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Full Length Research Paper

Operational performance of the mechanized picking of coffee in four soil slope

Tiago de Oliveira Tavares*, Rouverson Pereira da Silva, Felipe Santinato, Adão Felipe dos Santos, Carla Strini Segatto Paixão and Vantuir de Albuquerque Silva

Department of Agricultural Engineering, UNESP Universidade Estadual Paulista, Campus de Jaboticabal “Júlio de Mesquita Filho”, Campus de Jaboticabal, Via de Acesso Prof. Paulo Donato Castellane, s/n, 14884-900, Jaboticabal, São Paulo, Brazil.

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The coffee mechanized picking is an essential operation in modern coffee crop, however, is still an activity with few studies that emphasize the factors that could interfere in its operational performance. Assuming that the slope of the land can be one of these factors, it aimed to evaluate operational performance of a mechanized set of coffee picking in different terrain slopes. The treatments consisted of coffee mechanized picking in four slope lanes (0.0 to 5.0%, 5.1 to 10.0%, 10.1 to 15.0 and 15.1% to 20.0%) distributed in experimental design in lanes with three replications. The evaluation of the operational performance was materialized by means of timing and movements' analysis, collecting up time in operation, unloading and maneuvering, as well as efficiencies analysis of picking and cleaning. The operation was performed in crop with 1.133 kg of coconut coffee ha⁻¹ to be picked. The slope of the land, from 15.1%, interferes in the performance of the harvester, significantly reducing the effective and operational field capacity. Slopes of up to 20% do not harm the cleaning efficiency; on the other hand, for picking efficiency, slopes higher than 15% significantly reduce the performance of the machines.

Key words: *Coffea arabica* L., land slope, mechanical harvesting, machine performance, harvesting loses.

INTRODUCTION

The Brazilian coffee production experienced in recent years, a change of scenery, in which occurred the increase of costs with input and labor, but without the corresponding increase in prices received by the production (Fernandes et al., 2012). Thus, the producers had to adapt, reducing the possible costs and increasing crop yields. The way was to invest in technologies that

increase yields and reduce the demand for labor, such as the substitution of manual harvesting by mechanized (Lanna and Reis, 2012).

Coffee mechanized harvesting is currently constituted of two stages; the first being represented by the coffee harvest in the plant, while in the second, there is the coffee picking lying on the ground, also called sweeping

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

coffee (Tavares et al., 2015). Total replacement of manual harvesting by mechanized allows reducing the cost of harvesting up to 60% (Santinato et al., 2015a; Lanna and Reis, 2012; Silva et al., 2003).

While big part of the producing regions choose to mechanized harvesting, areas with sloping reliefs can reduce or even prevent the use of machinery (Fernandes et al., 2012). Höfig and Araujo-Junior (2015) classifies soil slope with potentiality for mechanization in the coffee culture in extremely apt (0 to 5%), very apt (5.1 to 10%), apt (10.1 to 15%) moderately apt (15.1 to 20%) and not recommended (> 20%). On the other hand Santinato et al. (2015b) reported that recent improvements in harvesters, as well as good planning of crops, have favored the harvest in areas with up to 30% of slope.

In the second step of mechanized harvesting, referring to the sweeping and picking, few studies are available in the literature. According to Tavares et al. (2015), there are many factors that affect the quality of these operations, such as differences in level and uneven ground, amount of impurities and quantity of coffee. On the other hand, there is no information if the slope interferes in the coffee mechanized picking operation efficiency.

In one of the few studies evaluating effects of slope in mechanized operations, Pereira et al. (2012) studying subsoiling found that to the measure in which the slope increases, the depth reached by the subsoiler decreases. On the other hand, Robert et al. (2013) found no significant losses in operating capacity of a forest harvester to the slope of 27%. Therefore it is liable to study each operation to verify their limitations about the slope of their workable areas.

In surveys conducted by Bernardes et al. (2012), in the state of Minas Gerais that represents 50% of national production, crops are found in almost all the slope tracks, however, there is a predominance of crops on slopes between 5 and 15%.

Assuming that the slope can affect the performance of coffee mechanized picking operation, the objective of this study was to evaluate, through the analysis of time and motion as well as the efficiency of picking and cleaning, the performance of the harvester in four slope lanes.

MATERIALS AND METHODS

The experiment was conducted in August 2015 in the agricultural area of the municipality of Presidente Olegário, Minas Gerais, near the geodetic coordinates latitude 18° 33' South and longitude 46° 20' West, with an altitude of 1030 meters. The soil is classified as Dystrophic Oxisol by the EMBRAPA classification (2006), having sandy texture with 70% of sand. The weather is Aw according to the classification of Peel et al. (2007), with average rainfall of 1,400 mm annually.

The experimental area corresponds to 2.0 ha with lines of 235 m in length, of Catuaí Vermelho IAC 144 variety, cultivated in level in the spacing of 4.0 m between rows and 0.5 m between plants (5,000 plants ha⁻¹) at 32 months of age, drip irrigated.

The coffee picking was conducted using the mechanized

combination of a tractor 4 x 2 with a nominal power of 55.2 kW (75 hp) and a Master II coffee harvester, operating at 540 rpm in TDP rotation and theoretical speed of 1.0 km h⁻¹. It is emphasized that, because it is an area with slope bigger than 15%, the tractor had liquid and metal ballast, in addition to working with larger track gauge (1.23 m). In this sense, it the front axle was equipped with 240 kg of metallic ballast and 220 kg of liquid ballast and on the rear axle was used 200 kg of metal ballast and 350 kg of liquid ballast, providing greater stability and safety in the operation.

The treatments consisted of collecting mechanically the fallen coffee in four slopes lanes: 0.0 to 5.0%; 5.1 to 10.0%; 10.1 to 15.0% and 15.1 to 20.0%. This slope was evaluated by the average of 15 points for interrow, spaced 15 m apart, with the aid of a digital clinometer 1.4 Apk. Thus, the experimental design was in lanes with three replications (3 lines of coffee for each treatment).

Previous to picking efficiency analysis, it was performed the area characterization. It was determined the quantity of coffee present in each plot, raking up in an interrow area of 30 m², obtaining the existing coffee load of 1,133 kg ha⁻¹ (8.1 bags ha⁻¹).

During the operation, it was evaluated the timing and movements, measuring with aid of stopwatch and a field notebook, the time spent picking, making maneuvers and unloading, as shown in Table 1.

After data acquisition, the times obtained were extrapolated to the area of one hectare. Operational efficiency was calculated according to ASABE EP 496.3 rules (2011), while the time efficiency and the operational and effective field capacity were determined in accordance with Mialhe (1974).

The effective field capacity was adapted from Mialhe (1974) and calculated by means of Equation 1.

$$Efc = \frac{S \times R}{10} \quad (1)$$

Where:

Efc: effective field capacity (ha h⁻¹);

S: displacement speed (km h⁻¹);

R: interrow spacing of coffee (m);

10: adequation fator of the units.

Operational field capacity has already been adapted from Mialhe (1996) according to Equation 2. Is worth emphasizing that the harvester efficiency is the percentage of time where the same is operating effectively, discounting the maneuvers and the unloading compared to the total time (Equation 3).

$$Ofc = \frac{S \times R \times Ef}{10} \quad (2)$$

Where:

Ofc: operational field capacity (ha h⁻¹);

S: displacement speed (km h⁻¹);

R: interrow spacing of coffee (m);

Ef: efficiency of harvester;

10: adequation fator of the units.

$$Ef = \left\{ \frac{Tc}{Tc + Tm + Tu} \right\} \times 100 \quad (3)$$

Where:

Ef: efficiency of harvester (%);

Tc: Collecting time (s);

Tm: Maneuver time (s);

Tu: Unloading time (s).

Table 1. Division of activities in the coffee mechanized picking.

Activity	Description
Total time	Time in which the harvester starts working (picking) to end of the unload, including picking time, maneuvering and unloading.
Picking time	Time demanded for the coffee picking, comprising the time the harvester platform remains positioned on the ground picking the windrows.
Maneuvers time	Time spent to transport the harvester from one row to another, counted from the moment in which the harvester platform is lifted of the ground, in the interrow end, until the repositioning of the same on the ground at the beginning of another interrow.
Unload time	Time required to unload and return to the crop, being the time counted after the removal of the platform from the ground, including the displacement until the transport unit (bucket, trailer or truck), the unload and the return to the crop, when the harvester platform is positioned again on the ground.

For evaluation of cleaning efficiency, it was collected directly from the elevator that carries the collected material for the machine deposit, three sub samples of 1 L, per repetition, resulting in twelve samples per treatment. And then, mineral and vegetable impurities were separated manually from the coffee. The materials have their mass determined in accurate weight balance to 0.1 g, and the values were transformed into percentage in order to obtain the purity and impurity of each sample, being the purity percentage that represents the separation efficiency of harvester.

The picking efficiency was calculated by the loss levels in each sample point (coffee not picked by the machine) according to the equation 4. Again, three random points per interrow were collected, totaling twelve points per treatment. These losses were collected with the aid of a metal frame of 3.8 m² (3.8 m x 1.0 m) subdivided into three parts, two of 1.1 m² in the extremities and one of 1.6 m² in the center part, positioned perpendicularly between the lines after the picking operation. Initially the fruits found in the central region of the frame were collected, which represents the place of the harvester performance and consequently the picking losses.

$$PE = \frac{(CW - L)}{CW} \times 100 \quad (4)$$

Where:

PE: Picking efficiency (%);

CW: Total amount of coffee in windrows (kg m⁻²);

L: Loss or remaining coffee (kg m⁻²).

The results were submitted to analysis of variance by F test of Snedecor and, when appropriate, Tukey test, both at 5% probability.

RESULTS AND DISCUSSION

In Figure 1, time spent on unloading is observed, maneuvers and in operation to perform the picking at one hectare. Given that the unloading time is influenced by the distance between the area and the place of unloading (trailer), it was used in this study the unloading average into the total area evaluated, obtaining the average time of sixteen minute unloading per hectare to the working conditions. On the other hand, the times of maneuvers and operation were affected by the slope. For the

maneuver times, it was noted that in areas from 10.1 to 15.0% and 15.1 to 20.0% of slope there was an increase in time spent on maneuvers in the order of 37 and 106%, respectively, in relation to the picking realized in area with lower slope (0.0 to 5.0%). The same occurred to the time spent on picking operations, in which to operate in the area from 15.1 to 20.0% of slope had an increase of 1 h 29 min ha⁻¹ (111%) on the time spent when compared to the same route in local lower slope (0 to 5%). This occurred by the fact that, in larger slopes; there are points of greater inclination that require the operator to change gears all the time to reduce speed and the risk of the harvester to fall over.

Similar results were found by Leite et al. (2014) in forestry mechanical harvesting, in which by working in areas of 17% of slope there an increase of 11% of the time is spent to perform the same amount of service to the area with 7% of slope, increasing the cost of harvesting. Höfig and Araujo-Junior (2014) emphasize the importance of considering the slope in the planning of the coffee mechanization, treating each slope level suitability in a unique way.

Efficiency of harvester was not affected by the slopes (Figure 2a) showing values between 82.9 and 83.6%. This fact is explained by the operation and maneuver times be harmed in a proportional way with increasing of the slope (Figure 2b). As also observed by Pereira et al. (2012), in which the slope increased the total time of subsoiling operation in pasture area. On the other hand, Robert et al. (2013) found no differences by studying the performance of a forest harvester working on high slopes, a fact that occurred due to the presence of continuous tracks.

In general, in places with greater irregularity, the picking operation has harmed their income significantly and may incur errors in the previous planning of time spent for this operation. This time interferes in the operational and effective field capacity (Figure 3) which decreases in a similar manner as long as it increases the slope of the terrain. The reason to present similar

