The genotype, *Ashuku* produced the highest yield in the two locations. However, the most stable genotypes across the locations were *Dadinkowa* and *Vom* while the ideal environments were Jalingo 2016 (ENV2) and Nsukka 2016 (ENV4) which produced 14.0 and 14.5 g, respectively. Similarly, Akwanga was discriminated as the overall best genotype across the two locations.

Key words: Genotype, biplot, environment, yield stability.

INTRODUCTION

The use of stable genotypes over several environments for high yield and quality characteristics is important in many crops. When genotypes are evaluated for seed yield in multilocational experiments, wide differences are commonly observed in yield performances of the genotypes over the environments. This differential yield response of genotypes from one environment to another is called genotype by environment (G x E) interaction (Jose et al., 2017). The G x E interactions is very important to the plant breeders in developing improved varieties and the introduction of new cultivar (Yan and Kang, 2003).

The ability of a genotype to demonstrate stability over a wide range of environment and its ability to yield well relative to the productive potential of a test environment is referred to as agronomic stability. Any genotype that demonstrate consistency of performance or slight variation across environment show general adaptation (Ojo et al., 2006). In a breeding programme, genotype x environment interaction effects are of special interest for

*Corresponding author. E-mail: elias.jandong@gmail.com.

Table 1. Agro-ecological characteristics of the experimental sites.

Location	Nsukka	Jalingo
Latitude	06° 52' N	08° 54' N
Longitude	07° 24' E	11° 22' E
Attitude (masl)	447.26	349
Agro-ecozone	Derived savannah	Northern Guinea savannah
Soil texture	Sandy clay loam	Sandy loam
Total rainfall (mm/annum)	1393.6	1137.8
Average mean temperature (0°C)	26.0	28.0
Average RH (%)	66.6	67.6

masl = meters above sea level; RH = relative humidity

identifying adaptation targets, adaptive traits and test sides.

The stability of seed yield in different crops has been statistically evaluated through analysis of G x E interaction in genotype-adaptation trails over several environments. The effective identification of superior genotypes is generally complicated by the presence of G x E interactions. A specific genotype does not always exhibit the same phenotypic characteristics under all environments and different genotypes respond differently to a specific environment.

Soybean (*Glycine max* (L). Merrill) designated as the "miracle bean" has established its potential as an industrially vital and viable oil seed crop in Nigeria. Interest in soybean production in Nigeria has increased considerably as it has the ability to fix high amount of nitrogen, thereby permitting farmers to use less fertilizer and reduce farm cost (IITA, 2014). To satisfy the demand by producers and consumers, soybean production needs to be extended to other parts of the country that were otherwise considered unsuitable or marginal for its production (Asiegbu and Okpara, 2002). This wide agro-ecological variability is the major challenge for soybean crops resulting in high genotype x environment interaction (GEI) effect. Identification of yield contributing traits and knowledge of GE interactions along with yield stability are important for breeding new cultivars with improved adaptation to the environmental constraints prevailing in the target environments. Therefore, the objectives of this study were to assess the magnitude of G x E interactions, stability of some local cultivars as well as elite soybean genotypes and thereby identify widely and/or specifically adapted genotypes under Nigerian conditions.

MATERIALS AND METHODS

The multilocational evaluation trail was carried out in 2015 and 2016 cropping seasons at two different locations: The Teaching and Research Farm, Department of Crop Science, University of Nigeria, Nsukka (Lat.06° 52' N and Long.07° 24' E) and the Teaching and Research Farm, Department of Agronomy, Taraba State University, Jalingo (Lat.08° 54' N and Long. 11° 22' E). Twenty (20) soybean genotypes comprising fifteen (15) farmers' cultivars and five (5) improved varieties were obtained from farmers in some soybean growing states of Nigeria and the International Institute for Tropical Agriculture (IITA), Ibadan, respectively for the research.

Experimental design

The experimental design was Alpha lattice design (Patterson and Williams, 1976), which was used for the multi-location experiment. There were 10 columns and two rows per super block replicated three times and the 20 soybean genotypes were randomly assigned to each super block. The improved varieties were of early maturity class while the farmers' cultivars are either medium or late maturity class. Each plot or column measured 1.5 x 1 m and seeds were sown at the spacing of 15 cm between stands and 30 cm between rows, resulting in 7 plants per row and 35 plants per plot (column).

Five plants were randomly selected from the two middle rows for data collection at the maturity on days to 50% flowering, plant height and yield traits such as number of pods, pod weight (g) per plant, seed yield (g) per plant and 100 seed weight (g) per genotype at harvest.

Statistical analysis

Analysis of variance (ANOVA) statistics using general linear model (GLM G x E) of SAS version 9.5 with 5% level of significance were used. The data collected were subjected to analysis of variance and GE biplot methodology as prescribed by Marjanovic-Jerumeln et al. (2011). This methodology uses a biplot to show the factors (G and GE) that are important in genotype evaluation and that are also the sources of variation in GEI analysis of yield data.

RESULTS

The experimental sites differed in altitude, rainfall, mean temperature, relative humidity and soil texture (Table 1). Nsukka is located in the southeastern part of Nigeria while Jalingo is in northeastern part. The amounts of rainfall in 2016 in both locations were higher than those of 2015. In 2016, Nsukka had a mean rainfall of 152.98 mm against 141.04 mm in 2015. Similarly, in 2016, Jalingo had a mean rainfall of 153.94 mm against 149.14 mm in 2015. During the growing seasons, mean monthly

Table 2. Combined analysis of variance for seed yield and yield components in two years and two locations.

SV	DF	DF1	PH (cm)	NP	PW (g)	SY (g)
Year (Y)	1	39.20	999.36**	63583.17**	9208.25**	4064.80**
Location (L)	1	413.44**	752.11**	7811.29**	686.14**	156.33*
Y x L	1	63.04	1365.84**	2426.98*	516.85**	278.00**
REP (Y,L)	8	11.97	58.16*	747.42*	117.19*	65.47*
Genotype (G)	19	63.54**	240.60**	815.80**	65.73*	29.52
G x Y	19	29.04*	23.37	239.11	23.47	14.09
G x L	19	45.69*	15.61	150.84	36.79	18.62
G x Y x L	19	48.10*	31.66	279.33	37.89	17.13
Error	140	4.17	4.45	15.67	5.67	3.89

*,** = Significant at 5 and 1%, respectively, SV = source of variation, DF = degree of freedom, DF1 = days to 50% flowering, pH = plant height, NP = number of pods, PW = pod weight, SY = seed yield/plant, Y = year, L = location, G = genotype, REP= replicate

temperature was higher in Jalingo when compared to that of Nsukka; however, relative humidity was higher in 2015 than 2016 in both locations. Meanwhile, in 2016, relative humidity was higher in Jalingo (66.41%) than Nsukka (61.76%). Also, the two locations varied in soil type with the soil of Nsukka being sandy clay loam while that of Jalingo is sandy loam.

The combined analysis of variance (ANOVA) was performed to determine the effects of year (Y), location (L) and genotype (G) as presented in Table 2. Variance due to genotypes (G) were highly significant ($p<0.01$) for all the traits studied, except for pod weight. Similarly, location (L) was highly significant ($p<0.01$) for all the traits, except seed yield that was significant only at $p<0.05$. However, year (Y) effect was highly significant for all the traits with the exception of days to 50% flowering. The Y x L interactions were highly significant ($p<0.01$) for all the traits except days to 50% flowering. The G x Y interaction on the other hand were non-significant for most of the traits except for days to 50% flowering which was significant only at 5% level of probability. Also, triple interaction (G x Y x L) was found non-significant for all the traits except days to 50% flowering.

G x E is a major problem when comparing the performance of crop genotypes across environments because it reduces the efficiency of the genetic gain through selection (IITA, 2011). The mean seed yield value of genotypes averaged over environments (Table 4) indicated that the genotypes "*Ashuku*" and "*Akwanga*" had the highest and lowest seed yield of 13.0 and 8.5 g, respectively. The environments mean seed yield ranged from 4.1 g (ENV3) to 14.5 g (ENV4) and averaged seed yield over environments and genotypes is 10.1 g. ENV4 and ENV2 showed the most favorable performance for seed yield (14.5 and 14.0 g, respectively) and are rich environments. ENV3 and ENV1 were unfavorable since they presented the lowest mean for seed yield (4.1 and 7.9 g, respectively).

The best genotype across the two locations in terms of seed yield per plant is *Akwanga*. It performed best in ENV1 when compared to the other environments (Figure 1). However, the genotype *Gwantu* is the most stable genotype across the two locations. Also, *Lau* was found to be the closest to *Akwanga* in terms of seed yield per plant. As graphically revealed on the biplot, the most stable environment for the genotypes performance in terms of seed yield is ENV3 which is very close to the horizontal axis that divides the graph into the poorest (below average and the best (above average).

The general mean performance of the genotypes across the two locations revealed that *Akwanga* is leading by its impressive performance in ENV4 (Figure 2) among all the environments. On the other hand, *Dadinkowa* and *Vom* were the most stable genotypes due to their proximity to the horizontal axis. These genotypes were closely followed by *Kagoro*, *Mangu* and TGX1485-ID, respectively. The most stable environment for mean performance of the twenty soybean genotypes is ENV1 and is closely followed by ENV3.

DISCUSSION

Combined analysis of variance (ANOVA) for seed yield and yield components showed highly significant variations among environments (L) and genotypes (G) but without similar variations in genotype x environment (G x E) interaction in most of the traits with the exception of days to 50% flowering ($p< 0.05$). Significant variations were observed for days to 50% flowering among the genotypes across the locations indicating the existence of variability in the source of the genotypes. The result showed that, both the genotypes and the environmental conditions had significant influence on the yield and yield components performance of the soybean. Adugna and Labuschgne (2003) also reported significant variations among locations for days to 50% flowering in linseed. In Jalingo, soybean genotypes were taller, had more branches with longer root lengths and higher fresh and dry root weights than those in Nsukka. Similarly, seed yield and yield

Table 3. Mean of quantitative characters of 20 soybean genotypes from two locations.

Genotype	DF (50%)	PH (cm)	NP	PW (g)	SY (g)	100 seed weight (g)
	(NSK/JAL)					
Agbon kagoro	43.17±45.67	25.42±29.84	35.66±37.29	12.33±12.33	8.10±7.08	12.50±14.00
Akwanga	42.14±44.64	29.10±33.21	54.69±63.55	20.09±25.02	12.44±16.58	14.00±13.50
Andaha	44.90±46.90	29.79±32.12	44.67±53.87	14.84±21.34	8.57±13.65	12.00±12.00
Ashuku	43.97±44.81	32.65±39.25	63.99±79.92	22.09±27.89	14.21±18.88	13.00±13.50
Dadinkowa	45.28±46.28	29.63±31.87	38.43±40.36	12.13±16.03	8.07±10.32	14.00±13.00
Garkawa	42.00±45.00	33.32±37.06	48.29±59.06	15.93±19.70	10.78±13.50	14.00±13.00
Gwantu	43.97±44.47	30.10±34.56	46.09±56.22	16.22±20.72	10.98±13.61	12.00±13.00
Kafanchan	42.48*±48.32*	30.18±31.76	43.62±54.18	14.24±21.54	9.37±14.56	13.50±12.00
Kagoro	43.44±44.61	31.67±37.63	52.70±57.76	15.56±19.46	11.43±13.59	9.50±14.50
Langtang	46.44*±50.28*	29.13±32.30	50.43±55.96	21.90±24.46	14.50±16.48	11.50±12.50
Lau	50.51±52.01	30.56±37.03	57.20±74.84	20.57±25.37	12.54±16.89	10.50±13.00
Mangu	42.47±44.64	34.18±38.35	60.45±67.42	22.62±25.46	14.20±16.85	14.50±14.00
Mararaba	45.44±46.61	30.27*±38.00*	49.16±59.96	14.56±18.86	9.70±13.45	13.50±13.00
TGX1485-ID	38.73±40.37	31.82±30.32	53.07±51.43	19.68±20.54	12.21±12.95	14.00±14.00
TGX1448-2E	40.37*±44.37*	34.94±38.67	47.28±72.08	12.81*±22.35*	8.13*±14.59*	14.50±13.50
TGX1987-10F	41.57±43.71	31.52±34.35	38.83±54.20	17.98±23.11	10.51±15.41	15.50±15.00
TGX1835-10E	39.21*±43.71*	31.44±33.01	41.68±47.28	14.88±17.41	10.80±11.59	13.00±14.50
TGX1987-62F	47.87±48.64	35.94±41.83	42.44±65.65	13.45±21.74	8.50±14.97	12.00±13.00
Tiv local	41.23±42.73	33.29±36.22	50.77±68.30	18.18±24.78	11.44±16.65	15.00±13.00
Vom	56.07±54.73	49.85±53.35	76.20±86.77	21.98±23.18	12.47±14.68	9.50±11.00
LSD(0.05)	3.83	6.69	24.90	9.27	6.35	5.70

DF = Days to 50% flowering, PH = plant height, NP = number of pods, PW = pod weight/plant, SY = seed yield, NSK = Nsukka, JAL= Jalingo, LSD= least significant difference.

components such as number of pods and pod weight were higher in Jalingo than Nsukka. The low yield in Nsukka location may be as a result of the soil nature which is sandy clay loam with pH of 4.9 whereas Jalingo soil is sandy loam with pH 6.0. However, genotypes had more leaves in Nsukka location even though the difference is of no statistical significance. In Jalingo location, elite varieties such as TGX1448-2E, TGX1987-10F and TGX1987-62F had a fairly impressive yield performance that compared favorably with *Ashuku* and that had the highest yield in both locations. In Nsukka location, despite the poor performance of all the genotypes, TGX1987-10F still compared with *Ashuku* statistically. Non-significance of genotype × environment and genotype × year for traits such as plant height, number of pods, pod weight and seed yield indicated the relative consistency in performance of the genotypes across the two locations and years. This implies that in any of the two locations, the same genotype will have the same plant height, number of pods, pod weight and seed yield. The findings are in agreement with the report of Ojo et al. (2010) who recorded non-significance of genotype × year interaction in plant height, as well as number of pods and seed yield in soybean. Highly significant variations were observed for most of the parameters studied among the genotypes across the environments indicating the existence of variability among the soybean genotypes.

However, any genotype that demonstrates consistency of performance or little variation across the environments is said to be generally adapted. In this study, most genotypes revealed little variation in performance across the two locations (Table 3). Significant ($p<0.05$) variation was observed in pod weight per plant and seed yield per plant in TGX1448-2E. The study also revealed that most of the genotypes showed little variation in performance across the two locations. With particular interest to note is TGX1485-1D that recorded the same value for 100 seed weight (14.00 g) across the two locations. This consistent or little variation in performance of a genotype across the environments showed general adaptation as observed by Adeseye et al. (2018). It was also observed that there were variations between the two locations with respect to days to flowering especially in Kafanchan, Langtang, TGX1448-2E and TGX1835-10E. Similar findings were obtained by Yan and Tinker (2006), and Jese et al. (2017) who reported variation between two locations in respect to days to flowering in cowpea. Likewise, there was variation between the two locations with respect to plant height particularly in Mararaba. In the same vein, there were variations between the locations with respect to pod weight and seed yield in TGX1448-2E. The purpose of stability analysis is to identify soybean

Table 4. Mean of soybean seed yield evaluated in the 4 environments.

Genotype	Environment				Mean
	ENV 1	ENV 2	ENV 3	ENV 4	
ANDAHA	5.5	11.5	2.4	5.0	6.1
AGBON KAGORO	**11.9**	13.4	3.4	**19.6**	12.1
AKWANGA	5.1	10.5	3.9	14.5	8.5
ASHUKU	9.8	19.0	4.4	18.6	13.0
DADINKOWA	6.9	10.9	4.2	12.3	8.6
GARKAWA	4.9	17.4	3.5	10.9	9.2
GWANTU	6.5	14.9	3.7	12.1	9.3
KAFACHAN	7.3	11.9	3.2	17.7	10.0
KAGORO	10.5	14.0	4.6	15.7	11.2
LANGTANG	7.3	**23.3**	4.3	12.2	11.8
LAU	10.7	13.6	4.1	18.0	11.6
MANGU	**11.9**	16.9	4.4	16.7	12.5
MARARABA	7.3	13.7	4.1	15.7	10.2
TGX1485-1D	3.4	12.5	5.1	17.0	9.5
TGX1835-10E	10.9	11.9	4.0	11.7	9.6
TGX1987 -10F	7.2	14.0	3.9	9.5	8.7
TGX1448-2E	6.8	12.6	4.9	15.9	10.1
TGX1987-62F	5.8	10.8	4.7	17.4	9.7
TIV LOCAL	7.1	14.1	**6.1**	16.8	11.0
VOM	10.8	12.5	3.5	12.9	10.0
Mean	7.9	14.0	4.1	14.5	10.1

ENV1 = Jalingo 2015, ENV2 = Jalingo 2016, ENV3 = Nsukka 2015, ENV4 = Nsukka 2016

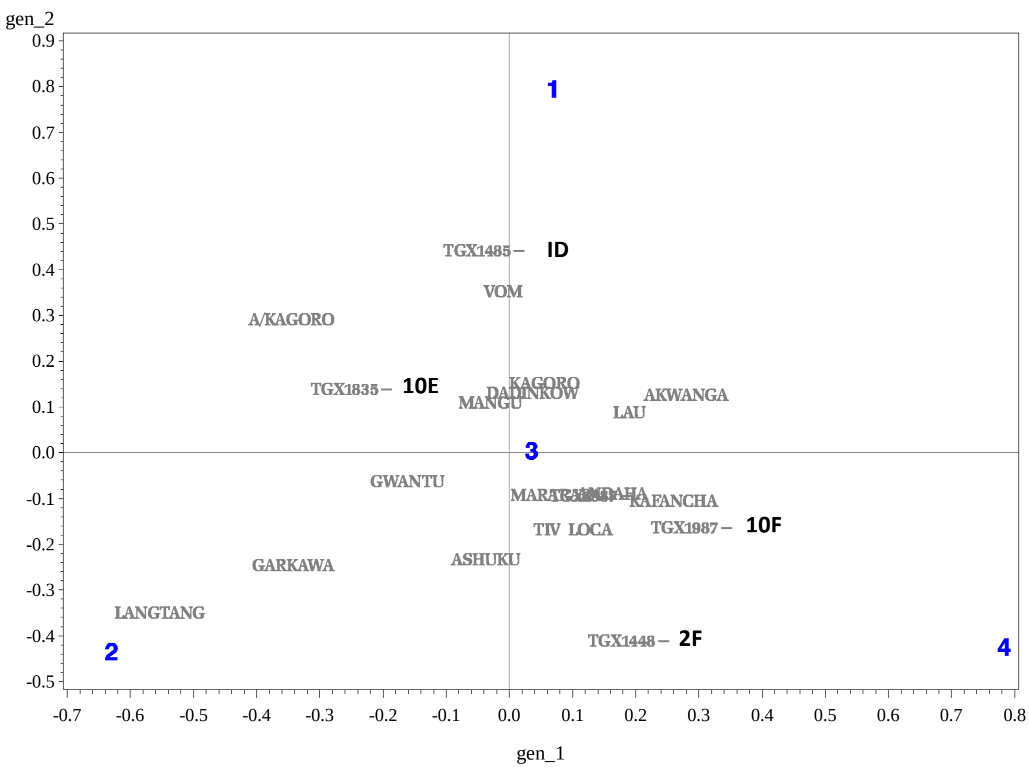

Figure 1. Biplot of G*E interaction: for seed yield.

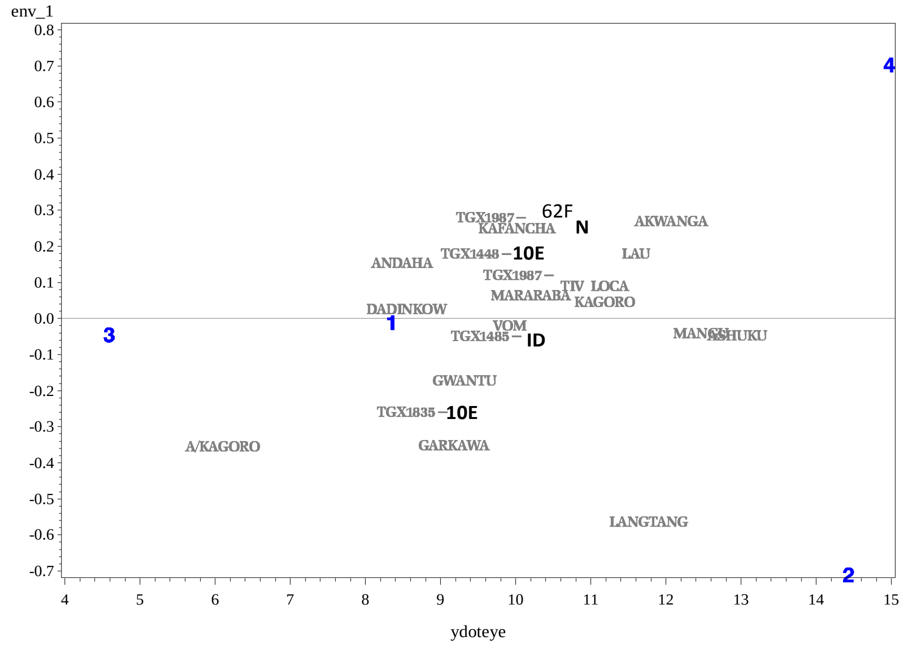

Figure 2. Biplot of first E*Vector vs Means.

genotypes with wide geographic adaptation, high agronomic performance and high seed yield (preferably above the overall mean of 10.1 g) as observed in this study in heterogeneous environments. The identification of genotypes with specific adaptations can be extremely useful for more regionalized genotypic recommendations.

Based on mean performance of the genotypes, the environments were classified into three mega environments. The first include ENV1 and ENV4 with genotype *Akwanga* having the highest seed yield and was joined by *Mangu* only in ENV1. The second mega environment is ENV2 in which *Langtang* performed the best. The third mega environment is ENV3 with *Tiv local* as the outstanding genotype. The superiority of mega environments formed from the mean seed yield can be attributed to the portion of noise incorporated into estimates of raw data as reported by Silveira et al. (2013).

The results of biplot showed that *Akwanga* performed very well in the overall performance and was closely followed by *Lau*. However, *Dadinkowa* and *Vom* were the most stable genotypes across the two locations. Also, the biplot result identified ENV1 and ENV3 as the ideal environments across the two locations. Therefore, the use of GGE in this study has not only identified the most stable genotypes across locations but is also able to identify the locations that optimize the genotypes performance as confirmed by Agyeman et al. (2015).

CONCLUSIONS AND RECOMMENDATION

Crop yield is a complex trait that is influenced by a number of component characters along with the environment either directly or indirectly. The G × Y and G × L effects were not significant for most of the traits indicating general adaptation of the genotypes across the locations. However, the study is able to identify the most stable genotypes and the ideal environments across the locations that optimize the genotypes performance.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaluation of yield and yield components of some groundnut genotypes under rainfed condition in Mali using biplot analysis

Ousmane Sanogo[1,2]*, Pangirayi B. Tongoona[1], Kwadwo Ofori[1], Samuel K. Offei[1] and Haile Desmae[2]

[1]West Africa Centre for Crop Improvement, University of Ghana, P. M. B. 30, Legon, Accra, Ghana.
[2]International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), BP 320 Bamako, Mali.

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Sixteen groundnut genotypes were evaluated under three different environmental conditions of Mali during 2015/2016 rainy season. The environments were Tioribougou, Djijan and Samanko affiliated at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The experiments were conducted in a 2×8 alpha lattice with three replications. Within the environment, the main effect of a genotype was significant. Genotypes by environmental interaction were also significant. Results showed that three genotypes ICGX-IS 13005F2-B1-287-1 (grain yield 2,197.1 kg/ha), ICGX-IS 13005F2-B1-205-1 (grain yield 1,922.3 kg/ha) and ICGX-IS 13012F2-B1-29-1 (grain yield 2,106.0 kg/ha) were found to be stable across environments. The genotypes with high pod yield for each specific environment were ICGX-IS 13005F2-B1-287-1 with 2197.1 kg/ha in Tioribougou and ICGX-IS 13005F2-B1-252-1 with 2382.8 kg/ha in Samanko.

Key words: Groundnut, yield, genotype × environment interaction.

INTRODUCTION

Groundnuts are main food product for thousands of small scale farmers in Mali. FAOSTAT (2015) data on groundnut production showed that, for the country, the increase in groundnut production resulted from the expansion of the area cultivated and increase in the number of farmers involved in the production rather than the increase of yield productivity *per se* for more than 50 years. Other studies indicated that severe drought occurred twenty times during 55 years in Mali (Ndjeunga et al., 2003). Moreover, SAS Institute 2009 argued that in West Africa, groundnut productivity follows similar trends with the rainfall pattern, which is mostly dominated by the occurrence of recurrent drought spells. The groundnut production is rain-fed in Mali and most of the time; the growing phase terminates under a period of drought. This exposes the crop to end-of season drought causing

*Corresponding author. E-mail: ouzbi777@gmail.com. Tel: +223 79180938.

yield loss ranging from 44 to 85% in Mali (Sanogo et al. unpublished). Though, breeding for drought tolerance should be an important objective for breeders in the Sahelian region, Ravi et al*.* (2011) proposed the development of varieties that are better adapted to water-limited conditions. One of the most important steps in a breeding programme is the assessment of new breeding materials in target environments. Assessing the performance of breeding lines is crucial because it involves both breeders and farmers and allows critical judgments from both sides before the acceptance of the promising lines by farmers. Testing of potential new genotypes in diverse environments can reveal wide adaptation, or yield stability of cultivar, and good mean performance (Simmonds, 1991). According to Kang et al*.* (2006), genotype-by-environment interaction (GEI) is expected in trials that involve cultivars with diverse genetic backgrounds in diverse test sites. Estimates of significant GEI effects is an indication that genotypes respond differently under different growing conditions, suggesting that environments have effect on the genotypes' performance (Worku et al., 2001). In Sub-Saharan Africa, groundnut breeders generally select genotypes with high pod yield to specific environments. GEI is common under drought situations (Bänziger et al*.,* 2004), and drought events are unpredictable and occur randomly. In a GEI study across Niger and India, Hamidou et al*.* (2012) observed a high GEI between the two countries suggesting the need for environment-specific selection in groundnut. The present study was designed to assess the new developed drought tolerant groundnut lines along with their four parental lines and the two landraces and to identify promising genotypes across three different locations in Mali. The specific objectives were to: (i) determine the importance of genotype x environment interaction in the different genotypes, (ii) identify varieties with stable performance or specific adaptation to be recommended to farmers in Mali for cultivation.

MATERIALS AND METHODS

Genetic material

Sixteen genotypes comprising 10 $F_{2:4}$ drought tolerant groundnut and six controls (4 parental lines and 2 landraces) were evaluated in this study (Table 1).

Field location and experimental conditions

The ten superior elites genotypes and their four parents were evaluated at Tioribougou (580 m above sea level masl, latitude 13°22´ N, longitude 7°69´ W), Djijan (320 m asl latitude l3°05' N, longitude 9° 28' W) and Samanko ICRISAT Research Station (331 m, latitude 12°54'N, longitude 8°40'W), during the rainy season 2015/2016. The average annual rainfall at Tioribougou, Djijan and Samanko affiliated with ICRISAT are 700, 900 and 800 mm, respectively. Currently, two local controls: 47-10 and Tigaba which are the most popular in Mali were included. All experiments were laid out as 8×2 alpha lattice designs with 3 replications. Each plot consisted of a row with a length of 4 m with 60 cm within-row spacing and 15 cm between-row spacing. Prior to planting, basal fertilizer was applied as 100 kg ha^{-1} Simple Super phosphate. Standard cultivation practices, including hand planting, hand weeding.

Data collection and analysis

Data collected included: 50% flowering [50%DF] (in days), Biomass weight [BIO] (g), Pod Yield [PY] (kg/ha), one hundred seed weight [HSW] (g), Shelling percentage [SP] (%), Harvest index [HI], and Grain Yield [GY] (kg/ha).

Data were analyzed in analysis of variance (ANOVA) across locations using PROC GLM in SAS (SAS Institute, 2009). Replications, Environments' and incomplete blocks were considered as random effects while genotypes were considered as fixed effects. PROC CORR was used to perform correlation analysis. The GGE biplot analysis (Yan and Tinker, 2006) was performed using GenStat software Edition 15 for grain yield means adjusted for block effects to obtain information on the genotypes in the three experimental environments. It was also applied to estimate genotypic mean performance across environments for stability analysis. GGE biplot analysis allows the disintegration of the G x E interactions. The first two principal components (PC1 and PC2) were constructed in GGE biplot that were derived from subjecting environment-centered grain yield means for each location to singular value disintegration. The data were not transformed ('Transform=0'), but standardized ('Scale=1), and were environment-cantered (Centering=2').

RESULTS

Mean squares from ANOVA for yield and drought traits in 16 groundnut lines

Results of the analyses of variance combined across environments and for each environment are presented in Table 2. ANOVA revealed highly significant (P<0.01) effects of genotypes for 50%flowering, hundred seed weight, harvest index, shelling percentage whereas genotypes effects were significant (P<0.5) for pod and grain yield (Table 2). Environment effects were highly significant (P<0.01) for 50% flowering, hundred seed weight, harvest index, shelling percentage, pod yield and grain yield (Table 2).

Environmental mean performance and coefficient of variation of traits in 16 genotypes

By comparing the three environments for their mean performance across the 16 genotypes, higher values were recorded in Djijan compared to Tioribougou and Samanko for most of the traits except for 50% DF, pod yield and grain yield (Table 3). Fifty percent date to flowering of plants ranged from 25 days in Tioribougou and Samanko to 26 days in Kita. Biomass production varied from 290 g in Djijan to 172.20 g in Samanko.

Table 1. Groundnut genotypes use for the GEI experiment in three environments in Mali, 2015.

ID	Genotype	Pedigree	Source	Status
G1	ICGX-IS 13005F2-B1-205-1	ICGV 91317/ICGV 87378	ICRISAT	F_4
G2	ICGX-IS 13005F2-B1-252-1	ICGV 91317/ICGV 87378	ICRISAT	F_4
G3	ICGX-IS 13005F2-B1-287-1	ICGV 91317/ICGV 87378	ICRISAT	F_4
G4	ICGX-IS 13005F2-B1-46-1	ICGV 91317/ICGV 87378	ICRISAT	F_4
G5	ICGX-IS 13005F2-B1-91-1	ICGV 91317/ICGV 87378	ICRISAT	F_4
G6	ICGX-IS 13012F2-B1-29-1	ICIAR 19BT / ICGS 44	ICRISAT	F_4
G7	ICGX-IS 13012F2-B1-297-1	ICIAR 19BT / ICGS 44	ICRISAT	F_4
G8	ICGX-IS 13012F2-B1-40-1-1	ICIAR 19BT / ICGS 44	ICRISAT	F_4
G9	ICGX-IS 13012F2-B1-525-1	ICIAR 19BT / ICGS 44	ICRISAT	F_4
G10	ICGX-IS 13012F2-B1-576-1	ICIAR 19BT / ICGS 44	ICRISAT	F_4
G11	ICIAR 19BT	Introduced control[§]	ICRISAT	P_1
G12	ICGS 44	Introduced control	ICRISAT	P_2
G13	ICGV 87378	Introduced control	ICRISAT	P_3
G14	ICGV 91317	Introduced control	ICRISAT	P_4
G15	47-10	Landrace (control)	Mali	P_5
G16	Tigaba	Landrace (control)	Mali	P_6

F_4=F_2-derived F_4 progenies. P_1 to P_4= parents used as introduced controls; P_5 and P_6= local controls.

Table 2. Mean squares for yield and yield components in 16 groundnut lines, evaluated across three environments in Mali.

Source of variation	df	50%DF	BIO	HI	HSW	SP	PY	GY
GENOTYPE (G)	15	70.70***	9.43*	24.11***	16.69***	26.54***	5.47*	6.34*
ENV (E)	2	0.38***	1.66***	2.02***	0.45***	1.21	0.17***	0.24***
REP(ENV)	4	0.47	2.49*	2.24*	3.14**	4.39*	1.95*	1.46*
G x E	30	10.05**	15.38*	21.08*	9.64**	34.59***	10.36*	12.10*
ERROR	90	13.58	30.79	38.36	11.21	33.13	29.16	32.92

*, **, *** implies P ≤ 0.5, P ≤ 0.01 and P ≤ 0.001, respectively; Rep = Replication, DTF=Date to 50% flowering, BIO = biomass production, HI = harvest index, HSW=hundred seed weight, SP = shelling percentage, PY = pod yield, GY = grain yield.

Harvest index ranged between 79.30% in Tioribougou and 67.70% in Samanko. Hundred seed weight ranged from 29.50 g in Samanko to 40.90 g in Djijan. Shelling percentage ranged between 73.90% in Samanko and 74.20% in Djijan and Tioribougou. The overall mean of groundnut pod yield was variable between 1,868 kg/ha in Samanko and 3,406.74 kg/ha in Djijan. Grain yield ranged from 1,980.50 kg/ha in Samanko to 2,365 kg/ha in Tioribougou. Coefficient of variation obtained ranged from 2.32% for SP in Tioribougou to 28.08% for GY in Djijan. The low yielding environment (Samanko) exhibited lower coefficient of variation for several characters than the two higher yielding environments (Djijan and Tioribougou) (Table 3).

Correlation of grain yield and other traits between locations

In Djijan, grain yield had positive and highly significant correlation (P<0.001) with pod yield (*r = 0.78*), biomass (*r = 0.53*) and harvest index (*r= 0.38*) (Table 4). Likewise in Tioribougou, highly significant (P<0.001) correlation existed between grain yield and pod yield (*r = 0.95*), biomass (*r = 0.49*) and harvest index (*r = 0.38*). Across the three environments, highly significant (P<0.001) and positive correlation occurred between grain yield, biomass (*r= 0.70*), harvest index (*r= 0.40*), 100-seed weight (*r= 0.58*) and pod yield (*r= 0.90*) (Table 4).

GGE biplot analysis

Figures 1 to 3 provide graphical results of the GGE biplot analysis. The GGE biplot of the grain yield of the 96 genotypes revealed that PC1 explained 61% of the total variation while PC2 explained 28%. The total variation for grain yield of the genotypes across the three environments account for 89% with PC and PC2 (Figure 1). The GGE biplot was based on genotype-metric

Table 3. Environmental means performance, coefficient of variation of studied traits of 16 genotypes evaluated in Mali.

Trait	Djijan			Tioribougou			Samanko			Across locations		
	§Mean ± SE	CV (%)	R^2	Mean ± SE	CV (%)	R^2	Mean ± SE	CV (%)	R^2	Mean ± SE	CV (%)	R^2
50% DF	26 ± 0.4	6.11	0.84	25.6 ± 0.4	4.88	0.88	25 ± 0.4	3.98	0.91	26 ± 0.2	5.14	0.86
BIO	290.8 ± 10.7	22.73	0.54	262.4 ± 8.5	19.46	0.57	172.2 ± 7.5	22.74	0.67	241.8 ± 6.7	23.13	0.69
HI	69.4 ± 1.9	17.15	0.54	79.3 ± 1.8	12.54	0.63	67.7 ± 2.3	18.31	0.64	72.1 ± 1.2	15.91	0.62
HSW	40.9 ± 0.7	9.19	0.69	40.4 ± 0.6	6.34	0.77	29.5 ± 0.6	6.22	0.88	36.9 ± 0.6	7.83	0.89
SP (%)	74.2 ± 0.6	4.58	0.61	74.2 ± 0.4	2.32	0.82	73.9 ± 0.5	3.14	0.73	74.1 ± 0.3	3.45	0.67
PY	3309.2 ± 121.3	24.36	0.47	3406.74 ± 97.2	21.83	0.30	1868.0 ± 62.9	18.77	0.63	2861.3 ± 80.9	23.09	0.71
GY	2231.3 ± 91.3	28.08	0.44	2365.0 ± 68.8	21.38	0.35	1345.2 ± 41.3	17.26	0.62	1980.5 ± 55.2	24.21	0.67

§Mean and SE of studied traits in three locations and across. 50% DF =Date to 50% flowering, 50% DF= Day to 50% flowering (days), HSW = hundred seed weight (g), SP = Shelling percentage (%), PY= pod yield (kg ha^{-1}), GY = grain yield (kg ha^{-1}), CV (%) =Coefficient of Variation, R^2=R-square.

Table 4. Person correlation coefficients of grain yield of 16 groundnut genotypes with other traits at Djijan, Tioribougou, Samanko, and across environments.

Trait	Djijan	Tioribougou	Samanko	Across locations
50% date to flower	-0.13*	-0.11*	0.14*	0.08*
Biomass	0.53***	0.49**	0.55***	0.70***
Harvest index	0.38***	0.43**	0.27	0.40***
100-Seed weight	0.06***	-0.01	0.31*	0.58***
Shelling per cent	0.27*	0.14*	0.07	0.15*
Pod yield	0.78***	0.95***	0.94***	0.90***

*, **, *** implies P ≤ 0.5, P ≤ 0.01 and P ≤ 0.001, respectively; 50% DF = Date to 50% flowering (days), Biomass (kg), SLAz = Specific leaf area (cm^2 g^{-1}) at 80 DAS, 100 seed weight (g), SP = Shelling percent (%), PY= pod yield (kg ha^{-1}).

preserving (SVP = 1) which is more appropriate for comparing genotypes. Genotypes ICGX-IS 13005F2-B1-287-1 (G3) and ICGX-IS 13005F2-B1-205-1 (G1) were higher yielding while genotypes ICIAR 19BT (G11) and ICGX-IS 13005F2-B1-252-1 (G2) were the lowest yield performers and their absolute higher PC2 scores were associated with genotypic instability (Figure 1). The genotype ICGX-IS 13012F2-B1-297-1 (G6) was the most stable across the three environments based on its PC1 score and PC2 near-zero.