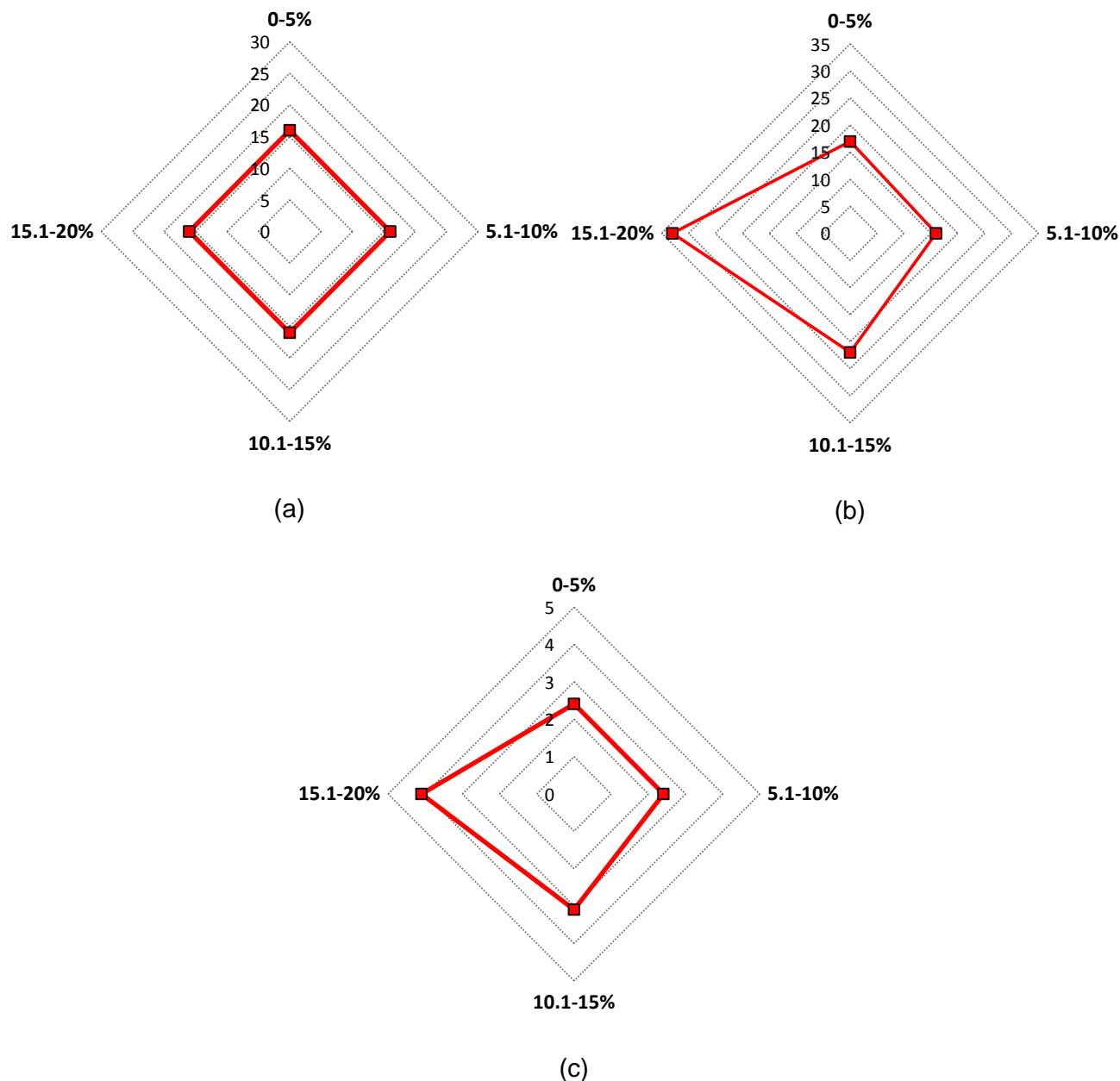


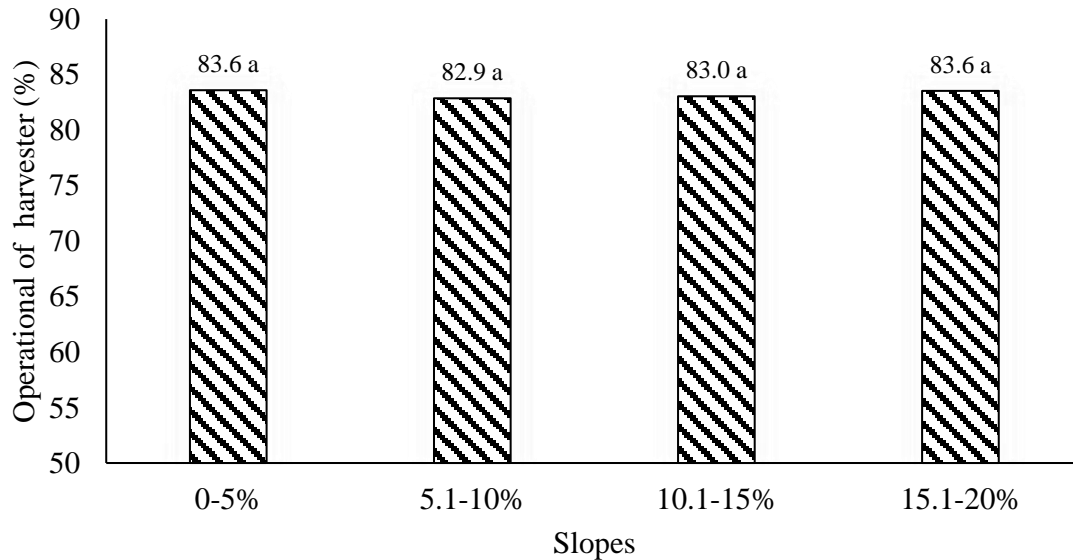
Figure 1. Estimated times for unloading (a), maneuvers (b), and time in operation (c) in min ha^{-1} . Means followed by the same letters do not differ by Tukey test at 5% probability.

behavior is only due to the fact that there was no difference in efficiency of harvester (Figure 2a) for the studied slopes. Therefore, in this case, the operational field capacity is equivalent to approximately 83.55% of the effective field capacity.

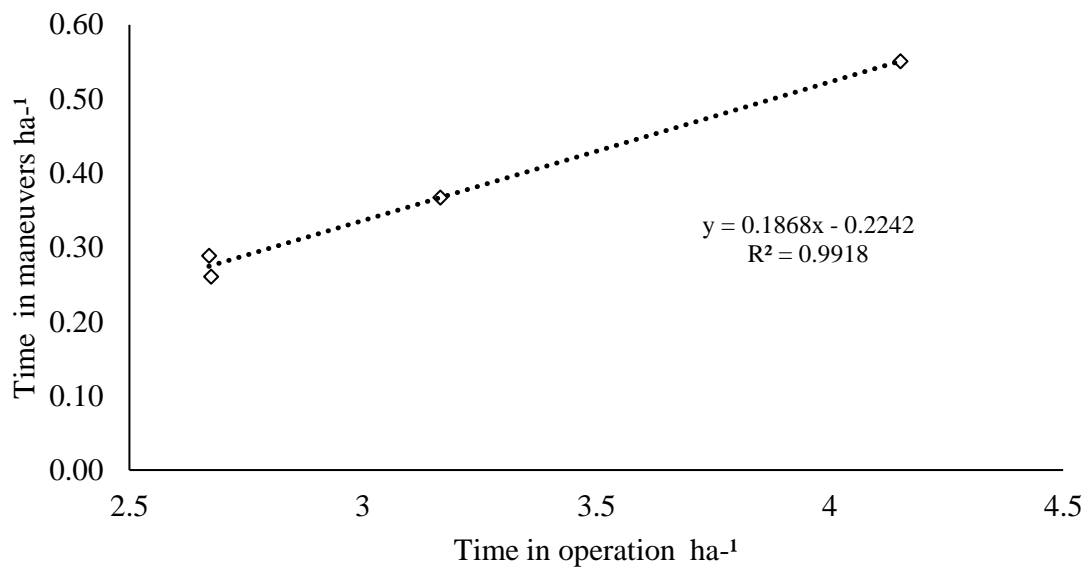
Also in Figure 3, it was observed that for standard working speed used on the farm, it would be possible to perform the picking of 0.31 ha in a one hour period (without stopping) in areas from 0.0 to 10.0% of declivity, however, for areas with 10.1 to 15.0% and 15.1 to 20.0% of slope had reduced by 13 and 42%, respectively, the

operational field capacity. This fact should be considered in the harvest planning, and can be adjusted the number of tractor-harvester sets to perform the picking in the required period.

Molin et al. (2006) reported that information on the performance and working capacity of agricultural machines are of great importance in the management of agricultural mechanized systems, helping in decision making. Thus, it is necessary to adjust the number of mechanized sets to the crop situation and the time to perform the service. Corroborating with this, Leite et al.



(a)



(b)

Figure 2. Efficiency of harvester (a) and correlation between time in operation and time in maneuvers (b) in function of the slope, equivalent to 1 h^{-1} .

(2014) report that for the eucalyptus mechanical harvesting there is a demand service 11% higher in declivous locations when compared to flat areas.

Besides the operational characteristics, we should also analyze the quality of the operation itself. In this way, we used two variables: picking efficiency and cleaning. The results obtained are shown in Figure 4, by which it is noted that the picking efficiency is significantly influenced

by the slopes, which is not observed in the cleaning efficiency.

The harvester picked on average 70.1% of the ground coffee, then the remaining coffee was not picked for two reasons: first because the area is of the first crop, with certain irregularity of the ground surface. Usually this irregularity was adjusted over the years as a result of other tracts such as weed control with macerator (brush);

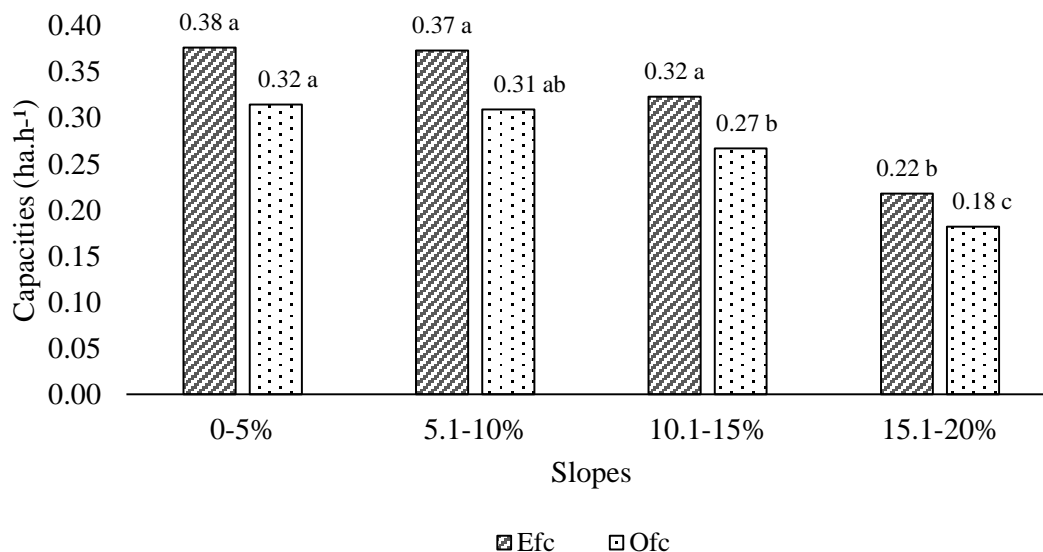


Figure 3. Effective field capacity (Efc) and operational field capacity (Ofc) in function of the slope, in hectares h⁻¹.

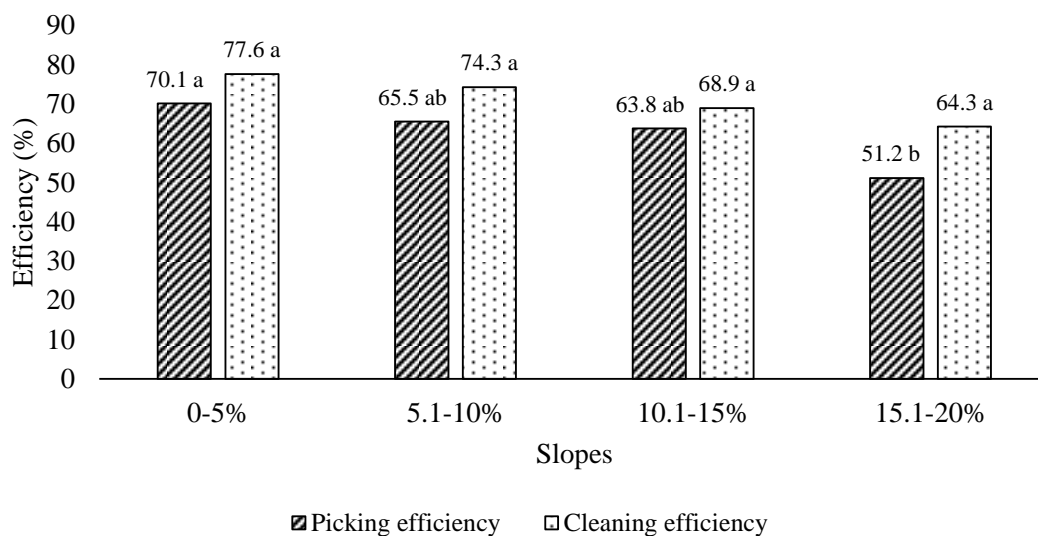


Figure 4. Picking and cleaning efficiency of the harvester due to the slope of the terrain.

the second reason is related to the type of soil that had a high percentage of sand, favoring the moment of squaring, the burying of the fruit, preventing them to be captured by the harvester platform.

Tavares et al. (2015) explain that the harvesters have great sensitivity to the shape and composition of the windrows, as well as the surface soil disuniformity, being necessary to perform previous operations to facilitate the process of picking and cleaning the sweeping coffee. Santinato et al. (2015) points out that the mechanization of harvesting activities have an important role to reduce

costs as well as increases the operational capacity, being of great importance for sustainability of the activity.

The cleaning efficiency had average between 77.6 and 64.3%, lower values than those found by Tavares et al. (2015) conducted in adult crops with soft relief (3% of slope), in which they obtained average of 85% of cleaning efficiency. It was also noted that the slope did not affect significantly on the harvester cleaning process. In principle this can be explained by the existence of partitions in the cleaning sieves which prevent the material to concentrate only on one side of the harvester

when it is inclined. In this way, the material is distributed during the cleaning process, assists in the separation capability and in the elimination of impurities. In case of does not exist these partitions, the material would concentrated only on one side and would not occur the separation of the coffee impurities, that could increase them in the picked coffee and raise the losses levels.

Conclusions

- 1) The coffee mechanized picking may be made with the same performance in slopes of 0 to 15%.
- 2) From 15.1% of slope there is a reduction of 42% of operational and effective field capacities when compared to plain areas.
- 3) In areas with slopes up to 15.1% the demand for mechanized sets increases by 72% should be considered in the dimensioning of the fleet.
- 4) The cleaning efficiency is not affected by slopes of 20%, on the other hand, the picking efficiency; from 15.1% of slope was significantly hampered, picking only 51.2% of the coffee contained in the area.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) for analyzing the agronomic performance of corn

Maicon Nardino^{1*}, Diego Baretta², Ivan Ricardo Carvalho², Tiago Olivoto³, Diego Nicolau Follmann⁴, Vinícius Jardel Szareski⁵, Mauricio Ferrari², Alan Junior de Pelegrin², Valmor Antonio Konflanz⁶ and Velci Queiróz de Souza⁷

¹Department of Mathematics and Statistics, Federal University of Pelotas, Capão do Leão, Rio Grande do Sul, Brazil.

²Plant Genomics and Breeding Center, Federal University of Pelotas, Capão do Leão, Rio Grande do Sul, Brazil.

³Department of Agronomic and Environmental Sciences, Federal University of Santa Maria Frederico Westphalen, Rio Grande do Sul, Brazil.

⁴Agronomy Department, Federal University of Santa Maria, Santa Maria, Rio Grande do Sul, Brazil.

⁵Department of Crop Science, Federal University of Pelotas, Capão do Leão, Rio Grande do Sul, Brazil.

⁶Breeder Company Plants KSP Seeds Ltda, Pato Branco, Brazil.

⁷Federal University of Pampa, Dom Pedrito, Rio Grande do Sul, Brazil.

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Adoption of accurate and simplistic biometric models that estimate variance components, predicting genotypic effects are desired in plant breeding. The aim of this study was to estimate the variance components and predict genotypic values by REML/BLUP for combinations of maize inbred lines derived from two heterotic groups with F₁'s evaluation in four locations. The crosses originated 25 hybrids that were evaluated in four trials. Genotype x environment interaction provided oscillations regarding the best combinations in the environments and must be individually analyzed in each environment, the superior crosses for grain yield, except 15x3' combination, which achieved good performance in all the trials. The combination of 5x4' is promising for obtaining high grain yield in Itapiranga and Pato Branco. The 5x3' combination have a higher overall average, being higher than the other combinations in Clevelândia and Ampere environments for plot yield, providing hybrids with fewer branches in the tassel.

Key words: Best linear unbiased predictor, restricted maximum likelihood, *Zea mays* L.

INTRODUCTION

The success of a corn breeding program is achieved, among other factors, with the launch of a hybrid of equal

or superior performance than already commercially available. Biometric models used for genetic constitutions

*Corresponding author. E-mail: nardinomn@gmail.com.

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evaluation in preliminary trials aiming at increasing efficiency and accuracy in selection of lines' combinations are very important for breeding programs achieve their goal.

The need for robust and accurate models in evaluating complex experiments (multi-sites trials, multi-year trials), is making the mixed models-based on restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) more and more popular in plant breeding programs (Resende, 2004) due in many cases, the effect of local/year considered random, where the inferences are general (Piepho et al., 2007). REML/BLUP-based procedures are scarcely penalized by the non-additive nature of traits and by the experimental unbalance as compared to ANOVA-based models (Hu, 2015). In maize, these methods were effective in assessing the performance of hybrids and in accurate prediction of the variance components and breeding values (Nardino et al., 2016; Baretta et al., 2016).

In annual or biennials plants, the use of mixed models is still limited, although growing, as reported in works by Borges et al. (2009). In Brazil, it has been used in several crops such as sugarcane (Bastos et al., 2007; Lopes et al., 2014), soybeans (De Melo Pinheiro et al., 2013), beans (Carbonell et al., 2007) oat (Coimbra et al., 2005) and in potato (Souza et al., 2005).