Genotypes ICGX-IS 13005F2-B1-287-1 (G3), ICGX-IS 13005F2-B1-205-1 (G1) and ICGX-IS 13012F2-B1-29-1 (G6) had the highest mean performance in the three experimental environments (Table 5). The absolute length of the projection of a genotype onto the Average Genotypic Ordinate (single blue line, a horizontal line passing through the origin of the biplot on the y-axis) is a measure of its stability. The shorter the projection, the more stable is the yield performance of the genotype. Thus, the genotypes ICGX-IS 13012F2-B1-297-1 (G7), ICGV 87378 (G13) and ICGX-IS 13012F2-B1-29-1 (G6) were the most stable in the three experimental environments (Figure 2). Among all, the ''ideal'' genotype was ICGX-IS 13005F2-B1-287-1 (G3) located in the centre of the circle (Figure 3). The desirable genotypes were ICGX-IS 13005F2-B1-205-1 (G1) and ICGX-IS 13012F2-B1-29-1 (G6) while the undesirable ones were ICGS 44 (G12), ICGX-IS 13005F2-B1-91-1 (G5) and Tigaba (G16). The three environments were classified as follows: Tioribougou > Djijan > Samanko in discriminating genotypes for grain yield (Figure 3). Overall, the ''ideal genotype'' and the desirable ones were the new developed drought tolerant genotypes. Also, the highest yielding as well as the most stable genotypes belongs to the new genotypes. It is important to confirm the superiority of the new drought tolerant genotypes over the six controls (four parents and two landraces) since the genetic material was evaluated in one season.

DISCUSSION

The first objective of this study was to evaluate genotypes to random drought. Drought is, though not predictable but occurs frequently in Mali. However, rainfall patterns during the period of the experiment from planting to harvesting across the three environments were favorable for plant growth. As a result, there was no drought spell affecting the crop during the reproductive phase. Hence the true potentials of the newly developed

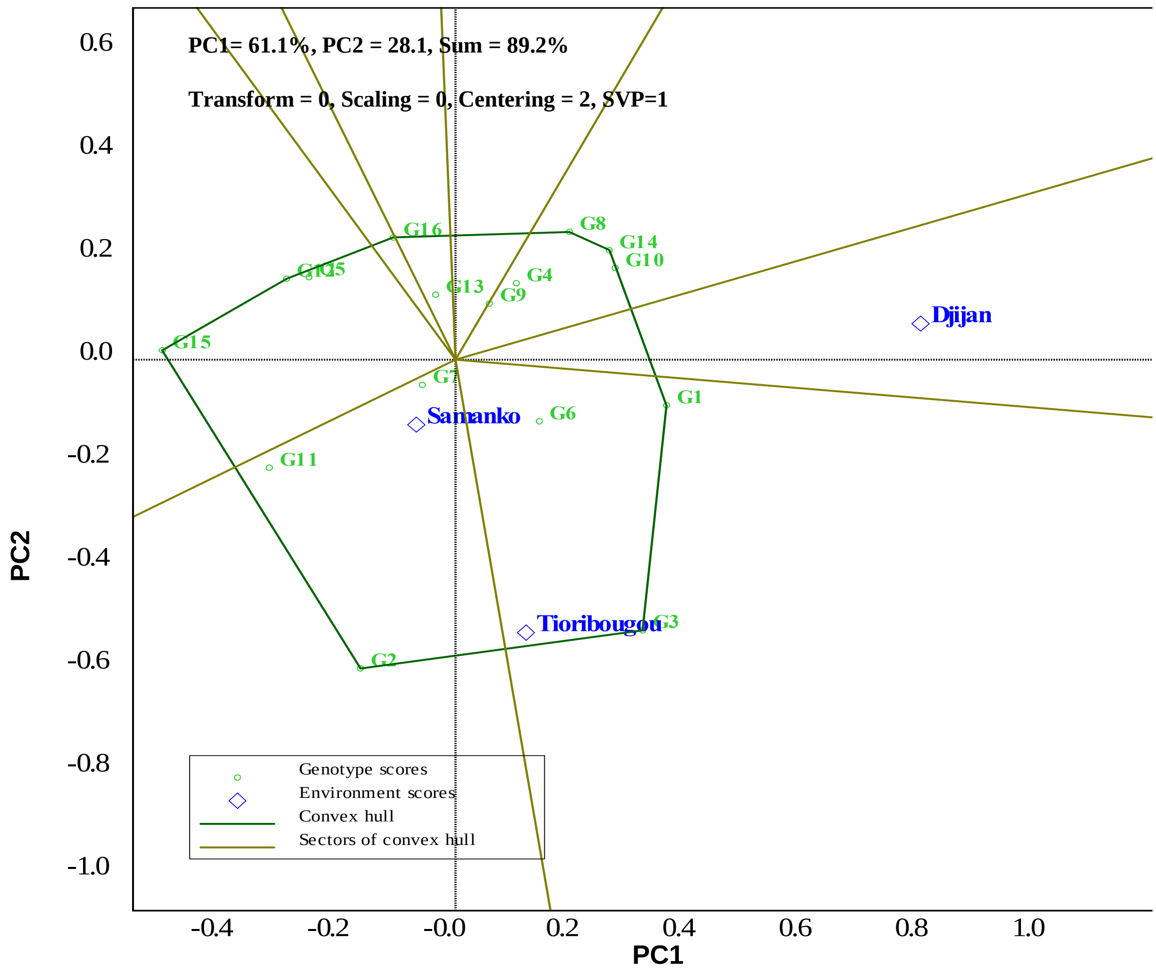

Figure 1. The ''Which-Won-Where'' GGE biplot based on groundnut grain yield data of 16 genotypes in three environments (Djijan, Tioribougou and Samanko).

lines under drought are yet to be determined. Therefore the testing of the lines under controlled drought conditions is necessary to confirm the presence of drought tolerance alleles in the newly developed lines. In the present study, correlations were calculated in each environment separately and also based on the mean values obtained from the pooled analysis. The 50% DF and hundred seed weight were correlated with grain yield in one environment but not in other environment indicating that environment might have some influence. Therefore, selection of these traits would need attention for further characterization and improvement. This suggests that these traits are not stable across environments and are therefore unreliable as secondary traits for genetic improvement of grain yield. Pod yield, shelling percentage, harvest index and biomass production exhibited a positive and significant (<0.5) phenotypic correlation with grain yield in all the environments or at least two environments indicating selection of these traits will simultaneously improve the yield. Similar results were obtained by Sharma and Varshney (1995), Johnson et al. (2008) and Ravi Kumar et al. (2012) who reported a significant and positive correlation of grain yield with pod yield. Wunna et al. (2009) detected strong correlation between grain yield and shelling percent, biomass production. The results from the current study were not in agreement with other findings such as those reported by Uddin et al. (1995) who found negative correlation between 100-seed weight and grain yield while Sumathi and Ramananthan (1995) and Sah et al. (2000) showed positive correlation between 100-seed weight and grain yield in groundnut. The correlation between grain yield and several characters in groundnut were reported by a number of investigators. For example, Sharma and Varshney (1995), Johnson et al. (2008) and Ravi Kumar et al. (2012) reported significant and positive association of grain yield with pod yield. Wunna et al. (2009) detected strong correlation between grain yield and shelling percent, biomass production. The results of the current

Table 5. Mean performance of 10 $F_{2:4}$ drought tolerant genotypes and the 6 controls in the three experimental environments for studied traits in Mali.

Genotype	50%DF	BIO	HI	HSW	SP	PY	GY
$F_{2:4}$ genotypes							
G1	26	197.0	78.8	38.7	0.8	2602.9	1922.3
G2	28	242.6	79.8	36.2	0.8	3278.5	2382.8
G3	24	219.3	86.1	36.6	0.8	3140.8	2197.1
G4	28	257.3	66.6	34.4	0.8	2803.6	1973.4
G5	25	244.6	75.0	33.4	0.8	3072.4	2119.0
G6	24	255.9	70.0	33.9	0.7	2984.4	2106.0
G7	23	240.0	71.4	37.4	0.7	2822.3	2050.9
G8	24	257.0	69.8	38.1	0.8	2913.1	1976.1
G9	23	266.8	72.1	37.2	0.7	3115.8	2086.0
G10	23	225.2	65.8	34.8	0.8	2466.3	1804.9
Mean of $F_{2:4}$	*25*	*240.6*	*73.5*	*36.1*	*0.8*	*2920.0*	*2061.8*
Controls							
G11	24	236.8	79.2	33.6	0.7	3020.7	1808.2
G12	29	193.6	78.2	37.7	0.7	2542.8	1753.7
G13	25	242.1	67.7	38.1	0.7	2722.2	1894.5
G14	25	276.9	64.1	36.9	0.8	2905.7	1990.1
G15	31	283.9	55.8	45.2	0.7	2632.2	1771.7
G16	29	230.2	73.8	39.2	0.7	2757.4	1851.7
Mean control	*27*	*243.9*	*69.8*	*38.4*	*0.7*	*2763.5*	*1845.0*
Overall							
Mean	*26*	*241.8*	*72.1*	*37.0*	*74.1*	*2861.3*	*1980.5*
SE±	*0.2*	*6.7*	*1.2*	*0.6*	*0.3*	*80.9*	*55.2*
CV (%)	*5.1*	*23.1*	*15.9*	*7.8*	*3.5*	*23.1*	*24.2*
R^2	*0.9*	*0.7*	*0.6*	*0.9*	*0.7*	*0.7*	*0.7*
Contrast: $F_{2:4}$ vs Controls	***	*ns*	*ns*	*	**	*ns*	*

ns = non-significant, *P<0.05, **P<0.01, ***p<0.0001, respectively. 50% DF= Day to 50% flowering (days), SCMRf = SPAD meter reading at 60 DAS, SCMRz = SPAD meter reading at 80DAS, SLAf = Specific leaf area (cm^2 g^{-1}) at 60 DAS, SLAz = Specific leaf area (cm^2 g^{-1}) at 80 DAS, HSW = hundred seed weight (g), SP = Shelling percentage (%), PY= pod yield (kg ha^{-1})and GY = grain yield (kg ha^{-1}).

study have some implications in breeding for agronomic and yield components traits in groundnut in Mali. Grain yield associated negatively with 50% DF suggests delayed crop growth may reduce grain yield. This is probably because of the possibility that the crop may be exposed to several prevailing abiotic stresses like drought and thereby reducing yield (Nagabhushanam, 1981). This scenario should be avoided in the major groundnut cultivation areas in Mali such as Kolokani by selecting drought tolerant materials or short duration varieties. The correlation between grain yield and other yield components indicated that possible superior segregants could be selected in combinations of traits such as days to 50% flowering, hundred seed weight and shelling percentage. The multi-environmental trial analyses conducted in three locations Djijan, Tioribougou and Samanko revealed that genotypes, environments and their interactions were significant for almost all traits which agreed with a number of previous results such as Nath and Alam (2002), Bucheyeki et al*.* (2008), Hamidou et al*.* (2012) and Makinde et al*.* (2013) working on groundnut. Both of genotypic and environmental differences played important roles in the expression of the different traits with significant GEI reflected in combined analysis. The genotypes revealed a considerable variability for agronomic traits and yield components that could be potentially useful for the improvement of drought related traits as well as yield components. The combined analysis across the three locations for the F_4 progenies compared to the checks revealed improvements made in some traits of interest. This may be due to new genetic combinations produced in the hybridization process. It is important to note that the ten elites genotypes were selected as the top 10 F_4

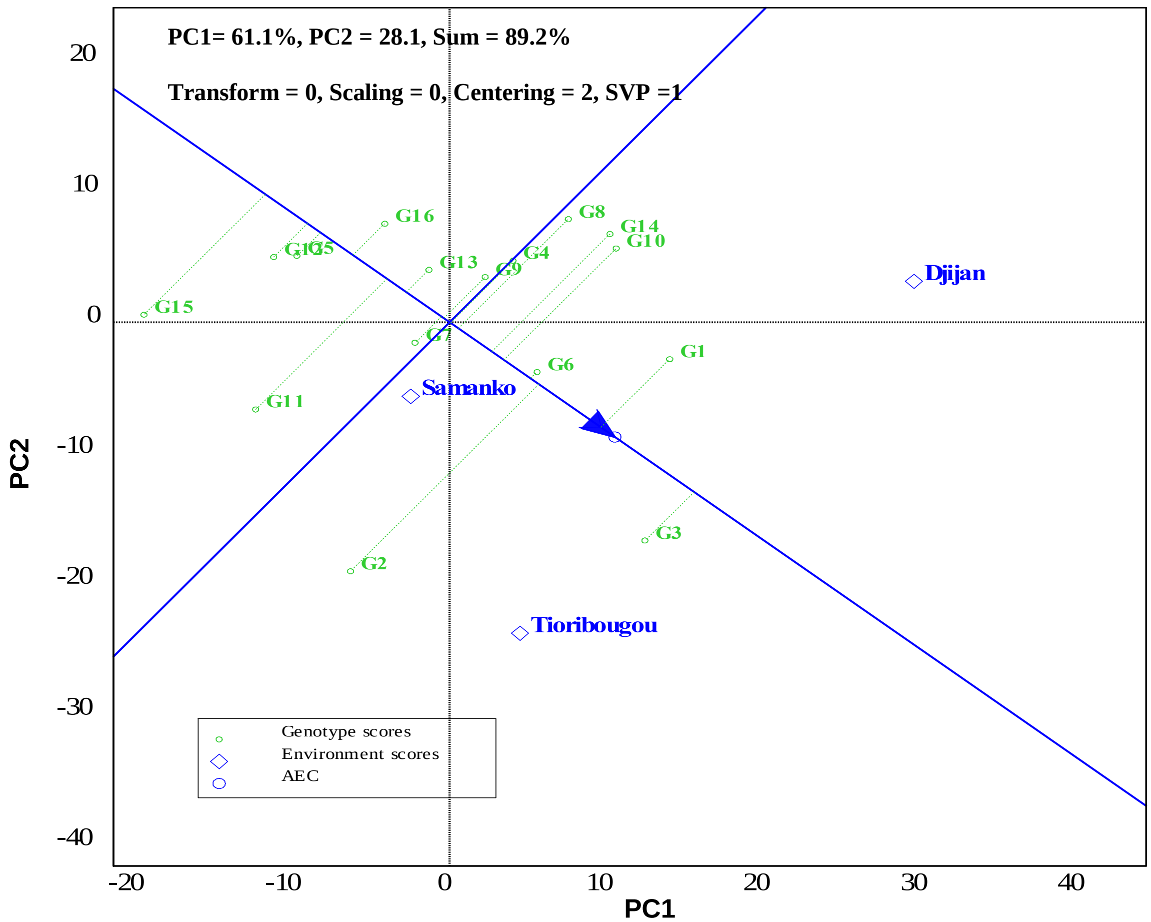

Figure 2. GGE biplot based on groundnut grain yield performance and stability for 16 genotypes in three environments (Djijan, Tioribougou and Samanko).

high performance among 90 drought tolerant genotypes in the breeding process.

Each of the ten F_4 genotypes had a good yield compared to controls and the farmers' best control (Tigaba) in the three experimental condition except ICGX-IS 13012F2-576-1. Four genotypes (ICGX-IS 13005F2-205-1, ICGX-IS 13005F2-252-1, ICGX-IS 13005F2-91-1 and ICGX-IS 13012F2-29-1) were identified with significantly higher pod yield compared to the best control (ICIAR 19BT). The best F_4 genotype (ICGX-IS 13005F2-252-1) with 3,278.80 kg/ha represented 24.5% higher yield than the best control ICIAR 19BT. Farmers normally adopt varieties that yield more than their locally adapted cultivars; and meet the preferred traits which differ from one community to another (Gowda et al., 2000). The selection criteria of variety largely depend on the importance of the crop in the farming system and their uses (Abebe et al., 2005). Genotypes out yielding with more than 20% over landraces open the possibility of introduction or replacing with the landrace Tigaba, a late maturing variety. Tigaba cannot be cultivated in low falling periods or drought years. The variety 47-10, the most widely grown variety in Mali, produces a lot of pods with few seeds resulting in low yield. In addition to that, the variety is suspected to have high aflatoxin levels which is damaging to humans and cattle when consumed. These new genotypes should be evaluated for other farmers and end-users before adoption. Each of the ten F_4 genotypes had a good yield performed well compared to mean controls and the farmers' best check (Tigaba) except ICGX-IS 13012F2-576-1. The genotype-by-environment interactions effects on pod yield were significant. Genotype-by-environment interaction effects on pod yield have been reported in a number of previous studies but the most recent results from Bucheyeki et al. (2008), Jogloy et al. (2009), Zhang et al. (2011), Balota et al. (2012) and Makinde et al. (2013) were consistent with the present results. The presence of genotype by environment interactions resulted in the yield performance of genotypes and ranking of genotypes varying from one environment to another, which suggests that environment specific varieties could be selected.

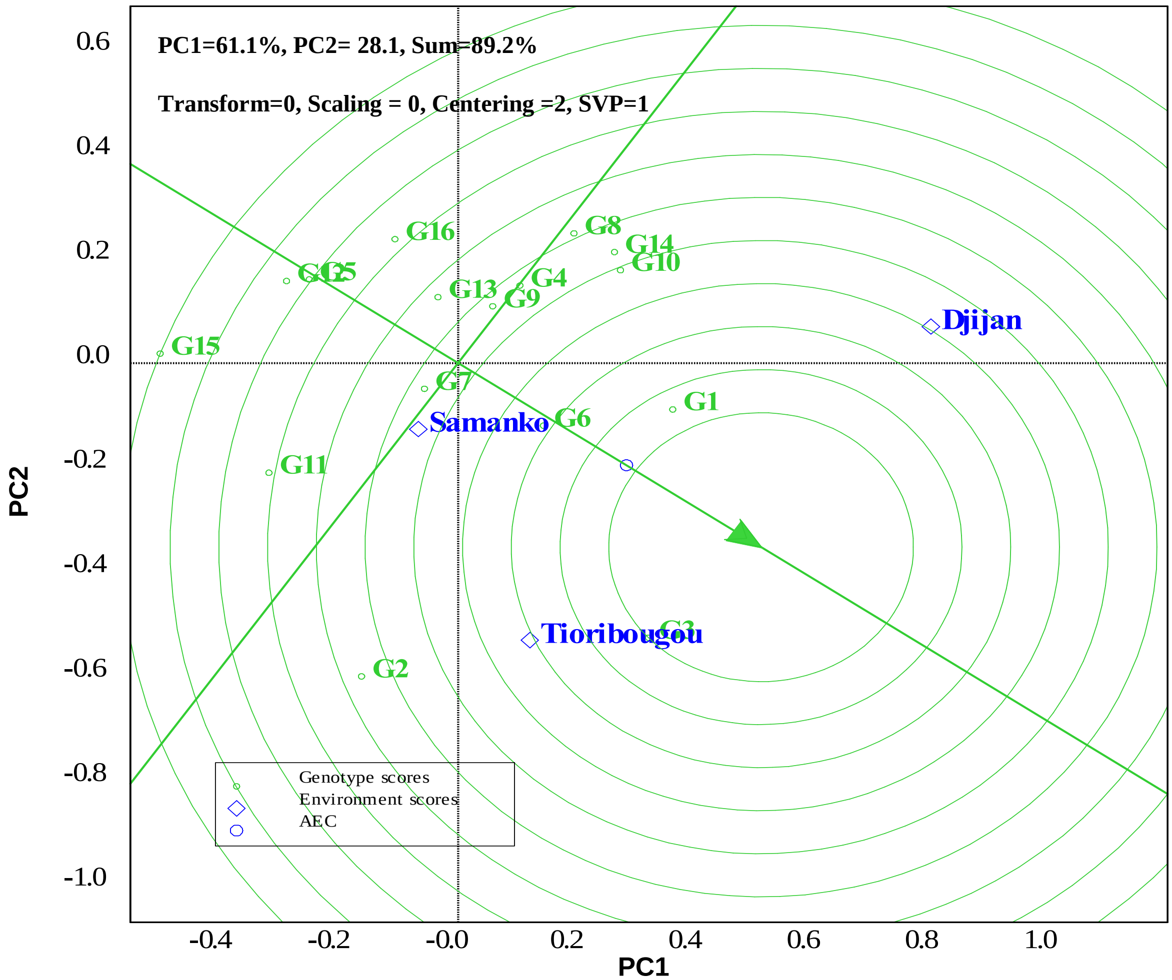

Figure 3. GGE-biplot based on genotype-focused scaling for comparison the genotypes with the ideal genotype across three environments (Djijan, Tioribougou and Samanko).

Genotypes that has significantly a better yield than the controls were identified specifically for each environment including ICGX-IS 13005F2-B1-287-1 (G3) for Tioribougou, ICGX-IS 13005F2-B1-205-1 (G1), ICGX-IS 13005F2-B1-252-1 (G2) for Samanko and ICGX-IS 13012F2-B1-29-1 (G6) for Djijan. In the three experimental environments, genotype ICGX-IS 13012F2-B1-29-1 (G6) whereas ICGX-IS 13005F2-B1-205-1 (G1) and ICGX-IS 13005F2-B1-287-1 (G3) had high yield and high stability.

Conclusion

The genotype by environment interaction influenced drought and traits related to yield or yield components. Some environments were better than others in the expression of the quantitative traits. The difference in ranking genotypes based on yield performance across the three environments confirmed the presence of the genotype by environment interactions. The genotype by environment interaction analysis using GGE biplot method was powerful to visually analyze the yield performance of genotypes in the three locations. Genotypes that performed significantly better than the checks were identified specifically for each environment including ICGX-IS 13005F2-B1-287-1 (G3) for Tioribougou and ICGX-IS 13005F2-B1-252-1 (G2) for Samanko. Genotypes showing little crossing-over interactions and great potentials for high genetic gains were ICGX-IS 13012F2-B1-29-1 (G6), ICGX-IS 13005F2-B1-205-1 (G1) and ICGX-IS 13005F2-B1-287-1 (G3). Six new drought tolerant genotypes had a good yield of up to 18% over the six controls and three of the same genotypes showed yield superiority of 36% six checks. Increase in yield of the new drought tolerant genotypes over the controls showed substantial achievement in breeding for tolerance to drought. The new genotypes will contribute to enhancing the production of groundnut in Mali especially in these areas experiencing cycles of drought. Despite these substantial results, further generations and evaluations will enable better homogeneity (fixation of alleles) of lines and clear varietal recommendations to farmers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Biochemical characterization of four less exploited edible fruits in Congo-Brazzaville: *Passiflora edulis f. flavicarpa, Aframomum alboviolaceum, Saba comorensis* and *Clitandra cymulosa*

Josiane Enzonga*, Jean Paul Latran Ossoko, Yves Okandza, Arielle Makimouha-Kali and Mvoula Tsieri

Laboratoire de Contrôle et Qualité des aliments de l'Ecole Nationale Supérieure d'Agronomie et de Foresterie, Université Marien NGOUABI, BP 69 Brazzaville, Congo.

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The aim of this study was to determine the biochemical characteristics (moisture, crude protein, crude lipids, ash, pH, titrable acidity, minerals and free sugars) of four popular edible fruits (*Passiflora edulis f. flavicarpa*, *Aframomum alboviolaceum*, *Saba comorensis* and *Clitandra cymulosa*), but less exploited. The pulp and seeds of *P. edulis f. flavicarpa* and *A. alboviolaceum* was also investigated in order to identify the nutritional quality of seeds which are by-products in juice and nectar production. The results showed that all the fruits had a high water content, which limited their conservation. The *P. edulis f. flavicarpa* contains significant protein content (9.42±1.56%), and the lipid content of *P. edulis f. flavicarpa* (11.65%) and *A. alboviolaceum* (10.58%) was higher than that of the other two fruits. The pulps of *Saba comorensis* and *Clitandra cymulosa* were acidic with not negligible free sugar contents. The ashes of these four fruits contained minerals such as iron, phosphorus, calcium and magnesium, with the last two being the major elements. The comparative study of the seeds and pulps of *P. edulis f. flavicarpa* and *A. alboviolaceum* demonstrated the seeds nutritional quality. In view of these results, the four fruits as well as the *P. edulis f. flavicarpa* and *A. alboviolaceum* seeds could constitute an appreciable source of nutrient intake and also be valued in the food, pharmaceutical and cosmetic industry.

Key words: *Passiflora edulis f. flavicarpa*, *Aframomum alboviolaceum*, *Saba comorensis*, *Clitandra cymulosa*, mineral elements, biochemical characteristic, Republic of Congo.

INTRODUCTION

In the Republic of Congo, as in most developing countries, the problem of food security remains a major

*Corresponding author. E-mail: josiane0204@yahoo.fr.

challenge. Nutritional deficiencies are the cause of acute malnutrition affecting mostly women of childbearing age and children (OMS, 2009; Stevens et al., 2013; N'goran, 2014). One of the ways out of this impasse is the valuation of edible fruits including wild ones available but less exploited.

Fruits are considered as very good sources of minerals, vitamins, carbohydrates, phenolic compounds and antioxidants (Ahodegnon et al., 2018) and can contribute to a qualitative improvement in the health of populations (Kuhnlein, 1989).

For this reason, all scientists now agree that people who consume enough fruit are less likely to suffer from cardiovascular disease, obesity, cancer and diabetes (FAO/WHO, 2004). Fruits are an important link in the food chain both qualitatively and quantitatively. In terms of nutrition, fruits in general constitute an essential supplement of the basic diet consisting of cereals and starchy foods which are poor in mineral salts and vitamins (Kouyaté et al., 2009; Krishnamurthy and Sarala, 2012).

In the Republic of Congo, despite its usefulness in improving the nutritional status of populations, conventional fruits are still inaccessible to the middle class because of its high cost. This situation could lead to nutritional deficiencies that increase the risk of non-communicable diseases (NCDs). However, there are under-exploited pick fruits such as *Passiflora edulis f. flavicarpa*, *Aframomum alboviolaceum*, *Saba comorensis* and *Clitandra cymulosa* that are highly valued by urban and rural populations, which could be important sources of nutrients and thus play an important role in food security and the improvement of nutritional status of the populations.

Grenadilla (*P. edulis f. flavicarpa*), known as "sour passion fruit", native to South America (Koko et al., 2018; Carr, 2013), is a climbing plant in the Passifloraceae family (Hoff and Cremers, 2005) grown for its edible pulp fruits. The Passifloraceae family has more than 500 species divided into 18 genera among which the *Passiflora* genus (Corrêa et al., 2016). Its fruits have a round shape with a diameter ranging from 8 to 10 cm, a yellowish green skin when mature and contain multiple seeds surrounded by a gelatinous yellow pulp with a tangy taste and intense aroma (López-Vargas et al., 2013). The fruit is marketed worldwide with Brazil, Ecuador and Colombia as the largest producers (Cardoso et al., 2012). Its leaves are shiny on their upper surfaces and dull on their lower surfaces (Zas and John, 2016) with a thickness of 7.5 to 20 cm.

Maniguette (*Aframomum*), of African origin, is a plant that grows for example in Ivory Coast, Cameroon, Gabon, Congo, the DRC, Madagascar, and is found mostly in the undergrowth. *Aframomum* species are large herbaceous plants that reach 5-6 m (Ngakegni-Limbili et al., 2013). They are perennial and aromatic, and have large trumpet-shaped yellow or pink flowers, purple petals and peduncles which are covered with sterile, superimposed bracts (Fankam et al., 2011). The pericarp, of variable woodiness, contains an edible whitish flesh dotted with dark brown seeds measuring 2-3 mm in diameter while the flesh has a very aromatic and refreshing taste (Herzog et al., 1994).

S. comorensis of the Apocynaceae family (Okullo et al., 2014) is a strong forest liana, up to 20 m long on other trees. It is used for its edible fleshy fruits in the form of berries (Ouattara et al., 2016). The fruits contain many almonds coated with orange-yellow pulp and are consumed during the lean season (Atato et al., 2011).

C. cymulosa (Benth) of the Apocynaceae family is native to tropical West Africa and has fruits in the form of berry containing almonds coated with red edible pulp (Mosango and Szafranski, 1985).

Despite the importance of these fruits in the food chain, very few studies on their biochemical characterization and their evaluation have been carried out up until now, to our knowledge. It is in this context that the present study was performed and is aimed at determining the biochemical characteristics of these four popular edible fruits in order to contribute to their evaluation.

MATERIALS AND METHODS

Biological materials

The biological materials used consist of fruits of *P. edulis f. flavicarpa* (yellow passion fruit), *A. alboviolaceum* (sweet maniguette), *S. comorensis (Bojer)* and *C. cymulosa* (Benth) presented in Table 1. They were bought fresh in the different markets of the city of Brazzaville (Republic of Congo).

Sample preparation

The fruits are washed and then cut in half with a kitchen knife (passion fruit, *S. comorensis* and *C. cymulosa*) or split longitudinally by pressing the fruit pod with both hands (*A. alboviolaceum*) to expose the fruit. The pulp and seeds or the pulp and almond are extracted with the spatula for the different analyses.

Chemical analyses

The four fruit samples, the pulp and seed of *P. edulis f. flavicarpa* and *A. alboviolaceum* were analyzed in triplicate for moisture, crude protein, crude lipids and ash using the standard AOAC methods (1995, 2005). Free sugars were determined from the pulp of *S. comorensis* and *C. cymulosa* by anthrone-sulfuric acid method (Yemm and Willis, 1954).

After mineralization of the different samples in the oven at 450°C, the ash was recovered, moistened with water and concentrated hydrochloric acid, and then minerals elements were determined employing standard methods. Phosphorus was assayed by the cold colorimetric method using Murphy and Riley's reagent. Calcium and magnesium were determined by atomic absorption under the following spectral conditions: calcium (I = 5A, λ = 422.7 nm) and magnesium (I = 3A, λ = 285.2 nm). Iron was determined by atomic absorption spectrometry (AAS). After plotting the calibration lines for each element, the concentrations read for the sample and blank

Table 1. Different samples used in this work.

Sample	Fruits	Seeds
1. *Passiflora edulis f. flavicarpa*		
2. *Aframomum alboviolaceum*		
3. *Saba comorensis* (Bojer)		
4. *Clitandra cymulosa* (Benth)		

were derived.

The pH was determined with *S. comorensis* and *C. cymulosa* pulp according to the potentiometric method using the electrode of a pH counter (55).

Titratable acidity was determined according to the normalized method FP7n°245025 (AFTER, 2011) with some modifications. The acidity has been obtained according to the following formula:

$$Acidity\ (mEq/100\ g\ MF) = N * V * \frac{50}{Vo} * \frac{100}{m}$$

where N is the normality of the soda used; V is the volume (ml), of the sodium hydroxide solution; m is the mass (g) of the sampled product; 50 is the final volume of the solution in the volumetric flask; and V_o is the volume (ml) of the aliquot test sample of the solution.

The titratable acidity can also be expressed in grams of acids per 100 g of product, multiplied by a factor equivalent to the chosen acid. In our case, we used citric acid so this formula was multiplied by 0.07 (AFTER, 2011).

RESULTS AND DISCUSSION

Table 2 shows that, like most fleshy fruits, the four fruits analyzed (*P. edulis f. flavicarpa, A. alboviolaceum, S.*

Table 2. Chemical composition of four fruit (%).

Fruit	Moisture	Crude protein	Crude lipid	Ash
Passiflora edulis f. flavicarpa	68.77 ± 0.05	9.42±1.56	11.65	3.77 ± 0.33
Aframomum alboviolaceum	66.86 ± 1.66	5.78±0.83	10.58	3.84 ± 0.07
Saba comorensis Bojer	64.82±1.09	3.76 ± 0.06	0.72 ± 0.02	3.60 ±0.02
Clitandra cymulosa (Benth)	60.49±1.28	5.23 ± 0.13	0.79 ± 0.069	1.35±0.49

comorensis Bojer and *C. Cymulosa* (Benth) contained high water content.

These moisture contents were higher than the value found by Boamponsem et al. (2013) with *Saba senegalensis* fruits, similar to those obtained by Diop et al. (2010) in the pulps from *Detarium senegalense* J.F. Gmel fruits harvested in five localities of Senegal, and by Kone et al. (2018) in the fruit pulp of black plum (*Vitex doniana*) from Ivory Coast. However, our values were lower than those obtained by Corrêa et al, (2016) in the pulp of five species of *Passiflora* (72.93 - 95.6%).

Moisture content is important for the stability and quality of food. Fruits that contain a large amount of water are subject to rapid deterioration due to mold growth and insect damage (Boamponsem et al., 2013).

The *P. edulis f. flavicarpa* had the highest protein content while the *S. comorensis* had the lowest protein content. These protein levels were lower than those found by Ayessou et al. (2011) in five Senegalese forest fruits. However, these values were higher than those reported in the literature (Favier, 1993) on some pick fruits such as passion fruit (2.6%), cinnamon apple (1.8%), medlar (0.4%), desert date (1.8%), and *Aframomum* (1.1%) and by Corrêa et al. (2016) in five *Passiflora* species.

They were also close to the values obtained in the pulp of *Hippophae rhamnoides* fruit (Dhyani et al., 2007). These values could make these fruits a significant source of protein necessary for human nutrition compared to other fruits already valued or exploited.

From analysis of Table 2, the four fruits had a lipid content that varied between 0.72 ± 0.02% and 11.65%. *S. comorensis* and *C. cymulosa* had very low lipid content. However, the lipid contents of *P. edulis f. flavicarpa* and *A. alboviolaceum* were high and similar, and these values were close to those found in the pulp of *H. rhamnoides* fruit (Dhyani et al., 2007) making these two fruits a significant source of lipid.

Table 2 showed ash content between 1.35 ± 0.49% and 3.84 ± 0.07%. The ash content found in the pulp of *C. cymulosa* is lower compared to that obtained in *S. comorensis*, *P. edulis f. flavicarpa* and *A. alboviolaceum*. These values were similar to those obtained by Ayessou et al. (2011) in two Senegalese fruits (*F. gnaphalocarpa* and *S. latifolius*). In comparison with the work of Boamponsem et al. (2013) on the pulp of *S. senegalensis*, we noted that the pulp of *S. comorensis* had higher ash content.

The composition of acidity and free sugars is given in Figure 1. From this figure, it can be observed that the pulp of two fruits contained low free sugar content. Nevertheless, the pulp of *C. cymulosa* (3.54%) was richer in reducing sugars than that of *S. comorensis* (2.52%). These values were close to those obtained by Diop et al. (2010) on the pulp of *D. senegalense* fruit (2.72 - 3.69%) already valued. In addition, our values were slightly lower than those obtained in wild *Spondias mombin* fruit available locally in Nigeria (Adepoju, 2009).

The pH of the *C. cymulosa* pulp (3.55) was higher than that of *S. comorensis* (3.2). These values were similar to those by Diop et al. (2010) who had worked on the pulp of *D. senegalense* (3.51) and superior to the results by Boamponsem et al. (2013) on the pulp of *S. senegalensis* (2.27). These results showed that the pulp of these fruits could give a juice with a favorable rate of acidity for the conservation against the degradation by the fungi.

Figure 1 showed that the pulp of *C. cymulosa* had titrable acidity expressed in citric acid equivalent content lower than that of *S. comorensis*. These results showed the concordance between the pH value and that of the acidity of the pulp of these two fruits.

Table 3 gives the results of mineral composition of *P. edulis f. flavicarpa, A. alboviolaceum* and *S. comorensis* Bojer fruits. The iron content was higher in the *S. comorensis* pulp compared to the two other fruits (*P. edulis f. flavicarpa* and *A. alboviolaceum*) with similar values. These values were higher than those found by Dike and Nnamdi (2012) with other fruits such as *Gambeya albida, Dialium guineense* and *Aframomum melegueta*. The *S. comorensis* fruit gave higher content of calcium, phosphorus and magnesium compared to the fruits of *P. edulis f. flavicarpa* and *A. alboviolaceum*.

In comparing our samples with four samples of Senegalese forest fruits and five Chinese jujube cultivars (Pareek, 2013) (Table 3) as well as three batches of jujube of Senegalese origin (Danthua et al., 2001), we could deduce that our samples constitute a source of mineral elements by their richness in magnesium, calcium and iron. Despite the low phosphorus content compared to the values of the literature (Ayessou et al., 2011), the consumption of these fruits could thus contribute to the satisfaction of the need of the human organism in terms of minerals and thus participate in a good growth, good metabolic process and prevention of

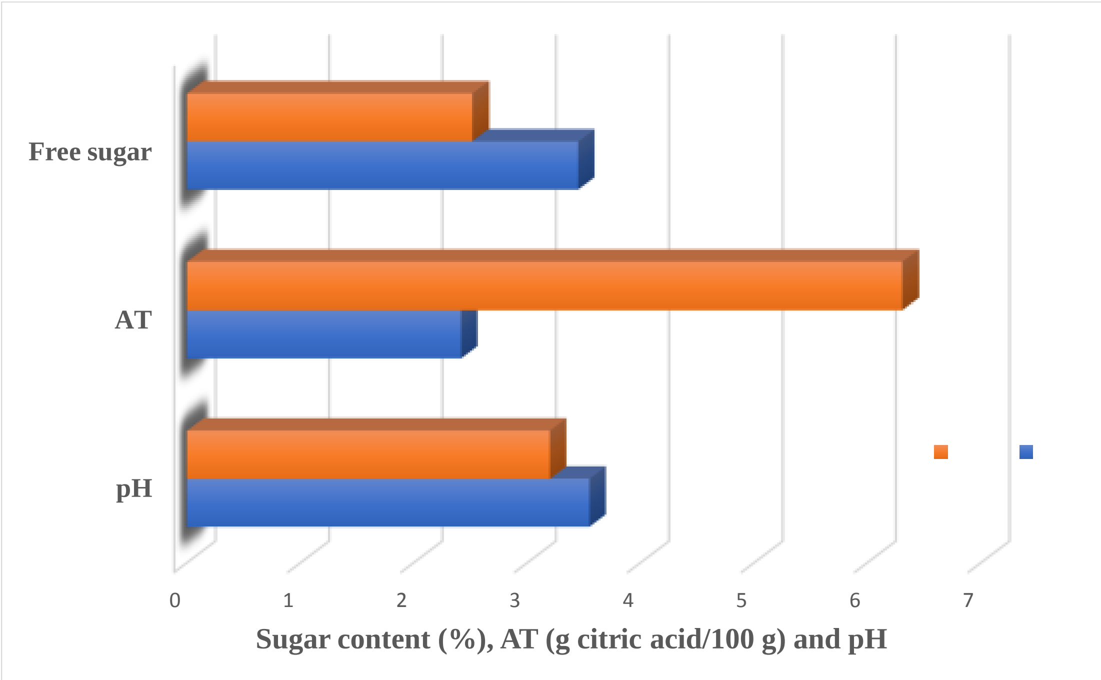

Figure 1. Contents of free sugar, AT and pH of *S. comorensis* and *C. cymulosa* fruit pulp.