Adoption of accurate and simplistic biometric models that estimate variance components and predict the genotypic effects are desired in plant breeding, largely due to effects of genotype x environment interaction. In this context, the aim of this research was to estimate the variance components and predict genotypic values by REML/BLUP of maize inbred lines' combinations from two heterotic groups, crossed in partial diallel scheme with F_1 's evaluation in four locations.

MATERIALS AND METHODS

The tests were based on artificial crosses among inbred lines, from company's research station KSP Seeds Ltda., in the city of Clevelândia-PR, Brazil in 2010-2011 growing season. The crosses were carried out in partial diallel design resulting in 25 F_1 's hybrids, which were evaluated at different locations. The hybrid seeds were hand harvested, dried and prepared for the trials' sowing in four environments.

Sowing of trials was carried out in 2011-2012 growing season in four different locations of Santa Catarina and Paraná States, in southern part of Brazil (Table 1). In previous sowing, each experimental area was analyzed in order to identify potentially disruptive features. A randomized complete block design with three replications was used. Blocks were allocated in order to maintain homogeneity within the block and heterogeneity between the blocks. Experimental units were composed of two 5-m-long cultivar rows, spaced by 0.7 m, adjusting the stand to 42 plants per experimental unit, equivalent to 60,000 plants ha^{-1} .

The following traits were assessed: plot grain yield (GY, kg per plot), ear height (EH in centimeters) distance from the last node of the stem to the first branch of the tassel (DLN in centimeters), number of tassel branch (NTB, units) and thousand-kernel weight (TKW in grams), measured by counting eight replicates of 100

kernels.

Estimates of genetic parameters were carried out based on the restricted maximum likelihood and the best linear unbiased predictor (REML/BLUP). The data set was subjected to analyses in order to estimates genetic parameters based on the procedures of the restricted maximum likelihood and the best linear unbiased predictor (REML/BLUP). The softwares used in the analyses were Selegen (Resende, 2007b) and SigmaPlot v.11.

RESULTS AND DISCUSSION

Components of variance estimated by REML shows that for the DLN trait, genetic variance (σ^2_G) represents 9.76% of total phenotypic variance (σ^2_F), and the variance of interaction ($\sigma^2_{G \times E}$) 16.71%, being the great part of total variation coming from environment (σ^2_E) 73.53%. Components of variance for the TKW trait show 11.40% for σ^2_G , 19.70% for $\sigma^2_{G \times E}$ and 68.90% for σ^2_E . Total variance for EH was explained by 12.61% σ^2_G , 20.43% σ^2_E and the great contribution was from $\sigma^2_{G \times E}$ (66.95%). Total variance for GY was decomposed into 65.52 % from $\sigma^2_{G \times E}$, 10.34% from σ^2_G and 24.14% from σ^2_E , indicating that much of the variation is due to effects of genotype x environment interaction. Variance components for NTB trait are great for σ^2_E (46.44%), for σ^2_G (39.31%) and for $\sigma^2_{G \times E}$ (14.25%). Variance component of GxE interaction is superior to the other variances, except phenotypic, for EH (66.95%) and GY (65.52%). For other traits, the environmental variance represents the largest fraction of the phenotypic variation; however, it can be considered that there is genetic variation among hybrids, especially for NTB trait (Figure 1).

The accuracy values show the precision of inferences of the average of genotype (Table 2). Accuracy values for the traits were classified as moderate too high (Resende and Duarte, 2007). According to Candido et al. (2009), obtaining a successful breeding program depends, among other on parameters for conducting trials with efficient analysis methodologies.

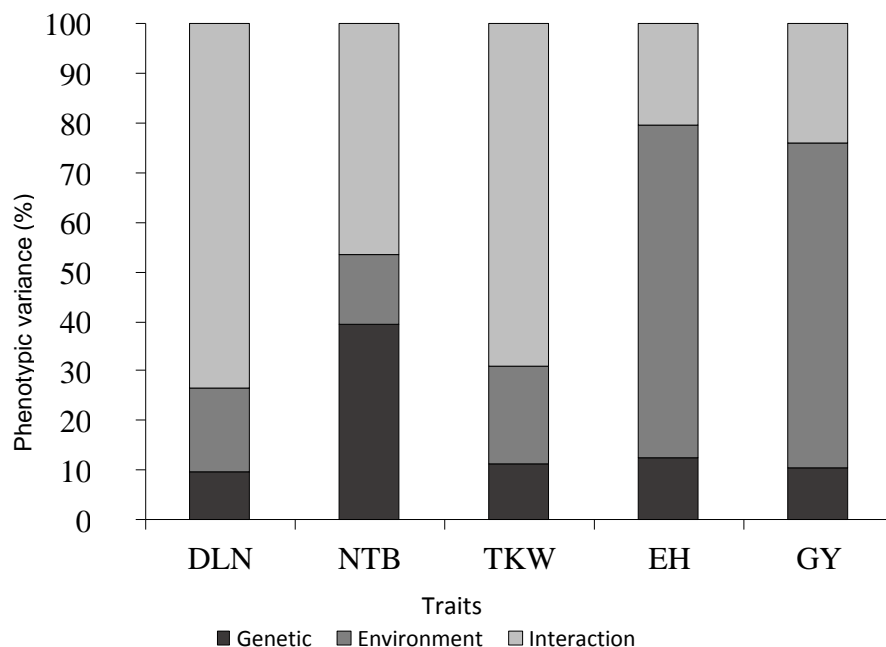
The magnitudes of $\sigma^2_{G \times E}$ were lower as compared to σ^2_G and H^2_G only for NTB trait, resulting in a genotypic correlation between the environments (r_{gloc}) of 73%. These results indicate the tendency of genotypes' stability in different locations, which is too upper and lower for the trait. For the other traits; however, the magnitude of $\sigma^2_{G \times E}$ was over σ^2_G and high as compared to h^2_G , resulting in lower values of r_{gloc} for DLN ($rg_{loc} = 0.37$), TKW ($rg_{loc} = 0.37$), EH ($rg_{loc} = 0.16$) and GY ($rg_{loc} = 0.15$).

Genetic correlations between environments for these last traits show that hybrids do not have the same behavior in different environments, occurring variations in the ordering of genotypes. GxE interaction contains a part related to the difference between the genetic variance of trait in different environments and over the lack of association between genetic treatments in one environment to another. The first is called simple

Table 1. Location and climate characteristics of experimental areas.

State	City	South LAT	West LONG	MASL	Climate ⁺	Average temperature ^{+,*} (°C)		Annual rainfall ⁺ (mm)
						T _{cold}	T _{hot}	
Santa Catarina	Itapiranga	27°10'10"	53°42'44"	206	Cfa			1760
	Ampére	25°54'65"	53°25'39"	580	Cfa	15.9	>22.0	1960
Paraná	Pato Branco	26°13'44"	52°40'15"	760	Cfa			1947
	Clevelândia	26°21'52"	52°28'22"	860	Cfb	13.4	20.0	2243

⁺ The climate classification is according to Alvarez et al. (2014). ^{*} Average air temperature for the two climate classifications presented in the trial areas. T_{hot} = Average air temperature in the hottest month of the year, T_{cold} = Average air temperature in the coldest month of the year.

**Figure 1.** Partitioning of phenotypic variance into genetic, environment and interaction effects.**Table 2.** Variance components (VC) estimated by restricted maximum likelihood (REML) for the traits distance from the last node to the first branch of the tassel (DLN), number of tassel branch (NTB, units), thousand-kernel weight (TKW), ear height (EH) and grain yield (GY).

VC	DLN(cm)	NTB (units)	TKW (g)	EH (cm)	GY (kg)
σ^2_G	1.01	4.8	168.37	20.33	0.09
$\sigma^2_{G \times E}$	1.73	1.74	290.91	107.9	0.57
σ^2_E	7.61	5.67	1017.44	32.93	0.21
σ^2_F	10.35	12.21	1476.72	161.16	0.87
h^2_{gIndiv}	0.098(±0.05)	0.392(±0.10)	0.117(±0.05)	0.126 (±0.05)	0.112(±0.05)
C^2_{int}	0.17	0.14	0.19	0.67	0.66
h^2_{min}	0.48	0.84	0.52	0.41	0.43
\hat{r}_a	0.70	0.91	0.72	0.64	0.60
rg_{loc}	0.37	0.73	0.37	0.16	0.15
Overall average	21.82	15.90	334.42	121.85	8.47

σ^2_G : gen|Etic variance; $\sigma^2_{G \times E}$: variance of Gx E interaction; σ^2_E : environmental variance; σ^2_F : phenotypic variance; h^2_{gIndiv} : individual heritability without interaction effects; C^2_{int} : coefficient of determination of the interaction; h^2_{min} : Average heritability; \hat{r}_a : selective accuracy; rg_{loc} : correlation between locations.

Table 3. Estimates of average components by best linear unbiased predictor (BLUP) for the traits distance from the last node to the first branch of the tassel (DLN), number of tassel branch (NTB, units), thousand-kernel weight (TKW), ear height (EH) and grain yield (GY).

Ranking*	DLN (cm)		NTB (units)		TKW (g 1000 kernels ⁻¹)		EH (cm)		GY (kg plot ⁻¹)	
	Cross***	u+g**	Cross	u+g	Cross	u+g	Cross	u+g	Cross	u+g
1	2x3	23.82	5x3	18.92	15x5	351.92	15x3	122.50	5x3	8.88
2	11x3	22.90	14x4	18.80	13x3	347.88	10x5	122.05	5x4	8.77
3	5x3	22.73	4x7	17.47	1x4	345.29	6x3	122.01	1x4	8.75
4	4x6	22.58	15x3	17.12	15x2	342.54	13x3	121.91	15x3	8.73
5	4x7	22.77	2x3	17.10	5x3	342.48	1x1	121.60	13x3	8.63
6	4x3	22.73	4x3	17.03	4x7	339.34	12x3	121.53	12x3	8.57
7	3x1	22.44	6x3	16.75	10x5	338.33	5x3	119.34	15x2	8.51
8	14x4	22.40	11x3	16.42	3x1	338.23	4x3	119.16	11x3	8.51
9	6x4	22.33	7x4	16.22	15x3	337.41	15x8	119.10	4x7	8.49
10	8x4	22.32	6x4	16.12	6x3	335.95	7x4	119.10	10x5	8.48
11	3x4	22.29	3x4	16.12	12x3	334.68	1x4	118.89	6x3	8.46
12	6x3	22.27	4x6	15.92	4x3	333.79	13x4	118.88	9x4	8.46
13	13x3	22.14	12x3	15.86	5x4	333.55	15x5	118.80	3x4	8.44
14	7x4	22.13	3x1	15.63	4x6	331.81	2x3	118.56	1x1	8.43
15	13x4	22.03	1x1	15.42	13x4	331.32	15x2	118.08	7x4	8.42
16	1x1	21.94	8x4	15.14	9x4	330.38	11x3	117.94	4x3	8.41
17	15x3	21.90	13x4	14.91	2x3	328.49	8x4	117.52	6x4	8.37
18	5x4	21.81	9x4	14.75	3x4	327.89	4x7	117.05	2x3	8.37
19	1x4	21.76	10x5	14.70	7x4	326.16	3x4	116.50	15x5	8.37
20	15x2	21.74	1x4	14.43	1x1	325.29	3x1	116.43	4x6	8.33
21	15x5	21.74	13x3	14.42	15x8	323.96	9x4	115.92	3x1	8.33
22	10x5	21.66	15x5	14.37	6x4	322.69	14x4	114.30	15x8	8.32
23	9x4	21.65	15x8	13.69	11x3	321.95	6x4	113.53	13x4	8.29
24	15x8	21.45	5x4	12.52	14x4	318.66	5x4	112.70	14x4	8.28
25	12x3	21.22	15x2	11.82	8x4	318.59	4x6	112.13	8x4	8.14

*Classification in descending order by the predicted average of the cross's combinations of partial diallel; **Component of genotypic average without GxE interaction for 25 combinations of a partial diallel; ***Combination related to the crosses in partial diallel scheme of 25 hybrids obtained.

interaction and the second complex or cross interaction (Resende, 2007a). The presence of complex interaction always indicate the existence of specifically adapted cultivars to specific environments, which require the adoption by cautious measures for recommending cultivars (Ramalho et al., 2012).

The predicted estimates of crossings BLUP, resulting in a hybrid with smaller distance from the last node to the first branch of the tassel, are sought, because the greater length of the tassel have negative effects on grain yield (Table 3). This is due to increased demand for assimilates and low performance of hybrids in biotic and abiotic stress conditions (Sangoi et al., 2002b); thus, crosses with average genotypic of lesser magnitude would be desired for selection. The combinations between lines 13x3', 7x4', 13x4', 1x1', 15x3', 5x4', 1x4', 15x2', 15x5', 10x5', 9x4', 15x8' and 12x3' have revealed predictions below genotypic overall average (Table 3), standing out among the other combinations. The main

contributing factor for selecting smaller size tassel in breeding programs, is because the tassel mass is directly related to the size, negatively influencing the production of grain due to competition with the ear by nutrients. Because of this, larger tassels would be greater-power sink, reducing the availability of assimilates to the ear (Hallauer et al., 2010).

Regarding the predicted components for NTB trait, averages of crossings with lower magnitude are prioritized, because smaller tassels require less assimilate and nutrients. This minimizes protandric nature of the plant, reducing the ontogenic interval between male and female flowering (Sangoi et al., 2002a). The power demand and lower apical dominance of the tassel over the spikes are important characteristics for nutrients to be used for balanced allometric development of inflorescences of the plant. This is reflected in a greater number of ears per plant and best floral synchrony of modern hybrids, especially in high densities. In this

context, the predicted genotypic averages of crosses between the hybrids 3x1', 1x1', 8x4', 13x4', 9x4', 10x5', 1x4', 13x3', 15x5', 15x8', 5x4' and 15x2' are lesser than other crosses (Table 3).

For the TKW trait, the crosses between inbred lines 15x5', 13x3', 1x4', 15x2', 5x3', 4x7', 10x5', 3x1', 15x3', 6x3', 12x3', 4x3' and 5x4' has shown magnitudes largest than overall average (Table 3), being considered as promising crosses to increase TKW and contribute to produce hybrids with high grain yield.

Regarding the predicted components for EH trait, the crosses combination of 15x2', 11x3', 8x4', 4x7', 3x4', 3x1', 9x4', 14x4', 6x4', 5x4' and 4x6' can be highlighted due its average, which is lesser than overall average (Table 3). Such criteria are established due to the maize genetic breeders seeking lines with lower height of ear insertion, being among the major changes sought with the lowest height on the cob, the higher nitrogen use efficiency, allow the center of gravity of plant to stay more balanced, reducing lodging and stem's breakage and favoring the absorption and translocation of nutrients to the grain filling (Sangoi et al., 2002b).

Combination with genotypic averages for GY that can be highlighted among predicted estimates are respectively: 1x3', 1x4', 5x4', 15x3', 12x3', 13x3', 15x2', 10x5' and 11x3' (Table 3). These crosses have greater GY than the overall genotypic average of the trials, proving to be promising to produce hybrids with increased GY in the four environments. In this context, the identification of promising crosses for a greater number of environments becomes important, since there are components of genetic, environmental and GxE origin involved in phenotypic expression, which can make difficult and complicate the breeders' work. Ramalho et al. (2012) points out that not always do hybrids with broader adaptation have higher grain yield. This fact can prevent a generalized way recommendation, being the most widely used alternative to solve this problem, to identify hybrids with greater phenotypic stability for different environments and to make a stratification of environments aiming to discover locations' groups within which the variance component associated with the effect of interaction is minimized.