Table 3. Comparison in mineral elements of studied fruits with other ones (mg/100 g).

Fruits	Fe	P	Ca	Mg
Passiflora edulis f. flavicarpa[a]	6 ± 0	24.5 ± 3.5	75 ± 7.07	65 ± 7.07
Aframomum alboviolaceum[a]	5.5 ± 0.7	17.5 ± 0.7	70 ± 14.14	170 ± 28.28
Saba comorensis Bojer[a]	25 ± 7.07	35 ± 7.07	460 ± 84.5	1090 ± 71
Clitandra Cymulosa (Benth)[a]	nd	nd	Nd	nd
I. Senegalensis[b]	8.1	172	612	210
F. gnaphalocarpa[b]	7.1	116	309	138
C. pinnata[b]	4.1	137	46	79
S. lutifolius[b]	5.4	214	470	154
Jinsixiaozao[c]	4.68	110	65.2	nd
Yazao[c]	6.93	59.3	91.0	nd
Jianzao[c]	6.42	72.3	45.6	nd
Junzao[c]	7.90	105	118	nd
Sanbianhong[c]	6.01	79.7	76.9	nd

Source: [a] This work; [b] Ayessou et al. (2011); [c] Pareek (2013).

certain diseases (FAO/WHO,2002). Magnesium is essential for the normal functioning of ATP (adenosine triphosphate) and glucose metabolism and therefore has extensive cellular effects. It is critical for normal ATP (adenosine triphosphate) function and glucose metabolism and therefore has widespread cellular effects. Magnesium is also important in cellular cytoskeleton contraction and at the myoneural junction (Moe, 2008).

Figures 2 and 3 showed the chemical composition of seeds and pulps of *P. edulis f. flavicarpa* and *A. alboviolaceum*. In the analysis of Figure 2, except for the ash content which was higher in the two pulps (3.82 ± 0.04% for *P. edulis f.* and 10.41% ± 0.02 for *A. alboviolaceum*), the other nutrients (proteins and lipids) were present in high quantities in the seeds of two fruits. The seeds of *P. edulis f.* had the highest lipid content (17.86%), and this value was lower than that obtained by Malacrida and Jorge (2012) who worked on the same fruit, but native from Brazilia. In addition, this oil content

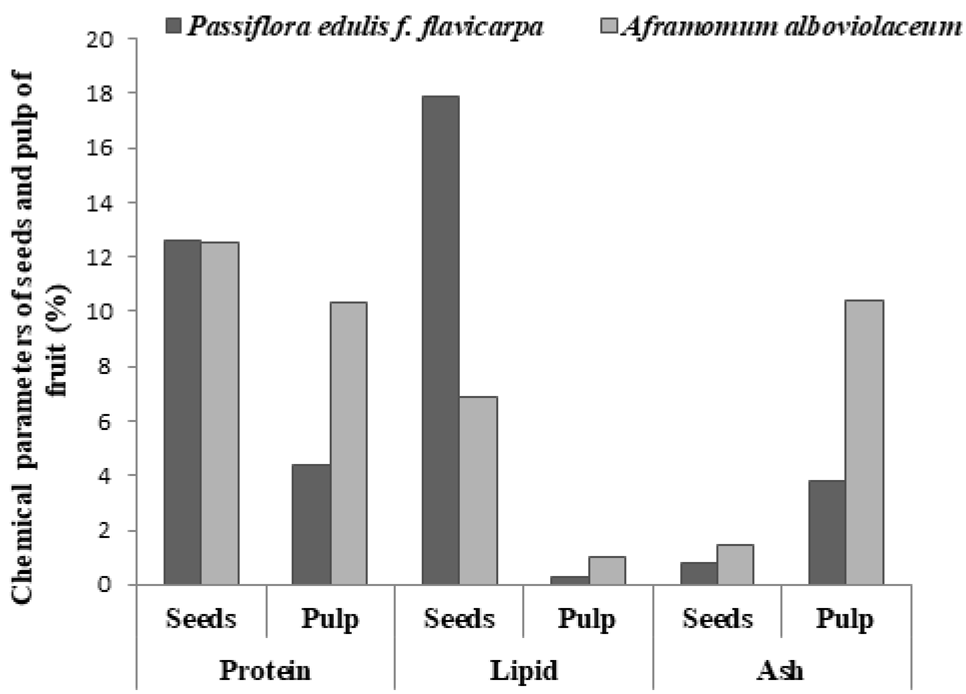

Figure 2. Chemical composition of seeds and pulp of *Passiflora edulis f. flavicarpa* and *Aframomum alboviolaceum*.

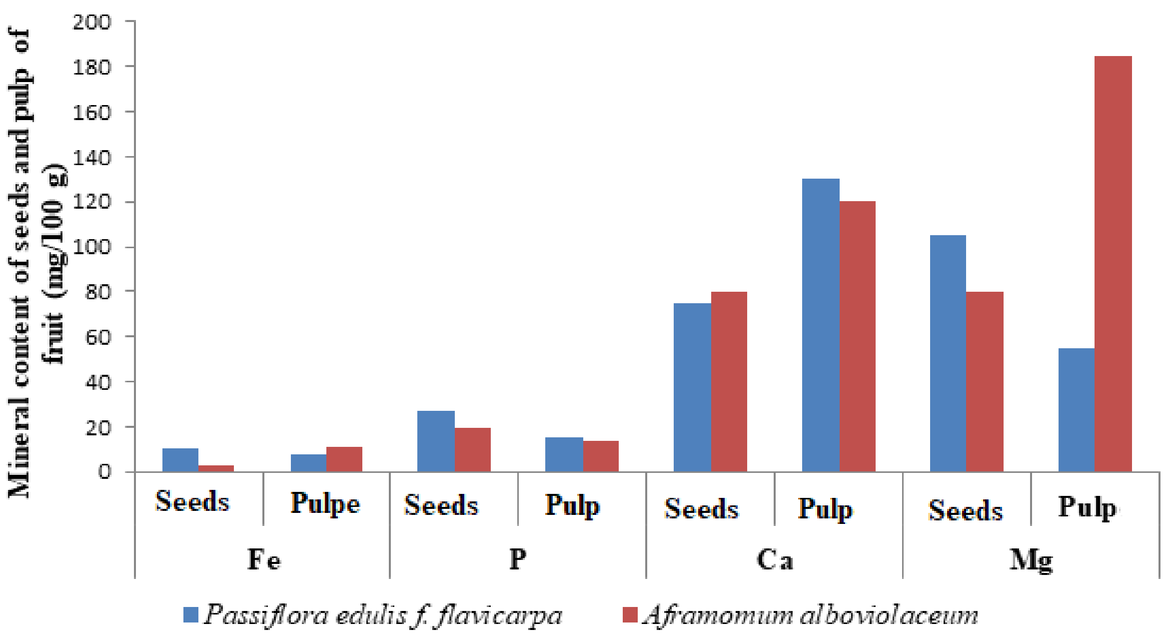

Figure 3. Mineral composition of seeds and pulp of *Passiflora edulis f. flavicarpa* and *Aframomum alboviolaceum.*

was similar to that obtained by Bireche et al. (2014) in *Citrullus colocynthis* seeds and by El Hachimi et al. (2015) in the seeds of two grenadier varieties. The seeds of *P. edulis f* also presented oil content higher than that obtained both in the seeds of the prickly pear (El Hachimi et al., 2015) and the guava (Bourgeois et al., 1998).

Figure 3 shows the mineral content in the seeds and pulps of *P. edulis, f. flavicarpa* and *A. alboviolaceum*.

Concerning the *P. edulis f. flavicarpa* fruit, iron content (seeds: 10 ± 1.41 mg/100 g and pulp: 8 ± 1.41 mg/100 g), phosphorus (seeds: 27.5 ± 2.12 mg/100 g and pulp: 15.5 ± 0.7 mg/100 g) and magnesium (seeds: 105 ± 21.21 mg/100 g and pulp: 55 ± 7.07 mg/100 g) were higher in the seeds than in the pulp. However, calcium was more abundant in the pulp (130 ± 1.41 mg/100 g) than in the seeds (75 ± 7.07 mg/100 g). The magnesium and iron contents were similar to those found in guava seeds (Bourgeois et al., 1998) which already had values. With regard to the fruit of *A. alboviolaceum*, the analysis of Figure 3 showed, except the phosphorus which was more abundant in the seed (19.5 ± 2.12 mg/100 g) than in the pulp (14 ± 1. 41 mg/100 g), iron (seeds: 3 mg/100 g and pulp: 11 mg/100 g), calcium (seeds: 80 mg/100 g and pulp: 120 mg/100 g) and magnesium (seeds: 80 ± 14.14 mg/100 g and pulp: 185 ± 21.21 mg/100 g) were present in greater quantity in the pulp than in the seeds. These results showed that the seeds of two fruits which were edible, but considered as waste during processing into juice or nectar had very interesting characteristics because of their essential nutrient composition. Thus, they could be valued in the same way as the pulp. These seeds could be used in human food by making flours utilized as a supplement in the formulation of infant flours and in cosmetology by extraction of essential oil.

Conclusion

This study allowed us, on the one hand, to determine the biochemical characteristics of the four (*P. edulis flavicarpa*, *A. alboviolaceum*, *S. comorensis* and *C. cymulosa*) popular edible fruits in the Republic of Congo and, on the other hand, to compare the pulp and seeds of *P. edulis f. flavicarpa* and *A. alboviolaceum*. The four fruits were characterized by a wealth of water and were a significant source of proteins, lipids, ashes and minerals. Nevertheless, *S. comorensis* and *C. cymulosa* presented very low lipid content. The pulp of *S. comorensis* and *C. cymulosa* were characterized by an important content of acidity and reducing sugar. Ashes contained iron, phosphorus, calcium and magnesium. All these mineral elements were in greater quantity in the pulp of *S. comorensis*. The comparative study of the seeds and pulps of *P. edulis f. flavicarpa* and *A. alboviolaceum* showed that the seeds contained higher levels of protein and lipids. The seeds of the passion fruit were rich in iron, calcium and magnesium. However, the values obtained in those of *A. alboviolaceum* were not negligible. These fruits including their seeds could be an important source of nutrients and are valued in the food, pharmaceutical and cosmetic industries. The encouraging results of this study deserve to be further investigated.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Socioeconomic and ecological consequences of Parthenium weed (*Parthenium hysterophorus L.*) in Boset Woreda, Ethiopia

Gadisa Duguma, Daniel Fitamo* and Firew Kebede

Department of Biology, College of Natural and Computational Sciences, Hawassa University, Hawassa, Ethiopia.

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Parthenium weed (*Parthenium hysterophorus* L.), an invasive alien species, has been spreading at alarming rate in Ethiopia, causing biodiversity degradation, yield losses in field and horticultural crops, health problems to human beings and livestock. A study on the socioeconomic and ecological impacts of P. hysterophorus was conducted in five Kebeles (lowest administrative division) of Boset Woreda (District), Ethiopia. Data was collected using Ecological Survey, Semi Structured Interviews, Focus Group Discussion, and Field Observations. 200 quadrats were employed where every plant species found in each quadrat were counted, recorded and identified. Data on informant's perception about the first appearance, infestation levels, agents of dispersal, impact, and cultural management of the Parthenium weed were analyzed using descriptive statistics. Shannon Diversity Index (H′), Species Richness, Evenness, and Jaccard's Similarity Index were executed to evaluate Parthenium's effect on species diversity of the weed flora. 78 Herbaceous plants belonging to 59 genera and 21 families were collected. Poaceae (28.2%) and Asteraceae (16.7%) were the dominant families of weeds observed in the study Kebeles. Digalu and Merko Kebeles had high infestation of *P. hysterophorus* represented by high distribution, abundance, and dominance of the weed, but with corresponding low Richness, H′, and evenness of herbaceous plants. Species Richness of herbaceous flora and abundance of Parthenium weed reveled significant negative association ($P < 0.01$; $R^2 = 0.93$). Most of the informants believed that Parthenium affected crop and livestock production as well as human health. Farmers employed hand weeding, plowing, and manual clearing to manage the weed. For effective use of the weed, Integrated Weed Management approaches are required to check the spread and reduce the adverse impacts.

Key words: Abundance, distribution, diversity, Ethiopia, Herbaceous Vegetation, *Parthenium hysterophorus*, Perception, socioeconomic impacts.

INTRODUCTION

Parthenium weed, *Parthenium hysterophorus* L. (hereafter referred to as Parthenium), belongs to the family Asteraceae, an extremely diverse family with a cosmopolitan distribution (Hundessa and Belachew,

*Corresponding author. E-mail: danielfitamo@gmail.com. Tel: +251-911-996720.

2016; Hundessa et al., 2016). It is described as an annual (Tessema et al., 2010; Khan et al., 2012; Adkins and Shabbir, 2014; Abdulkerim-Ute and Legesse, 2016; Hundessa et al., 2016; Mekonnen, 2017) or, under certain conditions, a short-lived perennial (Adkins and Shabbir, 2014), procumbent (Tessema et al., 2010; Hundessa and Belachew, 2016; Hundessa et al., 2016) or with an erect stem (Tadesse, 2004; Adkins and Shabbir, 2014; Bagachi et al., 2016; Mekonnen, 2017). At maturity, the weed develops several branches in its top half (Tadesse, 2004; Adkins and Shabbir, 2014; Abdulkerim-Ute and Legesse, 2016; Bobo and Abdeta, 2016; Bagachi et al., 2016; Mekonnen, 2017) and becomes a diffused leafy herb with a height of 0.5 to 1.50 m, reaching a maximum of 2 m in good soils (Tessema et al., 2010; Abdulkerim-Ute and Legesse, 2016; Hundessa and Belachew, 2016; Hundessa et al., 2016; Mekonnen, 2017).

Parthenium weed is characterized by deep tap root, pale green leaves and an erect stem that becomes woody gradually (Abdulkerim-Ute and Legesse, 2016; Mekonnen, 2017). The alternately arranged leaves (Tadesse, 2004; Tessema et al., 2010; Bagachi et al., 2016) are simple with stalks (petioles) narrowly winged (Tadesse, 2004) up to 2 cm (Bagachi et al., 2016) or 2.5 cm long (Tadesse, 2004) and form a basal rosette during the early stages of growth (Bagachi et al., 2016; Bobo and Abdeta, 2016). The lower leaves are comparatively large (3 to 30 cm long and 2 to 12 cm wide) (Bagachi et al., 2016) and are strongly dissected (bi-pinnatifid or bi-pinnatisect) (Bagachi et al., 2016; Bobo and Abdeta, 2016) than the leaves on the upper branches (Bagachi et al., 2016). Mature stems are greenish (Tadesse, 2004; Bagachi et al., 2016) and longitudinally grooved (Tadesse, 2004; Bagachi et al., 2016; Royimania et al., 2019), covered in small stiff hairs (hirsute) (Bagachi et al., 2016).

Parthenium, the most obnoxious, allergenic, and environmental pollutant weed (Maszura et al., 2018), which is supposed to have originated in the area surrounding the Gulf of Mexico, Southern USA (Adkins and Shabbir, 2014), West Indies, and Central South America (Bagachi et al., 2016). The aggressive (Maszura et al., 2018) and pernicious weed (Saini et al., 2014) is recognized as one of the top ten worst weeds in the world (Zelalem and Tora, 2019) and has colonized and naturalized in many regions of the world, including Asia, Australia and Africa (Royimani et al., 2018). African countries are at high risk of invasion (Bagachi et al., 2016; Bobo and Abdeta, 2016) and in Africa, Parthenium has become prevalent in the eastern and southern parts of the continent (Royimani et al., 2018).

While *P. hysterophorus* was first documented in Ethiopia in 1968 (Haramaya University, Herbarium) (Lisanework and Sharma, 2013), there is no tangible evidence hitherto concerning its mode of introduction (Tessema et al., 2010; Lisanework and Sharma, 2013). Notwithstanding this, it is supposed that the weed was introduced accidentally as a seed contaminant of food grains imported from overseas where Parthenium occurred on farmlands or during the Ethio-Somalia war in 1976 to 77 by army vehicles (Tessema et al., 2010; Lisanework and Sharma, 2013; Hundessa and Belachew, 2016).

Parthenium is currently spreading at an alarming rate in various parts of Ethiopia (Bobo and Abdeta, 2016; Zelalem and Tora, 2019) mainly following the direction of low slope (Kebede, 2008; Belachew and Tessema, 2015; Hundessa et al., 2016) and waterways (Kebede, 2008; Hundessa et al., 2016). The seeds of the weed are primarily dispersed through transport, agricultural implements (Lisanework and Sharma, 2013; Bobo and Abdeta, 2016; Maszura et al., 2018), crop seeds, wind (Bobo and Abdeta, 2016; Maszura et al., 2018), compost, organic manures (Maszura et al., 2018), flood water, and tire-carried mud of vehicles (Kebede, 2008; Lisanework and Sharma, 2013; Maszura et al., 2018).

Following its introduction into Ethiopia, it dispersed across the whole country within a few years (Tessema et al., 2010). The high germination capacity (Tessema et al., 2010; Abdulkerim-Ute and Legesse, 2016), a high seed production (Tessema et al., 2010; Kilewa and Rashid, 2013; Lisanework and Sharma, 2013; Seta et al., 2013; Saini et al., 2014; Abdulkerim-Ute and Legesse, 2016), an easy distribution mechanism, allelopathic effect on other plants (Tessema et al., 2010; Seta et al., 2013; Abdulkerim-Ute and Legesse. 2016), a short life cycle (Kilewa and Rashid, 2013; Saini et al., 2014; Abdulkerim-Ute and Legesse, 2016), and unpalatability to grazers (Royimania et al., 2019) contributed to the spread of the weed. Likewise, small and light seeds (Kilewa and Rashid, 2013), absence of natural enemy (Lisanework and Sharma, 2013), large viable seed bank (Kilewa and Rashid, 2013; Saini et al., 2014; Abdulkerim-Ute and Legesse, 2016; Royimania et al., 2019), high survival rate and a good adaptation to a wide range of environmental factors (Tessema et al., 2010; Dogra et al., 2011; Kilewa and Rashid, 2013; Saini et al., 2014; Abdulkerim-Ute and Legesse, 2016; Royimania et al., 2019) have been associated with the rapid spread of the weed in Ethiopia.

It aggressively colonizes natural and manmade ecosystems and causes major negative impacts on grassland habitats, open woodlands, riverbanks, flood plains, wildlife parks, open field of settlement areas, and bare areas along road sides (Shiferaw et al., 2018). Consequently, Parthenium causes immeasurable ecological losses each year (Adkins and Shabbir, 2014), through displacement of native flora and fauna as well as the significant decline in local biodiversity (Royimania et al., 2019). On the other hand, Parthenium affects agriculture (crop and livestock production) through its effect on crops and grazing lands. In Ethiopia, the noxious weed species is seriously affecting crop yields (Bajwa et al., 2018) where it has become a grave poser in the cultivation of major crops in eastern part of the country in addition to being a major problem on range and waste lands (Bobo and Abdeta, 2016). Conversely, Parthenium is known to affect animal health, milk and meat production (Shashie, 2007; Hundessa and Belachew, 2016; Royimania et al., 2019). The notorious weed can cause serious allergic reactions (Bobo and Abdeta, 2016; Bajwa et al., 2018), respiratory problems and other health complications (Bajwa et al., 2018) in livestock including eye irritation, skin lesions, anorexia, pruritus, alopecia, dermatitis, diarrhea, mouth ulcers with excessive salivation (Mekonnen, 2017), and sometimes death (Mekonnen, 2017; Birhanu and Khan, 2018) due to rupturing and hemorrhage of internal tissues and organs (Mekonnen, 2017). Besides, the toxins derived from the weed reduce quality of meat, cause tainting in milk, and reduce yields of milk of Goat, Sheep and Cow (Kilewa and Rashid, 2013). Effects of Parthenium are very conspicuous in agricultural ecosystems leading to economic losses to the nation due to reduced crop productivity (Saini et al., 2014). Subsequently, invasion of Parthenium weed in a crop lands may contribute to social and economic instability, causing poverty and food insecurity (Kilewa and Rashid, 2013).

Parthenium clearly poses a major threat to the health of humans (Tamado et al., 2002; Kathiresan et al., 2005; Kumar, 2013; Kilewa and Rashid, 2013; Seta et al., 2013; Zuberi et al., 2014; Hundessa and Belachew, 2016; Maszura et al., 2018). In humans, the weed causes Allergic Respiratory Problems, Mutagenicity (Roy and Shaik, 2013), contact dermatitis (Tessema et al., 2010; Roy and Shaik, 2013; Hundessa and Belachew, 2016), Allergic Rhinitis (Tessema et al., 2010; Kilewa and Rashid, 2013; Hundessa and Belachew, 2016), Asthma, Bronchitis and Dermatitis (Kilewa and Rashid, 2013; Hundessa and Belachew, 2016).

East Shoa, a Zone where the Boset Woreda is located, is one of the areas in Ethiopia with perceptible infestation of the weed (Hundessa and Belachew, 2016; Hundessa et al., 2016). Besides, despite the fact that Parthenium is reckoned to be a culprit to initiate serious damage on crop production, animal husbandry, and biodiversity in Ethiopia, there is still palpable dearth of adequate information concerning the impact of Parthenium weed in the study Woreda. Therefore, this study was conducted to assess the socioeconomic and ecological impact of Parthenium weed in the study area.

METHODOLOGY

Description of the study area

The study area (Boset Woreda/District) lies between 8°24’ to 8°51’North latitude and 39°16’ and 39°50’ East longitude which is located about 125 km south east of the capital, Addis Ababa. It is bounded by Fentale Woreda in the East, Awash River in the West, Arsi Zone in the south and Amhara Region in the north (Figure 1).

The Woreda is divided into 33 Rural Kebeles (the smallest unit of local government) and 9 Urban Kebeles (BWANRO, 2017). Based on the CSA (2007), the total population of the Woreda is estimated to be 142,112. The total area of the Woreda is 1378.4 km^2. The Woreda extends from 1000 up to 2000 m.a.s.l. Notwithstanding this, virtually 90% of the Woreda is below 1500 m.a.s.l. and hence, it predominantly falls within the Kolla (Lowland) Agroclimatic Zone, which is characterized by Warm Climate typical of the Arid and Semi-Arid areas. The Woreda is categorized by hot and dry weather with the annual average temperature in the range of 25 to 37°C and receives an average 700 to 800 mm of rainfall per annum.

The natural vegetation of the study area is principally Savannah Grassland. The vegetation is primarily characterized by Acacia trees with the bushes and shrubs common to the lowlands portion of Ethiopia. Among the important tree species characterizing the area are *Acacia albida (Faidherbia albida), Acacia etbaica, Acacia nilotica, Acacia senegal, Acacia tortilis,* and *Balanites aegyptiaca.* Conversely, *Eucalyptus camaldulensis* is planted around homesteads. The soils of the Woreda is mostly derived from volcanic ash origin, where the major soil types in descending order are Andosols (49.4%), Lithosols (36.1%), Cambisols, Luvisols (11.4%) and Fluvisols (3.1%). A survey of the land in this Woreda (BWANRO, 2017) shows that 26.2% is Arable, 30% Pasture, 15.8% Forest, and the remaining is considered barren, degraded or otherwise unusable. The people of the area practice various income generating activities mainly crop production and animal husbandry. Crop production plays a major role in income generation in the area and cereals such as maize, teff, haricot bean, wheat, barley and sorghum are the major crops grown (BWANRO, 2017).

Data collection

Based on the consultation with the Woreda Agricultural Experts on the severity of the invasion and distribution of Parthenium in the Woreda, and subsequent information collected during reconnaissance survey, 5 Kebeles were selected (Merko and Digalu: High Parthenium Infestation; Sifa, Tiyo, and Bekektu: Moderate Infestation). Subsequently, a study on the distribution, abundance, socioeconomic and ecological consequences as well as people’s awareness/perception of *P. hysterophorus* and cultural management practices employed to deal with the weed was conducted in the five Rural Kebeles of the study Woreda during the main cropping season (July to September) of 2017.

Perception of local people on socioeconomic and ecological effects of Parthenium weeds

A total 110 sample households were randomly selected from the overall of 3751 Households (Table 1) in the 5 Kebeles using Fluid Surveys Team (2014) method. Subsequent to the determination of the number of Households representing each Kebele employing proportional sampling technique (Dale, 2006; Trochim, 2006), the respective informants/farmers were randomly selected in each of the 5 Kebeles. Besides, key informant interviews, Woreda experts (Crop Extension, 4; Human and Veterinary Medicine, 4 each), and development agents/DAs (2 from each Kebele) were purposively selected. Semi structured interview (SSI) was conducted to collect requisite data from all the informants.

Focus Group Discussions (FGD) were conducted with eight selected farmers representing Elders, Women, Literate, Illiterate, Youth, Poor and Rich Farmers, etc. in their respective Kebeles. Direct observations were also made during the study period. The Interview Questions, and Discussion Topics meant for SSI, and FGD, respectively, were translated to Afan Oromo (the Local Language) from English. The cardinal points captured in the above instruments principally include the following: (1) Informants view of the first appearance of the weed in the area (2) whether the

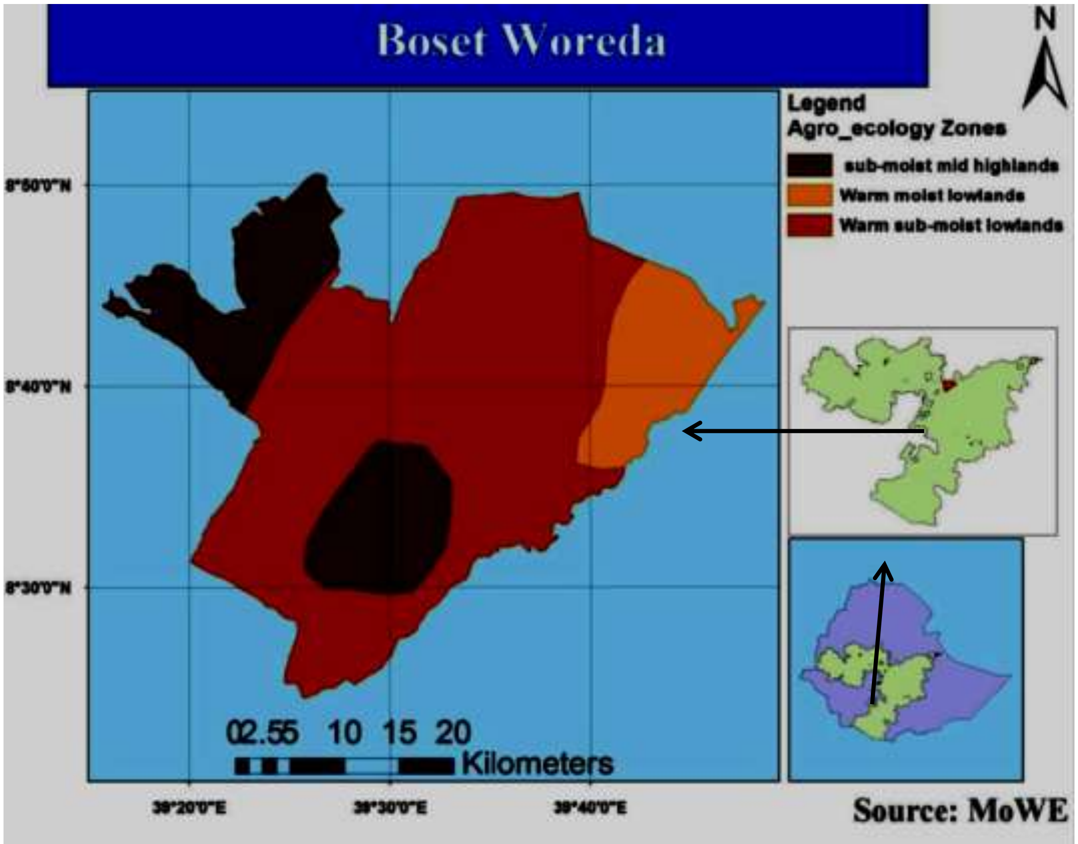

Figure 1. Map of the study area (Boset Woreda). Source: Ministry of Water Resources and Energy, MoWE (2017).

Table 1. Number of Households (HHs) and the selected Farmers (Informants).

Kebele	Total number of households	Number of HHs/informants selected
Sifa	415	12
Tiyo	1702	50
Bekektu	676	20
Digalu	571	17
Merko	387	11
Total	**3751**	**110**

informants knew the agents for the fast spread of the weed in the study area, (3) Informants view on the impacts of the weed (4) the types of measures used so far to control dissemination of the weed in the study area. Finally, the interviewees' responses were collected and analyzed.

Sampling of weed species

Field identification of Parthenium was conducted using plant characteristics thoroughly described in Grierson and Long (2001) and Tiwari et al. (2005). A survey on Parthenium distribution and herbaceous plant species grown in affected areas were carried out in the selected five Kebeles of the Woreda. At each selected Kebele, two parallel transects of each 1 km length and 500 m apart from each other and varying in terms of slope, drainage and soil types (Belachew and Tessema, 2015), and land use were established for plant data collection. In each Kebele, accordingly, herbaceous vegetation data associated with Parthenium were collected from 40 evenly spaced 1 m × 1 m sample quadrats at fifty meter interval. The numbers of plants were recorded per species in each quadrat following Wittenberg et al. (2004). Identification included both local and scientific name of each plant species. Many of weed species collected from the quadrats were identified in the field. For species difficult to identify in the field, voucher specimen were collected, pressed and dried properly and transported to Hawassa University for identification and proper naming. The nomenclature of the plant species followed the flora of Ethiopia and

Eritrea (Hedberg and Edwards, 1995).

Data analysis

Evaluation of within-community diversity

The Species Richness and the Abundance of herbaceous plants (Plant m^{-2}) were determined for each quadrat sampled. Diversity of the species for the vegetation data was analyzed using Shannon Diversity Index (H′) (Shannon and Wiener, 1949) using the following formula:

$$H' = -\sum pi(lnpi)$$

Where H' = Shannon diversity index; Pi = the importance value of the i^{th} species; S = total number of species in the sample quadrat.

$$E = H'/\ln S$$

Where E = Evenness

The evenness of species was calculated as it explains how equally abundant each species would be in the plant community and high evenness is a sign of ecosystem health. The evenness or equitability assumes a value between 0 and 1 with 1 being complete evenness and 0 a single species dominating the area. One Way ANOVA followed by a Post Hoc pairwise comparison (Tukey-HSD test at $\alpha < 0.05$ level) was performed using SPSS 16.0 (SPSS, 2007) in order to identify significant differences ($P < 0.05$) between average values of the Species Richness, Evenness, and Shannon Diversity between the five Kebeles.

Between-community diversity

The similarity of the standing vegetation (herbaceous vegetation layer) among the sample sites in the study area were compared using Jaccard's coefficient of similarity (JCS) (Magurran, 2004). JCS = a /a + b + c, where JSC = Jaccard's Coefficient of Similarity; a = species common to quadrat 1 and 2; b = species present in quadrat 1 but absent in quadrat 2; c = species present in quadrate 2 but absent in 1. The coefficient has a value from 0 to 1, where 1 reveals complete similarity and 0 complete dissimilarity.

Assessment of weed frequency, abundance, density and dominance

Frequency, Abundance, Density (Ramadhan and Amzath, 2013), and Dominance (Taye et al., 1998) was determined as described below:

$$\text{Frequency (\%)} = \frac{\text{Number of Quadrats in which a plant occurred}}{\text{Total number of Quadrats studied}} \times 100$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a plant in all Quadrats}}{\text{Total number of Quadrats in which the plant occurred}}$$

Density = Total number of Quadrats studied

$$\text{Dominance} = \frac{\text{Abundance of a species}}{\text{Total abundance (of all species)}} \times 100$$

RESULTS AND DISCUSSION

Species composition of herbaceous plants in the study *Kebeles*

The Herbaceous plants collected belong to 59 genera and 21 families. The family Poaceae was represented by the highest number of species (22 species), accounting for 28.2%. This was followed by Asteraceae (16.7%), Fabaceae (7.7%), Convolvulaceae (7.7%), and Solanaceae (6.4%), whereas Euphorbiaceae, Polygonaceae and Amaranthaceae constitute 5.1% each (Table 2). It is worth noting that the aforementioned 8 families alone represent the bulk of (82%) herbaceous species documented in the study area. The families were also reported to be economically important and common in different parts of Ethiopia (Firehun and Tamado, 2006; Lisanework and Sharma, 2013). Besides, in agreement with the present study, Poaceae, Asteraceae (Etana et al., 2011; Seta et al., 2013; Ayele et al., 2014; Gebrehiwot and Berhanu, 2015), Fabaceae (Etana et al., 2011), Solanaceae (Etana et al., 2011; Seta et al., 2013), Euphorbiaceae (Seta et al., 2013), and Amaranthaceae (Etana et al., 2011; Seta et al., 2013; Gebrehiwot and Berhanu, 2015) were the most dominant families in terms of number of species in Parthenium affected areas.

Frequency of occurrence, abundance, density and dominance of herbaceous flora

Averaged across all sites, there was considerable variability in the distribution of the weed species in the five Kebeles studied. Accordingly, the frequency of the herbaceous flora ranges from 93% (*Cassia tora*) to 5% (*Ageratum conyzoides, Amaranthus hybridus* and *Bidens pilosa*). Besides, *Argemone mexicana, Cynodon dactylon, Digitaria abyssinica* and *Parthenium hysterophorus* were species with high degree of dispersal with frequency that ranged from 83.5 to 87.5% (Table 3). The distribution of the most frequent weeds mentioned previously, although variable among the 5 Kebeles studied, it is worth noting that *P. hysterophorus* had comparatively lower value in Sifa Kebele (77.5%) but revealed relatively high occurrences, particularly in Digalu (87.5%) and Merko (90%) Kebeles (Figures 2 to 6). In a Parthenium invaded areas, *C. tora* (82%) and *C. dactylon* were commonly reported species (Karaki, 2009). In their review on harmful effect and management of Parthenium, Jayaramaiah et al. (2017) indicated that *C. tora* was one of the plants which was found to compete with *P. hysterophorus* weed since its extract have an allelopathic potential.

As to Banerjee and Srivastava (2010), frequency of an individual species represents its spatial pattern, importance and the evenness of spatial distribution in community as well. Hundessa et al. (2016) reported that Parthenium weed invaded a wide range of environmental

Table 2. Number and proportion of plant species within the eight top diverse families observed in the five Kebeles of the study area.

Family	Number of species	Percent (%)
Poaceae	22	28.2
Asteraceae	13	16.7
Fabaceae	6	7.7
Convolvulaceae	6	7.7
Solanaceae	5	6.4
Euphorbiaceae	4	5.1
Polygonaceae	4	5.1
Amaranthaceae	4	5.1
Total	64	82

Table 3. Frequency, abundance, dominance, and density of herbaceous species averaged over the study Kebeles.

S/N	Scientific name	Local name	Family name	LC	F (%)	A (N^o/m^2)	D (%)	D' ($N\underline{o}/m^2$)
1	*Ageratum conyzoides* L.	Aremagunyato(O)	Asteraceae	A	5	1.2	0.97	0.055
2	*Sorghum arundinacieum (Desv.) Stapf*	Matane(O)	Poaceae	A	16.5	1.23	0.99	0.17
3	*Achyranthes aspera* L.	NF	Amarantaceae	A	6	1.05	0.87	0.09
4	*Sonchus asper (*L.) Hill	NF	Asteraceae	A	8.05	0. 83	0.66	0.135
5	*Agrostis alba L.*	NF	Poaceae	A	6	0.8	0.61	0.06
6	*Solanum nigrum* L.	K'ey-awuti-i(A)	Solanaceae	A	10.5	0.87	0.72	0.115
7	*Amaranthus spinosus* L.	NF	Amaranhaceae	A	11	1.11	0.89	0.13
8	*Solanum incanum* L.	Imbway (A)	Solanaceae	A	8	1.37	1.01	0.1
9	*Amaranthus hybridus* L.	NF	Amaranthacea	A	5	0.87	0.68	0.055
10	*Snowdenia polystachya Fresen*	Muja(A,O)	Poaceae	A	7.5	0.91	0.72	0.085
11	*Amaranthus dubius* Thell.	NF	Amaranthaceae	A	10.5	0.88	0.73	0.115
12	*Sida alba* L.	NF	Malvaceae	P	9	1.1	0.83	0.12
13	*Ambrosia maritime* L.	NF	Asteraceae	A	7.5	1	0.78	0.08
14	*Sida acuta Brum. f.*	NF	Malvaceae	P	7.5	0.95	0.72	0.08
15	*Alternanthera sessilis* (L.) DC	NF	Amaranthaceae	A	26.5	1.27	0.94	0.605
16	*Setaria verticillata (L.) P. Beauv.*	NF	Poaceae	A	7	1.13	0.86	0.11
17	*Anagalis arvensis* L.	Henenur(O)	Primulaceae	A	20	1.28	0.97	0.33
18	*Setaria pumila Michx*	NF	Poaceae	A	7	1.05	0.88	0.08
19	*Argemone Mexicana L.*	Medafe(A)	Papaveraceae	A	87.5	5.27	3.83	4.64
20	*Setaria abyssinica L*	NF	Poaceae	A	11.5	0.92	0.77	0.135
21	*Artemisia arborescens* L.	NF	Asteraceae	A	9.5	1.1	0.87	0.065

Table 3. Contd.