Individual BLUPs in each location allow analysis of each combination in a more thorough form, informing the oscillations of the hybrid and selecting the best combination for a specific micro-region (environment). In this sense, using REML/BLUP-based procedures has numerous advantages and provides more security to the breeder. Resende and Duarte (2007) points that for selection, genotypic averages will represent better the future average of genotypes than phenotypic averages. According to the same authors, even which the assessments are in the same place or region, the effects of blocks and plots are unlikely to be repeated, thus, if the tests are conducted in different regions, the effect on the average will be higher.

Regarding the predicted estimate and their confidence intervals for the 25 combinations for the DLN trait (Figure 2), considering location's average as discriminatory parameter to identify the best combinations, the intersections whose average are lower than the overall average were highlighted, due to the increased demand for energy directed to the growth and development of the tassel, providing competition with the ear (Sangoi et al., 2002a). In Ampère, it was highlighted, the combinations of 1x4', 10x5', 12x3', 13x4' and 15x2' with the smallest magnitudes in relation to overall average (21.73 cm). In Clevelândia, the combinations that can be highlighted are 1x1', 9x4' and 15x8', considering the predicted overall average (22.98 cm). For Itapiranga, the lowest magnitudes for the overall average (21.5) are the crosses, 1x4', 8,4', 9x4', 12x3' and 15x8'. In Pato Branco, the combinations 12x3', 15x2' and 15x8' were lower than overall average (21.44 cm). Based on obtained estimates, it can be considered that none combinations were the same for the four environments.

Individual BLUPs for NTB trait (Figure 3), it is considered as optimal combinations, those that reveal lower magnitudes to predict average in each location. In Ampère, the crosses 5x4', 9x4', 13x3', 15x5', 15x8' and 15x2' has shown lower magnitudes than average of this environment (15). In Clevelândia, the combinations 1x4', 4x6', 5x4', 15x8' and 15x2' are lower than average of this location (15.79). In Itapiranga, the crosses 5x4', 15x5', 15x8' and 15x2' showed lower magnitude than predicted average (16.05). In Pato Branco, there were lower magnitudes of the crosses 15x8' and 15x2', considering the average of 14.7 branches.

Regarding MMG trait (Figure 4), the crosses that were higher than the local average in Ampere (302 g) are, respectively, 1x4', 5x3' 13x3' 15x3', 15x5' and 15x2' in Ampere environment. The higher predicted estimates in Cleveland are 1x4', 4x7' and 13x3' whose predicted average was 378.79 g, showing that there was a high homogeneity of the crossings for this site. In Itapiranga, the average predicted was 312.63 g, and the superior combinations for this estimate were the combinations 1x4', 4x7', 6x3', 10x5', 12x3' and 15x5'. The promising combinations in Pato Branco are 1x4', 3x1', 5x3', 10x5', 13x3', 15x5' and 15x2' above average of 344.97 g. Combinations with superior magnitudes for this trait are desirable in maize breeding, because this trait presents positive association with grain yield.

The ear height allows the plant, together with the stem diameter allows greater resistance to lodging. The predicted average for EH in Ampere was 113.24 cm (Figure 5). The crosses with the lower estimates than local average were 3x4', 4x7', 4x6', 5x4', 6x4', 13x4' and 15x8'. In Clevelândia, crosses with the predicted average that stood out are 2x3', 3x1', 4x6' , 5x4', 6x3', 6x4', 9x4', 10x5' and 11x3' below average of this location (136.49 cm). Under the conditions of Itapiranga, smaller ear heights were achieved by the combinations 3x4', 4x7',

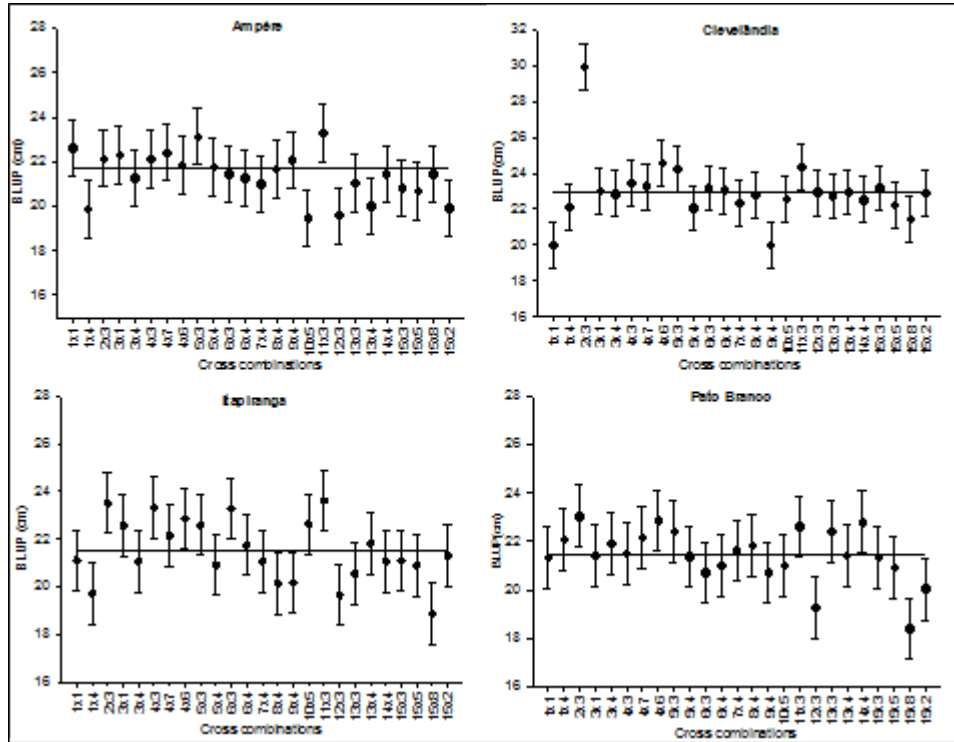


Figure 2. Estimates of genotypic averages for the trait distance from the last node to the first branch of the tassel in Ampère, Clevelândia, Itapiranga and Pato Branco regarding 25 combinations of a partial diallel.

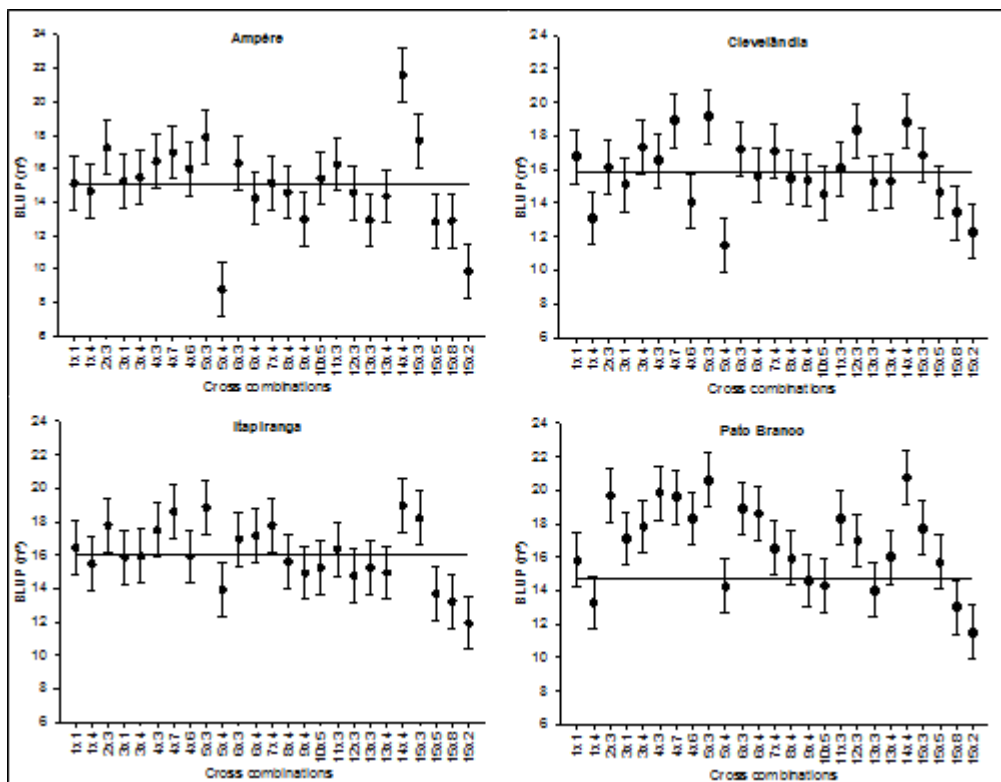


Figure 3. Estimates of genotypic averages for the trait number of tassel branch in Ampère, Clevelândia, Itapiranga and Pato Branco regarding 25 combinations of a partial diallel.

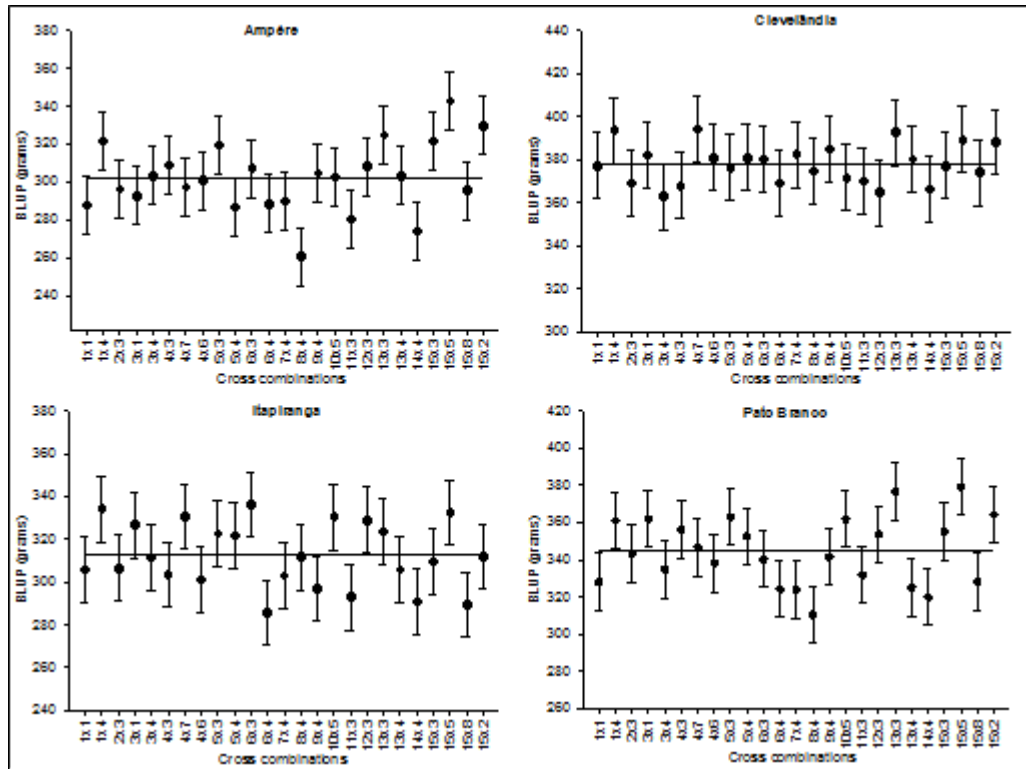


Figure 4. Estimates of genotypic averages for the trait thousand-kernel weight in Ampère, Clevelândia, Itapiranga and Pato Branco regarding 25 combinations of a partial diallel.

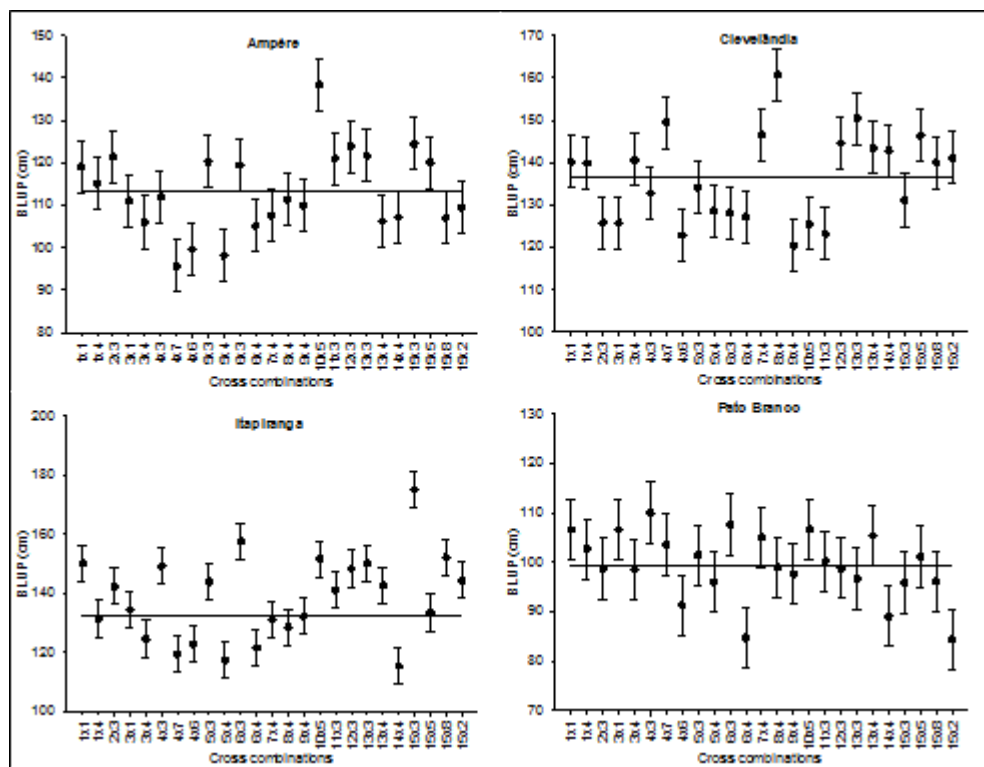


Figure 5. Estimates of genotypic averages for the trait ear weight in Ampère, Clevelândia, Itapiranga and Pato Branco regarding 25 combinations of a partial diallel.

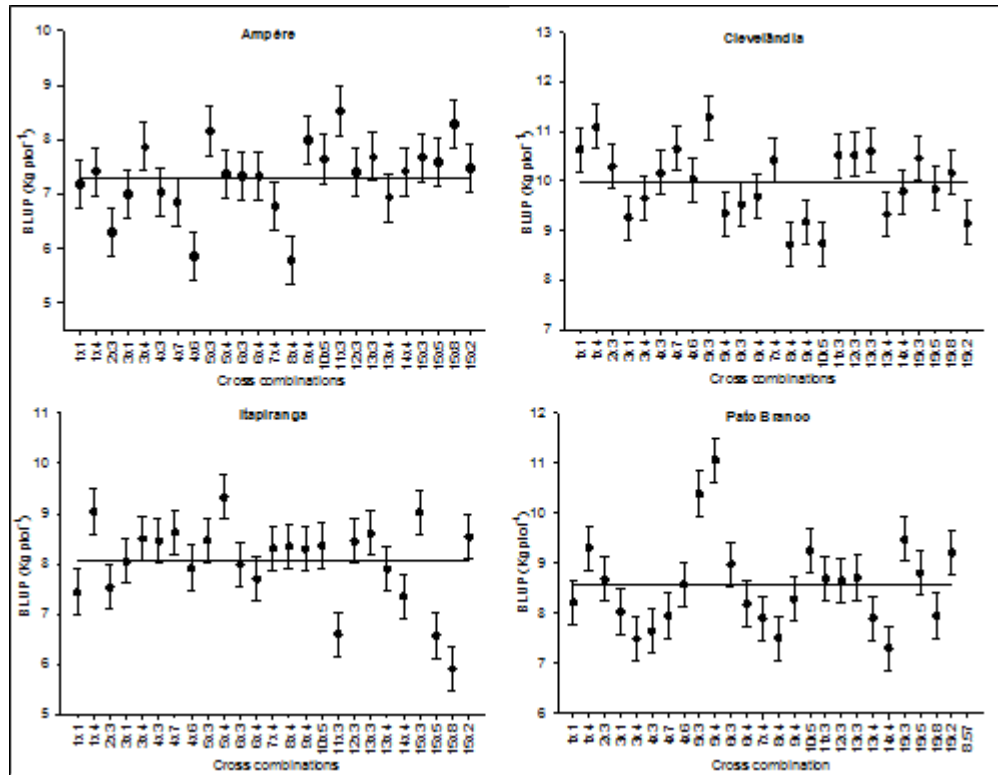


Figure 6. Estimates of genotypic averages for the grain yield per plot in Ampère, Clevelândia, Itapiranga and Pato Branco regarding 25 combinations of a partial diallel.

4x6', 5x4', 6x4' and 14x4', whose environmental average was 132.32 g. In Pato Branco environment, the combinations that revealed the magnitude smaller than the predicted average (99.37 cm) were 4x6', 6x4', 14x4' and 15x2'. According to Sangoi et al. (2002b), the reduced ear insertion height is among the traits which have improved absorption and transport of nutrients to the grain filling.

The GY (Figure 6), target trait of the breeders who seek incessantly cultivars or increasingly productive hybrids, is among the traits more influenced by environmental conditions, due to its complex action in response to different stimuli, resulting in a number of complications to identify more specific hybrids. Under the conditions of Ampere, combinations of superior crosses to average of 7.31 kg plot⁻¹ were from combinations 3x4', 5x3', 9x4', 11x3' and 15x8'. Cleveland revealed between the environments, the highest average (9.96 kg plot⁻¹), with the combinations 1x1', 1x4', 4x7', 5x3', 7x4', 11x3', 12x3', 13x3' and 15x3' located above this. The crosses that stood out for Itapiranga were 1x4', 3x4', 4x3', 4x7', 5x3', 5x4', 13x3', 15x3' and 15x2', with their average greater than 8.05 kg plot⁻¹. For Pato Branco combinations 1x4', 5x3', 5x4', 6x3', 10x5', 15x3' and 15x2' were, respectively, they were higher than the average of 8.57 kg plot⁻¹. The combination of lines 15x3' is higher than the average of the tests in all the environments. The

combinations that also showed themselves promising are between 5x4' lines in Itapiranga and Pato Branco environments and 5x3' that reveals superiority in the overall average of all combinations (Table 3), which is promising mainly for Clevelândia and Ampere. The fluctuations revealed by other diallel combinations are in agreement, because of the high effects shown in the variance component GxE. Grain yield is a complex and polygenic trait (Hallauer et al., 2010) controlled by a large number of genes. High effects of GxE interaction component is expected to occur, making it important biometric analysis with accurate models for estimating the components and predicting genotypic values, being REML/BLUP, favorable procedures in estimating these parameters (Resende, 2007a).

Conclusions

Estimates of variance component has revealed that the ear height and grain yield per plot suffer sharp action of GxE interaction.

The GXE interaction has provided oscillations regarding the best combinations in the environments and must be individually analyzed in each environment, the superior crosses for grain yield, except for 15x3' combination which achieved good performance in all

locations.

The combination 5x4' is promising to get high grain yields in Itapiranga and Pato Branco. The combination 5x3' has a higher overall average, which is higher than the other combinations in the environments of Clevelândia and Ampere and provides hybrid with fewer branches in the tassel.

Conflict of Interests

The authors have not declared any conflict of interests.

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Abbreviations

BLUP, Best linear unbiased prediction; **DLN**, distance from the last node of the stem to the first branch of the tassel; **EH**, ear height; **GY**, plot grain yield; **NTB**, number of tassel branch; **REML**, restricted maximum likelihood; **TKW**, thousand-kernel weight.

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Full Length Research Paper

Morphological characteristics and linear body measurements of Doyogena sheep in Doyogena district of SNNPR, Ethiopia

Taye M.^{1,2*}, Yilma M.³, Rischkowsky B.⁴, Dessie T.⁵, Okeyo M.⁶, Mekuriaw G.¹ and Haile A.^{4,5}

¹College of Agriculture and Environmental Sciences, Bahir Dar University, P. O. Box 79, Bahir Dar, Ethiopia.

²Department of Agricultural Biotechnology, Seoul National University, Seoul 151-742, Republic of Korea.

³Areka Agricultural Research Center, P. O. Box 79, Areka, Ethiopia.

⁴International Center for Agricultural Research in the Dry Areas (ICARDA), C/O ILRI, P. O. Box 5689, Addis Ababa, Ethiopia.

⁵International Livestock Research Institute (ILRI), P. O. Box 5689, Addis Ababa, Ethiopia.

⁶International Livestock Research Institute (ILRI), P. O. Box 30709, Nairobi, Kenya.

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Description of the physical characteristics of livestock breeds is very important for developing a breeding strategy in a particular production system. Doyogena sheep are among the potential breeds of Ethiopia reared in the mixed perennial crop and livestock production system of Southern Ethiopia. This research was conducted to characterise the morphological features of Doyogena sheep in an attempt to develop a breeding strategy that suits the production system of the area. A total of 512 sheep were characterized for different morphological features. Most (74.6%) of the sheep in the flock were females and 34.4% were old sheep of four and above dentition classes. Light red and red coat colour was abundant (71.5%) and 74% of the colour pattern was plain. Doyogena sheep are long fat-tailed (100%) and short haired (93.4%). The overall least square mean body weight was 31.64 ± 0.43 kg and was affected by sex and age of sheep. The mean heart girth (74.08 ± 0.39 cm), body length (58.84 ± 0.30 cm), and height at rump (69.71 ± 0.29 cm) were also affected by sex and dentition. Positive and significant correlations were obtained between body weight and other linear body measurements. The highest correlation coefficient was between body weight and heart girth. The positive and significant correlation of weight with linear body measurements indicate that linear body measurements can be used as a marker to estimate weight for different purposes. Different models can be used for different purposes. For simplicity, models with one variable can be used for marketing and by farmers. For breeding and selection purposes, since there is a need to be more precise, use of models involving more number of variables is important.

Key words: Doyogena sheep, morphological characteristics, rump height, regression equation.

INTRODUCTION

Ethiopia is endowed with 26 million heads of sheep (CSA, 2008) which are identified into nine breeds (Gizaw

et al., 2007) and maintained in different agro-ecological zones. Sheep production is among the most important

agricultural activities in the mixed perennial crop (*Enset*; *Ensete ventricosum*) and livestock production system of Southern Ethiopia providing cash income from the sale of live animals, as an insurance during crop failure, source of meat, and manure (Kocho, 2007).

Doyogena sheep, characterized as Adilo sheep (Gizaw et al., 2007), is a breed of sheep reared in the wet¹ highlands of Doyogena district of Southern Nations Nationalities and Peoples Regional (SNNPR) state. It is kept by Wolayta, Kembata and Hadya peoples in the region. This sheep breed is grouped in the long fat-tailed sheep. Doyogena sheep is among the potential breeds of the country with better market preferences in the local market and nearby markets like Shashemene and Addis Ababa markets (Kocho, 2007). However, like other breeds of Ethiopia (ESGPIP, 2008; Getachew et al., 2010; Taye et al., 2010), the productivity level is below its genetic potential due to low level of management, high incidence of disease and lack of knowledge of farmers to use appropriate breeding strategy that is suitable for the production system under which the breed is kept. It is very important for the physical body characteristics of the breed to be described in order to develop a breeding strategy (Melesse et al., 2013a).

Information on the weight of sheep is important for different sheep management practices such as medication, marketing, breeding and sometimes for supplemental feeding. Under traditional farm conditions where access to a weighing scale is difficult, other easier options are mandatory. The most widely used methods for estimating the weight of sheep under farm condition are using a regression equation developed from other linear body measurements for the breed/population of interest (Melesse et al., 2013b). This paper characterizes Doyogena sheep using morphological characteristics and established weight estimating regression models from linear body measurements in Doyogena district in an effort to develop a sheep breeding strategy.

MATERIALS AND METHODS

Ethical standards

The body measurements were taken after a consent from the local authorities (district office of Agriculture and Areka Agricultural Research Centre) and owners of the animals. No additional specific permissions were required from the Ethics Committee of the International Livestock Research Institute at the time of measuring of the animals. During body measurement, animals were handled properly.

Study areas

The study was conducted in Ancha, Serera and Awora peasant associations (PAs; the smallest administrative unit of Ethiopia) of

Doyogena district which is found in Kembata Tembaro Zone of SNNPR state, Ethiopia. The district is situated AT 258 km from Addis Ababa (national capital) and 171 km from Hawassa (the regional capital).

Doyogena district lies between 7°20' N latitude and 37°50' E longitude. It has altitude that ranges from 1900 to 2300 m above sea level (m asl). The mean annual rainfall is 1200 to 1600 mm, and the mean temperature varies between 10 and 16°C (Bureau of Agriculture (2012), unpublished). There are two rainy seasons. The main rainy season spans from June to September and a small shower falls from February to May. The mean land holding of the district is 0.75 hectares (Bassa, 2016). About 86% of the area is cropping land, 11.8% is covered with forest and bushes, 2% is grazing land and 0.2% is degraded land (Asmare et al., 2016). The major livestock species reared by the community include cattle, sheep and goat, equines, poultry, and honey bee. The major crops grown in the district include *Enset*, Faba bean, wheat, barley, field pea, vegetables and others (Asmare et al., 2016).

Sampling and data collection

The study areas were purposively selected; those PAs that are going to be involved in the sheep breeding strategy and development project were selected. In the study areas, 120 farmers involved in sheep production were randomly selected and their sheep were used for characterization. Morphological data were collected from sheep with an age (dentition was used to estimate age) of about nine months (0 pairs of permanent incisors (PPI) considered as yearlings) up to old age groups (gummy dentition groups), and from all sex groups in the flock. Accordingly, a total of 512 sheep were sampled and used for data collection. Both qualitative and quantitative linear body measurement data were collected as per the descriptor lists recommended by Food and Agriculture Organization (FAO, 1986).

Qualitative body characteristics collected include coat colour, coat colour pattern, hair type, head profile, presence/absence of wattle, presence/absence of toggle, presence/absence of horn, horn shape, horn orientation, ear orientation, tail type, and tail type shape. Quantitative linear body measurements taken were: heart girth (HG), body length (BL), height at wither (HW), height at rump (HR), pelvic width (PW), ear length (EL), tail length (TL), tail circumference (TC), horn length (HL), and scrotal circumference (SC).

All the body measurements were taken using flexible metal tape (3-m length) to the nearest 0.5 cm precision after restraining and holding the animals in an unforced position. Body weight was taken using suspended Salter balance (50 kg capacity with 200 g precision).

Data analysis

Data collected from the field were entered, cleaned and analysed using Statistical Package for the Social Sciences (SPSS, 2008). Qualitative morphological characteristics were analysed using the frequency and descriptive statistical procedures of the package. The General Linear Model (GLM) procedures were used to estimate least squares means and standard errors of quantitative linear body measurements. Sex and dentition were considered as fixed effects for the analysis of quantitative traits. Dentition was classified (ESGPIP, 2008) as: (1) Yearlings, these are sheep with zero PPI, but estimated to be approximately above nine months of age; (2) 1 PPI, sheep with one PPI (sheep from about 1 to 2 years); (3) 2 PPI, sheep with two PPI; (4) 3 PPI, sheep with three PPI; ≥ 4 PPI, sheep with four PPI and gummy.

The model used to analyse weight and linear body measurements was:

¹wet highland – altitude range of 3,200-2,300, Rain fall >1,400 mm, very high vegetation. Source: MoA 1998.

Table 1. Sex and age composition of sampled sheep.

Dent	Male		Female		Castrate		Total	
	N	%	N	%	N	%	N	%
Total	92	18.0	382	74.6	38	7.4	512	100
Yearling	55	39.3	71	50.7	14	10.0	140	27.3
1 PPI	27	22.5	76	63.3	17	14.2	120	23.4
2 PPI	8	11.9	59	88.1	0	0.0	67	13.1
3 PPI	0	0.0	9	100.0	0	0.0	9	1.8
>4 PPI	2	1.1	167	94.9	7	4.0	176	34.4

$$Y_{ij} = \mu + S_i + T_j + (ST)_{ij} + e_{ij}$$

where Y_{ij} is the observation on body weight and other linear body measurements; μ is the overall mean; S_i is the fixed effect of sex (i = Female, Male, Castrate); T_j is the fixed effect of dentition (j = 0, 1, 2, 3, ≥ 4); $(ST)_{ij}$ is the interaction effect of sex with dentition; e_{ij} is the effect of random error.

Effect of sex and the interaction between sex and dentition were not used for the analysis of scrotal circumference. Pearson's correlation coefficient was estimated between body weight and other body measurements and each other using the correlation procedures of SPSS (SPSS, 2008). Linear body measurements were regressed on body weight to develop simple linear, multiple linear and quadratic regression equations that can estimate body weight. The stepwise elimination procedure was used to develop multiple linear regression equations.

The models used to develop weight prediction regression equations were:

$$Y = \alpha + \beta X \text{ (Simple linear)}$$

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_1^2 \text{ (Quadratic)}$$

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \text{ (Multiple linear)}$$

where Y is the response variable, body weight; α is the intercept; β is the regression coefficient; X is the body measurements; and n is the n^{th} number of body measurement.

RESULTS AND DISCUSSION

Flock structure

Flock composition in terms of sex and age classes (presented in Table 1) is an important indicator of the management system and objective of sheep production (Ibrahim, 1998). About 34% of the animals on which body measurement data has been collected were sheep with 4 PPI and above, of which most of them were females (94.9%), followed by yearlings (27.3%), and 1 PPI (23.4%), respectively. With regard to the sex of animals, females were abundant (74.6%) followed by males (18.0%). Within males, yearlings were abundant than

other age groups. The proportion of female sheep increases as age increases in the flock which indicates that females are retained for a long period for breeding purposes. Because castrates are maintained for a short period of time after castration, most of them were with one PPI and of yearling age. The male to female ratio found (1:4.15) is said to be safe for proper breeding which is 1:20 to 25 in a year-round breeding (ESGPIP, 2008).