22	*Sonchus oleraceus* L.	NF	Asteraceae	A	8.5	0.8	0.67	0.085
23	*Bidens pilosa L.*	Yeseyit'anmerfe(A)	Asteraceae	A	5	0.6	0.48	0.05
24	*Savignya parviflora (Delile) Webb*	NF	Brassicaceae	A	6.5	1	0.81	0.08
25	*Rumex abyssinicus Jacq.*	Mek'meko(A)	Polygonaceae	A	20.5	1.2	1.1	0.3
26	*Cassia tora L.*	Yefiyel-abish(A)	Fabaceae	A	93	13.49	11.1	12.62
27	*Rhyncossia malacophylla (Spreng.) Boj.*	NF	Fabaceae	A	9	0.82	0.64	0.14
28	*Chloris amentnytea Hochest*	NF	Poaceae	A	14.5	1.15	0.93	0.16
29	*Polygonum salicifolium Brouss ex* Willd.	Gumamila (A)	Polygonaceae	A	14.5	0.92	0.78	0.18
30	*Chenopodium album* L.	Amedmaho(O)	Chenopodiaceae	A	15.5	0.87	0.69	0.17
31	*Phyllanthus amarus Schumach. & Thonn.*	NF	Phyllanthaceae	A	14	0.91	0.7	0.155
32	*Plantago lanceolata* L.	Gort-eb(A)	Plantaginaceae	P	7	1.37	1.1	0.115
33	*Convolvolus arvensis* L.	NF	Convolvulaceae	P	9.5	1.35	1.05	0.13
34	*Pimpinella anisum L.*	NF	Apiaceae	A	10.5	0.83	0.69	0.11
35	*Crotalaria sp.*	NF	Fabaceae	A	18	1.53	1.2	0.52
36	*Parthenium hysterophorus* L.	Fermsisa(O)	Asteraceae	A	83.5	15.72	12.9	13.25
37	*Cyperus rotundus* L.	Kundi(O)	Cyperaceae	A	9	1.62	1.26	0.15
38	*Panicum maximum Jacq.*	Sar(A)	Poaceae	P	29	1.9	1.42	0.67
39	*Cyperus squauiflorus (*Torr) Matiff	NF	Cyperaceae	P	30.5	1.41	1.05	0.68
40	*Oxygonum sinuatum* (Meisn.) Dammer	Rafu hare/Sogdo(O)	Polygonaceae	A	13.5	1.21	0.9	0.185
41	*Cynodon dactylon (L.) Pers.*	Serdo (A)	Poaceae	P	87.5	6.16	4.6	5.41
42	*Oxalis corniculata* L.	NF	Oxalidaceae	P	21	0.91	0.71	0.2
43	*Cynodon nlemfuensis Vanderyst*	NF	Poaceae	P	20	1.13	0.85	0.6
44	*Orobanche minor* Smith	Sete-yejib-ras(A)	Orobanchaceae	A	9.5	1.05	0.81	0.095
45	*Datura innoxia* Mill.	NF	Solanaceae	A	12	0.92	0.72	0.135
46	*Oplismenus hirtellus (L.) P.Beauv.*	NF	Poaceae	P	6.5	0.74	0.6	0.1
47	*Datura stramonium* L.	Manji(O)	Solanaceae	A	8	0.87	0.72	0.085
48	*Nicandra physaloides* (L.) Gaertn*.*	NF	Solanaceae	A	8.5	0.89	0.7	0.095
49	*Desmodium adscendens (*Sw.) DC.	NF	Fabaceae	A	10	0.84	0.67	0.105
50	*Mercurialis annua L.*	NF	Euphorbiaceae	A	11.5	1.1	0.87	0.095
51	*Dinebra retroflexa (Vahl) Panz.*	NF	Poaceae	A	8.5	0.85	0.67	0.09
52	*Mentha arvensis* L.	NF	Labiatae	A	11	1.13	0.85	0.135
53	*Digitaria abyssinica (A.Rich.) Stapf*	Ura(O)	Poaceae	P	85	2.92	2.22	2.5
54	*Matricaria chamomilla* L.	Kamomela(A	Asteraceae	A	11.5	1.02	0.8	0.145
55	*Digitaria horizontalis Willd.*	NF	Poaceae	A	11.5	0.9	0.7	0.13
56	*Leucasmartinicensis* (Jacq) R.Br	Bokuferda(O	Labiatae	A	27.5	0.85	0.67	0.29
57	*Digitaria sanguinalis (L.) Scop.*	NF	Poaceae	A	12	0.87	0.68	0.13
58	*Lantana camara* L.	Yewof kolo	Verbenaceae	P	14	1.47	1.16	0.21

Table 3. Contd.

59	*Digitaria ternata (A.Rich.) Stapf*	Hufe(O)	Poaceae	P	24	1.25	0.98	0.31
60	*Ipomoea hederifolia L.*	NF	Convolvulaceae	A	18.5	1.26	0.97	0.3
61	*Digitaria velutina (Forssk) P, Beauv.*	Shubo(O)	Poaceae	A	19	1.14	0.93	0.235
62	*Ipomoea cordofana* Choisy in DC.	NF	Convolvlaceae	A	23.5	1.36	1.08	0.315
63	*Echinochloa crus-galli (L.) P.Beauv.*	Asandawa(A	Poaceae	A	39	2.01	1.52	0.97
64	*Ipomoea carica* (L) Sweet	NF	Convolvulaceae	A	15.5	1.05	0.84	0.16
65	*Echinochloa colona (L.) Link*	NF	Poaceae	A	16.5	1.35	1.06	0.22
66	*Ipomoea acuminate (*Vahl) Roem and Schultes	NF	Convolvulaceae	A	17.5	1.08	0.87	0.17
67	*Eleusine indica (L.) Gaertn.*	NF	Poaceae	A	10.5	1.15	0.93	0.12
68	*Indigo feraspicata* Forssk.	Ye'ayitmisir (A)	Fabaceae	P	17.5	0.93	0.77	0.205
69	*Eragrostis cilianensis (All.)Vign. ex Janchen*	NF	Poaceae	A	20	1.52	1.16	0.365
70	*Heliotropium cinerascens* DC and ADC	Banganapsi(O)	Boraginaceae	A	15	0.95	0.75	0.18
71	*Eriochloa fatmensis (Hochst. & Steud.) Clayton*	NF	Poaceae	A	15.5	1.22	0.98	0.185
72	*Guizotia scabra(Vis) Chiov.*	NF	Asteraceae	A	20.5	1.93	1.05	0.36
73	*Euphorbia heterophylla L.*	NF	Euphorbiaceae	A	18	1.12	0.9	0.195
74	*Galansoga parviflora Cav.*	Ye shwaarem(A)	Asteraceae	A	27.5	1.34	1.11	0.46
75	*Euphorbia hirta L.*	NF	Euphorbiaceae	A	21.5	1.44	1.12	0.31
76	*Euphorbia thymifolia L.*	NF	Euphorbiaceae	A	23	1.69	1.37	0.34
77	*Euphorbia indica Lam.*	NF	Euphorbiaceae	A	21	1.27	1.01	0.265
78	*Xanthium strumarium L.*	Metene	Asteraceae	A	36	1.83	1.41	0.93

LC = Life Cycle; F = Frequency; A = Abundance; D = Dominance; D' = Density.

habitats. Khan et al. (2013) and Kilewa and Rashid (2013) indicated that invasion and distribution of Parthenium weed could be due to ecological and morphological characteristics of the weed that enable it to adapt a wide climatic and soil conditions, photo insensitivity, and drought tolerance. According to Tessema et al. (2010) and Hundessa et al. (2016), Parthenium grow in different habitats from hot arid and semi-arid low altitude to humid high-mid-altitude (900 to 2500 m). It flourishes on any type of soil (sandy, loamy or clayey) (Tessema et al., 2010) and in different habitats, that is, roadsides, rangelands, crop fields (Tessema et al., 2010; Hundessa et al., 2016), wastelands, villages, gardens (Niguse Hundessa et al., 2016), national park, water ways, bank of rivers, urban green spaces, grasslands, bush lands and forestlands, crop field borders and urban settings (Hundessa et al., 2016) indicating its adaptability to different climate and soil types (Tessema et al., 2010; Hundessa et al., 2016). The noxious weed *P. hysterophorus* expanded in horrible rate in most districts of East Shewa (Hundessa et al., 2016), which is a region where the Study District is located. Conversely, *P. hysterophorus* (15.72) followed by *Cassia tora* (13.49) had the highest average abundance in the study area, while *Bidens pilosa* was a species with the lowest abundance value of 0.6 (Table 3). Apart from this, *Cynodon dactylon* and *Argemone Mexicana* revealed sizable mean abundance (over the Study Area) of 6.16 and 5.27, in that order, with the corresponding higher values observed in Tiyo (10.81 and 10.53, respectively) and Sifa (8.97 and 9.46, respectively) Kebeles. Notably, the *P. hysterophorus* exhibited relatively lower abundance in the aforementioned Kebeles (Tiyo and Sifa). Nkoa et al. (2015) indicated that the weed abundance is associated with density or frequency, and hence, Maszura et al. (2018) suggested density and frequency could influence the abundance positively in their study. Species

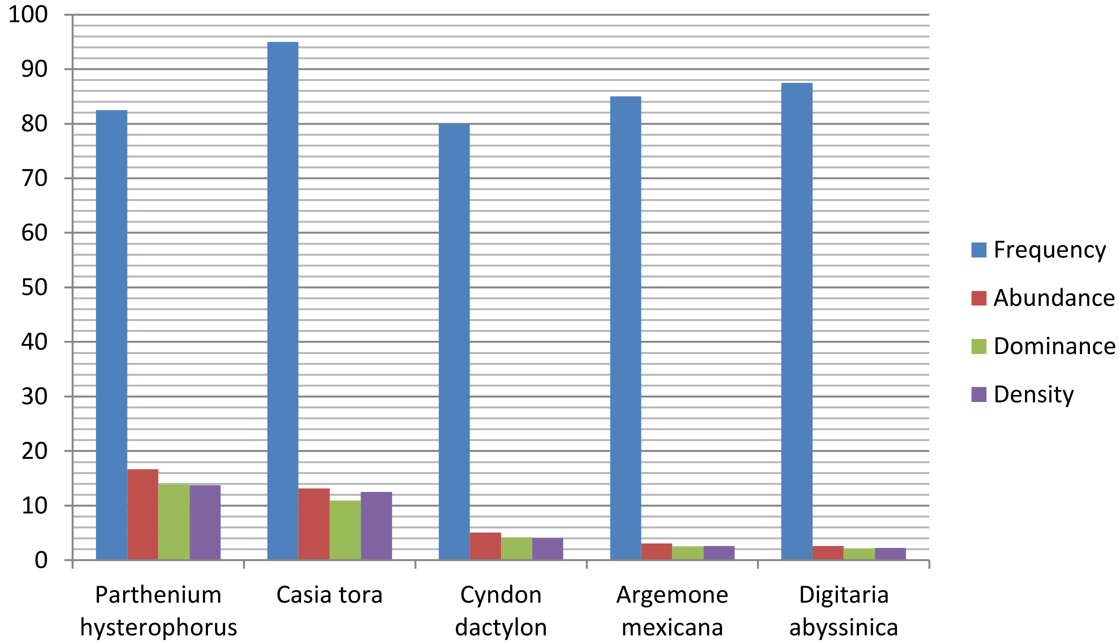

Figure 2. Frequency, abundance and dominance of the top five herbaceous plants identified from Bekektu Kebele.

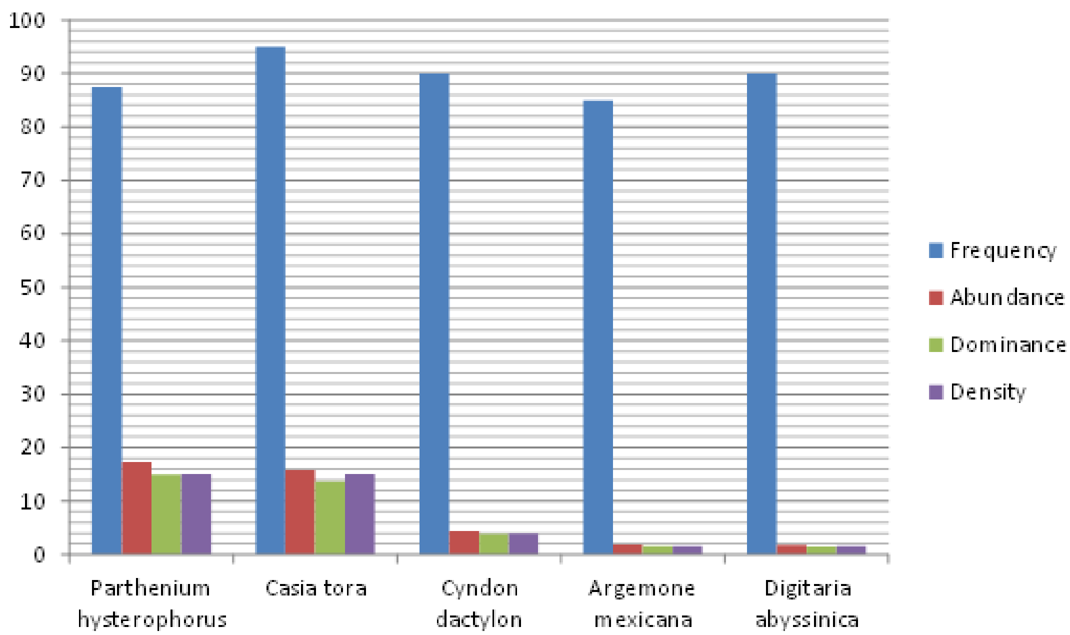

Figure 3. Frequency, abundance and dominance of the top five herbaceous plants identified from Digalu Kebele.

depending on frequency values distribution and abundance can vary both temporally and spatially, and may therefore, differ regionally in response to the species life history, habitat characteristics, resource availability as well as based on natural and anthropogenic disturbances (Banerjee and Srivastava, 2010). Moreover, sound knowledge on species abundance is also requisite for the efficient management of introduced generalist species, which may live in a wide range of environmental conditions (Banerjee and Srivastava, 2010). As in the

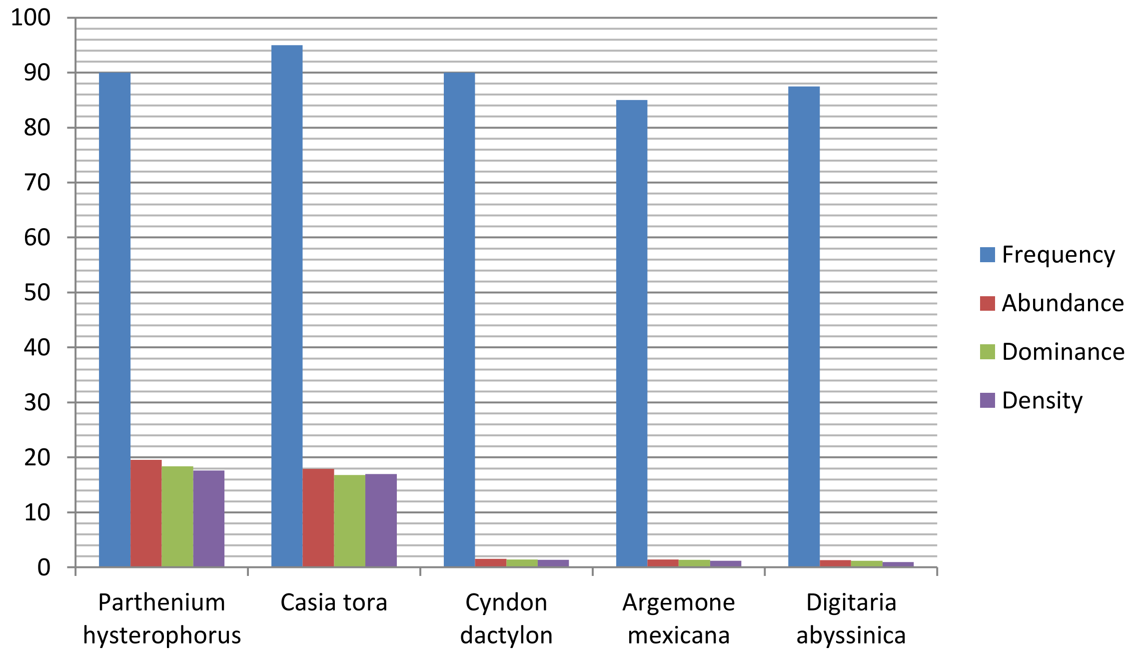

Figure 4. Frequency, abundance and dominance of the top five herbaceous plants identified from Merko Kebele.

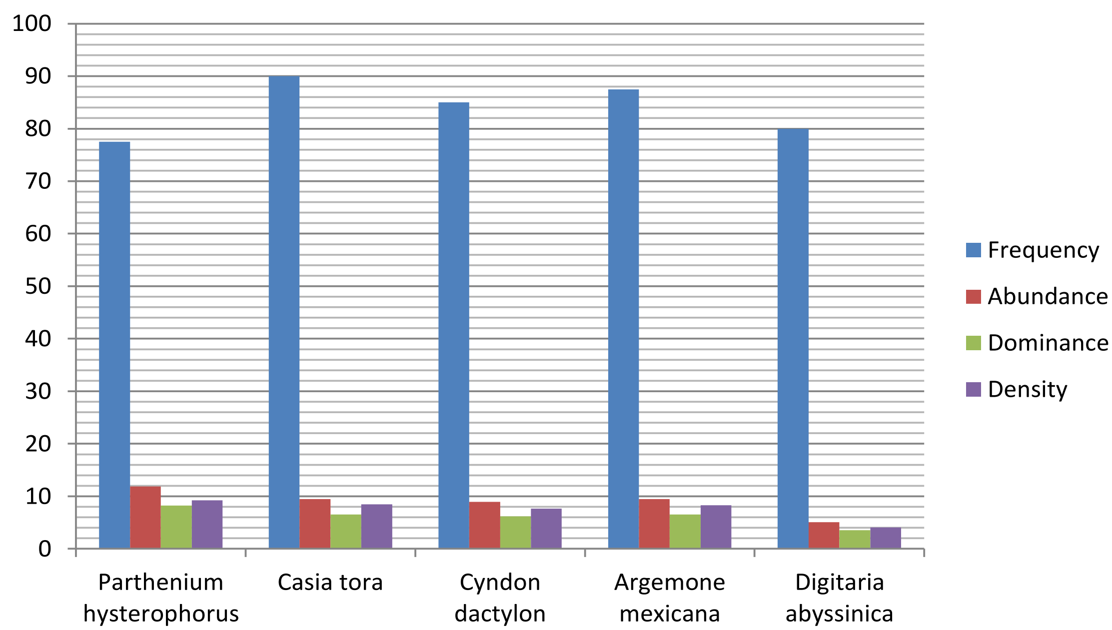

Figure 5. Frequency, abundance and dominance of the top five herbaceous plants identified from Sifa Kebele.

case with abundance, *P. hysterophorus* surpassed the weeds observed in the present study in terms of the average density (13.25) and dominance (12.9). Likewise, *Cassia tora* followed by *Cynodon dactylon*, *Argemone mexicana* and *Digitaria abyssinica* showed relatively higher mean values of density (12.62, 5.41 and 4.64, respectively) and dominance (11.1, 4.6 and 3.83, respectively). As with frequency and abundance, dominance and density of *Parthenium hysterophorus* (as well as other common weeds) varied between the study

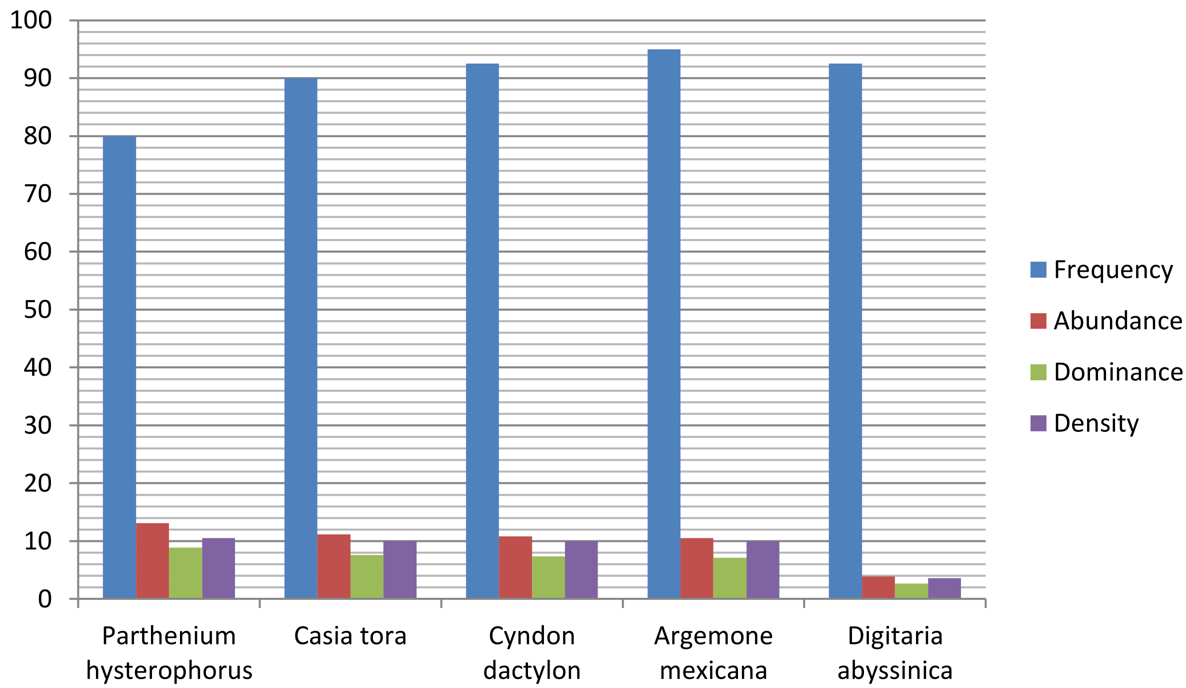

Figure 6. Frequency, abundance and dominance of the top five herbaceous plants identified from Tiyo Kebele.

Kebeles with the highest recorded density and dominance found in Merko (17.63 and 18.37) followed by Digalu (15.12 and 15) and Bekektu (13.75 and 13.85). Density, which measures the strength of species in the community, is considered as one of key important character in determining community structure (Banerjee and Srivastava, 2010). On the other hand, Parthenium is one of the major dominant invader weed (Hundessa et al., 2016). Likewise, Bufebo and Elias (2018) indicated that Parthenium has become the most dominant weed in much of the low lands of Wello (Ethiopia), which agroclimatically correspond to the study area. Moreover, in their study in the Gamo Gofa area, Ethiopia, Gebrehiwot and Berhanu (2015) reported that Parthenium weed was highly dominant species. In a similar vein, Khan et al. (2013) pointed out that in rangelands, and roadsides, dominance of Parthenium weed over other weeds was conspicuous.

On the contrary, Sifa and Tiyo revealed comparatively lower density and dominance of the *P. hysterophorus* in the present study (Figures 2 to 6). Although diverse factors (perhaps the interplay among the factors) could account for the variation in the density of *Parthenium hysterophorus*, the discrepancy in weed densities might be due to natural selection (Maszura et al., 2018). As to the graphs depicting the frequency, abundance, and dominance of the five prevalent weed species across the Kebeles studied, *Cassia tora* had the highest frequency in all except Tiyo (Figures 2 to 6). Apart from this, when averaged over the study area, the selfsame species still maintains high degree of dispersion (average 93%) followed by *Argemone mexicana* (87.5%) and Cynodon dactylon (87%). On the contrary, it is worth noting that *Parthenium hysterophorus* stood out in terms of both abundance and dominance in every kebele (Figures 2 to 6). The closest rival to Parthenium weed in Abundance as well as Dominance is *C. tora*. Besides, *Cynodon dactylon* and *Argemone mexicana*, particularly in Tiyo and Sifa, revealed their relative presence in terms of either abundance or dominance (Figures 2 to 6). The higher frequency, abundance, and dominance values of *C. tora, Argemone mexicana, and Xanthium strumarium* (Figures 2 to 6) suggested that these species can grow in competition with *Parthenium*. The survey conducted in India by Wahab (2005), also showed that species like *C. tora, C. auriculata, H. suaveolens,* and *M. jalapa* suppressed *Parthenium* in natural habitats.

Impact of Parthenium weed on herbaceous species diversity

As is presented in Table 4, Sifa Kebele had the highest total number and average number of herbaceous species which was followed by Tiyo Kebele. In contrast, Merko accommodated the least total number and average number of species (Richness) in the present study. Although the mean Richness of herbaceous species of Sifa exceeds that of Tiyo, the same were statistically comparable ($P > 0.05$). Besides, both Kebeles revealed statistically higher average ($P < 0.05$) Richness of herbaceous species than the other three Kebeles (that is,

Table 4. Mean ± SD of Richness, Evenness, and Shannon diversity of different herbaceous plant species in the 5 Kebeles studied.

Kebele	Number of Quadrats	Total Number of Species	Richness	Evenness	H´
			Mean ± SD	Mean ± SD	Mean ± SD
Bekektu	40	68	50.6±8.09 [a]	0.63±0.06[a]	2.65±0.17 [a]
Digalu	40	67	51.1±8.98 [a]	0.59±0.04[b]	2.47±0.15[b]
Merko	40	65	47.3±9.10 [b]	0.49±0.04[c]	2.07±0.16 [c]
Sifa	40	74	63.3±5.39 [c]	0.70±0.05 [d]	2.99±0.40 [d]
Tiyo	40	70	60.6±4.76 [c]	0.64±0.03 [a]	2.74±0.07 [e]

H´ represents Shannon Diversity Index. Means with different superscript letters are significantly different (P<0.05).

Bekektu, Digalu and Merko). On the other hand, the mean Richness values of Bekektu and Digalu were not statistically different ($P > 0.05$), but both Kebeles had significantly higher average Richness than Merko Kebele (Table 4).

Sifa revealed the highest values for Evenness (E) and Shannon Diversity Index (H') that were significantly different ($P < 0.05$) from the same in other Kebeles (Table 4). In Merko, on contrary, appraisal on Evenness and Diversity showed the lowest mensurations which were significantly different ($P < 0.05$) from the rest. Although Bekektu and Tiyo revealed statistically similar ($P > 0.05$) mean Evenness values, the same had significantly different Shannon Diversity Index (H’). In this regard, it is worth noting that the average Species Richness of Bekektu and Tiyo Kebeles differed significantly, which could have contributed to the significant variation in terms of H’. Conversely, Bekektu and Tiyo Kebeles had Evenness and Shannon Diversity Index that differed significantly ($P < 0.05$) from other Kebeles (Table 4). As Table 4 presents, Digalu and Merko exhibited statistically different ($P < 0.05$) mean E and H' values. The abovementioned results regarding the effect of Parthenium on Diversity parameters are consistent with Qureshi et al. (2018) who reported that Parthenium invasion exhibited variable impacts across districts and invasion status by reducing Species Number per Plot (S), Species Richness (R), Species Evenness (J'), and Shannon Index of Diversity (H'). Similarly, Kumar (2014) noted that there was a sharp decline in the native Biodiversity Index, Evenness and Species Richness over the time, clearly indicating the threat of Parthenium on native biodiversity of other weeds. Besides, Tafese (2015), and Abdulkerim-Ute and Legesse (2016) indicated that Parthenium has the capacity to decrease the composition and diversity of plant species. According to Masum et al. (2013), Teka (2016), and Qureshi et al. (2018), Parthenium weed is known to exert significant impact on the natural communities as they cause their displacement and hence exert imbalance in the natural and agricultural ecosystems. Parthenium weed rapidly invades new surroundings and often replaces the indigenous species and pose a serious threat to biodiversity (Khan et al., 2013). Infestation of Parthenium weed can degrade natural ecosystem because it has a very high invasive capacity and allelopathic properties which has the potential to disrupt any type of natural ecosystem (Kumar, 2014).

Wide environmental adaptability, drought tolerance, photo and thermo-insensitivity (Khan et al., 2013; Qureshi et al., 2018), high seed production (Abdulkerim-Ute and Legesse, 2016; Qureshi et al.,2018), short life cycle (being an annual) (Qureshi et al., 2018), small and light seeds capable of long distance travel via water (Abdulkerim-Ute and Legesse, 2016; Qureshi et al., 2018), wind, birds (Qureshi et al., 2018), animals and vehicles (Abdulkerim-Ute and Legesse, 2016; Qureshi et al., 2018), machinery, stock feed (Abdulkerim-Ute and Legesse, 2016), longevity of seeds in soil seed banks, strong competition and allelopathy contribute to the invasiveness of Parthenium weed (Qureshi et al., 2018).

The impact of Abundance of Parthenium weed on the Species Richness of the five study kebeles is graphically presented in Figure 7. The same figure laid it bare that Species Richness of herbaceous flora and Abundance of Parthenium weed had significant negative association ($P = 0.006$) with the slope (b) = -1.046. Besides, $R^2 = 0.93$, which is the Coefficient of Determination, indicates that 93% of the variation in the Species Richness is explained by the Model ($Y = -1.04644X + 85.2428$) and hence, 93% of the variation in Species Richness is due to the Abundance of Parthenium Weed in the Study Kebeles. Furthermore, the R, which is the square root of the R^2, depicts the Linear Correlation between the Observed and the Model Predicted values of the Species Richness where its large value (that is, $0.93^{1/2} = R = 0.96$) represents strong relationship between them. Moreover, the significance value of the F-Statistic ($P < 0.05$) from the ANOVA test revealed that the variation explained by the model ($Y = –1.04644X + 85.2428$) is not due to chance or it is real. Consequently, there is a strong negative correlation ($P < 0.05$) between the Richness of Herbaceous Flora and the Abundance of Parthenium weed in the study kebeles (Figure 7). In a similar vein, Seta et al. (2013) found that there was a high negative correlation between mean Parthenium Density and Shannon Diversity Index with $R^2 = 0.89$, $p < 0.001$, which portrays the effect of Parthenium on the biodiversity of

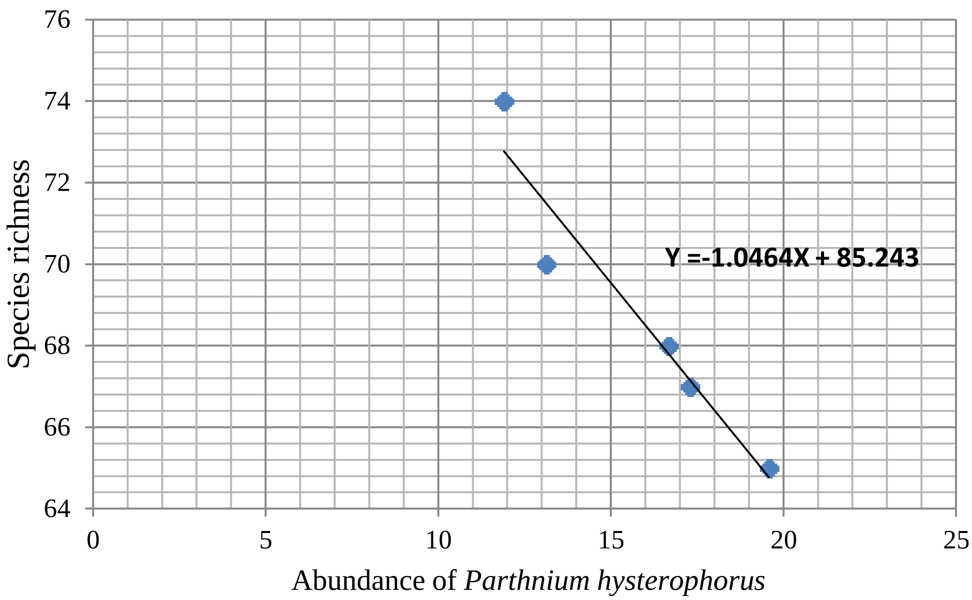

Figure 7. The effect of abundance of Parthenium weeds on species richness of herbaceous flora in the five kebeles of the present study. P = 0.006; R2 =0.93; Slope (b) = -1.046.

Table 5. Jaccard's coefficient of similarity (Similarity Index) of herbaceous plant community in the study Kebeles of Boset Woreda.

	Bekektu	Digalu	Merko	Sifa	Tiyo
Bekektu	1				
Digalu	0.85	1			
Merko	0.80	0.82	1		
Sifa	0.78	0.76	0.72	1	
Tiyo	0.79	0.77	0.75	0.87	1

plants.

Invasive and Alien Species (IAS) can impact Species Diversity, Richness, Composition, Abundance and Interactions (including Mutualisms) (Reaser et al., 2007). Likewise, Shiferaw et al. (2018) indicated that Introduced invasive species could decrease habitat complexity which tends to engender a reduction in abundances and/or species richness (Shiferaw et al., 2018). These processes can eventually cause population declines and resultant species extirpations and extinctions (Reaser et al., 2007). Consequently, Invasive Alien Species (IAPS) pose a global threat to the conservation of biodiversity through their proliferation and spread, displacing or killing native flora and fauna (Shiferaw et al., 2018) and affecting ecosystem services (Bufebo and Elias, 2018; Shiferaw et al., 2018), reducing native species abundance and richness, and decreasing genetic diversity of ecosystems (Bufebo and Elias, 2018).

Similarity in composition of herbaceous species

Similarity index was also calculated as it explains the similarity of plant species composition among different study Kebeles in Boset Woreda. The result showed a similarity index value of 0.72 to 0.87 among the study kebeles (Table 5). The higher (0.87) and lower (0.72) similarities were observed between Sifa/Tiyo and Merko/Sifa, in that order. As indicated by Adane Kebede (2008), if the similarity index is below 60%, it is said that the two locations or soil types have different weed communities. Belachew and Tessema (2015) stated that when the similarity indices for the dissimilar locations exceed 60%, it can be reasoned that the locations display comparable weed community, which hence makes it possible to employ similar weed management decisions/ alternatives.

Socioeconomic impacts of Parthenium weed

Characteristics of respondents involved in the study

Table 6 presents information gathered about respondents regarding their age, sex, educational (for all Informants), work experience, household size, livelihood activities and

Table 6. Characteristics of Informants that participated in the study.

Characteristics of the informants		Farmers		DAs		WEs		Vets		HWs	
		F	%	F	%	F	%	F	%	F	%
Sex	Male	110	100	9	90	4	100	4	100	3	75
	Female	0	0	1	10	0	0	0	0	1	25
Age (years)	18-30	0	0	6	60	1	25	1	25	1	25
	31-40	0	0	2	20	1	25	2	50	3	75
	41-50	0	0	2	20	2	50	1	25	-	-
	51-60	31	28.2	0	0	0	0	0	0	-	-
	61-70	32	29.1	0	0	0	0	0	0	-	-
	71-80	39	35.4	0	0	0	0	0	0	-	-
	>80	8	7.3	0	0	0	0	0	0	-	-
Education	Illiterate	47	42.7	0	0	0	0	0	0	-	-
	Read and write	39	35.5	0	0	0	0	0	0	-	-
	Primary education	18	16.4	0	0	0	0	0	0	-	-
	Secondary education	6	5.4	0	0	0	0	0	0	-	-
	Level Ш	0	0	3	30	0	0	0	0	-	-
	Diploma	0	0	2	20	0	0	1	25	-	-
	B.Sc.	0	0	5	50	4	100	3	75	4	100
Work experience (Years)	1-5	-	-	0	0	0	0	0	0	-	-
	6-10	-	-	0	0	0	0	1	25	1	25
	11-15	-	-	6	60	1	25	1	25	2	50
	16-20	-	-	3	30	1	25	1	25	1	25
	>20	-	-	1	10	2	50	1	25	-	-
Household size (Number)	1-3	35	31.8	-	-	-	-	-	-	-	-
	4-6	55	50.0	-	-	-	-	-	-	-	-
	>6	20	18.2	-	-	-	-	-	-	-	-
Livelihood activities	Farming only	20	18.2	-	-	-	-	-	-	-	-
	Animal husbandry	8	7.3	-	-	-	-	-	-	-	-
	Mixed farming	82	74.5	-	-	-	-	-	-	-	-
Other income sources	Firewood/charcoal selling	14	12.7	-	-	-	-	-	-	-	-
	Petty trade	52	47.3	-	-	-	-	-	-	-	-
	Daily labor work	44	40.0	-	-	-	-	-	-	-	-

DA: Development Agent; WE: Woreda Crop Extension Experts; Vets: Veterinarians; HW: Health Workers.

other income sources (for selected farmers). Most of the study participants were males. While the Farmers were >50 years old, the other respondents (DAs, Woreda Agricultural Experts, Veterinarians, and Health Professionals) were < 50 years of age. Conversely, the educational level of farmers extends from those that were Illiterate up to the secondary educational level whereas the other informants had Level III to B.Sc. (College/University). Education is fundamental to appreciate the newly emerging problems and their impacts and it is reckoned as one of the most crucial factors that impinge on the dissemination and adoption of new technologies (Hundessa and Belachew, 2016).

Although most of the farmers (78.2%) who participated in the present study were illiterate (42.7%) or just can only read and write (35.5), which coincided mainly with age group above 50, they are generally regarded as an important repository of traditional knowledge and wisdom as well as know the area pretty well than their younger counterparts. As to Hundessa and Belachew (2016), Age is essential in the appraisal of the year at which Parthenium was first introduced as well as to examine

Table 7. Informants view on the impacts of *P. hysterophorus* on crop production.

Type of impact	A (F)	A (%)	B (F)	B (%)
Yield reduction	62	56.4	8	80.0
Intensive labor requirements	81	73.6	9	90.0

F = Frequency; A = Number/Percentage of Farmers; B = Number/Percentage of DAs.

and note the differences of the problems and impacts before and after the weed introduction.

Most of the Government employed Respondents garnered over 10 years of experiential knowledge (Table 6). 81.8% of the farmers had a household size < 7, with a size of 4 to 6 accounting for half of the total. On the other hand, most of the farmers (74.5%) made known that they depended on mixed farming for their livelihood, which is quite typical of the farming communities in the rural parts of Ethiopia. Apart from this, the off-farm income is mainly derived from petty trade (43%) and working as daily laborer (40%).

Crop production

Impacts of *Parthenium* weed on crop production: A little more than a half (56.4%) of farmers and 80% of development agents (DAs) considered that the infestation of *Parthenium* weed cause yield reduction (Table 7). In general, the responses of the study participants could have been influenced by the distribution of the weed in the Agricultural Fields. As noted during the field observation, the infestation of Parthenium weed in the cropped area varied from field to field depending on the time of its introduction into the area and the efforts made by the farmers to control the weed with heavy infestation of Parthenium weed was observed along the margins of the field crops. Conversely, the issue of yield reduction proceeding from the Parthenium weed was appreciated by all Woreda Agricultural Experts as well as by most of the participants of the FGD. As to Adkins and Shabbir (2014), Parthenium weed is capable of invading a variety of crops including those cereals which are the major crops cultivated in the study area namely, wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), Tef (*Eragrostis tef* Zucc. Trotter) and sorghum (*Sorghum bicolor* L.). Self-same authors indicated that Parthenium weed has been shown to decrease yields by as much as 40% in India and by as much as 28% in Ethiopia. Apart from this, Masum et al. (2013) pointed out that leaf aqueous extracts of *P. hysterophorus* revealed substantial inhibitory effects on seed germination and seedling growth of three cereal crops, that is, *Oryza sativa, Triticum aestivum* and *Zea mays*; but also three Crucifer vegetables, that is, *Raphanus sativus, Brassica campestris, Brassica oleraceae*, and two Asteraceae species, that is, *Ageratina adenophora* and *Artemisia dubia.* On the other hand, most of the Farmers (73.6%) and DAs (90%) believed that Parthenium impinges on the crop production by way of the intensive labor requirement that is needed to deal with crop fields affected by the weed (Table 7). Likewise, discussants who participated in the FGD and Woreda Agricultural Experts intimated similar issues pertaining labor requirement to the impact of Parthenium on the crop production. Accordingly, most discussants and agricultural experts conceived that Parthenium weed affected crop production by suppressing growth, reducing moisture of the soil, poor grain fill, and ultimately resulting in yield loss.

Several studies (Tamado, 2001; Tamado et al., 2002; Masum et al., 2013; Kumar, 2014; Abdulkerim-Ute and Legesse, 2016; Teka, 2016; Mekonnen, 2017) have indicated about the losses of yield of a variety of crops ascribed to the Parthenium weed. Parthenium weed can infest the land where cereals, vegetables and horticultural crops found and reduce agricultural productivity due to its allelopathic effect (Tefera, 2002; Nihanthan et al., 2013; Abdukerim- Ute and Legesse, 2016; Shikha and Jha, 2016; Shinde, 2016). Field crops: [Maize (*Zea mays* L.), Sorghum (*Sorghum bicolor* L. Moench), Finger Millet (*Eleusine coracan* L. Gaertn.), Cotton (*Gossypium hirsutum* L.), *Haricot Bean* (*Phaseolus vulgaris* L.), Tef (Eragrostis tef Zucc. Trott.], Vegetables [Potato (*Solanum tuberosum* L.), Tomato (*Lycopersicon esculentum* Mill.), Onion (*Allium cepa* L.), Cabbage (*Brassica oleracea* L.), and Carrot (*Daucus carota* L.)], and Orchards [Citrus (*Citrus spp*.), Mango (*Mangifera indica* L.), Papaya (*Carica papaya* L.) and Banana (*Musa spp*.)] were found to be infested by Parthenium (Tessema et al., 2010). Parthenium weed is known to be allelopathic with root and shoot leachates and is capable of reducing growth and germination of numerous crops (Kumar, 2014). Parthenium has Parthenin, Hysterin, Hymenin, and Ambrosin, and attributable to these chemicals, it exerts strong allelopathic effects on different crops (Kaur et al., 2014). Parthenin has been reported as a germination and radical growth inhibitor in a variety of dicot and monocot plants (Kaur et al., 2014).

Crop losses are engendered mainly due to allelopathic effects (Abdulkerim-Ute and Legesse, 2016) and its capacity to compete (Kumar, 2014; Abdulkerim-Ute and Legesse, 2016) for common resources like nutrients and moisture and its competitive nature is relatively very much higher than expected from a similar crop weed (Abdulkerim-Ute and Legesse, 2016). Besides, the effect of Parthenium crop productivity stems from the huge

Table 8. Types of impacts of *P. hysterophorus* on livestock production as perceived by key informants.

Type of impact	Number of farmers	(%)	Number of DAs	(%)
Spoil the quality of milk and meat	62	56.4	6	60
Encroaching grazing lands and suppressing grass species	34	30.9	8	80
Effects on livestock health	55	50	7	70

amount of Pollen it produces (Kaur et al., 2014; Kumar 2014; Teka, 2016), on an average 624 million/plant, which are carried away at least to short distance in clusters of 600 to 800 grains, and settles on the vegetative and floral parts (Kaur et al., 2014), including stigmatic surface of other plants and eventuates in inhibition of fruit or seed setting (Kaur et al., 2014; Kumar, 2014; Abdulkerim-Ute and Legesse, 2016; Teka, 2016) in maize, tomato, beans, and capsicum (Kaur et al., 2014; Kumar, 2014; Teka, 2016).

Livestock production (livestock production and health)

Impacts on animal health: As to the Veterinarians involved in the present study, allergic skin reactions, anorexia, pruritus, dermatitis and diarrhea were the prevalent animal health problems in the study area. Parthenium is poisonous to livestock when it is consumed or repeatedly in contact with the weed (Tafese, 2015). Every plant parts of Parthenium at any stage of growth are toxic to livestock (Mekonnen, 2017). Parthenium toxicity to livestock entails allergic skin reactions (Kumar, 2014; Tafese, 2015), Alopecia (Kaur et al., 2014; Kumar, 2014; Mekonnen, 2017), dermatitis (Knox and Paul, 2013; Masum et al., 2013; Kaur et al., 2014; Kumar, 2014; Tafese, 2015; Mekonnen, 2017), anorexia (Kaur et al., 2014; Kumar, 2014; Tafese, 2015; Mekonnen, 2017), Pruritus (Kaur et al., 2014; Tafese, 2015; Mekonnen, 2017), diarrhea (Kaur et al., 2014; Kumar, 2014; Tafese, 2015; Mekonnen, 2017), become highly emaciated (Knox and Paul, 2013), and death in extreme cases (Knox and Paul, 2013; Kaur et al., 2014; Kumar, 2014; Tafese, 2015) such as due to rupturing and hemorrhaging of internal tissues and organs (Knox and Paul, 2013; Masum et al., 2013; Mekonnen, 2017).

According to the farmers and the discussants involved in the FGD, the animal health impacts of Parthenium prevail mostly during the wet season (Summer). As a rule, seeds of Parthenium can germinate during any season of the year if the moisture is available (Abdulkerim-Ute and Legesse, 2016). Saving the high moisture requirement during germination, there are no observable climatic conditions that could restrain the germination of Parthenium in Ethiopia (Tamado et al., 2002). Consequently, the moisture stress may be the key factor that may restrict the germination Parthenium seeds during the dry season (Abdulkerim-Ute and Legesse, 2016).

Impacts on livestock production: 56.4 and 60% of the farmers and DAs, respectively, expressed their feeling that the Parthenium weed could spoil the quality of Milk and Meat. Besides, virtually a third of informant farmers (30.9%) and 80% of the development agents observed that the weed has already colonized grazing fields, thus causing fodder/feed scarcity. Moreover, sizable proportion of the selfsame informants made known that the notorious weed may affect the livestock production through its effect on livestock health (Table 8). On the other hand, the Woreda Agricultural Experts revealed that *Parthenium* weed, due to infestation of the different land uses, could reduce livestock production by way of the toxic chemicals it releases (that inhibits the germination and growth of plants including pasture grasses and affects the health of the stock), reducing stock growth or by inflicting mechanical damage.

According to 30% of discussants in the focus group discussion, they have encountered milk having bitter taste at least once. Apart from this, 20% of them are aware of the fact that the weed is infringing the grazing areas, particularly in areas highly affected by the weed. Conversely, it was noted during the field observation that *P. hysterophorus* dominated some of the grazing lands in the most affected Kebeles. The hepatoxic allelochemical *Parthenium* adversely affects animal health, and the quality of milk (taste bitter) and meat (Shashie, 2007; Kaba, 2008). Although Parthenium is usually not grazed by cattle as it is not palatable due to its irritating odor, bad taste and presence of trichomes, stray cattle, however, are often forced to feed on this weed during periods of fodder scarcity, thereby resulting in impairment of both quality and quantity of milk (Kumar, 2014). In general, conversely, goats and sheep have been found browsing the plant (Mekonnen, 2017). However, leaves of Parthenium, whenever eaten, can result in tainted sheep (Masum et al., 2013; Kumar, 2014) and goat meat (Mekonnen, 2017) and make diary milk unpalatable due to its irritating odor (Masum et al., 2013; Kumar, 2014; Mekonnen, 2017). Besides, like the case with cattle, the weed can also reduce milk yield of the caprine animals (Mekonnen, 2017).

Parthenium reduces production of livestock by way of scarcity of animal fodder and through invading pasture lands as well as due to various animal health problems

(Tafese, 2015). Parthenium releases chemicals that inhibit the germination and growth of pasture grasses and other plants, which reduces the species biodiversity (Abdulkerim-Ute and Legesse, 2016), pasture carrying capacity (Abdulkerim-Ute and Legesse, 2016; Teka, 2016), forage productivity (Kumar, 2014; Abdulkerim-Ute and Legesse, 2016; Teka, 2016). Conversely, Adkins and Shabbir (2014) elaborated that Parthenium weed contains a number of potential allelochems which are not only poisonous to livestock, but also can alter the microbial composition of the rumen of the dairy cattle, which consequently can impart bitter taste to the milk and the meat. In line with the present findings, Shashie (2007), Karki (2009), Yadav (2010) and Adkins and Shabbir (2014) reported that Parthenium weed impacted the livestock production by affecting grazing land, animal health, milk and meat quality.

Human health: As to the Woreda Health Experts, health problems that are believed to be associated with Parthenium including allergic and irritating dermatitis and allergic reaction of the respiratory organs, particularly in those areas highly affected by the weed. Besides, the some of the most affected individuals manifest cough, sneezing, rhinitis, and enhanced lacrimal discharge (shedding tears). Conversely, when the issue of possible health impacts related to Parthenium was raised to discussants of the FGD and farmers, some of the discussants and 56% of the latter mentioned that some individuals could develop certain kind of skin allergies (allergic dermatitis), problems in the throat area associated with cough. Moreover, the DAs in the study Kebeles also intimated that they have received complaints from some farmers about health problems (dermatitis) during the weeding season.

Mekonnen (2017) pointed out that every part of Parthenium at any stage of growth is toxic to humans. Besides, when milk from the livestock grazed around Parthenium invaded grazing land could be hazardous to man (Masum et al., 2013). It has been established that Parthenium weed is related to health problems for some people living or working in close proximity to it (Masum et al., 2013). When humans come in contact with this weed, they may develop sensitivity to the plant which may then manifest as an allergy-type response (Kumar, 2014; Masum et al., 2013). The usual Allergens found in the weed are Parthenin, Coronopilin, Tetraneuris and Ambrosin (Kaur et al., 2014).

In human, the pollen grains, air borne pieces of dried plant materials, and roots of Parthenium (Masum et al., 2013; Kaur et al., 2014; Mekonnen, 2017) can cause allergy-type responses like photo-dermatitis (Masum et al., 2013; Tafese, 2015; Mekonnen, 2017), asthma (Tessema et al., 2010; Masum et al., 2013; Kaur et al., 2014; Kumar, 2014; Tafese, 2015; Abdulkerim-Ute and Legesse, 2016; Mekonnen, 2017), skin rashes (Kumar, 2014; Tafese, 2015; Mekonnen, 2017), peeling skin (Tafese, 2015; Mekonnen, 2017), puffy eyes (Tafese, 2015; Abdulkerim-Ute and Legesse, 2016; Mekonnen, 2017), excessive water loss (Tafese, 2015; Mekonnen, 2017), swelling and itching of mouth and nose (Tafese, 2015; Mekonnen, 2017), constant cough (Mekonnen, 2017), Rhinitis (Tessema et al., 2010; Masum et al., 2013; Kaur et al., 2014; Kumar, 2014; Tafese, 2015; Abdulkerim-Ute and Legesse, 2016; Mekonnen, 2017), eczema (Kumar, 2014; Tafese, 2015; Abdulkerim-Ute and Legesse, 2016; Mekonnen, 2017), severe contact dermatitis (Masum et al., 2013; Kaur et al., 2014; Kumar, 2014), allergic Bronchitis (Masum et al., 2013; Kaur et al., 2014; Tafese, 2015), black spots and blisters around eyes (Kumar, 2014; Abdulkerim-Ute and Legesse, 2016), burning rings and blisters over skin (Kumar, 2014; Abdulkerim-Ute and Legesse, 2016). Besides, Tessema et al. (2010) reported that the major allergenic symptoms caused by Parthenium were sneezing, coughing, running noses, itching of eyes and the skin, headaches, stomach ache and fatigue (Tessema et al., 2010). Moreover, Kumar (2014) indicated that Parthenium may induce increased allergic reaction to other plant species (cross sensitivity).

Farmers' perception and management of Parthenium weed

Farmers' perception on the first appearance of the weed

Regarding the time when the weed was introduced to the study area, interviewed key informant farmers varied considerably on their perceptions. However, all the informants knew the local name of the weed as it is called *Feremsisa* which means sign to leave the land. The majority (57.27%) of the informants had the perception that it was introduced to the areas 22 years ago (Table 9). During focus group discussion, significant number of participant farmers elaborated that Parthenium weed was introduced into their area following the Rail Way route from Dire Dawa to Addis Ababa in 1990s. Since then it expanded at alarming rate in all directions mainly following the main road. According to the informants, the weed was spread into the areas through vehicles during road construction and through different means since 1990s. In addition, construction materials had played a significant role for fast rate of dissemination/distribution of the weed. It was also noted that in the focus group discussion those local farmers having awareness about the early introduction of the weed to the area, had better elaboration and perception about the weed than those that perceived its recent introduction to the study area.

In line with this study, Tamado (2001) indicated that Parthenium weed was first reported from Ethiopia in 1988 at Dire Dawa and Hararge, subsequently spreading through the Eastern route of Ethiopia particularly along Dire Dawa-Addis Ababa railroad line. On the other hand, Seta et al. (2013) reported that the first appearance of

Table 9. Year of infestation of *P. hysterophorus* (%) as perceived by key informants (Farmers, n = 110) in the study Kebeles of Boset Woreda.

Year	Frequency	Percent
1991	9	8.2
1996	63	57.3
2001	32	29.1
2006	6	5.4

Table 10. Farmers' (n = 110) view of the first appearance of Parthenium weed in the study area.

Land use type	Frequency	Percent
Grazing land	5	4.5
Roadside	97	88.2
Wasteland	8	7.3

Parthenium in Gedeo Zone (Ethiopia) was observed mainly in specific localities of Dilla town at the beginning of 2001 where donated food grain was stored and temporary station for grain carrying trucks.

Concerning the first appearance of the Parthenium in the study Kebeles, majority of the informant farmers (88.18%) indicated that the weed first came along mainly on the roadsides followed by wasteland and grazing land (Table 10). Likewise, all discussants agreed that the weed was first observed on roadsides. Conversely, the Woreda Agricultural Experts and the DAs elaborated that its first appearance on roadside could be due to transportation of sand and gravels from Parthenium infested area to non-infested area for the purpose of construction and during grading of road verges. When discussants of the FGD were inquired about the possible ways for introduction of the weed such as soil transported from somewhere else to the areas for what so ever reason, a couple of them pointed out that certain vehicles came up loading livestock with some amounts of sands to keep their balance and the trucks might have shed sand in the areas during loading and unloading of the livestock.

In agreement with the present study, Niguse Hundessa et al. (2016), in their study on the Distribution and Abundance of Parthenium in East Shewa and West Arsi Zones of Ethiopia, found that the invasion of Parthenium was first perceived on roadside, which later radiated to different habitats and expanded at alarming rate in all directions. In a similar vein, Seta et al. (2013) also reported that most Parthenium invasion was observed along roadsides of town due to long distance dispersal of the seed by the vehicles and farm implements. The same authors maintained that the weed seeds may have arrived with introduced grain and vehicles that carry the grain.

Informants' perception on infestation levels and agents of weed dispersal

In congruence with the case with the first appearance of the weed, 96.43 and 86.59% of the informant farmers in high (Digalu and Merko) and moderate (Bekektu, Sifa, and Tiyo) infested Kebeles, respectively, perceived that Parthenium weed to be denser along the roadsides followed by Wastelands. Likewise, all Development Agents from both infestation levels recognized that dense infestations, principally on roadsides, but in the wastelands as well. Conversely, the farmers and DAs made known that cultivated lands, grazing lands, and river banks were land uses that were also considerably infested by Parthenium (Table 11). Corresponding information acquired from FGD also depicted that roadsides and wastelands support dense Parthenium vegetation. In addition, the Woreda Agricultural Experts clearly indicated that barren lands, roadsides, fallow farmlands, and grazing lands were highly invaded, especially in high infestation Kebeles. Apart from this, during direct field observation, it was noted that Parthenium weed population was high in places where the soils were disturbed constantly for purposes of construction of road and hence the weed prevailed along the roadsides, rangelands, as well as on wastelands. This observation is in line with reports from Masum et al. (2013), and Kassa (2016), who reported that *Parthenium* can adjust heavily to disturbed and barren or uncultivated lands from their study areas. Besides, Seta et al. (2013) reported that the Farmers placed Parthenium first attributable to its high spread and invasion observed on roadsides and margin of farmlands. Tessema et al. (2010) noted that, Parthenium was observed to thrive on roadsides, vacant sites, towns, villages, gardens,

Table 11. Informants' perception on the dispersal status of *Parthenium.*

Abundance of *Parthenium* weed in different habitats	Infestation level							
	High				Moderate			
	A (F)	A (%)	B (F)	B (%)	A (F)	A (%)	B (F)	B (%)
Grazing land	19	67.86	2	50	51	62.20	3	50
Cultivated land	22	78.57	2	50	61	74.39	4	66.67
Roadside	27	96.43	4	100	71	86.59	6	100
Wasteland	25	89.29	3	75	69	84.15	6	100
River banks	17	60.71	2	50	44	53.66	2	33.33

High infestation level: Kebeles = Digalu and Merko; = Number of Farmers = 28; and Number of DAs = 4. Moderate infestation level: Kebeles = Bekektu, Sifa, and Tiyo; Number of Farmers = 82; Number of DAs = 6. A = Farmers; B= DAs; F=Frequency.

Table 12. Informants' perception on agents facilitating dispersal of *Parthenium* from place to place.

Agents for the spread of the weed	Infestation level							
	High				Moderate			
	A(F)	A (%)	B (F)	B (%)	A(F)	A %)	B (F)	B (%)
Through fodder	13	46.43	2	50	64	78.05	3	50
Animal movement	19	67.86	2	50	75	91.46	3	50
Transport of construction materials	16	57.14	3	75	72	87.80	5	83.33
Seed	18	64.29	3	75	73	89.02	4	66.67
Wind	21	75	3	75	76	92.68	5	83.33
Flood	27	96.43	4	100	77	93.90	6	100

waterways, grasslands and in crop fields both during the crop season and after harvest so long as enough moisture is available.

Table 12 reveals that 96.43% of the Farmers from high infestation areas and 92.90% of those from moderate infestation areas responded that flood is the most important means for the fast dissemination of *Parthenium* weed. Apart from this, the farmers also put across that wind, animal movement, seeds (of other crops), and transport of construction materials as agents of dispersal for Parthenium. This response was confirmed by DAs from both infestation levels as well as from the overall consensus reached by discussants over the same issue during the FGD. Furthermore, the agricultural experts elaborated that of the various factors that promote fast distribution of the weed, flooding and transporting of construction materials like sand and soils are the major agents in the study area. In addition, the Woreda Agricultural Experts suggested that the high seed dispersal by the movement of vehicles might have helped the dispersal of the weed thereby contributing to severe infestation and invasion of *Parthenium* weed in the high infestation Kebeles.

On the other hand, the information acquired during the direct field observation also made evident that those spots along the flood course and mostly inundated areas have relatively high infestation compared to other nearby areas. In agreement to the present study, Hundessa and Belachew (2016) reported that the major agents for fast dispersal of *P. hysterophorus* in the East Shoa and West Arsi Zones, Ethiopia, include vehicles (65%), wind (55%), flood (46%), livestock (45%), seeds (41%) and construction materials (28%). Likewise, the study conducted by Kebede (2008) reported that flood and vehicle were the major dispersal agents of the weed. According to Beyene and Tessema (2015), farmers noted that *P. hysterophorus* was disseminated due to the movement of the cattle, by flood, with seeds by the farmers during market exchange and by wind. Seta et al. (2013) found that apart from the extensive dispersal of Parthenium seed which was mainly with introduced grain (food aid), the weed was dispersed by way of vehicle, farm implements, flood and animal movement.

Existing management practices of Parthenium weed

The result of the survey indicated that about 89.1% of the farmers and 90% of the development agents indicated that hand weeding is employed as a predominant cultural method followed by plowing and manual clearing to control the weed in the study Kebeles (Table 13). Besides, 11.8% of the farmers and 30% of the DAs acknowledged about the use of Herbicides to manage

Table 13. Informants' response on the type of measures to control dissemination of *Parthenium* weed.

Method of control of *Parthenium* weed	Farmer		DAs	
	Frequency	%	Frequency	%
Hand weeding	98	89.1	9	90
Oxen plowing	74	67.3	6	60
Manual/mechanical clearing	65	59.1	5	50
Herbicides	13	11.8	3	30

Parthenium weed. It is worth noting that literally no farmer is willing to spare the meager resource he has to be spent on purchasing herbicide/s exclusively meant for dealing with Parthenium. Notwithstanding, acting on the advice of the DAs and Woreda agricultural experts, some farmers have utilized those Herbicides (e.g., 2-4D) on cereals (e.g., Teff and maize) to control the broad-leaved plants/dicots, which could also contain Parthenium. Likewise, Agricultural Experts of the Woreda explained that *Parthenium* removal in Farmlands is mostly done by hand weeding; however, it is not feasible to carry out hand weeding for infested pastures and wastelands of wider coverage. On the other hand, the agricultural experts indicated that hand weeding and/or hoeing is not a permanent solution to control the invasions as the weed multiplies itself in the next crop season.

During the FGD, discussants indicated that traditional methods often employed in the study area to contend with Parthenium weed were hand weeding and plowing where most of them plow their plots three times before sowing. Despite their effort, however, they still reckon that the cultural methods happened to be not always effective as the same could not stop the spread of the weed over time and space in the study area.

Various methods, namely physical, chemical, bio-herbicidal, and integrated, are being practiced to manage Parthenium weed across the globe (Kaur et al., 2014). In agreement with the present study, Hundessa and Belachew (2016) found that tillage and hand weeding were the most practiced control methods used against Parthenium. Likewise, farmers in Parthenium infested areas of Ethiopia often try to maintain their lands free of the weed through hand hoeing, hand weeding (Tessema et al., 2010; Seta et al., 2013; Beyene and Tessema, 2015; Mekonnen, 2017), herbicides (Hundessa and Belachew, 2016), burning (Seta et al., 2013; Beyene and Tessema, 2015), intensive cultivation, and inter-cropping (Tessema et al., 2010),

In croplands, Mekonnen (2017) suggested that hand hoeing and weeding before the plant blooms should be done, which should be repeated 3 to 4 times in a season to check for all the flushes. Kaur et al. (2014) also stated that manual uprooting of Parthenium before flowering and seed setting is the most effective method; uprooting the weed after seed setting will increase the area of infestation. Besides, such physical control like hand weeding involves a time consuming and unpleasant job, made worse by the health hazards involved with handling Parthenium weed (Kaur et al., 2014). Moreover, chemical control is conceived to involve a number of negative impacts including its high cost in vast area, possible negative impacts upon human and animal health, and environment as well as resource poor farmers of Ethiopia may not afford the purchase of herbicides (Mekonnen, 2017). As to Tamado and Milberg (2004), no single method of control of *P. hysterophorus* has proved satisfactory as each method suffers from one or more limitations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Genotype-by-environment interaction and stability analysis of soybean genotypes for yield and yield components across two locations in Nigeria

Jandong, E. A.[1*], Uguru, M. I.[2] and Okechukwu, E. C.[2]

[1]Department of Agronomy, Faculty of Agriculture, Taraba State University, P. M. B. 1167, Jalingo, Nigeria.
[2]Department of Crop Science, Faculty of Agriculture, University of Nigeria, Nsukka, Nigeria.

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A multilocational evaluation of 20 soybean genotypes was conducted in two distinct locations (Nsukka in Derived Savanna agro-ecology and Jalingo in Northern Guinea Savanna) of Nigeria in 2015 and 2016 cropping seasons. The experiments were laid out in an Alpha lattice design and replicated three times in each location. The main objective of the research was to determine the genotype-by-environment interaction (G x E) for specific traits and yield stability. The results revealed highly significant differences among the genotypes and locations for all the traits except for seed yield. Genotype x environmental interaction was not significant for most of the traits except days to 50% flowering indicating relative consistency in time of flowering among the genotypes across the locations and year. The genotype, *Ashuku* produced the highest yield in the two locations. However, the most stable genotypes across the locations were *Dadinkowa* and *Vom* while the ideal environments were Jalingo 2016 (ENV2) and Nsukka 2016 (ENV4) which produced 14.0g and14.5g, respectively. Similarly, Akwanga was discriminated as the overall best genotype across the two locations.

Key words: Genotype, adapted, biplot, environment, yield stability.

INTRODUCTION

The use of stable genotypes over several environments for high yield and quality characteristics is important for many crops. When genotypes are tried in terms of seed yield in multilocational experiments, great differences are commonly observed in yield performance over the environments. This differential yield response of genotypes from one environment to another is called genotype x environment (G x E) interaction (Jose et al., 2017). The G x E interactions is of major importance to the plant breeder in developing improved varieties and the introduction of new cultivar (Yan and Kang, 2003).

The ability of the genotype to demonstrate stability over a wide range of environment and its ability to yield well relative to the productive potential of a test environment is referred to as agronomic stability. Any genotype that demonstrates consistency of performance or slight variation across environment is said to show general adaptation (Ojo et al., 2006). In a breeding programme,

*Corresponding author. E-mail: elias.jandong@gmail.com.

genotype x environment interaction effects is of special interest for identifying adaptation targets, adaptive traits and test sides.

The stability of seed yield in different crops has been statistically evaluated through analysis of G x E interaction in genotype-adaptation trails over several environments. The effective identification of superior genotypes is generally complicated by the presence of G x E interactions whereby genotype relative yields vary across different environments due to different factors. A specific genotype does not always exhibit the same phenotypic characteristics under all environments and different genotypes respond differently to a specific environment.

Soybean (*Glycine max* (L). Merrill) designated as the “miracle bean” has established its potential as an industrially vital and viable oil seed crop in Nigeria. Interest in soybean production in Nigeria has increased considerably as it has the ability to fix high amount of nitrogen, thereby permitting farmers to use less fertilizer and reduce farm cost (IITA, 2014). To satisfy the demand by producers and consumers, soybean production needs to be extended to other parts of the country that were otherwise considered unsuitable or marginal for its production (Aseigbu and Okpara, 2002). This wide agro-ecological variability is the major challenge for field crops resulting in high genotype x environment interaction (GEI) effect. Identification of yield contributing traits and knowledge of GE interactions and yield stability are important for breeding new cultivars with improved adaptation to the environmental constraints prevailing in the target environments. To avoid genetic vulnerability associated with the narrowing of the genetic base of any crop, the GE interactions of the germplasm are important. Therefore, the objectives of this study are to determine the magnitude of G x E interactions and stability of some local cultivars and elite soybean genotypes and thereby identify widely and/or specifically adapted genotypes under Nigerian conditions.

MATERIALS AND METHODS

The multilocational evaluation trail was carried out in 2015 and 2016 cropping seasons in two different locations: The Teaching and Research Farm, Department of Crop Science, University of Nigeria, Nsukka (Lat.06o 521N and Long.07o 241E) and the Teaching and Research Farm, Department of Agronomy, Taraba State University, Jalingo (Lat.08o 541N and Long. 11o 221E). Twenty (20) soybean genotypes comprising of fifteen (15) farmers’ cultivars and five (5) improved varieties were obtained from farmers in some soybean growing states of Nigeria and the International Institute for Tropical Agriculture (IITA), Ibadan, respectively for the research.

Experimental design

The experimental design was Alpha lattice design (Patterson and Williams, 1976), which was used for the multi-location experiment. There were 10 columns and two rows per super block replicated three times and the 20 soybean genotypes were randomly assigned to each super block. Each plot or column measured 1.5 × 1 m and seeds were sown at the spacing of 15 cm between stands and 30 cm between rows, resulting in 7 plants per row and 35 plants per plot (column). Five plants were randomly selected from the two middle rows for data collection at the maturity stage on the agronomic and yield characters.

Statistical analysis

Analysis of variance (ANOVA) statistics using general linear model (GLM G x E) of SAS version 9.5 with 5% level of significance were used. The data collected were subjected to analysis of variance and GE biplot methodology as prescribed by Marjanovic-Jeromela et al. (2011). This methodology uses a biplot to show the factors (G and GE) that are important in genotype evaluation and that are also the sources of variation in GEI analysis of yield data.

RESULTS

The experimental sites differed in altitude; rainfall, mean temperature, relative humidity and soil texture (Table 1). Nsukka is located in the southeastern part of Nigeria while Jalingo is in northeastern part. The amounts of rainfall in 2016 in both locations were higher than those of 2015. In 2016, Nsukka had a mean rainfall of 152.98 mm against 141.04 mm in 2015. Similarly, in 2016, Jalingo had a mean rainfall of 153.94 mm against 149.14 mm in 2015. During the growing seasons, mean monthly temperature was higher in Jalingo when compared to that of Nsukka; however, relative humidity was higher in 2015 than 2016 in both locations. Meanwhile, in 2016, relative humidity was higher in Jalingo (66.41%) than Nsukka (61.76%). Also, the two locations varied in soil type with the soil of Nsukka being sandy clay loam while that of Jalingo is sandy loam.

The combined analysis of variance was performed to determine the effects of year (Y), location (L) and genotype (G) as presented in Table 2. Variance due to genotypes (G) were highly significant ($p<0.01$) for all the traits studied, except for pod weight that was significantly ($p<0.05$) different and seed yield that was not significant. Similarly, location (L) was highly significant ($p<0.01$) for all the traits, except seed yield that was significantly ($p<0.05$) different. However, year (Y) effect was highly significant for all the traits with the exception of days to 50% flowering that was not significant. The Y x L interaction was highly significant ($p<0.01$) for all the traits except days to 50% flowering. The G x Y interaction on the other hand was not significant for most of the traits except for days to 50% flowering which was significant at 5% level of probability. Similarly, the interaction between genotype and location (G x L) affected only days to 50% flowering leaving the rest of the traits unaffected. Also, triple interaction (G x Y x L) was found not significant for all the traits except days to 50% flowering.

Mean quantitative characters of the 20 soybean genotypes across the two locations for the two cropping

Table 1. Agro-ecological characteristics of the experimental sites**.**

Location	Nsukka	Jalingo
Latitude	06°52[1]N	08°54[1]N
Longitude	07°24[1]E	11°22[1]E
Attitude (mas)	447.26	349
Agro-ecozone	Derived savannah	Northern Guinea savannah
Soil texture	Sandy clay loam	Sandy loam
Total rainfall (mm/year)	1393.6	1137.8
Average mean temperature	26.0	28.0
Average RH (%)	66.6	67.6

MASI = meters above sea level; RH = relative humidity.

Table 2. Combined analysis of variance for seed yield and yield components in two years and two locations.

SV	DF	DF1	PH (cm)	NP	PW (g)	SY (g)
Year (Y)	1	39.20	999.36**	63583.17**	9208.25**	4064.80**
Location (L)	1	413.44**	752.11**	7811.29**	686.14**	156.33*
Y x L	1	63.04	1365.84**	2426.98*	516.85**	278.00**
REP (Y,L)	8	11.97	58.16*	747.42*	117.19*	65.47*
Genotype (G)	19	63.54**	240.60**	815.80**	65.73*	29.52
G x Y	19	29.04*	23.37	239.11	23.47	14.09
G x L	19	45.69*	15.61	150.84	36.79	18.62
G x Y x L	19	48.10*	31.66	279.33	37.89	17.13
Error	140	4.17	4.45	15.67	5.67	3.89

*,** = significant at 5 and 1%, respectively, SV = source of variation, DF = degree of freedom, DF1 = days to 50% flowering, pH = plant height, NP = number of pods, PW = pod weight, SY = seed yield, Y = year, L = location, G = genotype.

seasons are presented in Table 3. In this study, some genotypes showed significant ($p<0.05$) variations across the locations. It was observed that days to 50% flowering significantly varied across the locations in genotypes such as Kafanchan, Langtang, TGX1448-2E and TGX1835-10E. Similarly, the genotype, Mararaba varied significantly in height across the locations whereas pod weight and seed yield of TGX1448-2E were significantly ($p<0.05$) different across the locations recording 12.81 ± 22.35 and 8.13 ± 14.59, respectively. However, all the genotypes either demonstrated small variation or consistency in number of pods and 100 seed weight per genotype.

The mean seed yield value of genotypes averaged over environments (Table 4) indicated that the genotypes "*Ashuku*" and "*Akwanga*" had the highest and lowest seed yield of 13.0 and 8.5 g, respectively. The environments mean seed yield ranged from 4.1 g (ENV3) to 14.5 g (ENV4) and averaged seed yield over environments and genotypes is 10.1 g. ENV 4 and ENV2 showed the most favorable performance for seed yield (14.5 and 14.0 g, respectively) and are rich environments. ENV3 and ENV1 were unfavorable since they presented the lowest mean for seed yield (4.1 and 7.9 g, respectively).

For easy understanding, a biplot was drawn (Figure 1) where aspect of both genotypes and environments were plotted on the axis so that the inter relationship can be visualized. The vertical line in the middle of the biplot represents the grand mean. Genotypes and environments on the right side of this line has higher yield than those of left hand side. Consequently, TGX1987-10F, Akwanga, Kafanchan, Lau, TGX1448-2E, Andaha, TGX1987-62F, Tiv local, Mararaba and Kagoro by being on the right side of the biplot, constitute the most to least yield mean, respectively. However, Akwanga, Lau and Kagoro generally exhibited high yield with high mean (additive) genotype, Akwanga being the overall best. Other genotypes showed below average yield. Agbonkagoro was moderately stable across the environments but below average yield.

DISCUSSION

The result showed that, both the genotypes and the environmental conditions had significant influence on the yield and yield components performance of the soybean.

Table 3. Mean quantities characters of 20 soybean genotypes from two locations.

Genotype	DF (50%)	PH (cm)	NP	PW (g)	SY (g)	100 seed weigh (g)
	NSK/JAL	NSK/JAL	NSK/JAL	NSK/JAL	NSK/JAL	NSK/JAL
Agbon kagoro	43.17±45.67	25.42±29.84	35.66±37.29	12.33±12.33	8.10±7.08	12.50±14.00
Akwanga	42.14±44.64	29.10±33.21	54.69±63.55	20.09±25.02	12.44±16.58	14.00±13.50
Andaha	44.90±46.90	29.79±32.12	44.67±53.87	14.84±21.34	8.57±13.65	12.00±12.00
Ashuku	43.97±44.81	32.65±39.25	63.99±79.92	22.09±27.89	14.21±18.88	13.00±13.50
Dadinkowa	45.28±46.28	29.63±31.87	38.43±40.36	12.13±16.03	8.07±10.32	14.00±13.00
Garkawa	42.00±45.00	33.32±37.06	48.29±59.06	15.93±19.70	10.78±13.50	14.00±13.00
Gwantu	43.97±44.47	30.10±34.56	46.09±56.22	16.22±20.72	10.98±13.61	12.00±13.00
Kafanchan	42.48*±48.32*	30.18±31.76	43.62±54.18	14.24±21.54	9.37±14.56	13.50±12.00
Kagoro	43.44±44.61	31.67±37.63	52.70±57.76	15.56±19.46	11.43±13.59	9.50±14.50
Langtang	46.44*±50.28*	29.13±32.30	50.43±55.96	21.90±24.46	14.50±16.48	11.50±12.50
Lau	50.51±52.01	30.56±37.03	57.20±74.84	20.57±25.37	12.54±16.89	10.50±13.00
Mangu	42.47±44.64	34.18±38.35	60.45±67.42	22.62±25.46	14.20±16.85	14.50±14.00
Mararaba	45.44±46.61	30.27*±38.00*	49.16±59.96	14.56±18.86	9.70±13.45	13.50±13.00
TGX1485-ID	38.73±40.37	31.82±30.32	53.07±51.43	19.68±20.54	12.21±12.95	14.00±14.00
TGX1448-2E	40.37*±44.37*	34.94±38.67	47.28±72.08	12.81*±22.35*	8.13*±14.59*	14.50±13.50
TGX1987-10F	41.57±43.71	31.52±34.35	38.83±54.20	17.98±23.11	10.51±15.41	15.50±15.00
TGX1835-10E	39.21*±43.71*	31.44±33.01	41.68±47.28	14.88±17.41	10.80±11.59	13.00±14.50
TGX1987-62F	47.87±48.64	35.94±41.83	42.44±65.65	13.45±21.74	8.50±14.97	12.00±13.00
Tiv local	41.23±42.73	33.29±36.22	50.77±68.30	18.18±24.78	11.44±16.65	15.00±13.00
Vom	56.07±54.73	49.85±53.35	76.20±86.77	21.98±23.18	12.47±14.68	9.50±11.00
LSD(0.05)	3.83	6.69	24.90	9.27	6.35	5.70

DF = days to 50% flowering, PH = plant height, NP = number of pods, PW = pod weight, SY = seed yield, NSK = Nsukka, JAL= Jalingo.

Table 4. Mean soybean seed yield evaluated in four environments.