Qualitative morphological traits

The qualitative morphological characteristics of Doyogena sheep is presented in Table 2. Figure 1 illustrates the common coat colour and physical features of Doyogena sheep preferred by the farmers. Most (56.1%) of the sheep had straight facial profile. Among sex groups, most of the males (82.6%) and castrates (71.1%) had concave facial profile while most of the females (68.10%) had a straight facial profile.

Light red and red coat colour was abundant (71.5%) in the population which accounted for 67.4 and 72.3% for males and females, respectively. Red and white mixed either as spotted or patchy coat colour pattern were the second most abundant coat colour types. Other colour types like plain white, plain black and/or mixed with any other colour and gray colours were rare. Plain coat colour pattern was dominant (74%) followed by the patchy one (21.5%). The coat colour types and coat colour pattern were almost similar among sex groups. This might be because coat colour and pattern has been gotten due to attention by the community as selection criteria.

Most of the sheep (93.4%) were short haired; while a few (6.6%) were long haired. The tail type was long fat (100%) which is pendulous straight towards the ground (91.1%). About 96.7, 92.9 and 100% of the males, females and castrates had straight tail shape. Curled and

*Corresponding author. E-mail: mengistietaye@yahoo.com. Tel: +251918768619.

Table 2. Physical body characteristics of Doyogena sheep in Doyogena district.

Body characteristics	Male		Female		Castrate		Total	
	N	%	N	%	N	%	N	%
Head profile								
Concave	76	82.60	122	31.90	27	71.10	225	43.90
Straight	16	17.40	260	68.10	11	28.90	287	56.10
Coat colour type								
Light red and red	62	67.40	276	72.30	28	73.70	366	71.50
Red and white	22	23.90	78	20.40	9	23.70	109	21.30
White	6	6.50	17	4.50	1	2.60	24	4.70
Black white red	1	1.10	8	2.10	0	0.00	9	1.80
Grey	1	1.10	3	0.80	0	0.00	4	0.80
Coat pattern								
Plain	66	71.70	284	74.30	29	76.30	379	74.00
Patchy	21	22.80	82	21.50	7	18.40	110	21.50
Spotted	5	5.40	16	4.20	2	5.30	23	4.50
Hair type								
Short hair	86	93.50	362	94.80	30	78.90	478	93.40
Long hair	6	6.50	20	5.20	8	21.10	34	6.60
Tail type								
Long fat	92	100.00	382	100.00	38	100.00	512	100.00
Tail shape								
Straight	89	96.70	355	92.90	38	100.00	482	94.10
Curled	1	1.10	20	5.20	0	0.00	21	4.10
Twisted	2	2.20	7	1.80	0	0.00	9	1.80
Presence of horn								
Present	91	98.91	272	71.20	37	97.36	400	78.13
Absent	1	1.08	110	28.79	1	2.63	112	21.87
Horn shape								
Curved	73	80.20	94	34.60	32	86.50	199	49.80
Straight	4	4.40	175	64.30	0	0.00	179	44.80
Spiral	14	15.40	3	1.10	5	13.50	22	5.50
Horn orientation								
Backward	78	85.70	149	54.80	28	75.70	255	63.80
Lateral	13	14.30	112	41.20	8	21.60	133	33.20
Obliquely upward	0	0.00	11	4.00	1	2.70	12	3.00
Toggle								
Absent	91	98.90	330	86.40	35	92.10	456	89.10
Present	1	1.10	52	13.60	3	7.90	56	10.90
Ear form								
Horizontal	46	50.00	327	85.60	28	73.70	401	78.30
Erect	46	50.00	55	14.40	10	26.30	111	21.70

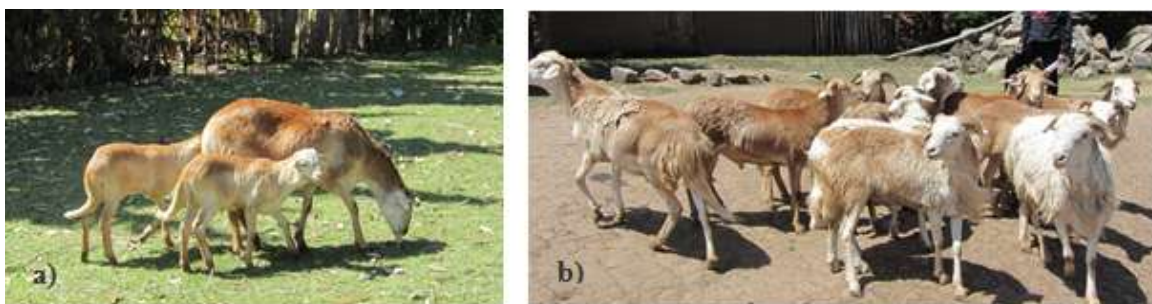


Figure 1. Typical Doyogena sheep with light red coat colour type and plain pattern. (a) Ewe with her twins, (b) Castrated sheep selected for fattening and marketing (Photo courtesy: Mengistie Taye).

Table 3. Description of physical body measurements of Doyogena sheep in Doyogena district.

Body characteristics	N	Mean	Std. Deviation	Range
Body weight (kg)	394	28.61	5.94	16.00-50.00
Height at wither (cm)	512	65.89	4.02	56.00-79.00
Height at rump (cm)	512	67.55	3.79	58.00-79.00
Body length (cm)	512	57.42	3.83	47.00-70.00
Heart girth (cm)	512	72.03	5.46	59.00-92.00
Pelvic width (cm)	512	14.82	1.34	11.00-18.00
Ear length (cm)	512	10.08	0.85	8.00-13.00
Scrotal circumference (cm)	83	24.78	2.44	19.00-31.00
Tail length (cm)	484	28.06	7.25	16.00-50.00
Tail circumference (cm)	483	17.33	4.61	7.00-33.00
Horn length (cm)	378	9.93	6.27	2.00-36.00

twisted tail shape types were few. Tail shape and length are important selection criteria for ram selection in Doyogena sheep (Taye et al., 2012).

Horn is an important trait in Doyogena sheep. Farmers in Doyogena area believe that horned ewes produce more milk and therefore they can support better lamb growth. 78.13% of the sheep population were found horned. Most of the males (80.2%) and castrates (86.5%) had curved horns that are oriented backward (85.7% for males and 75.7% for castrates). Most (64.30%) of the females had straight horn shape with backward orientation (54.8%) and lateral orientation (41.2%). All the sheep sampled had no wattle and only 10.9% of them were with toggle. Farmers cull sheep with toggle using different mechanisms like castration and slaughter and select against the trait. This is because, they believe that sheep with toggle are not productive. Most (78.3%) of the sheep had horizontal ear form.

Quantitative physical body measurements

The mean and standard deviation of linear body

measurements is presented in Table 3. There was a range of values for different traits which indicate the potential variation in the population for selection.

The least squares mean body weight obtained in the current study was 31.64 ± 0.43 kg (Table 4). This value is comparable with Gumuz sheep (Abegaz et al., 2011), but larger than the value reported for other breeds listed in Table 5 (Kocho, 2007; Getachew et al., 2010; Bimerow et al., 2011; Melesse et al., 2013a). Body weight was significantly affected by the sex of sheep that females had a lower weight than males and castrates. Dentition also affected body weight of sheep. Yearlings had a lower weight than other higher dentition groups, and this might be because of the fact that yearlings has not yet achieve mature body weight as depicted by the growth curve in Figure 2. The interaction effect of sex and dentition was also significant ($p < 0.001$). A significant effect of sex and age of sheep on body weight of sheep is reported by many scholars for different breeds of sheep (Edea et al., 2010; Getachew et al., 2010; Bimerow et al., 2011; Mavule et al., 2013).

The overall mean pelvic width obtained (14.73 ± 0.10) is similar to the value reported for Washera sheep (Taye et

Table 4. Least square means and standard errors of physical body measurements of Doyogena sheep in Doyogena district.

Parameter	Weight (kg)		Pelvic width (cm)		Heart girth (cm)		Body length (cm)		Height at Rump (cm)		Ear length (cm)	
	N	LSMeans±SE	N	LSMeans±SE	N	LSMeans±SE	N	LSMeans±SE	N	LSMeans±SE	N	LSMeans±SE
Overall	-	31.64±0.43	-	14.73±0.10	-	74.08±0.39	-	58.84±0.30	-	69.71±0.29	-	9.96±0.07
Sex	-	***	-	***	-	***	-	***	-	***	-	NS
Male	90	34.37±0.97 ^b	92	14.28±0.24 ^a	92	75.28±0.91 ^b	92	60.62±0.71 ^b	92	71.19±0.67 ^b	92	9.72±0.17
Female	269	27.05±0.45 ^a	382	14.87±0.09 ^b	382	71.37±0.35 ^a	382	57.03±0.28 ^a	382	67.25±0.26 ^a	382	10.09±0.07
Castrate	35	35.66±0.85 ^b	38	15.10±0.20 ^b	38	77.04±0.77 ^b	38	59.52±0.60 ^b	38	71.84±0.56 ^b	37	10.06±0.14
Dent	-	***	-	***	-	***	-	***	-	***	-	NS
Yearling	115	28.05±0.52 ^a	140	13.99±0.12 ^a	140	70.01±0.47 ^a	140	56.02±0.37 ^a	140	67.36±0.35 ^a	140	9.80±0.09
1PPI	101	32.03±0.54 ^{bc}	120	14.89±0.13 ^b	120	74.64±0.48 ^{bc}	120	59.11±0.38 ^b	120	70.37±0.36 ^b	119	10.07±0.09
2PPI	48	33.04±0.95 ^{bc}	67	15.12±0.22 ^b	67	74.18±0.83 ^b	67	59.33±0.65 ^b	67	70.23±0.61 ^b	67	9.95±0.15
3PPI	6	29.67±1.89 ^{ab}	9	15.22±0.38 ^b	9	74.22±1.46 ^{bc}	9	58.11±1.15 ^{ab}	9	70.00±1.08 ^b	9	9.94±0.27
>4PPI	124	34.57±1.27 ^c	176	14.88±0.31 ^b	176	77.51±1.18 ^c	176	61.34±0.93 ^b	176	70.97±0.87 ^b	176	10.03±0.22
Sex×Dent	-	***	-	**	-	***	-	NS	-	***	-	NS

Parameter	Height at wither (cm)		Horn length (cm)		Tail circumference (cm)		Tail length (cm)		Scrotal circumference (cm)	
	N	LSMeans±SE	N	LSMeans±SE	N	LSMeans±SE	N	LSMeans±SE	N	LSMeans±SE
Overall	-	68.06±0.30	-	15.40±0.33	-	19.59±0.34	-	32.91±0.39	-	26.05±0.62
Sex	-	***	-	***	-	***	-	***	-	-
Male	92	70.11±0.71 ^b	85	22.76±0.72 ^c	88	21.40±0.79 ^b	88	39.25±0.91 ^b	-	-
Female	382	65.33±0.28 ^a	256	7.91±0.44 ^a	357	16.06±0.32 ^a	358	24.54±0.37 ^a	-	-
Castrate	38	69.88±0.60 ^b	36	18.05±0.62 ^b	37	23.05±0.66 ^b	37	38.42±0.76 ^b	-	-
Dent	-	***	-	***	-	NS	-	*	-	*
Yearling	140	65.43±0.37 ^a	110	11.34±0.38 ^a	135	19.84±0.41	135	33.45±0.47 ^{bc}	54	24.18±0.32 ^a
1PPI	120	68.45±0.38 ^b	94	14.40±0.39 ^b	115	20.19±0.42	115	34.08±0.49 ^c	21	25.69±0.51 ^b
2PPI	67	68.94±0.65 ^b	38	14.45±0.75 ^b	59	19.94±0.76	59	31.08±0.88 ^b	5	26.40±1.04 ^b
3PPI	9	67.56±1.15 ^{ab}	3	13.67±1.95 ^{ab}	8	16.88±1.33	8	23.25±1.54 ^a	1	28.00±2.33 ^b
>4PPI	176	69.88±0.93 ^b	132	21.64±0.93 ^c	165	19.39±1.01	166	35.65±1.17 ^c	2	26.00±1.65 ^b
Sex×Dent	-	**	-	***	-	NS	-	NS	-	-

LS Means with different letters (a, b, c) within a trait in a column are different at indicated P-value; N number of observations, NS non-significant ($P>0.05$); * $P<0.05$; ** $P<0.01$; *** $P<0.001$.

al., 2010). However, it is higher than Farta sheep (Bimerow et al., 2011) and lower than Menz and Afar sheep (Getachew et al., 2010), and sheep in Kembata, Tembaro-Hadiya areas (Melesse et al., 2013a). Pelvic width was affected ($p<0.001$) by

both sex and age of sheep. The interaction was also significant ($p<0.01$) implying the importance of the trait for different age and sex groups. Yearling male sheep and young and old female sheep had a narrower ($p<0.05$) pelvis. Pelvic

width is an important trait affecting the productivity of the ewe through its effect on ease of lambing, perinatal ewe and lamb mortality rates, and lifetime rearing performances (Van Rooyen et al., 2012). Body condition, evaluated from touching the pelvic,

Table 5. Linear body measurements of some of Ethiopian sheep breeds characterized by different authors.

Breed/Group	Sex	Weight	Pelvic width	Heart girth	Body length	Height at wither	Ear length	Tail length	Tail circumf.	Horn length	Scrotal circumf.	Reference
Kembata, Tembaro-Hadiya	Male	27.5±6.0b	15.6±1.9	71.5±5.7	65.8±5.5	65.8±6.3	10.8±1.3	36.0±7.3	25.4±5.0	20.1±8.5	17.6±4.4	(Melesse et al., 2013a)
	Female	25.8±4.2	15.9±1.1	69.5±3.8	64.3±5.1	63.3±3.3	11.2±1.0	26.5±5.7	13.5±3.3	6.79±3.7	-	
Selale sheep	Male	27.23±0.4	-	73.13±0.5	60.30±0.3	65.0±0.3	9.48±0.1	34.02±0.4	-	-	21.90±0.26	(Abera et al., 2014)
	Female	27.96±0.2	-	76.23±0.2	63.51±0.2	65.6±0.2	9.50±0.1	31.63±0.3	-	-	-	
Gumuz	Male	34.6±6.77	-	77.9±4.91	68.3±3.78	67.3±4.14	11.9±1.44	35.2±5.25	-	14.4±1.82	-	(Abegaz et al., 2011)
	Female	31.4±3.94	-	76.1±4.0	66.0±2.46	63.6±2.83	11.6±1.06	34.7±3.17	-	-	-	
Farta	Male	28.0±0.51	12.5±0.20	71.4±0.71	56.5±0.56	65.2±0.58	8.9±0.21	-	-	-	-	(Bimerow et al., 2011)
	Female	23.6±0.21	12.8±0.08	69.4±0.28	54.3±0.22	62.1±0.23	9.8±0.08	-	-	-	-	
Menz	Male	22.0±0.27	18.2±0.13	65.7±0.39	53.9±0.29	59.6±0.28	7.4±0.18	20.0±0.27	18.1±0.27	20.15±0.46	23.1±0.24	(Getachew et al., 2010)
	Female	19.3±0.13	17.9±0.06	64.5±0.20	53.7±0.15	57.1±0.14	8.0±0.13	17.4±0.13	12.8±0.14	-	-	
Afar	Male	24.3±0.50	20.5±0.24	67.3±0.58	61.3±0.52	62.1±0.44	5.2±0.16	17.8±0.46	45.0±0.97	-	25.6±0.39	(Taye et al., 2010)
	Female	21.2±0.16	20.7±0.08	65.7±0.19	59.9±0.17	60.7±0.14	5.6±0.06	15.6±0.15	37.3±0.32	-	-	
Washera	Male	28.3	14.2	75.7	58.3	70.8	9.67	-	-	-	-	(Taye et al., 2010)
	Female	25.0	14.4	73.1	57.0	67.1	9.80	-	-	-	-	
Halaba sheep	Male	19.9±4.1	-	63.2±5.7	82.3±6.8)	60.6±4.6	-	-	-	-	-	(Kocho, 2007)
	Female	23.0±4.4	-	67.9±4.9	86.3±6.1	63.6±4.3	-	-	-	-	-	
Adilo	Mean	28.6	-	-	-	-	-	-	-	-	--	(Gizaw et al., 2007)
Doyogena sheep	Male	34.37±0.97	14.28±0.24	75.28±0.91	60.62±0.71	70.11±0.71	9.72±0.17	39.25±0.91	21.40±0.79	22.76±0.72	26.05±0.62	Present study
	Female	27.05±0.45	14.87±0.09	71.37±0.35	57.03±0.28	65.33±0.28	10.09±0.07	24.54±0.37	16.06±0.32	7.91±0.44	-	

showed a significant effect on lambs born per ewe and reproductive performances (Aliyari et al., 2012). A similar effect of sex and dentition on the pelvic width of sheep is reported in the literature (Getachew et al., 2010; Taye et al., 2010).