	Environment				
Genotype	ENV 1	ENV 2	ENV 3	ENV 4	Mean
ANDAHA	5.5	11.5	2.4	5.0	6.1
AGBON KAGORO	**11.9**	13.4	3.4	**19.6**	12.1
AKWANGA	5.1	10.5	3.9	14.5	8.5
ASHUKU	9.8	19.0	4.4	18.6	13.0
DADINKOWA	6.9	10.9	4.2	12.3	8.6
GARKAWA	4.9	17.4	3.5	10.9	9.2
GWANTU	6.5	14.9	3.7	12.1	9.3
KAFACHAN	7.3	11.9	3.2	17.7	10.0
KAGORO	10.5	14.0	4.6	15.7	11.2
LANGTANG	7.3	**23.3**	4.3	12.2	11.8
LAU	10.7	13.6	4.1	18.0	11.6
MANGU	**11.9**	16.9	4.4	16.7	12.5
MARARABA	7.3	13.7	4.1	15.7	10.2
TGX1485-1D	3.4	12.5	5.1	17.0	9.5
TGX1835-10E	10.9	11.9	4.0	11.7	9.6
TGX1987 -10F	7.2	14.0	3.9	9.5	8.7
TGX1448-2E	6.8	12.6	4.9	15.9	10.1
TGX1987-62F	5.8	10.8	4.7	17.4	9.7
TIV LOCAL	7.1	14.1	**6.1**	16.8	11.0
VOM	10.8	12.5	3.5	12.9	10.0
Mean	7.9	14.0	4.1	14.5	10.1

ENV1 = Jalingo 2015, ENV2 = Jalingo 2015, ENV3 = Nsukka 2016, ENV4 = Nsukka 20.

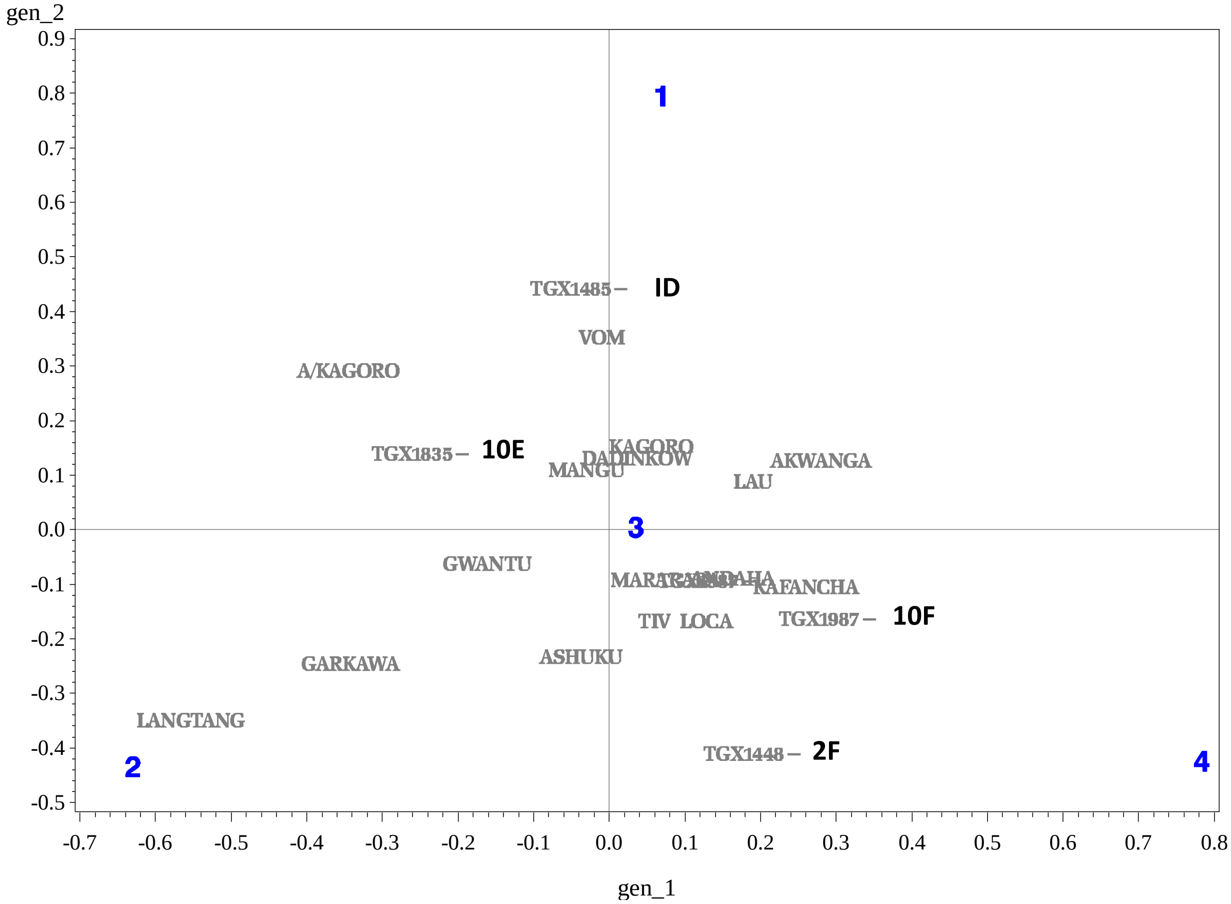

Figure 1. Biplot of G*E interaction: seed yield.

Adugna and Labuschgne (2003) also reported significant variations among locations for days to 50% flowering in linseed. The non-significant variation of GxY,GxL andGxYxL for almost all the traits with the exception of days to 50% flowering implies that in any of the two locations, the same genotype will have the same plant height, number of pods, pod weight and seed yield. The findings are in agreement with the report of Ojo et al. (2010) who recorded non-significance of genotype x year interaction in plant height, number of pods and seed yield in soybean. Highly significant variations were observed for most of the parameters studied among the genotypes across the environments indicating the existence of variability among the soybean genotypes.

The low yield observed in Nsukka location may be as a result of the soil fertility variation indicating that Jalingo is a more potential site for soybean production. This observation is in agreement with the results of previous researchers (Okpara and Ibiam, 2000; Osedeke and Ojeuiyi, 2005) who also reported low grain yield in some soybean genotypes in southeastern Nigeria. Genotypes produced low yield in areas where soil fertility is a limiting factor especially in Nsukka (southeastern Nigeria) which is in humid tropics as compared to Jalingo in northern Guinea savanna. The significant variation in mean pod weight and seed yield demonstrated by TGX1448-2E suggested that the four environments represented sufficient diversity to allow assessment of GE interaction and stability of performance of these traits. However, any genotype that demonstrated consistency in yield or little variation across the environments is said to be generally adapted. In this study, all the genotypes demonstrated little variation in yield and other traits across the two locations with the exception of TGX1448-2E which differed significantly in pod weight and seed yield (Table 3). This consistency or little variation in yield of most of the genotypes across the environments showed general adaptation as observed by Adeseye et al. (2018). Similar findings were obtained by Yan and Tinker (2006); Jose et al. (2017) who reported small variation between two locations in respect to days to flowering in cowpea. The purpose of stability analysis is to identify soybean genotypes with wide geographic adaptation, high agronomic performance and high seed yield (preferably above the overall mean of 10.1g) as observed in this study in heterogeneous environments. The identification

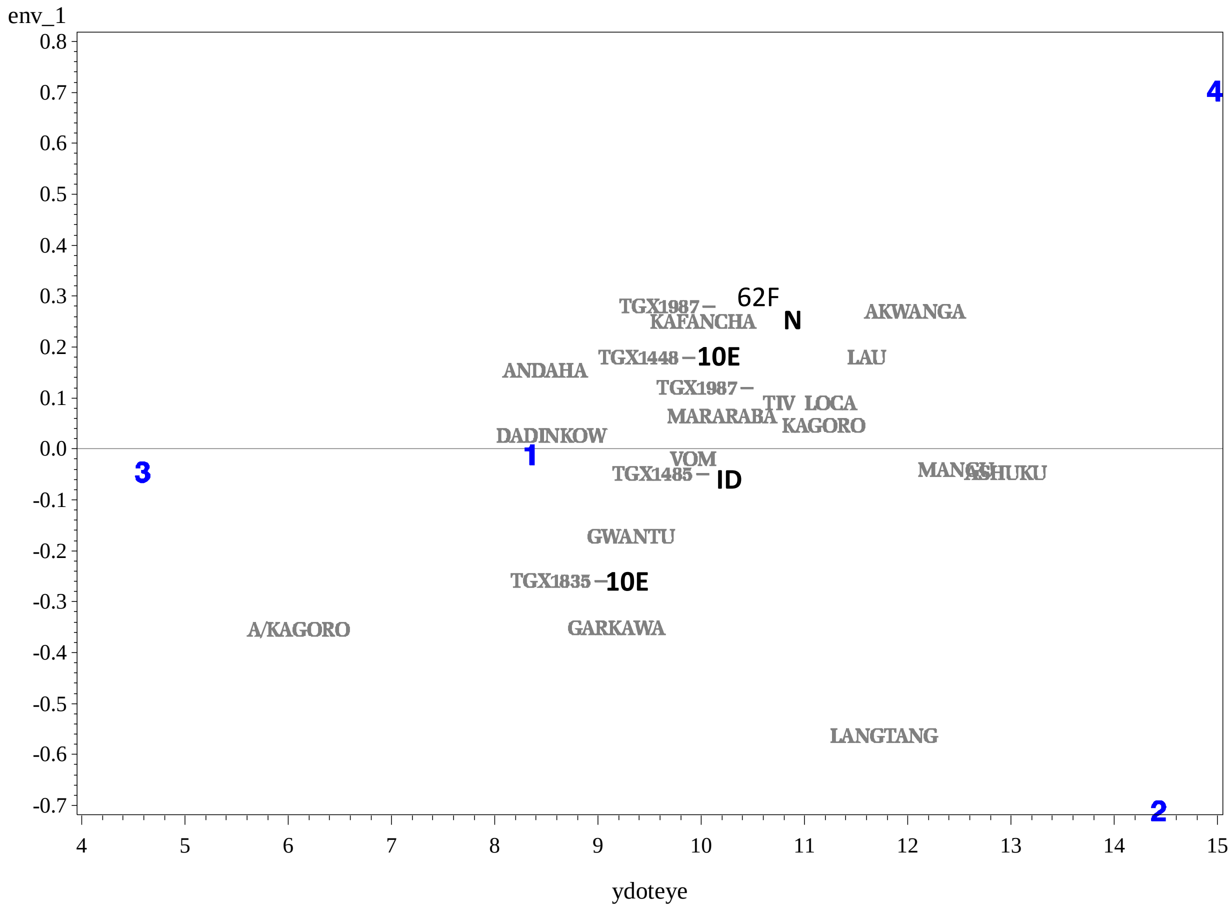

Figure 2. Biplot of first E*Vector vs. Means.

of genotypes with specific adaptations can be extremely useful for more regionalized genotypic recommendations.

The range of values for grain yield suggested that the four environments had different levels of productivity. Based on mean performance of the genotypes, the environments were classified into three mega environments. The first include ENV1 and ENV4 with genotype Akwanga having the highest seed yield and was joined by Mangu only in ENV1. The second mega environment is ENV2 in which Langtang performed the best. The third mega environment is ENV3 with Tiv local as the outstanding genotype. The general mean performance of the genotypes across the two locations revealed that Akwanga is leading by its impressive performance in ENV4 (Table 4) among the environments. The most stable for mean performance of the soybean genotypes in this study is ENV 1 and was closely followed by ENV3. Therefore, the use of GGE in this study have not only identified the most stable genotypes across locations but also is able to identify the locations that optimize the genotypes performance as confirmed by Agyeman et al. (2015).

The differences and genotype distributions in the biplot are a consequence of genotype variations in different environments (Figure 1). This indicates that the two locations and the two seasons had a large impact on yield variation. The clustering of some of the genotypes and their yield average on the biplot also explain their similarities in yield per plant variations (Marjanovic-Jeromela, 2005). In general, environments with scores near zero have little interaction across genotypes and provide low discrimination among the genotypes (Anandan et al., 2009) as seen in ENV 3 in this study. Genotype stability is considered a reaction to changing environmental conditions, which depend on unpredictable variation components (Kang, 2002). In this study, the two agro-ecological zones of the experimental sites were the source of this variation component.

Conclusions and recommendations

Crop yield is a complex trait that is influenced by a number of component characters along with the environment either directly or indirectly. The G x Y, G x L and GxYxL effects were no significant for most of the traits indicating general adaptation of the genotypes across the environments. However, the study is able to identify Akwanga as the highest yielding genotype in ENV1 and ENV4 (Table 4 and Figure 2), stable genotypes and the ideal environments (ENV 2 and ENV 4) across the locations that optimize the genotypes performance.

Conclusion

Crop yield is a complex trait that is influenced by a number of component characters along with the environment either directly or indirectly. The G x Y and G x L effects were no significant for most of the traits indicating general adaptation of the genotypes across the locations. However, the study is able to identify the most stable genotypes and the ideal environments across the locations that optimize the genotypes performance.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Gastrointestinal nematodiasis in Ethiopian sheep under community-based breeding program

Solomon Shiferaw Tufa[1,3], Gábor Mészáros[1], Aynalem Haile[2], Joram Mwacharo[2], Maria Wurzinger[1*] and Johann Sölkner[1]

[1]Division of Livestock Sciences, Department of Sustainable Agricultural Systems, University of Natural Resources and Life Sciences, Vienna, Gregor-Mendel-Str. 33, 1180 Vienna, Austria.
[2]International Center for Agricultural Research in the Dry Areas (ICARDA), P. O. Box 5689, Addis Ababa, Ethiopia.
[3]Department of Animal Science, College of Agriculture and Veterinary Science, Ambo University, P. O. Box 19, Ambo, Ethiopia.

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Gastrointestinal nematodes (GIN) are amongst the main health and production problems in sheep throughout the world. Faecal egg count (FEC) and FAffa MAlan CHArt (FAMACHA) score can be used as indictors to select genetically resistant animals against the infections. This study was undertaken to (1) determine intensity of and the factors associated with GIN infections in Ethiopian sheep under communal breeding program, and (2) examine relationships between the intensity of GIN infection and levels of anaemia related to blood feeding GIN parasites. A total of 1239 FEC and FAMACHA scores were measured on two Ethiopian sheep breeds during rainy and dry seasons. The data were analyzed using the mixed model procedure, accounting for differences in fixed effects of breed, season and their interaction and a random effect of animal. The interaction of breed and season (p < 0.01) influenced the intensity of infections with GIN. There was no significant (p > 0.05) relationship between FEC and FAMACHA scores; hence the latter is not a suitable indicator of infections with GIN in these animals. FEC should be recorded rather than FAMACHA as a nematode resistance trait to be incorporated into the sheep breeding programs of Bonga and Horro, Ethiopia.

Key words: Breeding program, Ethiopia, faecal egg count, FAffa MAlan CHArt (FAMACHA), gastrointestinal nematodes, sheep.

INTRODUCTION

Sheep is an economically important livestock species in Ethiopia (Leta and Mesele, 2014), and is ranked second to cattle by population (Gizaw et al., 2013). However, due to constraints emanating mainly from inadequate genetic and health improvement programs, sheep production and productivity remain low. Several attempts to sheep breeding programs in the country, mainly with a crossbreeding strategy have failed (Duguma, 2010), in part because of lack of participation of sheep farming communities in the breeding programs. Cognizant of this,

*Corresponding author. E-mail: maria.wurzinger@boku.ac.at. Tel: +43 1 47654-16918.

community-based breeding programs (CBBP) for three local sheep breeds of the country (Bonga, Horro and Menz) have been designed and implemented since 2009 (Duguma, 2010; Mirkena et al., 2012). Gastrointestinal nematodes (GIN) of sheep are worldwide problems of health, production and welfare (Roeber et al., 2013; Mavrot et al., 2015; Traoré et al., 2017). Similar problems may appear also in CBBP. Prior to designing appropriate GIN control strategy for CBBP, possibly with selective breeding, a better understanding of intensity and associated factors is needed. Factors determining the prevalence and severity of infection with GIN in sheep include: host-related (age, immunity, sex); parasite-related (survival and development of larvae in the environment, nematode species and their location in the host), and environmental factors (climate, weather, season and microclimate) (Roeber et al., 2013).

One way of measuring infection levels of GIN is by quantifying the number of eggs being passed in the faeces. Relatively high and low fecal egg counts (FEC) are usually seen in young and adult animals, respectively (Miller and Horohov, 2006). Selection for low FEC can be used to genetically enhance resistance to GIN parasites in growing lambs (Notter et al. 2017a), thereby incorporation of recording FEC into the CBBP could be possible. Another method, the (FAffa MAlan CHArt (FAMACHA) system, can be used to identify the ability of the animal to cope with GIN infection; hence allowing animals for genetic selection and lowering of selection pressure on *Haemonchus contortus* for anthelmintic resistance (Wyk and Bath, 2002; Notter et al., 2017b). *H. contortus* is a haematophagus GIN parasite, which may cause severe/fatal anemia in grazing sheep (Moors and Gauly, 2009; Roeber et al., 2013). Compared to FEC, FAMACHA scores are less expensive to record, providing opportunity to replace FEC as phenotypes for selection in situations with moderate to high H. contortus prevalence (Heckendorn et al., 2017). When this species is a predominant GIN infection in sheep, higher FAMACHA scores are associated with higher FEC (Kaplan et al., 2004; Notter et al., 2017b). The objectives of this study were to investigate gastrointestinal nematodiasis in Ethiopian sheep breeds under communal breeding programs, and to examine relationship between intensity of GIN and levels of anaemia related to haematophagous species of GIN.

MATERIALS AND METHODS

Study area and animals

The study was conducted in communities currently implementing CBBP for two local sheep breeds of Ethiopia, Bonga and Horro (Figure 1). The CBBPs were designed considering the communities' sheep population, which share communal grazing and watering points as one large flock (or a breeding unit) that comprised ≥ 400 breeding ewes when the implementation was commenced in 2009 (Duguma, 2010; Mirkena et al., 2012). The CBBP communities (two per breed) are located neighboring to each other. For Bonga sheep, these are Boka and Shuta which are situated at 26 and 29 km East of Bonga town. The altitudes of the CBBP sites range between 2500-2600 m above sea level (m a.s.l.), typically classed under highland agro-ecological zone (AEZ) of the country. Bonga is an administrative town of Kaffa Zone in Southern Nations Nationalities and People's Regional State (SNNPR), located about 450 km from Addis Ababa. The area around Bonga has the mean annual temperature of 12 to 25°C and mean annual rainfall of 2300 mm. For Horro sheep, the CBBP communities are Gitlo and Laku which are situated at about 7 km from Shambu and 3 km apart from each other. The CBBP sites have altitude ranging between 2700-2800 m a.s.l. (highland AEZ). Shambu is an administrative town of Horro Guduru Welega Zone in Oromia Regional State, located about 315 km from Addis Ababa. The area around Shambu has the mean annual temperature of 12 to 23°C and mean annual rainfall of 1800 mm. The detailed characteristics of Bonga and Horro sheep breeds were described in the previous studies (Gizaw et al., 2007; Mirkena et al., 2012). In brief, both sheep are long fat-tailed breeds and highly valued for their meat production (Mirkena et al., 2012).

Sampling for FEC determination and FAMACHA scoring

A total of 1239 FEC and FAMACHA scores were sampled (Table 1) during two main seasons (rainy: July through September 2016; dry: December 2016 through February 2017) from Bonga CBBP (rainy, n=324; dry, n=235) and Horro CBBP (rainy, n=391 and dry, n=289). Animals of both sexes and all ages over 2 months in the CBBP were represented in the sample. The FEC was determined by McMaster egg counting technique, following procedures described by Urquhart et al. (1996). FAMACHA scoring was performed by classifying color of conjunctival mucous membranes of each sheep according to Kaplan et al. (2004) and Burke et al. (2007) into five categories: 1 = red, non-anemic; 2 = red-pink, non-anemic; 3 = pink, mildly anemic; 4 = pink-white, anemic; 5 = white, severely anemic.

Statistical analysis

FEC data were analyzed in SAS 9.4 (SAS Institute Inc 2012) using the mixed model procedure, after log transformation [Ln (FEC + 25)] to conform normality. The constant was added to include zero FECs. The model was fitted using the effect of animal identity as random to account for measurements on the same animal during two seasons. The fixed effects included were breed/location, season and interaction between the breed and the season, as follows:

$$y_{ijk} = \mu + breed_i + animal_{ij} + season_k + (breed * season)_{ik} + e_{ijk}$$

where y_{ijk} is the response variable of log transformed FEC, µ is overall mean, $breed_i$ is the fixed effect of the i^{th} breed (Bonga or Horro); $animal_{ij}$ is the random effect of animal j within breed i; $season_k$ is the fixed effect of the k^{th} season (rainy or dry); $(breed * season)_{ik}$ is the interaction of breed by season; e_{ijk} is the random error. The FEC results are presented as both log transformed and back-transformed least squares means and standard errors (LSM ± SE). Non-transformed FAMACHA scores were analyzed in the same way. Relationship between FEC and FAMACHA scores was explored by boxplots and further examined using Kruskal-Wallis Test. For this purpose, differences in FEC between classes of FAMACHA were tested for each pair of FAMACHA scores. The boxplots were constructed using R (R Core Team, 2017). Spearman's correlation of FEC and FAMACHA was also computed.

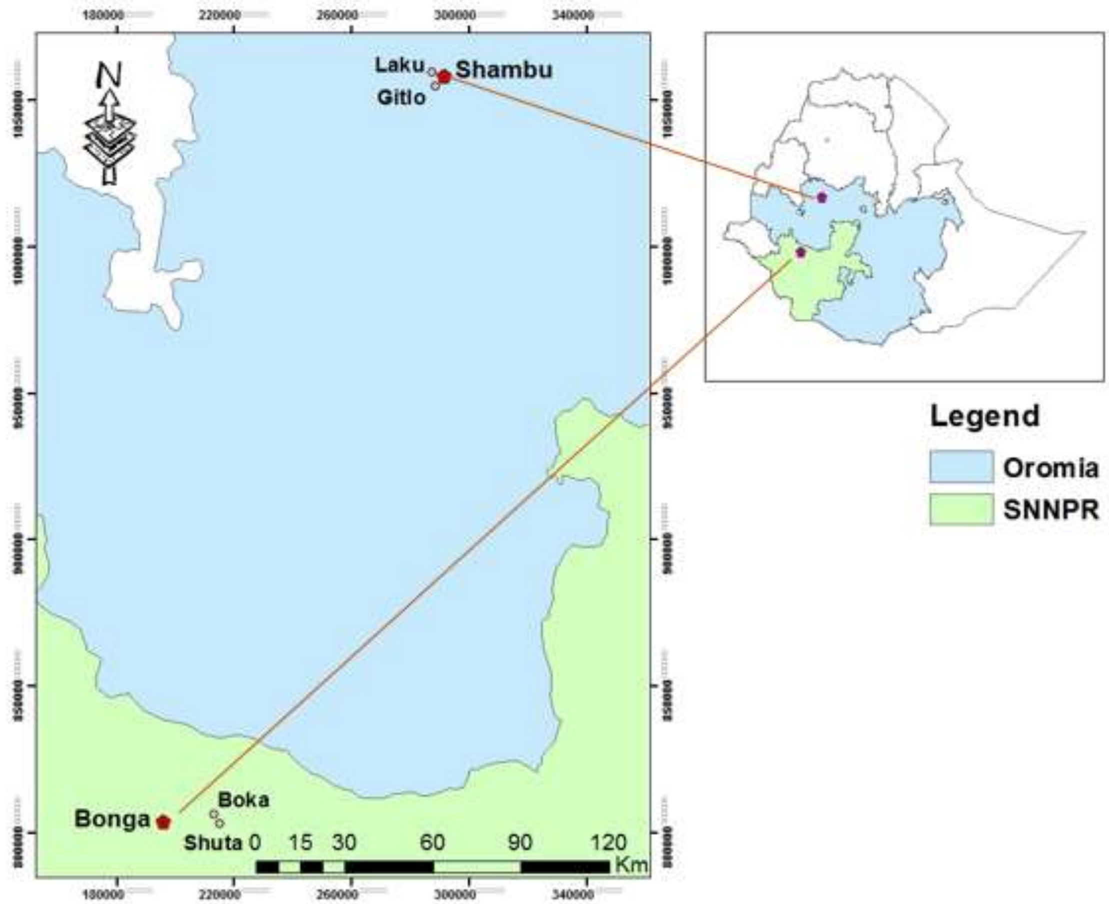

Figure 1. Map of Ethiopia illustrating the study sites for Horro sheep (Laku and Gitlo, in the vicinity of Shambu town, Oromia Region) and Bonga sheep (Boka and Shuta, nearby Bonga town, Southern Nations Nationalities and People's Regional State (SNNPR)).

Table 1. Number of sampled sheep for FEC and FAMACHA scores during two seasons from community-based breeding programs in Bonga and Horro, Ethiopia.

CBBP	Season						Total FEC and FAMACHA
	Rainy			Dry			
	FEC	FAMACHA	FEC and FAMACHA	FEC	FAMACHA	FEC and FAMACHA	
Bonga	388	324	324	310	236	235	559
Horro	530	391	391	398	378	289	680
Total			715			524	1239

RESULTS

Effects of breed and season on *FEC*

Table 2 shows factors associated with FEC under communal sheep breeding in Ethiopia. Season, breed and the interactions thereof, significantly ($p < 0.05$) influenced FEC. The least square means (LSM) and standard errors (SE) of log transformed FEC (or back-transformed FEC) during the dry season were 5.78 ± 0.08 (298.87 ± 10.72) and 3.82 ± 0.07 (20.727 ± 1.48), respectively, in Bonga and Horro CBBP. The corresponding values during the rainy season were 5.05 ± 0.07 (131.11 ± 9.38) and 4.91 ± 0.06 (110.02 ± 6.73).

Effects of breed and season on FAMACHA

Least square means (LSM) ± standard errors (SE) of FAMACHA scores for the effects of breed and season in

Table 2. Least square means (LSM) ± standard errors (SE) of log transformed FEC and back-transformed FEC and FAMACHA scores for the effects of season, breed and their interactions in sheep under CBBP.

Effect	LSM ± SE				
	N	Log transformed FEC	Back-transformed FEC	N	FAMACHA score
Season		*			ns
Dry	701	4.80 ± 0.05	96.69 ± 5.18	614	2.56± 0.04
Rainy	918	4.98 ± 0.05	120.18 ± 5.66	715	2.56 ± 0.03
Breed/Location		**			***
Bonga	698	5.42 ± 0.05	199.85 ± 10.72	560	2.48 ± 0.04
Horro	921	4.36 ± 0.05	53.57 ± 2.52	769	2.64 ± 0.03
Breed × Season		***			**
Bonga dry	310	$5.78^{a} \pm 0.08$	298.87 ± 23.92	236	$2.56^{b} \pm 0.06$
Horro dry	391	$3.82^{c} \pm 0.07$	20.72 ± 1.48	378	$2.57^{b} \pm 0.05$
Bonga rainy	388	$5.05^{b} \pm 0.07$	131.11 ± 9.38	324	$2.40^{b} \pm 0.05$
Horro rainy	530	$4.91^{b} \pm 0.06$	110.02 ± 6.73	391	$2.72^{a} \pm 0.05$

^{a,b,c}LSM with different letters within the same column and effect are statistically different (p<0.05). Significance of effects: ns = not significant; *= significant at p < 0.05; ** = significant at p < 0.01; *** = significant at p<0.001.

sheep under CBBP are presented in Table 2. Breed/location affected FAMACHA score ($p < 0.001$), while season had no effect ($p > 0.05$) on the trait. A significant ($p < 0.01$) interaction was found between breed and season in FAMACHA.

Relationship between intensity of GIN infection and levels of anaemia

The relationship between intensity of GIN infection and levels of anaemia is shown by boxplots (Figure 2a to d) for Bonga and Horro sheep during rainy and dry seasons. There were no significant differences in FEC between FAMACHA classes: Kruskal-Wallis Test; χ^2 = 1.53-4.643, df = 4, $p > 0.05$) in both breeds and seasons, though FAMACHA score increased with mean FEC in Bonga CBBP during rainy season. Also, Spearman's correlation test showed no evidence of significant relationships ($p > 0.05$) between the FEC and FAMACHA scores in both breeds and seasons (Table 3).

DISCUSSION

The pattern of interaction between season and breed showed that Bonga sheep had higher values of FEC than Horro sheep in the dry season. This could be attributed to the differences in agroclimatic factors of the breeds' locations. Our findings of a higher FEC during rainy season compared to the dry season in Horro sheep are in line with most studies in Ethiopia (Haile et al., 2010; Aga et al., 2013) and elsewhere in the world (Nwosu et al., 2007; Khan et al., 2010; Khajuria et al., 2013). But a lower FEC during the rainy season than the dry season in Bonga was inconsistent with these reports. This is possibly due to sheep flock management practices by farmers in this region; tethering of sheep on private land during the rainy season in Bonga may have lowered pasture contamination with nematode larvae, thereby reduced subsequent infection. This may alternatively be explained by the grazing of sheep on communal land (usually mixed with other livestock) coupled with a better precipitation received during the dry season in Bonga might have increased the risk of GIN infection. Though unexpected during the dry season, Abebe et al. (2010) also reported a high rate of GIN infection in sheep and goats, even a higher infection rate than our finding in the same region of southern Ethiopia. Generally, the FECs indicate that the intensity of infections with GIN was low in the CBBP of Bonga and Horro during both rainy and dry seasons. Taylor (2010) suggested classification of intensity of GIN infection in sheep based on FEC values: FEC < 500 as low infection; FEC = 500-1000 as moderate infection; FEC more than 1000 as high infection.

The least square means and standard errors of FAMACHA scores suggested that the levels of anaemia were mild. The differences of the least square means revealed that the FAMACHA scores in Horro sheep during rainy season were significantly different from the other groups. However, this highest level of anaemia may not be due to haemonchosis as indicted by absence of significant correlation between FEC and FAMACHA. Also, the correlation was negative (though non-significant), indicating that the cause of anaemia could be other factors rather than *H. contortus*. FAMACHA method suffers from the problem of non-specificity, for example, anaemia in sheep can be caused by many factors, consideration of other haematophagous parasites is always necessary, particularly Fasciola (Wyk and Bath, 2002; Kaplan et al., 2004).

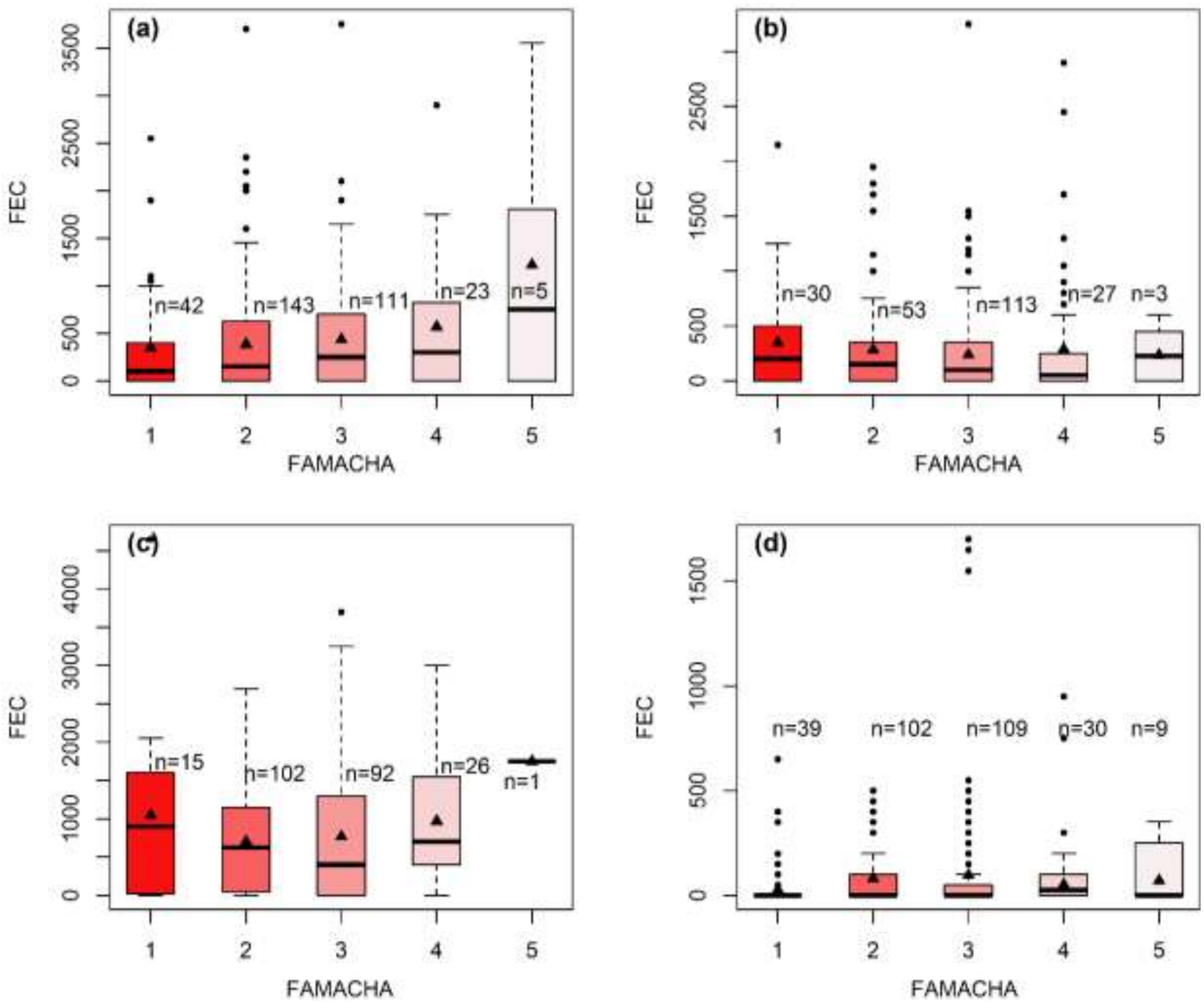

Figure 2. Boxplots showing the relationship between FEC and FAMACHA scores in CBBP sheep: (a) Bonga, rainy season; (b) Horro, rainy season; (c) Bonga, dry season; (d) Horro, dry season. Solid triangles show the mean and solid lines show the median of FEC in each FAMACHA category. The lower and upper boundaries of the boxes reveal the 1st and 3rd quartiles. The whiskers below and above the boxes indicate minimum and maximum non-outliers, and the circles (filled black) show outliers, and "n" indicates the number of observations.

Table 3. Spearman's correlation (r) between FEC and FAMACHA score in Bonga and Horro sheep in CBBP during rainy and dry seasons.

FAMACHA	**FEC**					
	Bonga			**Horro**		
	N	**r**	**p value**	**N**	**r**	**p value**
Rainy	324	0.05	0.409	235	-0.09	0.094
Dry	391	0.04	0.576	289	0.11	0.069

There was a tendency for the FAMACHA score to increase with the mean FEC in Bonga sheep during rainy season, though the correlation between them was not significant. The lack of association indicates that H.contortus is not a highly dominant GIN parasite in sheep of Bonga and Horro CBBP. This low prevalence of the parasite might be due to the higher altitudes of the present CBBP locations (≈ 2500 m). In lower altitudes (< 1500 m), however, H.contortus has been reported to be a dominant GIN species and may cause life threatening disease in all age groups of sheep (Balmer et al. 2015). Our finding is supported by Aga et al. (2013), who based on coproculture identification of nematode species, reported a lower prevalence rate of *H. contortus* in highland (16.1%) than midland and lowland (37.5 and 40.0%) in Horro sheep in Western Oromiya, Ethiopia. The applicability of the FAMACHA method is limited when a percentage of *H. contortus* in the flock is not greater than 60% (Vilela et al., 2012). A slightly lower prevalence of *H. contortus* (58.9%) in goat flocks under field conditions in Switzerland, Scheuerle et al. (2010) reported a significant correlation between FAMACHA and FEC in only one out of six occasions. Similarly, with a very lower prevalence of *H. contortus* (12-34%) in German sheep, Moors and Gauly (2009) did not find any significant correlation between FAMACHA and FEC. Other similar field studies conducted in Northern Germany on naturally infected sheep and goats by Koopmann et al. (2006) showed that at a comparatively low prevalence of H. contortus, the FAMACHA system proved not being sufficient in detecting all animals with high FEC.

Conclusion

In conclusion, the intensity of infection with GIN in sheep of Bonga and Horro under CBBP were low to moderate. FAMACHA was found not to be a suitable indicator of GIN infections in CBBP of Bonga and Horro. Therefore, FEC should preferably be recorded and incorporated as a nematode resistance trait into the CBBP. However, routine recording of FEC under the CBBP condition may be difficult due to complex logistics and trained personnel required to do the laboratory work.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effects of recommended improved crop technologies and socio-economic factors on coffee profitability among smallholder farmers in Embu County, Kenya

Daniel M. Wambua[1*], Samuel N. Ndirangu[1], Lucy K. Njeru[2] and Bernard M. Gichimu[3]

[1]Department of Agricultural Economics and Extension, School of Agriculture, University of Embu, P. O. Box 6-60100, Kenya.
[2]Department of Agricultural Economics, Faculty of Agriculture, University of Nairobi. P. O. Box 30197-00100, Nairobi, Kenya.
[3]Department of Agricultural Resource Management, School of Agriculture, University of Embu, P.O. Box 6-60100, Embu, Kenya.

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This study was carried out to determine the combined effects of recommended production technologies and farmer characteristics on coffee profitability at the farm level in Embu County, Kenya, using the profit function approach. Data were collected using semi structured questionnaires from a sample of 376 farmers who were randomly selected from six cooperative societies, using multistage stratified and probability proportional to size sampling techniques. Primary data on level of adoption of production technologies, level of usage of farm inputs, factor prices, coffee output and farmer demographics were collected. The data were entered in Excel sheets for initial analysis and tabulation then coded for primary analysis of the combined effect using the Profit function model. The results revealed that adoption of the recommended coffee varieties and rate of manure application were positive and significant in affecting coffee profitability at 5% level of significance. However, capping of coffee stems (bearing heads) had a significant negative effect on coffee profitability. Other factors that were found to have a significant negative influence on coffee profitability were the price of manure and foliar fertilizer. Surprisingly, increasing the wage rate had a significant positive influence on coffee profitability. These results portrayed that there is potential of increasing coffee profitability in the study area through adoption of the improved coffee varieties and recommended rates of manure as well as stabilizing factor prices of key inputs. In addition, paying a higher wage rate would act as an incentive and motivation for increased productivity hence increased coffee net returns.

Key words: Input, coffee variety, manure rate, capping, marginal product, marginal value product, Profit function.

INTRODUCTION

Kenya's economy is predominantly anchored in agriculture. One of the goals of the Kenyan Vision 2030 for the agricultural sector is to achieve an average growth rate of 7% per year (GoK, 2012). The agricultural sector contributes 51% of Gross Domestic Product (GDP) directly and indirectly, accounts for 65% of Kenya's total exports, 18% of formal employment and over 60% of informal employment in rural areas (GoK, 2012). Industrial crops contribute 55% of Kenyan agricultural exports, implying that a decline in productivity of these crops would mean reduced gross domestic product (GDP) and economic growth. Coffee, *Coffea arabica* is Kenya's fourth leading foreign exchange earner after tourism, tea, and horticulture (MoA, 2011). The 2016-2021 strategic plan for Agriculture and Food Authority (AFA) aims to increase local consumption of coffee by at least 5% and also promote production of clean coffee by at least 50% by the year 2020 (AFA, 2016). Due to the industry's effective forward and backward linkages, coffee is currently contributing 8% of the agricultural output (AFA, 2016). Increase in allocative efficiency will increase profit margins to small scale coffee farmers whose production accounts for 65% of total coffee output (Mati, 2016).

Despite increase in area under coffee from 109,000 ha in 2012/2013 crop year to 115,570 hectares in 2018/2019 crop year, profit margins from coffee have been on decline (ICO, 2019). Export licensing, growing inequality to value addition, minimum volumes for export and quality standards act as entry barriers for small scale coffee farmers to international markets leading to reduced economic incentives and low profit margins (AFA, 2016). Returns from coffee are majorly influenced by international market price and therefore beyond the farmers' control. However, increasing coffee productivity, which is largely within the farmers' control, would therefore mitigate the cost of production and hence improve incomes (AFA, 2016). Despite the decrease in coffee exports, coffee is still a major cash crop in many parts of the central highlands of Kenya and parts of western Kenya. In Embu County, coffee is one of the major industrial and export crops whereby nearly 70% of the crop is grown by smallholder farmers (GoK, 2013a). There is immense need to promote the crop by establishing linkages with government and private research institutions, disseminate market information, conduct farmers training programs, and develop varieties suitable for different agro-ecological zones (GoK, 2013b). These efforts are made to enhance productivity, product quality and competitiveness both in local and global markets. Increase in coffee productivity would reduce poverty, increase household income, stabilize market prices and hence increase household consumption and saving (GoK, 2007). High quality coffee will compete globally, and guarantee high prices and market access to enhance profitability and incomes to rural populations given the available technology among the small scale coffee farmers, hence the need to evaluate profit efficiency for these farms. Provision of adequate economic incentives to farmers could be the missing link between technology development and technology adoption in the coffee sub sector.

Agricultural technology adoption decisions are usually intertwined. Most studies to examine the impacts of agricultural technology have focused on single technology adoption choice and ignored interdependence among technologies (Kassie et al., 2018). Coffee production, both small and large scale farmers behave rationally and will be motivated to produce more in the current period if there was a guarantee of high prices in the previous period (Maitha, 1974). There are other non-price factors such as cost of inputs, labour costs and access to credit that influence production and export supply response of coffee in Kenya (Were et al., 2002). High production and transaction costs accompanied by declining productivity have adversely reduced coffee profitability but with a price incentive to farmers, there will be an increase in coffee returns (Were et al., 2002).

Effective technology development must ultimately increase the farm's profits or decrease its losses (Afolami et al., 2015). Several studies have focused on factors that influence technology adoption (Mignouna et al., 2010; Ak udugu et al., 2012; Musaba and Bwacha, 2014), such as farm size, credit access, expected pay off from technology adoption, extension services and education, but limited consideration on the effects of technology adoption on farm gross returns. Other studies (Chemura et al., 2010; Mohammed et al., 2013; Van der Vossen et al., 2015) were experimental (under controlled conditions) in considering one factor like organic manure or fertilizer at a time without considering possibilities of input substitution during the production process. Over the years, the Kenyan Government through Coffee Research Institute (CRI) has been conducting on-station research on coffee production and management. However, the research institute has been focusing on on-station research with limited on-farm research and technology transfer to assess the impact of research recommendations on gross returns at farm level. Inadequate empirical studies on relative economic efficiency of small scale coffee farmers is proving difficult for policy makers and researchers to reassess the impact of the released technologies at the farm level.

Research on coffee (on station) through Coffee Research Institute has recommended the following: improved crop technologies; disease resistant varieties (Ruiru 11 and Batian), recommended spacing, fertilizer, fungicide, herbicide and pesticide rates and canopy management for increased profitability and reduced cost of production. Disease resistant varieties are meant to reduce cost on agrochemicals for control of coffee berry disease and coffee leaf rust and also improve on the

*Corresponding author. E-mail: wambua.daniel@embuni.ac.ke

marketable value of coffee produced. The objective of this study was therefore to determine the effect of these recommended improved crop technologies on coffee profitability among the smallholder coffee farmers in Embu County, Kenya. The study undertook an in-depth analysis of gross margins and returns per shilling invested in coffee production through optimum input allocation among the smallholder coffee farmers in the county. An issue of great importance to policy makers is the gross margins' responsiveness for coffee given the recommended improved crop technologies, factor demands and prices which interact with other socioeconomic factors at the farm level. Therefore, understanding the reasons for decline in coffee returns and whether it may be reversed remains an important concern in Embu County, Kenya.

MATERIALS AND METHODS

Description of study area

The study covered Manyatta and Runyenjes sub-counties of Embu County which are the main coffee growing zones in the County and are mainly located in Upper Midland (UM) Zone 2-3 Agro-ecological zones (Ndirangu et al., 2017). The rainfall pattern in the study area is bimodal with two distinct rainy seasons. Long rains occur between March and June while the short rains occur between October and December. Rainfall quantity ranges between 1120-1495 mm annually with altitude ranging from 1600 to 1800 m above sea level. Temperatures range from a minimum of 12°C in July to a maximum of 21.6°C in March (GoK, 2013a). Agriculture is the main driver of the economy in the region with over 70% of the farmers being smallholders (MoA, 2011). The main industrial crops in the area are coffee and tea.

Sample size

The sample size for the study was 376 smallholder coffee farmers from the two sub-counties which was obtained from a population of 20,000 registered farmers in the sampled cooperative societies. The following formula was used to determine the sample size as recommended by Cochran (1963) and adopted by Muriithi (2016).

$$n_o = \frac{Z^2 pq}{e^2} \quad (1)$$

Where n_0 = required sample size

Z = t value at 95% confidence level from normal table (1.96)
p = probability that respondent has characteristic being measured
q = (1-p) probability that respondent has no characteristic being measured
e = 5% level of significance (0.05)
Using Equation 1 and assuming 50% probability that the respondent has the characteristic being measured, the sample size was calculated as shown below;

$$n_o = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = 384 \quad (2)$$

Given that the estimated target population was less than 100,000; then the sample size was adjusted using the following equation for finite population correction (Cochran, 1963).

$$n_o = \frac{n_o}{1 + \frac{(n_o - 1)}{N}} \quad (3)$$

$$n_0 = \frac{384}{1 + \frac{(384-1)}{20,000}} = 376 \text{ farmers} \quad (4)$$

Where n_0 = required sample size, N = total population (registered members)

Sampling procedure

Coffee cooperatives play a crucial role in provision of key inputs, affordable credit to farmers and also provision of social capital for local expertise and profits. The study applied multistage stratified random sampling to select the farmers to be interviewed. The study selected six cooperative societies; major three from each of the two sub counties. Out of the six cooperative societies selected, probability proportional to size sampling criteria using the random number register was employed to select 376 farmers from among the farmers who deliver coffee to the selected cooperative societies. The number of farmers from each cooperative society was determined using the following formula as applied by Ndirangu et al. (2017);

$$k = \frac{p}{M} * 376 \quad (5)$$

Where, k = number of farmers to be interviewed
p = number of members in a cooperative society
M = total number of smallholder coffee farmers in the selected cooperative societies

Data collection

The study used primary production data from various respondents for one crop season (2017/2018 crop year). The primary data were collected from the respondents using structured questionnaires. The key production variables were improved coffee varieties, spacing (tree population), fertilizer types and rates, fungicide types and rates, pesticide types and rates, adoption of capping and level of capping, as well as herbicide types and rates. The recommended practices as detailed in Coffee Research Institute Technical Circulars No. 804, 203 and 502 for all the above technologies were evaluated against farmers' practice (CRI, 2018). If a farmer was using the recommended rate was considered to have adopted and vice versa compared to the recommended rates. Other variables considered were coffee output, factor prices, variable costs and expenditure on labour and output prices for estimation of gross margins and returns on investment in coffee production. Data were also collected on socioeconomic factors of the respondents such as gender of the household head, education level, farm size, credit access, off-farm income and land ownership (title deed). The data collected were processed in Microsoft Excel sheets and coded before analysis.

Data analysis

Descriptive statistics were used to analyze the demographic characteristics of the farmers hypothesized to influence coffee profitability. To determine the effect of recommended technologies on coffee profitability, profit function model was used to show the relationship between coffee gross returns (profitability) with recommended technologies, factors of production used, factor prices and the farm socio-economic factors. The profit function model was preferred since the function is able to derive indirect estimates that link the coefficients of the profit function with those of the production function since it incorporates the factors of production (Adesina and Djato, 1996). The general stochastic profit model is specified as applied by Adesina and Djato (1996):

$$\ln \pi^* = \ln A + \sum \beta_k D_k + \sum \beta_i \ln W_i + \beta \ln Z_2 + \sum \beta_j \ln Y_j + \sum \beta_n Z_n - \beta_w \frac{w_i x_i}{\pi^*} - \varepsilon \quad (6)$$

Where ln = Natural logarithm, π^* = normalized profit, $\ln A$ = constant or intercept, β = vector parameters to be estimated, D = dummy variables for recommended technologies (1 = adopted, 0 = non adoption), W = factor prices, Z_2 = land size under coffee, Y = cost of variable inputs, Z = socioeconomic factors, w_i = wage rate per man day normalized by price of coffee, x_i = number of man days of labour used in production, k = 1,2,…11, i = 1,2,…6, j = 1,2,…6, n = 1,2,…9, D_1 = variety dummy, D_2 = spacing dummy, D_3 = fertilizer dummy, D_4 = foliar feed dummy, D_5 = manure dummy, D_6 = fungicide dummy, D_7 = herbicide dummy, D_8 = pesticide dummy, D_9 = pruning dummy, D_{10} = capping height dummy, D_{11} = heads per stem dummy, W_1 = normalized fertilizer price per kg, W_2 = normalized foliar price per litre, W_3 = normalized manure price per 15kg bucket, W_4 =normalized fungicide price per kg, W_5 = normalized herbicide price per litre, W_6 = normalized pesticide price per litre, Y_1 = fertilizer cost, Y_2 = foliar cost, Y_3 = manure cost, Y_4 = fungicide cost, Y_5 = herbicide cost, Y_6 = pesticide cost, Z_1 = gender, Z_2 = age, Z_3 = education, Z_4 = experience, Z_5 = household size, Z_6 = off farm income, Z_7 = land ownership, Z_8 = extension, Z_9 = credit access and ε = error term.

RESULTS AND DISCUSSION

Farm and farmers' characteristics of the respondents

Table 1 shows the demographic characteristics of the respondents in the study area hypothesized to influence coffee profitability. The findings indicated that 74.7% of the respondents were males, while 25.3% were females implying that majority of the coffee farms in the study area were managed by males due to intensity of farm operations involved. Men controlled key production resources such as land, capital hence dominated coffee production. Mohammed et al. (2013) and Nguezet et al. (2011) found the impact of gender on household income significantly higher in households headed by male than in those headed by females. Majority (75.8%) of respondents had attained secondary education and above (Table 1), implying diverse knowledge and basic skills which would play a key role in managing risks, taking mitigation strategies and long term production decisions. These findings concur to that by Akudugu et al. (2012) and Mignouna et al. (2010) that formal schooling was key in critical production decisions. Majority of farmers (77.6%) owned one acre of land and below and this was attributed to land fragmentation associated with population growth, leading to small and uneconomical land sizes for crop production (Murimi et al., 2019).

The study further showed that majority of the respondents (70.5%) had access to credit (Table 1), implying that farmers had access to key farm inputs and other efficiency enhancing technologies. The credit also provided a cushion against production risks and random shocks for increased coffee productivity. Credit access was a key facilitating factor of production and technology adoption (Akudugu et al., 2012; Chepng'etich et al., 2015). The family sizes in the study area comprised between 4-6 members (69.7%) per household which was an indication of a source of family labour for various farm operations. Mohammed et al. (2013) and Nguezet et al. (2011) found household size significantly and positively related to household income. In addition, less than half of the respondents (43.4%) had land ownership rights in form of land title deed, implying that majority of the respondents did not have security of land tenure. This was likely to negatively impact on coffee profitability, as farmers could not make long term investments due to uncertainties in the long run.

Estimation of gross returns (margins) from coffee enterprise

The study hypothesized that variations in coffee profitability were due to differences in input use, adoption of recommended technologies with interaction of farm socioeconomic characteristics of the farmers. The study analyzed the gross returns across the farms in the sample and descriptive statistics results are given in Table 2.

The results showed that coffee production was profitable despite some farmers making losses due to high cost of production. Although some farmers incurred losses, the gross margin averaged Kshs 37,400 ($ 374) per farm. Results of gross margin per tree had a mean of Kshs 249 ($ 2.49) and a standard deviation of 296.603. Gross margin per man day was estimated to be Kshs 1,052 ($ 10.52) with a standard deviation of1462.44 due to variations in labour usage. Gross margin per acre averaged Kshs 80,670 ($ 806.70) and a standard deviation of 115835.62. The study analyzed returns per

Table 1. Farm and farmer characteristics of the respondents.

Socioeconomic factors	Frequency	Percentage
Gender of the farmer		
Male	281	74.7
Female	95	25.3
Level of education		
Non formal	12	3.2
Primary	79	21
Secondary	245	65.2
Tertiary	38	10.1
Other	2	0.5
Farm size (acres)		
0 -0.5	111	29.5
0.51- 1.0	181	48.1
1.01- 1.5	39	10.4
> 1.5	45	12
Credit access		
Yes	265	70.5
No	111	29.5
Off-farm income		
Yes	323	85.9
No	53	14.1
Household size		
1 - 3	74	19.7
4 - 6	262	69.7
7 - 9	40	10.6
Land ownership (title deed)		
Yes	163	43.4
No	213	56.6

Table 2. Descriptive statistics on gross Margins (Kshs) from coffee production.

Returns (Kshs)	Min	Max	Mean	Std. Error	Std. deviation
GM	-30,450	552,897.20	37400	3318.95	64356.80
GM / tree	-268	3547	249	15.296	296.603
GM / man day	-1155	8353	1052	75.42	1462.44
GM / acre	-150,224	876755.60	80670	5973.77	115835.62
GM/shs	-0.72	11.37	1.7612	0.09074	1.75942
Returns/ Kshs	0.28	12.37	2.7612	0.09074	1.75942

GM = Gross Margin.

shilling invested in coffee production and found that for each shilling invested it generates Kshs 1.37 giving returns of Kshs 2.37 with a difference of one shilling. This gave an indication of positive returns or earnings for every shilling invested making coffee production a profitable enterprise.

Table 3. Descriptive statistics for variable costs per acre.

Factor	Unit	Price/unit	Av. cost	%TVC	S. E	Std. deviation
Fertilizer	kilogram	55.68	19628.61	19.8	759.89	14734.80
Foliar feed	Litre	956.20	7287.86	7.4	489.77	9497.06
Manure	Bucket (15 kg)	36.78	22427.12	22.7	1237.04	23987.14
Fungicide	kilogram	1057.60	10210.57	10.3	578.72	11221.74
Herbicide	Litre	782.16	3464.23	3.5	321.52	6234.60
Pesticide	Litre	1029.97	4670.30	4.7	281.83	5464.92
Labour	Man-day	307.20	31313.10	31.6	1486.21	28818.62

Estimation of variable costs for coffee production

The costs of major variable inputs used in coffee production are given in Table 3. The results show that the average price of fertilizer per kilogram was Kshs 55.68 ($ 0.55) with average expenditure on fertilizer being Kshs 19,630 ($ 196) per acre. Expenditure on fertilizer constituted 19.8% of total variable cost implying a key factor of production in coffee. Expenditure on foliar feed was 7.4% of total variable cost with an average of Kshs 956 per litre. Organic manure which acted as a substitute for inorganic fertilizer constituted 22.7% of total variable cost and an average expenditure of Kshs 22,400 per acre.

Fungicides which were commonly used for control of coffee berry disease (CBD) and coffee leaf rust (CLR) constituted 10.3% of total variable cost with average cost of Kshs 10,210.57 ($ 102.10) per acre and an average price of Kshs 1,057.60 ($ 10.57) per kilogram. Expenditure on herbicides constituted 3.5% of total variable cost with an average expenditure of Kshs 3,464.23 ($34.64) per acre. Pesticides constituted 4.7% of total variable cost with an average price of Kshs 1,029.97 ($ 10.29) per litre and an average expenditure of Kshs 4,670.30 ($46.70) per acre. Labour cost varied across the farms given the scale of production constituting majorly on total variable cost with 31.6% and average expenditure of Kshs 31,313.10 ($ 313.13) per acre. The average wage rate per man day was Kshs 307.20 ($ 3.07).

Effect of recommended technologies on coffee profitability (gross margin)

A stochastic normalized restricted profit function was used in the study to show the responsiveness of the predictor variables on gross margins per acre across the farms. Multiple correlation coefficient or coefficient of determination (R^2) is the proportion of variance explained by the regression model making it useful as a measure of success of predicting the dependent variable from the explanatory variables (Nagelkerke, 1991; Hanson, 2010). R square (R^2) should lie between 0 and 1 which is invariant to units of measurement and becomes larger as the model fits better (Magee, 1990).

The fitted model gave a coefficient of determination value (R^2) of 0.724, which implies that the predictor variables explained 72.4% of the observed variation in gross margins per acre. Results revealed a standard error of the estimate of 0.69168 which was the difference between actual and the predicted scores in the null hypothesis. The results also revealed an F-value which was significant at 1% level ($p<0.01$), implying that the predictor variables explained highly significant variation in the dependent variable. Variance Inflation Factor (VIF) measures the impact of multicollinearity among predictor variables in a regression (Robinson and Schumacker, 2009). The general rule is that the VIF should not exceed 10 (Belsley and Kuh, 1980). The predictor variables fitted in the model had a VIF value of less than 5 which implied no problem of multicollinearity between the variables.

The results of the multiple regression using the estimated profit function for the amounts of inputs used and their prices, recommended application rates and expenditure are shown in Table 4. The prices of inorganic fertilizer, fungicide, herbicide and pesticide were not significant in explaining profit variations. However, adoption of the recommended coffee varieties, rate of manure application and labour wage rate were found to have significant ($p<0.05$) positive effects on coffee profitability. On the other hand, capping of coffee stems (bearing heads) and the price of manure and foliar fertilizer had negative significant ($p<0.05$) effects on coffee profitability.

The coefficient for the recommended coffee varieties was positive 0.114 and significant at 5 % level ($t = 2.19$, $p < 0.05$), implying that the gross margin for adopters of recommended coffee varieties (Ruiru 11 or Batian) was 11.4% higher than that of non-adopters. The improved varieties (Ruiru 11 and Batian) were resistant to coffee berry disease (CBD) and coffee leaf rust (CLR) hence produced relatively higher yields of high quality and reduced the cost of production. This increased the marketable value of cherry which guaranteed high returns. These findings concur with those reported by other researchers on impact of improved coffee varieties on sustainable coffee production and profitability among

Table 4. Multiple regression results for effect of recommended technologies and socioeconomic factors on coffee profitability.

Dependent Var.(Profit)	Beta	Std. Error	t	Sig.	VIF
(Constant)	2.54	2.594	0.979	0.329	
Coffee varieties	0.114	0.125	2.19	0.030*	1.414
Tree spacing	-0.067	0.117	-1.397	0.165	1.217
Recommended fertilizer rate	0.008	0.116	0.171	0.865	1.262
Recommended foliar feed rate	-0.066	0.148	-1.051	0.295	2.066
Recommended manure rate	0.204	0.227	3.96	0.000***	1.397
Recommended fungicide rate	0.034	0.148	0.574	0.567	1.797
Recommended herbicide rate	-0.094	0.147	-1.547	0.124	1.937
Recommended pesticide rate	-0.075	0.121	-1.572	0.118	1.179
Pruning	-0.017	0.433	-0.372	0.710	1.156
Capping	-0.128	0.177	-2.554	0.012**	1.318
Heads per stem	-0.023	0.117	-0.474	0.636	1.267
Expenditure					
Fertilizer price	0.012	0.143	0.161	0.872	2.800
Fertilizer variable cost	0.118	0.159	1.474	0.143	3.381
Foliar feed price	-0.182	0.15	-2.204	0.029*	3.564
Foliar feed variable cost	-0.259	0.153	-3.291	0.001***	3.239
Manure price	-0.516	0.152	-7.026	0.000***	2.829
Manure variable cost	-0.398	0.145	-5.634	0.000***	2.612
Fungicide price	0.032	0.129	0.565	0.573	1.657
Fungicide variable cost	-0.121	0.138	-1.971	0.051	1.984
Herbicide price	0.061	0.123	0.878	0.381	2.533
Herbicide variable cost	-0.076	0.139	-1.174	0.242	2.212
Pesticide price	-0.038	0.118	-0.592	0.555	2.183
Pesticide variable cost	-0.031	0.117	-0.503	0.616	1.986
Wage rate	0.321	0.018	6.743	0.000***	1.192
Socioeconomic factors					
Land size (acres)	0.081	0.124	1.110	0.269	2.788
Gender (male=1, female=0)	0.058	0.148	1.164	0.246	1.298
Age of the farmer (years)	0.037	0.094	0.672	0.502	1.619
Level of education	0.024	0.102	0.444	0.658	1.540
Experience (years)	-0.021	0.117	-0.381	0.704	1.591
household size (number)	-0.042	0.108	-0.828	0.409	1.368
Off farm income (yes=1, no=0)	0.005	0.178	0.084	0.933	1.518
Land ownership (tenure)	-0.009	0.118	-0.19	0.850	1.305
Extension service (yes=1, no=0)	0.002	0.184	0.041	0.967	1.200
Credit access (yes=1, no=0)	-0.045	0.136	-0.918	0.360	1.245

***significant at 0.1%; **significant at 1%; *significant at 5%.

arable farms (Andrew and Philip, 2014; Van der Vossen et al., 2015; Haggar et al., 2017). However, Musaba and Bwacha (2014) found impact of improved maize seed varieties insignificant in influencing farm returns due to recycling of the planting materials. The coefficient of recommended manure rate per tree was positive 0.204 and significant at 5 % level (t = 3.96, $p < 0.01$). This implied that the gross margin for adopters of recommended manure rate was 20.4% higher than that of non-adopters. Apparently, manure use acted as a substitute for inorganic fertilizers which were relatively expensive. Organic manure has been used as a strategy for climate change and sustainable production with reduced impact on the environment, which would in turn increase environmental-economic benefits and trade-offs for sustainable production and high returns on coffee farms. Similar results were reported by Chemura et al. (2010); Mohammed et al. (2013) and McArthur and McCord (2017). On the contrary, Musaba and Bwacha (2014) found manure use insignificant in explaining variations in returns from maize production due to allocative inefficiencies.

The coefficient of recommended capping was -0.128 and significant at 5% level (t = -2.55, $p < 0.05$), implying that gross margin for adopters was lower than that of non-adopters by 12.8%. These findings concur with Van Asten et al. (2011), Castro et al. (2013) and Perdoná and Soratto (2015) on effect of capping and coffee returns. Capping would lead to dense canopy and shade thus limiting light penetration. Dense canopy would also act as alternate host for pests which would lead to expenditure on agrochemicals, reducing the production potential of coffee trees hence negatively influencing coffee returns (Gordon et al., 2007). Capping would also increase the cost of hired labour due to increased demand for pruning. However, capping is recommended in coffee estates to guide nutrient flow towards fruit bearing branches, enhance farm management and to facilitate coffee harvesting. However, Ghosh and Bera (2014) found capping significant and positively related to profitability of sweet oranges.

The price of foliar feed had a negative coefficient of 0.182 and significant at 5% level (t = -2.204, $p < 0.05$), implying that a 10% increase in unit price of foliar reduced coffee returns by 1.82%. The coefficient for expenditure on foliar feed had a negative coefficient of 0.259 and significant at 1% level (t = -3.29, $p < 0.01$), implying that a 10% increase in expenditure (amount used and the price) on foliar feed decreased coffee returns by 2.59%. The negative effect on gross margin implies that the increased coffee value from foliar fertilizer is lower than the price paid for foliar fertilizer. Foliar fertilizer is meant to correct micronutrient deficiency and since no soil or leaf analysis had been conducted to ascertain the status maybe its application was not important. The expenditure on foliar feed negatively influenced gross returns given the minimal marginal increase in coffee yields. These findings are similar to those reported by Castro-Tanzi et al. (2012), Alexander (2012), Andrew and Philip (2014) and Komarek et al. (2017) who found cost of foliar to be negatively related to coffee returns.

Manure price had a negative coefficient of 0.516 and was significant at 1% level (t = -7.03, $p < 0.01$), implying that a 10% increase in unit price for manure reduced gross margins by 5.16%. Cost of manure (both price and amount used) had a negative coefficient of 0.398 and significant at 1% level (t = -5.63, $p < 0.01$), which showed that a 10% increase in expenditure incurred on manure decreased coffee profit by 3.98%. This showed that the marginal value for coffee from manure was less than the unit price paid for manure. The farmers were using organic manure as an alternative for inorganic fertilizers and therefore higher prices of manure would result in its inadequate application. Other researchers also reported similar findings that cost of manure and agrochemicals negatively affected coffee profitability (Oerke et al., 2012; Bravo-Monroy et al., 2016; Haggar et al., 2017; Komarek et al., 2017).

Wage rate was positively related to gross margin with a coefficient of 0.321 and significant at 1% level (t = 6.743, $p < 0.01$), meaning that contrary to expectation a 10% increase in wage rate increases coffee profit by 3.2%. The plausible explanation is that hired labour would increase efficiency and supervisory roles given that the farmer incurred cost compared to family labour. Increase in wage rate would act as an incentive and motivation for increased labour productivity hence increased coffee net returns. Increase in wage rate implied that the marginal value product for coffee was more than the price of labour per man-day. These findings concur to those reported by Mohammed et al. (2013), Mathenge et al. (2015) and Kassie et al. (2018) that expenditure on labour use increased coffee returns. Fertilizer price was not significant in influencing the coffee returns since majority of the farmers used manure s an alternative to inorganic fertilizers. Komarek et al. (2017) found increase in fertilizer prices led to a decline in maize yield and household income. At higher fertilizer prices, households applied less fertilizer which had a negative effect on total household income. Socioeconomic factors hypothesized to influence coffee profitability were found not significant (Table 4).

Conclusion

Based on the study findings on effect of recommended improved crop technologies on coffee profitability, results revealed that recommended coffee varieties (Ruiru 11 or Batian) and manure rate had positive and significant effect on coffee gross returns. However, capping was found to have significant but negative effects on coffee returns at the farm level. Factor prices for foliar feed and manure and also expenditure on these inputs also had a significant negative effect on coffee gross returns. The study tested the hypothesis that the recommended technologies have no significant effects on coffee profitability. Therefore, the null hypothesis is rejected and the alternative that the recommended technologies have significant effect on coffee profitability is true.

RECOMMENDATIONS

Based on the study findings, there was evidence of variations in coffee gross returns across the farms. Therefore, the study came up with the following recommendations to guide the farmers and the policy makers in the efforts to increase coffee returns at the farm level.

(i) The farmers should adopt the recommended improved coffee varieties which are Ruiru 11 or Batian for they are disease resistant with high yield potential which will ensure a reduction in cost of agrochemicals hence high net returns.

(ii) The farmers should ensure application of organic manure at the recommended rate of one debe per tree per year as it is an organic substitute for inorganic fertilizer that is not only environmental friendly but also with proven agronomic advantages.

(iii) The farmers should maintain 2 -3 bearing heads to remove weak branches which compete with main fruit bearing branches for nutrients and light and also easiness of other management operations.

(iv) The Kenyan government should formulate an economic policy aimed at stabilizing factor prices of key inputs such as foliar feed and manure as expenditure on them significantly influenced coffee returns. This would in turn improve competitiveness of the crop in the international markets and exchange rate volatility in the long run.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Determinant of groundnut (*Arachis hypogaea* L.) yield improvement in the farmers' cropping systems in Benin

Faki O. Chabi[1*], Gustave D. Dagbenonbakin[2], Brice T. Oussou[3] and Saïdou A.[1]

[1]Integrated Soil and Crop Management Research Unit, Laboratory of Soil Sciences, Crop Sciences School, Faculty of Agronomic Sciences, University of Abomey-Calavi, 01 BP 526 RP, Cotonou, Benin.
[2]Institut National des Recherches Agricoles du Benin, 01 BP 988 RP, Cotonou 01, Benin.
[3]Laboratoire des Sciences du Sol, Eau et Environnement, Centre de Recherche d'Agonkanmey, Institut National des Recherches Agricoles du Benin, 01 BP 988 RP, Cotonou 01, Benin.

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Groundnut is an important crop in the farmers' cropping systems of Benin and one of the selected crops to be promoted by Benin Government. The aim of the present study is to analyze the traditional groundnut cropping systems in Benin. Farmers' socio-economic characteristics, cropping practices, farmers' perceptions of climate change manifestations on groundnut were information collected using an open ended questionnaire. In total, 382 farmers in three agro-ecological zones (AEZ) of Benin Republic were selected according to 121 farmers in the cotton zone of the northern Benin (AEZ 2), 159 farmers in the cotton zone of central Benin (AEZ 5) and 102 farmers in the "*terre de barre*" zone (AEZ 6) in the south. Descriptive statistics and multiple regression analysis were used to analyze data collected. Groundnut cultivation is mainly carried out by women in the AEZ 2, while in the two other AEZ, men are strengthly involved in the production. In the AEZ 5 and 6, groundnut is becoming nowadays a cash crop. Groundnut cultivation occupied less than 10% of the area owned by farmers in the AEZ 2 while it occupied more than half of the total area in the AEZ 5 and 6. Pod blank, pod attack by the termites were the main farmers' perceptions of the climate change effect on groundnut cultivation which is related to soil drought. In general, the sex of the farmers, supply of mineral fertilizer, crop rotation, crop residues management and supply of household waste have a significant and positive effects on the groundnut yield level. The study suggested that, balanced plant nutrition could be a challenge for enhancing groundnut production in Benin.

Key words: Source of income, farmer perception, soil fertility, climate change, crop nutritional balance, crop residues management.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is one of the most widely grown oilseeds in the world, especialy in the tropical regions (Shiyam, 2010; Fonceca, 2010) and contributes to 12% of the world oil production (Schilling,

*Corresponding author. E-mail: chabifaki@gmail.com. Tel: +22996107574.

2003). Production of groundnut is estimated at 47 million tonnes; 65.1% of this production comes from China and India (Faostat, 2017). African countries' production is dominated by Nigeria and Senegal (2,420,000 and 915,000 tonnes, respectively) (Freud et al., 1997; Faostat, 2017). Due to its high nutritional value, groundnut contributes to the national food security and provides income to farmers (Abbasi et al., 2010; Couto et al., 2011; Noba et al., 2014). The crop residus especially the shell are often used as livestock feed or as fuel (Schilling, 2001; Singh et al., 2010; Ahmad et al., 2007). Like most of the leguminous, it is used for soil fertility resplenishment due to its potential as biological nitrogen fixation source and it can also be used as green manure to improve nitrogen balance in the cropping systems (Smaling et al., 2008).

In Benin, groundnut production has increased in the recent years with about 153,762 ha of area cultivated and 134,229 tonnes of pods produced in 2013 (MAEP, 2014). Despite all the potential of this crop as an alternative to cotton (main cash crop of Benin), production is hampered by several constraints such as, decrease of soil fertility, erratic rainfall and shorter of the length of the growing seasons, weed infestation, high susceptibility to pests and diseases, soil mining due to non fertilizer supply (FAO, 2004; Kumar, 2012) leading to low yield (600 to 800 $kg.ha^{-1}$) (MAEP, 2014). In general, due to poor land management practice there is a continuous degradation of soil fertility (Didagbé et al., 2014; Didagbe et al., 2015). Given the importance of this crop, it is necessary to improve cropping system by developing appropriate fertilizer dose in order to enhance yield and reduce soil mining. This requires an in-depth knowledge of the current cropping systems in order to design appropriate crop and soil management practices.

The purpose of the present study is to characterize groundnut cropping systems in Benin for adequate crop and soil management practices. Specifically, the present study aims to i) determine the socio-economic profil of the groundnut producers in the different agroecological zones of Benin, ii) analyze variation of land management and cropping practices for groundnut production in the different agroecological zones of Benin and iii) finally identify the determinants of yield improvement in the different agroecological zones of Benin for setting sustainable land management practices.

MATERIALS AND METHODS

Study area

The work was carried out in three agro-ecological zones (AEZ) in Benin (Figure 1): the northern cotton zone (Banikora and Kandi) (AEZ 2), the centre cotton zone (Glazoué, Ouessè and Kétou) (AEZ 5) and the "*terre de barre* zone" in the south (Agbangnizou) (AEZ 6). The AEZ 2 was characterized by a Sudano-Sahelian climate with an annual average rainfall of 850 mm. There were two distinct seasons (a rainy season from May to October and a dry season from November to April). The Ferric and Plintic Luvisols (FAO, 2006) were the dominant soil types. In this area, cotton is the main cash crop. Leguminous mainly groundnuts, cowpeas and soybeans are also grown. The AEZ 5 was characterized by a Sudano-Guinean climate with two rainy seasons from April to July and October to November. The annual rainfall varies from 600 to 1400 mm over 80 to 110 days. The Ferric and Plintic Luvisol are also dominant soil types in the area. Black and hydromorphic soils are also found in the valleys of the rivers that cross the area. Cereals and leguminous are widely grown. The Sudano-Guinean zone on "*terre de barre*" (AEZ 6) located in the southern Benin has sub-equatorial rainy season. The cropping systems are based mainly on slash and burn agriculture, maize, cassava, groundnut and cowpea are predominant crops in the cropping systems and soil types are Acrisols (FAO, 2006). The rainfall pattern is highly erratic, leading to changes in the annual production cycles.

Sampling method

The sample size was obtained using the normal approximation of the binomial distribution (Dagnelie, 1998).

$$N= ((U_{1-\alpha/2})^2 \times p\ (1-p))/d^2$$

Where $U_{1-\alpha/2}$ = value of the normal random variable for the probability value of 1-α/2, α is the risk of error. For α = 5%, the probability 1-α/2 = 0.975 with $U_{1-\alpha/2}$= 1.96. p = the proportion of people involved in groundnut production in the study area and the margin of estimation error; in this study we used 5% value of p. Based on the p-values from the results of the exploratory phase, a total of 382 groundnut producers were surveyed, according to 121 in the AEZ 2, 159 in the AEZ 5 and 102 in the AEZ 6. In each locality, the respondents were identified using a simple random sampling technique.

Data collection methods and tools used

The study was carried out from September 2017 to October 2017 during groundnut growth period. An open ended questionnaire was used for data collection. Both quantitative and qualitative information was collected. Three students native from each area were recruited for the survey. Data on socio-economic characteristics of groundnut producers, cropping systems, and groundnut production constraints were collected. Finally, farmers' perceptions on the effect of the cropping practices on soil fertility were also collected.

Data processing and analysis

The Excel office 2013 spreadsheet was used for data processing. Software R version 3.5.2 was used for statistical analysis. Descriptive statistics especially for quantitative variables were computed. Hierarchical clustering was used to link groundnut cropping systems to the most efficient soil fertility management practices. This was followed by a multiple factor analysis to describe the different types of systems. The yield data were subjected to one-way analysis of variance AEZ used as the factor. Mean differences were done using Student Newman-Keuls test. Analyse of the determinants of land of crop management practices that affect the most groundnut yields was done using ordinal logistic regression. A Mapping Factor Analysis was carried out to analyse farmers' perceptions on the effects of climate change on groundnut yield.

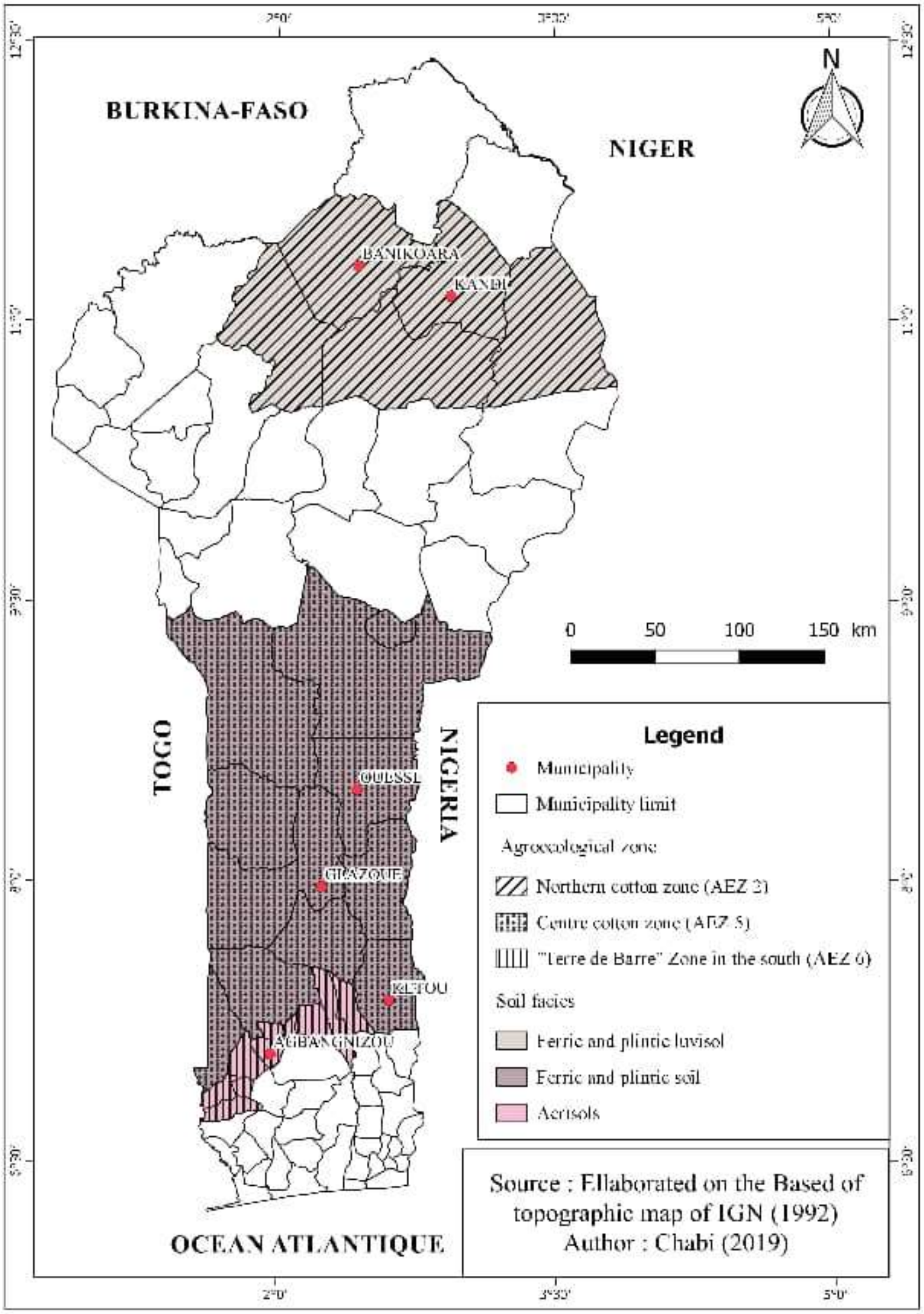

Figure 1. Localization of the surveyed areas in the study.