The least squares mean of heart girth, body length, height at rump, and height at wither of Doyogena sheep obtained in the current study were 74.08±0.39, 58.84±0.30, 69.71±0.29, and 68.06±0.30 cm, respectively. Sex and age of

sheep had a significant effect ($p < 0.001$) on heart girth, body length, height at rump, and height at withers that females and yearlings had lower values in all the traits. The interaction effect of sex and age (dentition) was significant ($p < 0.001$) for

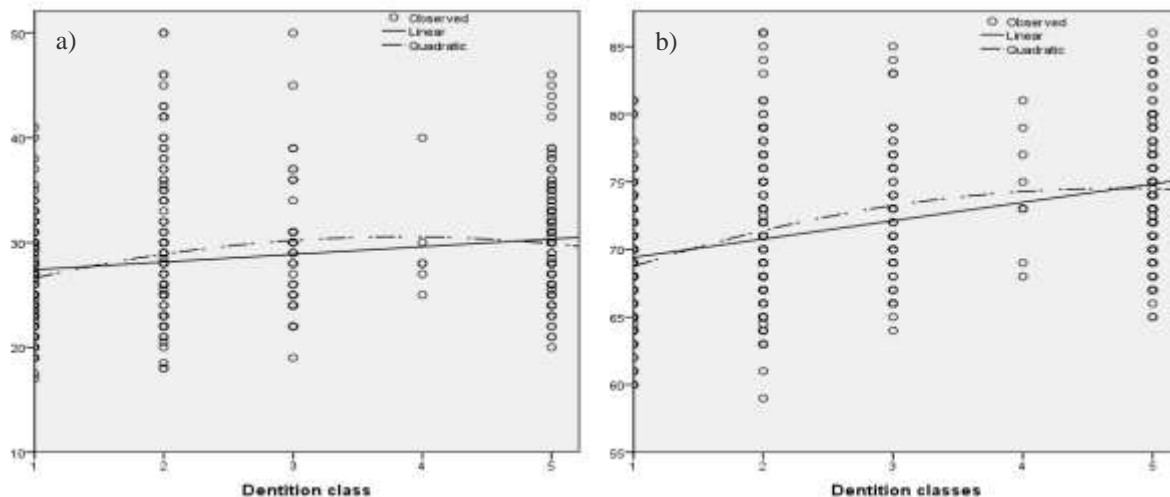


Figure 2. Growth curve of Doyogena sheep: (a) based on body weight, (b) based on heart girth.

heart girth, height at rump, and height at wither however, it did not affect the body length.

Doyogena sheep had similar heart girth with Washera Farta, and Gumuz sheep (Taye et al., 2010; Abegaz et al., 2011; Bimerow et al., 2011), but higher than Menz and Afar sheep (Getachew et al., 2010), and Halaba sheep (Kocho, 2007). Doyogena sheep has longer body length than Menz sheep (Getachew et al., 2010) and shorter body length than Gumuz (Abegaz et al., 2011) and Halaba sheep (Kocho, 2007). It has similar body length with Washera, Farta, and Afar sheep breeds (Getachew et al., 2010; Taye et al., 2010; Bimerow et al., 2011). The height at wither obtained was similar with Washera sheep (Taye et al., 2010), however, Doyogena sheep is taller than Menz and Afar (Getachew et al., 2010), Farta (Bimerow et al., 2011), and Halaba sheep (Kocho, 2007). In most of the traits considered, Doyogena sheep is better than other highland breeds of the country while it is comparable with sheep breeds known for their productivity in Ethiopia (Gizaw et al., 2007; Taye et al., 2010).

Horn length is an important trait in Doyogena sheep. The overall mean horn length (15.40 ± 0.33 cm), analysed among those with horn, was significantly affected ($p < 0.001$) by sex and age of sheep. Male sheep had longer horn followed by castrates. Horn length increased as the age of sheep increased. Tail length and tail circumference are important traits used as selection criteria especially for male sheep in the study area. The mean tail length (32.91 ± 0.39) and circumference (19.59 ± 0.34) obtained was larger than Menz sheep (Getachew et al., 2010), and Kembata, Tembaro-Hadiya (Melesse et al., 2013a). Tail length was similar with Gumuz sheep (Abegaz et al., 2011), and the circumference was narrower than Afar sheep (Getachew et al., 2010). Tail length and circumference of Doyogena

sheep were affected ($p < 0.001$) by sex of sheep. Females had short and narrow tail length and circumference, respectively. This might be because of the docking practice of farmers on female sheep and the selection practice towards longer and wider tail length and circumference of male sheep, respectively. Getachew et al. (2010) reported a similar effect of sex on tail circumference and length.

The mean scrotal circumference found in the current study (26.05 ± 0.62 cm) was almost similar with Menz, Afar and Gumuz sheep (Getachew et al., 2010; Abegaz et al., 2011), and greater than sheep in Selale area (Abera et al., 2014). The effect of breed on the scrotal circumference is reported in the literature (Kridli et al., 2006). Scrotal circumference was affected by age of rams; yearlings had a smaller circumference than other higher age group sheep which were similar. Scrotal circumference is an indirect measure of the breeding performance of rams. Rams within a breed at a given age having larger scrotal circumference are likely to produce better quality and quantity of semen and reproductive success (ESGPIP, 2008). Rams with larger testicles also tend to sire ewe lambs that reach puberty at a younger age (<http://www.sheep101.info/201/ramrepro.html>).

From the growth curve, estimated using body weight and heart girth fitted against dentition classes (Figure 3), it is possible to understand that Doyogena sheep do not achieve mature weight until it erupts two PPI (3rd dentition group in the curve). Heart girth continued growing up to old age; indicates that different body parts mature at different ages (Mavule et al., 2013). Both body weight and heart girth showed a decline at the fifth dentition group which might be because animals after this age group are old, and therefore starts to lose weight. It is important to consider culling of sheep after they start to lose weight because of age.

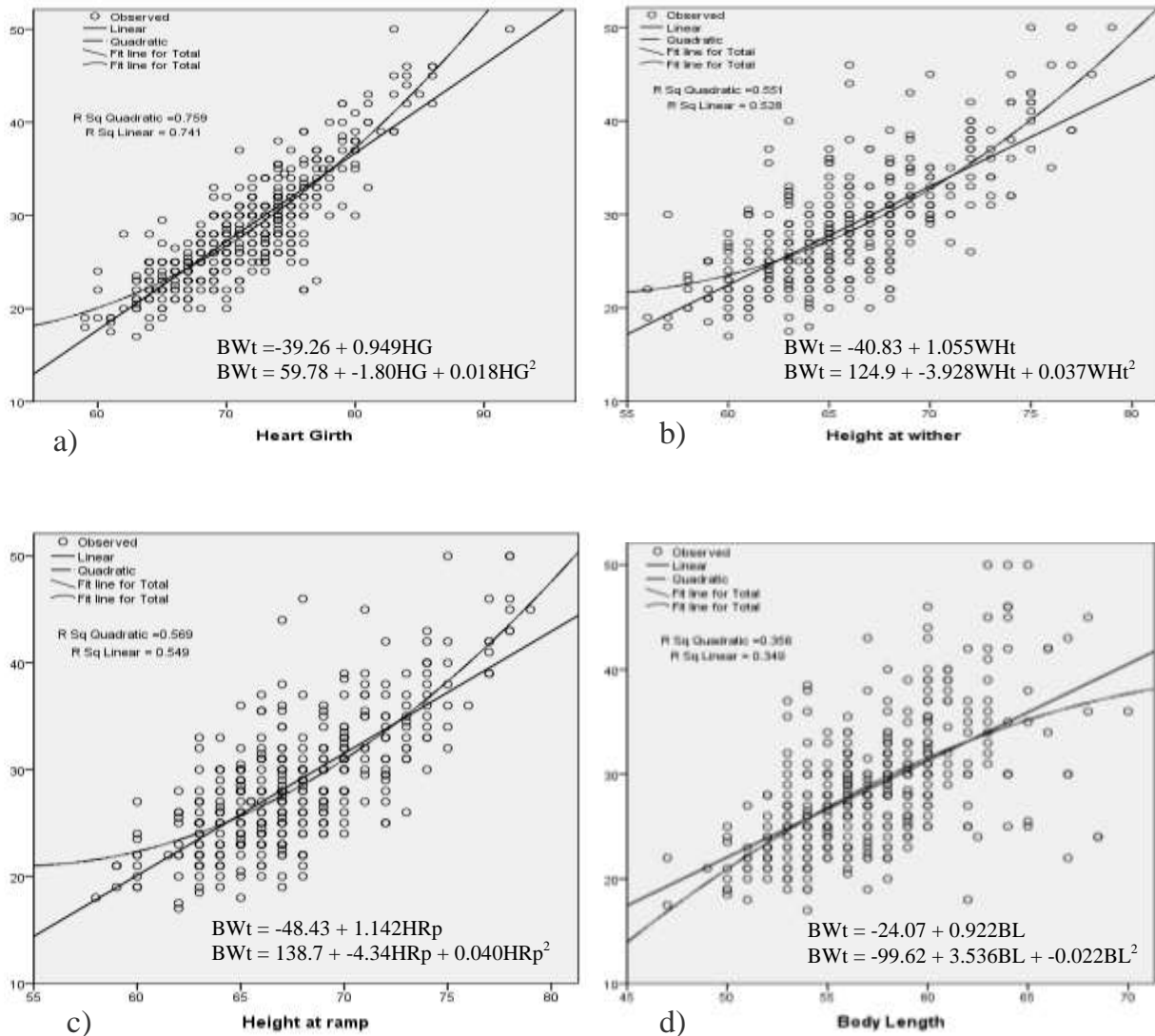


Figure 3. Linear and quadratic curve estimation of weight with: a) heart girth; b) height at wither; c) height at ramp; d) body length. Y-axis is body weight.

Correlation and regression

The Pearson's correlation of linear body measurements with weight and with each other is presented in Table 6. There was a positive and significant ($r > 0.45$; $p < 0.05$) correlation between weight and other body measurements except with ear length. The highest correlation coefficient obtained was between body weight and heart girth ($r = 0.86$) which was followed by weight with height at rump ($r = 0.74$). The higher correlation of linear body measurements with body weight indicates that these linear body measurements can be used as indirect selection criteria in the absence of weighing scale (Khan et al., 2006). The observed positive ($p < 0.05$) correlations between weight and other body measurements is in agreement with literature (Afolayan et al., 2006; Khan et

al., 2006; Sowande and Sobola, 2008; Melesse et al., 2013b). The correlation of ear length with body weight was not significant. Similar non-significant correlation of ear length with body weight is reported elsewhere (Mavule et al., 2013). The non-significant effect of ear length with body weight might be because ear length is determined by non-additive genetic effects and less affected by the environment (Mavule et al., 2013). Therefore, use of ear length as a phenotypic marker to improve body weight in breeding programs will bring no value (Mavule et al., 2013).

Regression equations used to estimate the weight of animals from other easily measured linear body measurements is very important in selection and marketing of animals. Different regression models have been developed with different level of complexity to give

Table 6. Pearson's correlation of linear body measurements.

Sex	Measurements	Weight	Heart girth	Height at rump	Height at wither	Body length	Pelvic width	Scrotal circum.	Tail circum.	Tail length	Horn length
Pool	Heart girth	0.855**									
	Height at rump	0.741**	0.665**								
	Height at wither	0.727**	0.684**	0.852**							
	Body length	0.591**	0.565**	0.567**	0.572**						
	Pelvic width	0.558**	0.660**	0.445**	0.478**	0.485**					
	Scrotal circumference	0.549**	0.519**	0.468**	0.459**	0.453**	0.562**				
	Tail circumference	0.668**	0.487**	0.476**	0.465**	0.309**	0.190**	0.486**			
	Tail length	0.455**	0.263**	0.426**	0.426**	0.205**	-0.049 ^{NS}	0.240*	0.586**		
	Horn length	0.538**	0.351**	0.513**	0.494**	0.292**	0.044 ^{NS}	0.397**	0.562**	0.713**	
Ear length	0.077 ^{NS}	0.095*	0.187**	0.151**	0.132**	0.238**	0.012 ^{NS}	-0.133**	-0.189**	-0.103*	
Male	Heart girth	0.903**									
	Height at rump	0.862**	0.850**								
	Height at wither	0.853**	0.859**	0.908**							
	Body length	0.733**	0.686**	0.683**	0.651**						
	Pelvic Width	0.781**	0.813**	0.730**	0.662**	0.644**					
	Scrotal circumference	0.532**	0.526**	0.449**	0.440**	0.446**	0.553**				
	Tail circumference	0.677**	0.592**	0.518**	0.528**	0.353**	0.520**	0.476**			
	Tail length	0.462**	0.517**	0.461**	0.496**	0.384**	0.374**	0.260*	0.460**		
	Horn length	0.668**	0.693**	0.578**	0.557**	0.480**	0.609**	0.370**	0.445**	0.377**	
Ear length	0.274**	0.249*	0.319**	0.313**	0.163 ^{NS}	0.256*	0.013 ^{NS}	0.006 ^{NS}	-0.031 ^{NS}	0.198 ^{NS}	
Female	Heart girth	0.809**									
	Height at rump	0.542**	0.576**								
	Height at wither	0.558**	0.625**	0.798**							
	Body length	0.477**	0.514**	0.495**	0.527**						
	Pelvic width	0.596**	0.672**	0.487**	0.546**	0.500**					
	Tail circumference	0.504**	0.441**	0.244**	0.251**	0.223**	0.249**	-			
	Tail length	0.140*	0.155**	0.168**	0.197**	0.044 ^{NS}	0.083 ^{NS}	-	0.196**		
	Horn length	0.287**	0.282**	0.259**	0.295**	0.138*	0.158**	-	0.221**	0.230**	
	Ear length	0.090 ^{NS}	0.098 ^{NS}	0.243**	0.178**	0.152**	0.196**	-	-0.054 ^{NS}	-0.084 ^{NS}	-0.010 ^{NS}
Castrate	Heart girth	0.868**									
	Height at rump	0.769**	0.661**								
	Height at wither	0.675**	0.551**	0.824**							
	Body length	0.495**	0.472**	0.596**	0.503**						

Table 6. Contd.