RESULTS

Socio-economic characteristics of the groundnut producers

In Table 1 the socio-economic characteristics of the respondents in the three AEZ are presented. In general, it is noticed a strong involvement of the men in groundnut production in the AEZ 5 and 6 while in the AEZ 2 women are much more involded. The age of the majority of the respondents (over 50%) range between 30 and 60 years old. More than 60% of the respondents have low

Table 1. Socio-economic characteristics of the groundnut producers in the three agro-ecological zones of Benin.

Variable	Modality	Frequency of respondents (%)		
		AEZ 2	AEZ 5	AEZ 6
Sex	Female	27.1	13.2	2
	Male	72.8	86.8	98
Age (years)	< 30	37.7	37.7	5.88
	30 - 60	56.3	61.2	88.2
	≥ 60	7.9	1	5.9
Educational level	None	90.7	60.46	91.2
	Primary	0.6	6.9	4.9
	Secondary	8.6	13.1	2.9
	University	0	0	0.9
Experience in groundnut production (years)	< 10	36.4	74.4	2.9
	10-20	26.5	37.9	97.1
	≥ 20	38.4	4.6	0
Duration (years) of land use	< 10	29.8	5.4	0
	10-20	33.1	89.9	77.4
	≥ 20	47.7	15.5	22.5
Area (ha) allocated for groundnut cultivation	< 10	82.9	4.6	19.6
	10 -75	15.1	91.5	61.7
	≥ 75	2	3.6	18.6
Reason for the groundnut cultivation	Self consumption	40	10.2	8
	Processing	23.7	1.6	0
	Sale	36.3	88.2	92
Contribution of groundnut to the household income	Very important	25.1	85.6	14.6
	Important	45.2	14.3	35.4
	Less important	29.7	0.1	50

AEZ 2 = Northern cotton agro-ecological zone; AEZ 5 = Centre cotton agro-ecological zone; AEZ 6 = Sudano-Guinean zone on "*terre de barre*".

education level. Experience in groundnut production ranges between 10 and 20 years in the AEZ 6, while some farmers in the AEZ 2 have more than 20 years old in groundnut production and less than 10 years in the AEZ 5.

Land use duration ranges betwen 10 to 20 years for the majority of farmers in the AEZ 5 and 6, against over 20 years (47.7% of the respondents) in the AEZ 2. The area allocated for groundnut cultivation is less than 10% of the total area owned by the majority of farmers in the AEZ 2, whereas, in the AEZ 5 and 6, it occupied between 10 and 75% of the total area. Autoconsumption is the main reason mentioned by farmers for groundnut cultivation in the AEZ 2 while it is becoming a cash crop in the AEZ 5 and 6 and market driven product with an important contribution to the household income.

Criteria used by farmers to select land for groundnut cultivation

Four criteria are used by farmers in the three AEZ to select land for groundnut cultivation (Figure 2) which included: soil characteristics (light soils without stones, good workability are preferred), yield level of the previous crop grown on the land, soils with high biological activity (presence of insect galleries, earthworm terricules, etc.) and soil with presence of striga (mentioned by farmers in

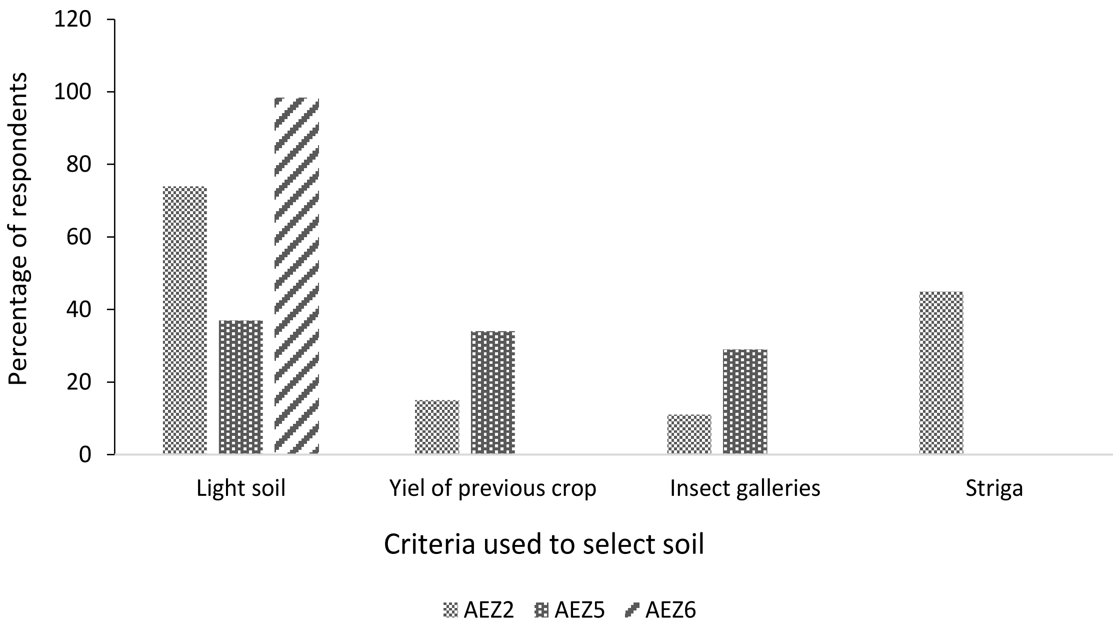

Figure 2. Criteria used by farmers to select appropriate land for groundnut cultivation in the three agro-ecological zones in Benin. AEZ 2 = Northern cotton agro-ecological zone; AEZ 5 = Centre cotton agro-ecological zone; AEZ 6 = Sudano-Guinean zone on "*terre de barre*"

the AEZ 2). Light soils easy to plough and well drained are an important criterion used by farmers in the study area (90% of the respondents). In addition to this criterion, the presence of insect galleries and striga are also used by 45% of farmers in the AEZ 2 and 29% of farmers in the AEZ 5 to select land for groundnut cultivation. Farmers (40% of the respondents) reported that, the presence of insect galleries reflects non compact soil, permeable and favourable for groundnut cultivation in most of the case.

Cropping practices adopted by farmers and groundnut yields in the three agro-ecological zones

Farmers' cropping practices for groundnut cultivation in the three AEZ are in the Table 2. Two ploughing modes are used in the area. Hundred percent of the respondents affirmed that flat ploughing practiced in the AEZ 2 often using cattle traction and ridging. Local varieties are widely used by most of the farmers' according to 80% of the respondents in the three AEZ. The seeds are mostly collected from the previous harvest. The improved varieties are used only in the AEZ 2 by 21% of the farmers. These improved varieties are introduced by traders. Each farmer can provide during the market days. Monocropping of groundnut is developed in the study area. Seeds are sown in rows in the AEZ 2, while in the AEZ 5 sowing method widely practiced, consisted of installing two seeding hills on the ridges side by side. The spacing depends on the biomass of the variety as mentioned by farmers in the AEZ 2. In the three AEZ, mostly cereal crops are rotated with groundnut. Maize is the most commonly cereal used in this rotation system according to 56% of the respondents. Rotation of groundnut with leguminous crops in the area was not observed. The results of the analysis of variance show significant difference ($P < 0.05$) among the three AEZ in terms of groundnut seed yields (Figure 3). Pods yields are significantly higher in the AEZ 2 compared to the two other zones. In all of the AEZ, pods yield is lower than 1 $t.ha^{-1}$.

Soil fertility management practices for groundnut cultivation

Soil fertility management practices for groundnut production in the three AEZ are presented in Figure 4. Crop rotation is mentioned by at least 50% of the respondents in each AEZ. Groundnut monocropping was developed in the AEZ 2. In opposite, farmers in the AEZ 5 and AEZ 6 practiced intercropping of groundnut with cereal crops (88.37 and 100% of the respondents, repectively). Supply of mineral fertilizer for groundnut production is not common in the AEZ 2, whereas, it is adopted by few farmers according to 14% of the respondents in the AEZ 5 and 6. In that case, fertilizers used were NPKSB (14-23-14-5-1) and urea. Doses applied were less than 50 kg ha^{-1}. Supply of household

Table 2. Groundnut producers' cropping practices in the three agro-ecological zones.

Practices	Modality	Percentage of respondents (%)		
		AEZ 2	AEZ 5	AEZ 6
Tillage	Flat plowing	100	0	0
	Ridge	0	100	100
Varieties used	Locale	78.2	95	100
	Improved	21.8	5	0
Sowing	Single seeding	100	6.3	45.8
	Twin seedings	0	94.7	54.2
Crops rotated with groundnut	Cereal	77.4	97.6	100
	Cotton	22.6	2,3	0
Weed management	Manual	22.3	100	100
	Herbicide	77.7	0	0

AEZ 2 = Northern cotton agro-ecological zone; AEZ 5 = Centre cotton agro-ecological zone; AEZ 6 = Sudano-Guinean zone on "*terre de barre*".

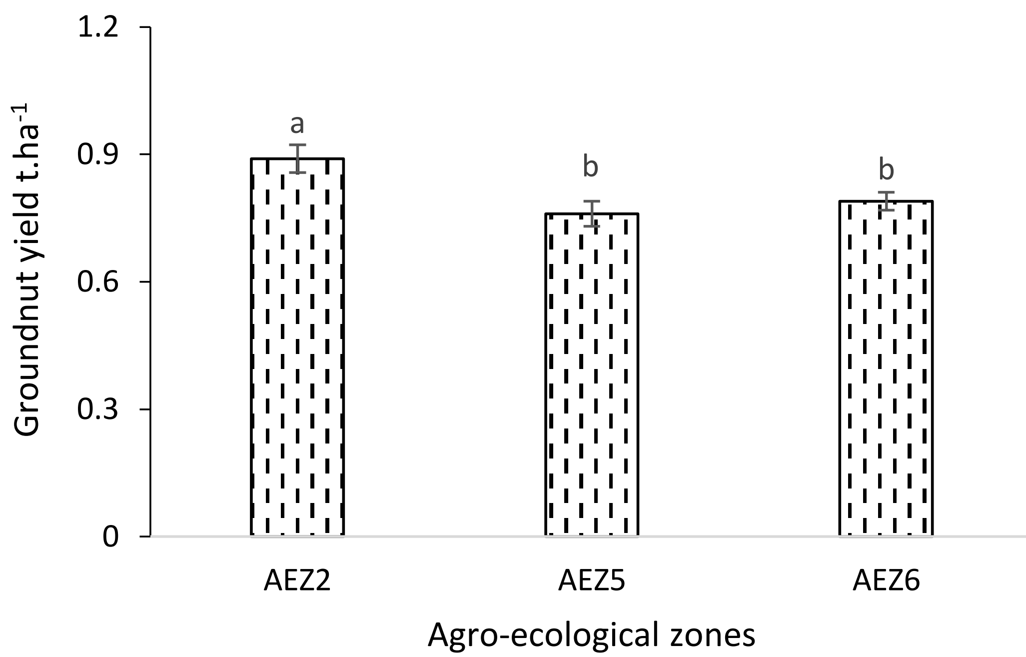

Figure 3. Groundnut seed yield variation among the different AEZ. Barre with the same alphabetic letters are not significantly different regarding groundnut seed yield; AEZ 2 = Northern cotton agro-ecological zone; AEZ 5 = Centre cotton agro-ecological zone; AEZ 6 = Sudano-Guinean zone on "*terre de barre*".

waste as organic manure to sustain soil fertility for groundnut production was observed in the AEZ 6 (18.2% of the respondents). The practices consisted of dumping the waste in the plots before ploughing. The waste was also spread during groundnut development phase. Ninety percent of farmers declared ths the use of organic manure is important in the AEZ 2, but it is marginal in the AEZ 5 and 6 (1.5 and 10.8% respectively). Organic

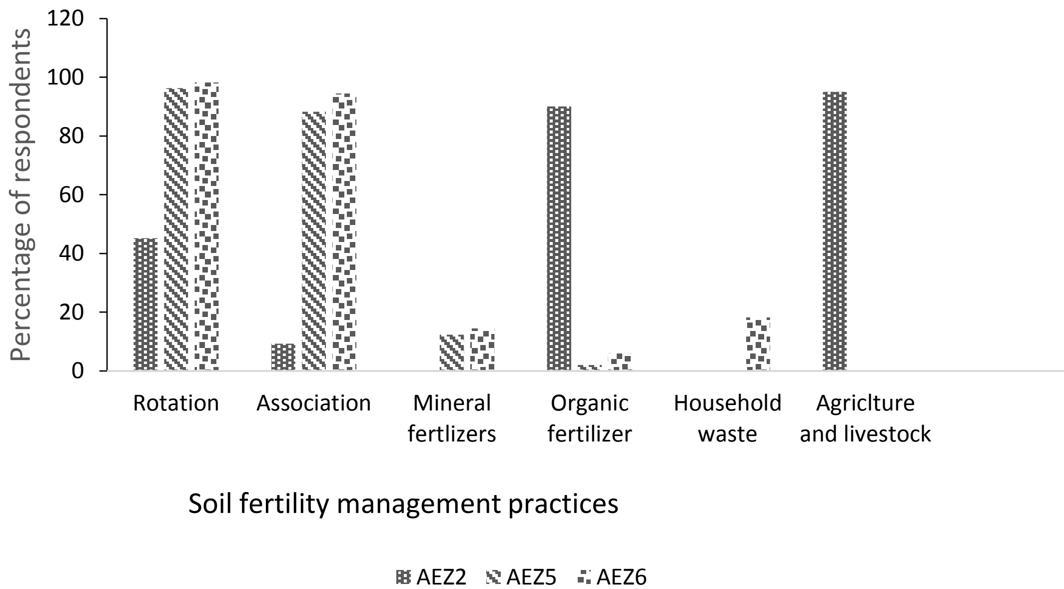

Figure 4. Soil fertility management practices for groundnut production in the three agro-ecological zones. AEZ 2 = Northern cotton agro-ecological zone; AEZ 5 = Centre cotton agro-ecological zone; AEZ 6 = Sudano-Guinean zone on "*terre de barre*".

manure used in the AEZ 2 was cow dung. In fact, integration of agriculture and livestock was only observed in the AEZ 2. In this farming system, livestocks were either parked directly on the plots or the excreta were collected and spread on the plots before ploughing. As a result of this integration in the AEZ 2, all of the respondents used crop residues especially groundnut haulms to feed livestock. Crop residues are also used as organic manure in the other two AEZ. Only 15.5% of the respondents in the AEZ 5 incorporated their crops residues in the soil before ploughing. In contrast, the majority of farmers in the AEZ 5 and 6 burnt their crop residues in the fields during land preparation for sowing.

In total, 6 groundnut cropping systems are generated (Figure 5) based on the characteristics of the cropping systems and soil fertility management practices with a determination coefficient R^2 of 0.50. The results of the multiple factor analysis carried out revealed that the first two axes explained 61.35% of the information related to the different systems. The first system was characterized by farmers who burnt crop residues in their field, practicing intercropping, crop rotation and applied mineral fertilizers. The Class 2 comprised group of farmers applying household waste as organic manure and practicing intercropping of groundnut with other crops residues especially maize. The third group of farmers comprised those practicing crop rotation and burning crop residues. The fourth group is farmers who did not practice intercropping and burn crop residues. The practice of crop rotation and avoiding intercropping of groundnut with cereal crop, the use of animal manure and integration of livestock and crop in the farming system characterized the Class 5. The sixth system comprised farmers that did not practice crop rotation but intercropped groundnuts with cereal crops and apply organic manure for soil fertility resplenishment. Farmers in this group use crop residues to feed the animals.

Farmer perceptions of the effects of climate change on groundnut productivity

The evidence of the effects of climate change on groundnut productivity was assessed (Figure 6). Farmers in the AEZ 2 mentionned that the presence of empty pods linked to leaf stunting and pods attack by termites were manifestations of climatic disturbance. While those in the AEZ 6 emphasized on poor pod filling and stunting of plants. Chlorosis remains the most appropriate manifestation for producers in the AEZ 5.

Derterminants of cropping practices for groundnut yield improvement

The results of the ordinal logistic regression used to assess the determinants of cropping practices that affect yield improvement are presented in Table 3. Variables used in the model are: supply of mineral fertilizers and organic manure, crop rotation, intercropping, crop residues management and supply of household waste. Thus, intercropping, supply of organic manure and integration of crop and livestock were practices that did not affect significantly groundnut productivity. However,

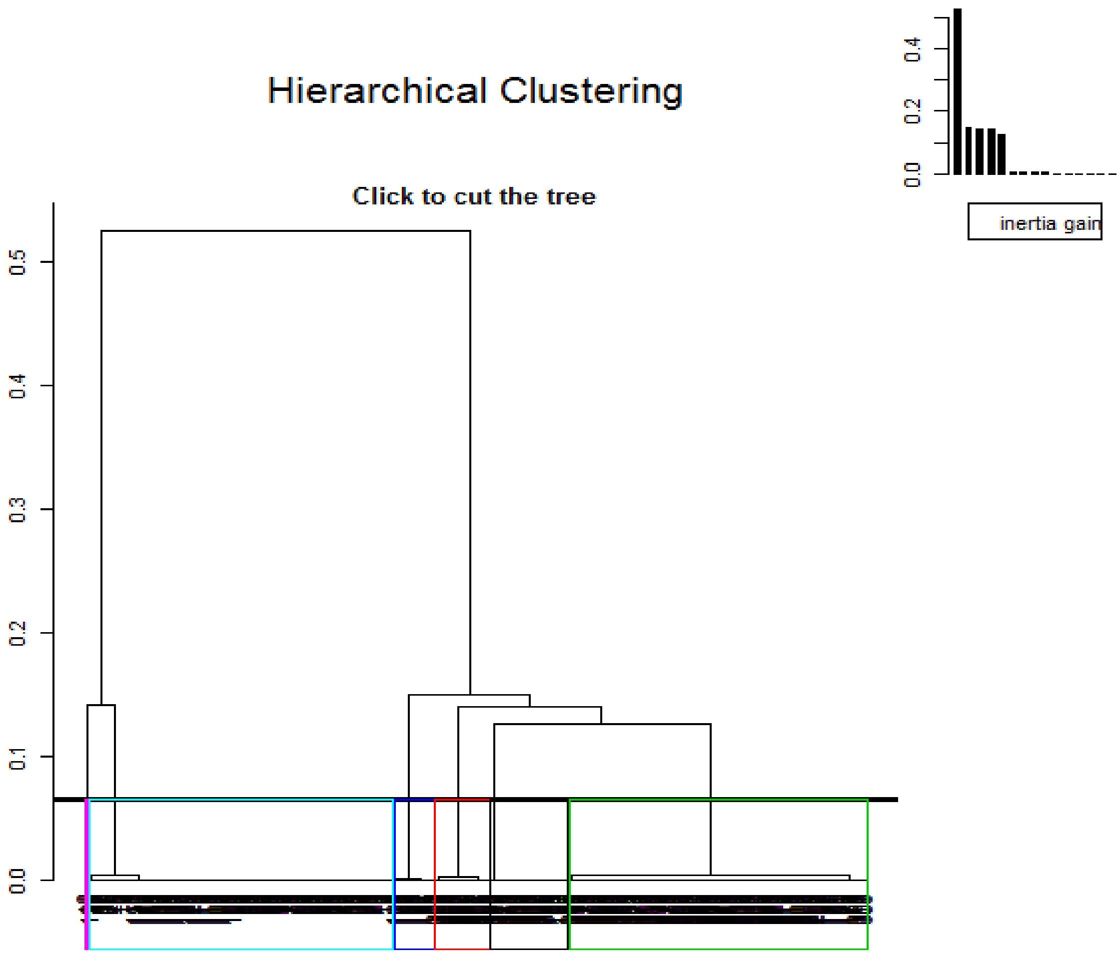

Figure 5. Soil fertility management practices dendrogram.

supply of mineral manure, crop rotation, crop residues management and the use of household waste had significant and positive effects on the groundnut yield level. Considering the socio-economic characteristics of the farmers and their cropping practices, it is observed that, the sex of the farmer affect positively groundnut yield while soil quality affects negatively the yield (Table 4). But, supply of mineral fertilizers, organic manure and household waste as soil fertitily management strategies in the one hand and farmers' age, its level of education and land use duration on the other hand did not affect significantly groundnut yield improvement.

DISCUSSION

Groundnut producers' socio-economic characteristics and cropping pratices

It is shown by our results that men were more involved in groundnut production than women. This may be due to the fact that women do not really have access to land according to the custom. In many part of Africa, the customary rules restrict land ownership right to women (Saïdou et al., 2007; Loko et al.., 2013). The strong involvement of women in groundnut production in the AEZ 2 could be explained by the fact that, groundnut was not a crop of choice for men; they were more interested in cotton production. But the plots were often donated by the husband. The age of the farmers varies between 18 and 80 years. This implies that, this population was young enough, vigorous and had enough physical energy to support the development of groundnut cultivation if they were attracted. Younger segments of the population had access to long-term portions of land, so this justifies their passion for annual crops, including groundnuts (Balogoun et al., 2014). Groundnut cultivation was practiced by a young segment of the population and thus represented labour force for groundnut production. Similar results were reported by Dogbe et al. (2013) in Ghana and concluded that leguminous production has promising future if these relatively young farmers could be motivated to remain in the sector.

The area allocated to groundnut cultivation and its

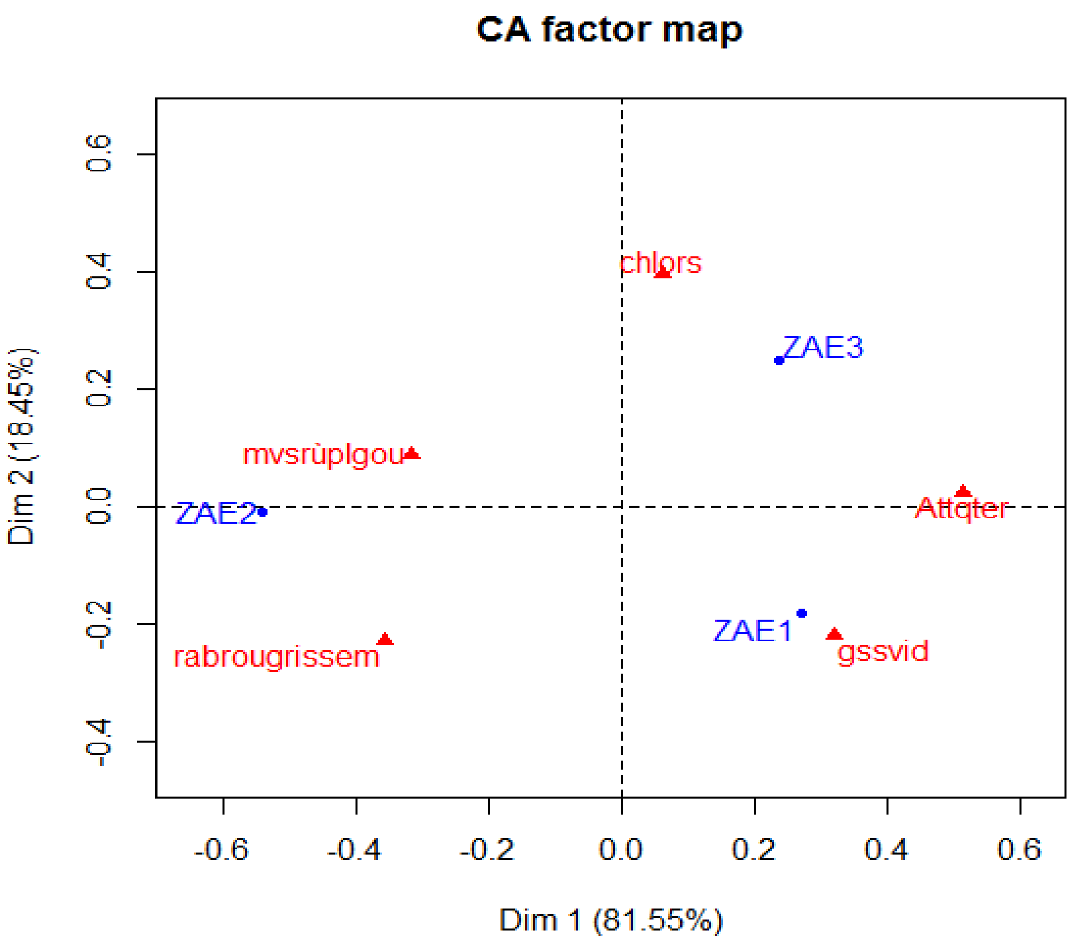

Figure 6: Farmers' perceptions on the effects of climate change on groundnut productivity. AEZ 2 = Northern cotton agro-ecological zone; AEZ 5 = Centre cotton agro-ecological zone; AEZ 6 = Sudano-Guinean zone on "*terre de barre*".Chlors = chlorosis of leaves; Attquer = pod attack by termites; stunting = stunting of plants; gssvid = empty pods; mvsrùplgou = poor pod filling.

Table 3. Determinants of groundnut yield improvement based on the cropping pratices using ordinal polychotomic logistic regression analysis.

Predictor	Coefficients	Standard error coefficients	Z value	Probability
Constante (1)	-5.1	2.8	1.8	0.05 ns
Constante (2)	-4.7	2.8	1.7	0.01*
Crop rotation	1.8	1.5	1.2	0.03*
Intercropping	-0.7	0.4	1.7	0.04*
Organic manure	-0.9	0.6	1.4	0.02*
Mineral fertilizer	0.05	0.4	0.1	0.03*
Crop residues management	1.7	0.5	3.4	0.001***
Household waste	1.9	0.8	2.4	0,02*
Integration of crop and livestock	-1.4	0.9	1.4	0,16 ns

ns = p > 0.05; * = $p < 0.05$ and *** = $p < 0.001$.

contribution to household income was very high in the AEZ 5. This could be explained by the fact that, groundnut crop was adopted earlier in this area and it is almost a cash crop for farmers (Naitormbaide, 2007; Didagbe, 2015). Shiyam (2010) also reported that groundnut is now gaining popularity as a high economic

Table 4. Determinants of groundnut yield improvement based on socio-economic characteristics of the farmers and cropping practices using ordinal polychotomic logistic regression analysis.

Predictor	Coefficients	Standard error coefficients	Z value	Probability
Constante (1)	-0.7	0.6	-1.2	0.04*
Constante (2)	1.6	0.6	2.5	0.02*
Sex	1.4	0.3	4.3	0.00***
Age	0.01	0.01	0.9	0.3 ns
Educationel level	-0.3	0.2	-1.3	0.2 ns
Experience in groundnut production	0.01	0.01	0.7	0.5 ns
Purpose of groundnut cultivation	-0.2	0.2	-0.9	0.4 ns
Duration of land use	-0.01	0.02	-0.6	0.6 ns
Organic manure	1.3	0.9	1.5	0.1 ns
Mineral fertilizer	0.5	0.4	1.1	0.3 ns
Household waste	0.3	0.5	1.2	0.9 ns
Integration of crop and livestock	-0.5	0.9	-0.6	0.6 ns
Soil quality	-0.8	0.2	-4.2	0.00***

ns = $p > 0.05$; * = $p < 0.05$ and *** = $p < 0.001$.

and cash crop for peasant households in the southern Nigeria.

In the three AEZ, mostly cereal crops were rotated with groundnut. Maize was the most commonly cereal used in this rotation sytem. In fact, farmers already noticed that groundnut has a fertilizing effect on subsequent cereal crop. On the one hand, the rotational system is based upon on the scientific evidence that leguminous crops planted in the first year will leave some nitrogen in the soil which will subsequently be fixed by the cereal crop in the next season and therefore will increase the potential yield of the cereal crop in that season unlike the continuous cereal system (Kabuli et al*.,* 2005; Nyemba and Dakora, 2010; Ngwira et al*.,* 2012). This practice was also a strategy for crop diversification in order to enhance food security (Ngwira et al*.,* 2012).

Intercropping of groundnut with cereal crops was soil fertility management pratice observed in the area. The main cereal crop involded is the maize. Several studies (Dagbenonbakin 2005; Li et al., 2006; Dahmardeh et al., 2010; Undie et al., 2012; Matusso et al., 2014) reported this common cropping pratices as a soil fertility management pratices with many advantages. Inter-cropping, was an old and commonly used cropping practice which aims to match efficiently crop demands to the available growth resources and labor (Lithourgidis et al., 2011). Moreover, intercropping improves soil fertility through biological nitrogen fixation with the use of leguminous, increases soil conservation through greater ground cover than sole cropping, and provides better lodging resistance for crops susceptible to lodging than when grown in monoculture. Intercropping provides insurance against crop failure or against unstable market prices for a given commodity, especially in areas subject to extreme weather conditions such as frost, drought, and flood (Tsubo et al*.,* 2005; Lithourgidis et al*.,* 2011). From this point of view, intercropping provides high insurance against crop failure and overall provides greater financial stability for farmers (Onduru and Du Preez, 2007). Thus, if a single crop may often fail because of adverse conditions, farmers reduce their risk for total crop failure by growing more than one crop in their field (Clawson, 1985).

Determinants of groundnut yield improvement

In general sandy texture of the soil was the most important criteria for groundnut cultivation. According to the groundnut producers' perception, this soil type facilitates root development and thus allows good pod production and also facilitates harvesting. This finding corroborates Schilling (2001) who reported that groundnut cultivation should be done on soils that are loose or loosened enough to allow the penetration of gynophores and then the removal of mature pods. In addition, groundnut requires well drained and aerated soils because the respiratory exchanges during pods setting are high. Fine textured soil, loose and permeable soils, especially sandy soils, were the most suitable.

Supply of mineral fertilizers, crop rotation, crop residues management and supply of household waste were the common soil fertility management practices noticed in tha area. Crop rotation is practiced by the majority of the farmers. In fact according to the perception of the farmers, growing groundnuts in rotation improves soil fertility and thus increases the yield of the subsequent crops. Bado (2002) showed that in a rotation system where sorghum is planted after groundnut, the yield is generally high. Most of the farmers burn their crop residues in the fields when preparing the land and few of them incorporate them in the soil when ploughing the land. The majority of the farmers did not know about the usefulness of incorporating crop residues in the soil when ploughing and when they are left in the field after harvesting, the herders' cattles destroye their crops when feading these crop residue. This is the reason for burning these crop residues.

In the AEZ 2 close to the sahelian zone, groundnut leaves are dried and used as animal feed during the dry season (Revoredo and Fletcher, 2002). According to Sossa et al*.* (2014), the return of crop residues is still a constraint for farmers noway day. Several constraints including the status of the land, the low technical capacity of producers and the lack of financial resources to purchase inputs can interfere with the acceptability and adoption of crop residues management for soil fertility replenishment (Scopel et al., 2013).

Supply of mineral fertilizers remains low among groundnut producers. This practice is essential for sustainable groundnut production (Pacharne et al*.*, 2016; Abbas et al*.,* 2018). The overall soil fertility management strategies developed previously can be considered as low external input for sustainable agriculture as they did not require mineral fertilizer. Such practices could result in severe mineral nutrient deficiency in the soil in the rainfed agriculture where erosion is important. This was probably one of the major factors responsible for low groundnut yield in the traditional cropping system (Veeramani and Subrahmaniyan, 2012). According to Dagbenonbakin (2005); Bajrang et al. (2013) an adequate integrated nutrient management based on farm yard manure and macronutrients supply is important to improve the pod yield and quality of oil. Developing appropriate fertilizer doses in the different AEZ could contribute to improve groundnut yield at farmers' field level.

Some indicators are used to assess soil fertility level before taking decision for improvement. Such observations were also mentioned by Saïdou et al. (2004); M'Biandoun et al*.* (2006) and Akpo et al. (2016). Important indicators used by farmers are much more similar with those mentioned by several autors in West Africa such as the occurrence and abundance of certain types of weeds (Saïdou et al., 2004; Akpo et al*.*, 2016), vegetation height and plant leaves color as green mean fertile soil, intensive biological activity (presence of earthworm casts, termites gallery, presence of insects etc.) and yield of previous crop.

The groundnut seed yields noticed vary from one agro-ecological zone to another and are mainly influenced by the producers' sex and soil quality. This result could be explained by the fact that, soil fertility management practices vary from one zone to another and also by the fact that, the cropping systems were not uniform in the study area *f.i* land preparation for growing groundnut varied from flat ploughing to ridging which may affect soil fertility level therefore groundnut yield. In the study area, as mentioned by Saïdou et al*.* (2004) and Akpo et al*.* (2016) poor soils were mostly lease to the women. In such situation they do not have other choice to grow groundnut in opposite with men who mostly exploit lately cleaned land for groundnut production before maize cultivation as observed in crop rotation system. Climate variability observed nowadays could also explain groundnut seed yield variability among the three AEZ as mentioned by Bello et al*.* (2016). These climate factors varied from one AEZ to another with different rainfall regime and temperature. Annual rainfall amount was less in the AEZ 2 compared with those in the AEZ 5 and 6 which known more rainfall. The main concern now is rainfall distribution during the growing season. All of these climatic factors could affect drastically crop yield. In the case of groundnut yield improvement, it has to be taken into account in the process.

Finally, the supply of mineral fertilizer to groundnut did not affect significantly the seed yields. This could be explained by the types, method or doses of fertilizer input applied and the type of soils. Mostly in Benin, only fertilizer for cotton crop (NPK-SB 14-23-14-5-1) is widely available in the market. There is no specific fertilizer for food crops such as maize, leguminous and tuber crops (Dagbenonbakin 2005; Dagbenonbakin et al*.,* 2015; Saïdou et al., 2018). Also, the extension services do not take care of this crop as it is considered as traditional crop and they emphasized only on cotton the main cash crop promoted by the government. This calling was for the development of specific fertilizer formula emphasizing on both macro and micronutrients for balanced groundnut plant nutrition and for enhancing production in the three AEZ.

Conclusion

Groundnut cultivation is an important economic activity for farmers of the AEZ studied. It contributed to the household income generation and played an important role in the cropping systems. Our result shows that groundnut cropping system varied from one AEZ to another. Results of this study point out that, supply of organic manure, crop rotation, crop residues management and supply of household waste had significant and positive effects on groundnut yield level. Furhtermore, the sex of the farmers affect significantly and positively groundnut yields while soil quality affects negatively the yield. Therefore, it is concluded from the present study that, soil fertility management strategies planned by farmers considering their sexes and their additional sources of income are factors determining groundnut cultivation or not.

Nevertheless, our result did not show significant groundnut seed variability among the AEZ when mineral fertilizer is applied. This was explained by the type of soils, the quality, dose and farmer management practices among the zones. We suggest the development of specific fertilizer formula emphasizing on both macro and micronutrients for balancing groundnut plant nutrition and for enhancing its production in the three AEZ.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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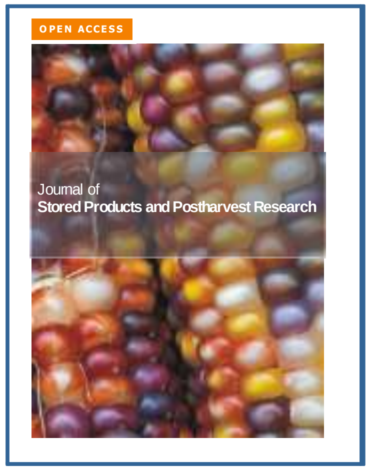

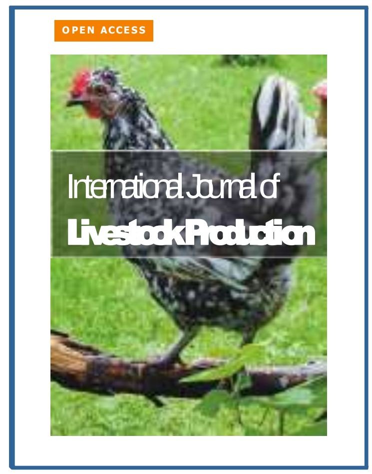

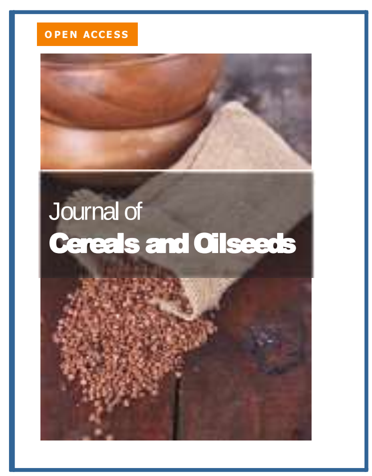

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