Pelvic width	0.717**	0.620**	0.462**	0.510**	0.352*						
Tail circumference	0.625**	0.530**	0.523**	0.531**	0.341*	0.551**	-				
Tail length	0.336*	0.381*	0.257 ^{NS}	0.346*	0.238 ^{NS}	0.245 ^{NS}	-	0.572**			
Horn length	0.286 ^{NS}	0.278 ^{NS}	0.290 ^{NS}	0.299 ^{NS}	0.332*	0.254 ^{NS}	-	0.039 ^{NS}	0.106 ^{NS}		
Ear length	0.069 ^{NS}	-0.144 ^{NS}	0.271 ^{NS}	0.274 ^{NS}	0.174 ^{NS}	0.063 ^{NS}	-	-0.208 ^{NS}	-0.069 ^{NS}	0.147 ^{NS}	

Table 7. Regression equations developed to estimate weight from linear body measurements.

Sex	Model	Bo	X1	X2	X3	X4	X5	X6	R2	R2 change	SE	Sig F Change
Pool	HG	-39.41	0.968	-	-	-	-	-	0.804	0.804	2.765	0.000
	HG+HR	-53.20	0.578	0.607	-	-	-	-	0.862	0.058	2.332	0.000
	HG+HR+TC	-50.59	0.474	0.604	0.250	-	-	-	0.882	0.019	2.176	0.001
	HG+HR+TC+BL	-52.94	0.390	0.519	0.278	0.235	-	-	0.896	0.014	2.052	0.002
	HG+HR+TC+BL+EI	-57.02	0.408	0.442	0.299	0.240	0.767	-	0.906	0.010	1.964	0.006
	HG+HR+TC+BL+EI+HL	-53.63	0.353	0.438	0.293	0.233	0.750	0.094	0.911	0.005	1.922	0.039
Male	HG	-39.823	0.975	-	-	-	-	-	0.825	0.825	2.594	0.000
	HG+HR	-51.569	0.632	0.527	-	-	-	-	0.865	0.041	2.289	0.000
	HG+HR+TC	-49.420	0.519	0.546	0.228	-	-	-	0.882	0.016	2.161	0.002
	HG+HR+TC+BL	-51.776	0.422	0.476	0.262	0.233	-	-	0.896	0.015	2.038	0.002
	HG+HR+TC+BL+EI	-56.019	0.436	0.393	0.287	0.241	0.829	-	0.908	0.012	1.930	0.003
Female	HR	-69.023	1.473	-	-	-	-	-	0.999	0.999	0.336	0.017
	HR+BL	-48.000	2.000	-1.00	-	-	-	-	1.000	0.001	-	-
Castrate	HG	-39.403	0.982	-	-	-	-	-	0.754	0.754	2.962	0.000

users an option to use for different purposes as medication, marketing, and selection for a replacement stock (Otoikhian et al., 2008; Sowande and Sobola, 2008). The models are presented in Figure 3 and Table 7.

Regression equations were fitted for the male, castrate, female and pooled data that estimated weight with a precision of 75.4 to 100%. The

highest coefficient of determination was depicted for female sheep (100%). Unlike other similar findings (Alex et al., 2010; Taye et al., 2010), heart girth was not the best variable to estimate body weight for female sheep. It was the height at rump and body length that were used to estimate weight for female sheep. In the pooled data, heart girth alone explained 96.8% of the variation in the

body weight of sheep. The result is generally in agreement with literature (Thiruvankadan, 2005; Alex et al., 2010; Taye et al., 2010) that heart girth is the best predictor of weight. Multiple regression models estimated weight with better accuracy; and accuracy of prediction increased with the increased number of variables (Taye et al., 2012; Melesse et al., 2013b). Therefore, choice of the

equations should be based on the accuracy needed and level of difficulty at field conditions. Regression equations with a number of variables can be used in breeding programs while those simpler ones can be used for marketing and medication purposes.

Development and use of regression equations to estimate weight from linear body measurements requires due care not to bias the measurement due to the posture of the animal. With this respect, heart girth is the least affected by the posture of the animal during measurement. In addition, computation and use of equations developed from three and above traits is difficult. At field condition, use of heart girth is encouraged for the above reasons.

Conclusion

Doyogena sheep is among the sheep breeds reared in the *Enset*-crop-livestock production system of the SNNPR state, Ethiopia. The breed has attractive morphological features with a great potential for fattening. As compared to other local breeds of the country, Doyogena sheep is better in most of the morphological characteristics. The range of values in different traits considered in the population indicates its potential response to selection. The positive and significant correlation of weight with linear body measurements indicate that linear body measurements can be used as a marker to estimate weight using regression equations. Different models can be used for different purposes. For simplicity, models with a single variable can be used for marketing and by farmers. For breeding purposes, since there is a need to be more precise, use of models involving a number of variables is encouraged.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Spatial distribution of soil chemicals attributes in sugar cane crop area

Anderson Antônio da Silva Gualberto¹, Marcos Rafael Nanni², Carlos Antonio da Silva Junior³, Everson Cezar¹, Luis Guilherme Teixeira Crusiol¹, Guilherme Fernando Capristo Silva^{1*} and Aline de Carvalho Gasparotto¹

¹Department of Agronomy (DAG), State University of Maringá (UEM), Av. Colombo 5790, Code 87020-900, Maringá, Paraná, Brazil.

²State University of Maringá (UEM), Av. Colombo 5790, 87020-900, Maringá, Paraná, Brazil.

³Geotechnology Applied in Agriculture and Forest (GAAF), State University of Mato Grosso (UNEMAT), Av. Perimetral Deputado Rogério Silva - Norte 2, Alta Floresta, Mato Grosso, Brazil.

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The aim of this paper was to quantify and evaluate the spatial distribution of soil chemical properties in different grid sampling sizes using descriptive statistics and geostatistics. The study was carried out in Bom Sucesso City, Paraná State, Brazil. Using GPS, a 50 x 50 m grid sampling size was set, comprising four samples per hectare. In each grid point positioned on the field, soil samples at a depth of 00 to 0.20m were extracted, resulting in 203 sampling points in a 51.15 ha area. Calcium, magnesium and potassium quantity were determined. Grid sampling size, with lower number of samples per area, were established from the first grid, removing randomly, soil samples, resulting in: 70.8 x 70.8 m (2 samples/ha), 100 x 100 m (1 sample/ha), 141.4 x 141.4 m (1 sample/2 ha), 173.3 x 173.3 m (1 sample/3 ha) and 200 x 200 m (1 sample/4 ha) grid sampling sizes. Each soil chemical properties in each grid sampling size were subjected to descriptive statistical and geostatistical analysis. An experimental semivariogram was developed to understand the spatial dependence structure. The attributes calcium, magnesium and potassium showed spatial correlation in almost all grids sampling, except for the 200 m grid sampling for calcium and magnesium.

Key words: Spatial distribution of attributes, spatial dependence, descriptive statistics, geostatistics.

INTRODUCTION

Brazilian agriculture, in recent decades, has undergone constant changes and technological advances, fast

automation by the introduction of agricultural machinery and implements, with the aid of computer controls and

*Corresponding author. E-mail: guilhermecapristo51@gmail.com.

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Figure 1. Location of the city of Bom Sucesso and study area.

global positioning technology (GPS), plant breeding, new active principles and positioning of pesticides, technology of controlled liberation of fertilizers, in order to increase yield number and reduce negative impacts on the environment (Silva, 2013). Although, several studies have been conducted regarding the spatial variability, especially in the soil-plant relationship, they have not reached the appropriate dissemination among technicians and engineers in agriculture.

Information regarding agricultural production are fairly disclosed, but little is known about their spatial behavior. Some teaching characterizations as "production environment" are constantly recommended in the agricultural sector, but they are also too subjective to who set the criteria, evaluation and production components (Silva, 2013).

In the quest of trying to understand and characterize the spatial distribution of production variables, establishing best parameters and criteria to classify "production environments", projects and research are needed so that they can contribute and assist agronomic practices and decisions.

Further studies regarding the spatial variability of physical, chemical and biological soil attributes are necessary since the management of agricultural practices depends on this variability, with direct impact on agricultural yield and on the environment. It seems to be the most elaborate way to understand the production of variables related to the soil-plant system. Knowledge of these variations is essential to the survey and classification of areas with productive potential, assessment of their fertility, development of appropriate systems of sampling, experimental design and definitions of appropriate management practices and recovery of agricultural areas. The number of samples required to represent the variability of the field has been a subject of discussion since at least, 1920 (Linsley and Bauer, 1929).

Systemic sampling is suggested by many researchers as the most widely used method to prove a field (Peck and Nelsted, 1973). Wisconsin research has shown that

the sampling density needed depends on the variability of the field, but generally recommends a grid fitting of 200 m, depending on historical fertility and management of the soil (Wollenhaupt et al., 1994). Regular grid samplings are typically used in soil sampling processes for the development of fertility maps and located fertilization, but samples may also be collected and used at different systematic strategies. An alternative to grid soil sampling is management zone sampling (also called directed or smart sampling). Nowadays, management zones are established using a variety of resources and/or datasets. This includes soil surveys, previous yield data, remote sensing imagery, landscape/topography, elevation, electrical conductivity, and/or previous knowledge of field characteristics (Thompson et al., 2004; Gelderman et al., 2006; Agricultural Research and Extension Council of Alberta, 2010). Franzen (2011) showed better adjustment in 1 acre grid sampling.

Therefore, this paper aimed to evaluate the soil spatial distribution and behavior of chemical attributes calcium, magnesium and potassium, providing subsidies for management of sugar cane crop area.

MATERIALS AND METHODS

Characterization of the study area

The area chosen for the studies is located in Bom Sucesso, northwest of Parana State, Brazil, between the coordinates 23° 39.890' S and 51° 46.558' W. The city of Bom Sucesso (Figure 1), founded in 1954, has a total area of 323 km² and an average altitude of 580 m with altimetry as reference, the tide gauge of Imituba.

Geology

The study area is located in the Serra Geral Formation belonging to the São Bento group, which appears in about 53% of the territory of Paraná (Leinz and Amaral, 1987). This formation consists predominantly of successive spills of toleithic basalts and, secondarily, by fine sandstones to interthreshold siltstones and breccias in continuous beds with varying thickness, and very rarely by small interleaved silt-sandy dykes (Gimenez Filho, 1993). These spills are cut by dykes and diaphragm sills with ophthalmic texture, having as essential minerals andesine and pigeonite feldspars, as well as potassic feldspars, chlorites, serpentines and quartz, and small portions of other minerals. Magnetite and ilmenite predominate in opaque minerals.

Data analysis

To perform the laboratory activities, the following computer programs were used: Excel (Microsoft), for assembly of data sheets; the System for Georeferenced Information Processing (SPRING version 5.2.2, 2012) to prepare the database and all the manipulation of geo-referenced information; VARIOWIN2.2 Pannatier (1996), to carry out the spatial dependence analysis and STATISTICA 8 (Statsoft) for descriptive statistics and geostatistical module/validation SPRING 5.2.2 (INPE) for the interpolation of soil attributes by kriging interpolation.

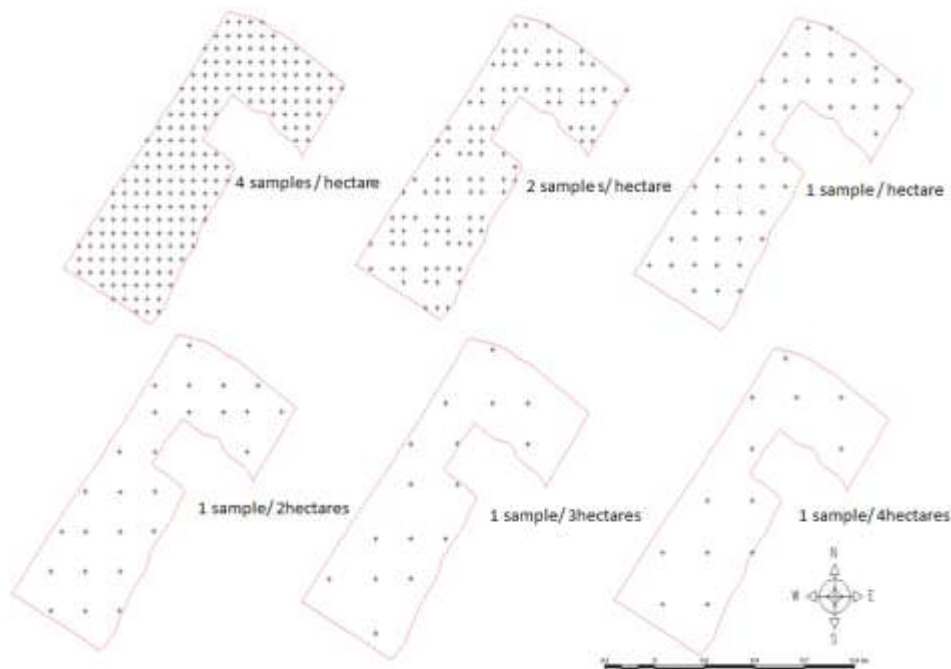


Figure 2. Regular sampling grids.

The work was initiated by map preparation CAD system in AutoCAD software and worked in the cartographic information system to enter it in a database. This map has been reconfigured within the geocoded Information Processing System - SPRING developed by INPE. According Câmara et al. (1998), SPRING is a state of the art GIS system designed for object-oriented programming, with multiple functions and algorithms for database processing georeferenced.

Sample collection

For sampling of soil, a regular grid was established (Figure 2) sampling distance of 50 in 50 m as a base grid (reference), comprising four samples per hectare in an area of 51.14 ha. Other grids were established by this decreasing the amount of sample points (Nanni, 2011): 70.8 x 70.8 m comprising 2 (two) samples per hectare; 100 x 100 m comprises one sample per hectare; 141.4 x 141.4 m comprising a sample every two acres; 173.3 x 173.3 m comprising a sample every three acres; 200 x 200 m a sample comprising the four acres (Figure 2).

Sampling was collected in depth 00-0.20 cm in the surface of soil horizon for 50x50 m grid one sample per point without subsample. The depth of 00-0.20 cm was chosen for analysis because it was considered the most effective depth explored by the roots of the culture of cane sugar, and represents the diagnostic horizon correction/fertility.

For the collection of soil samples, the points were located by GPS system, facilitating the process of exploration, as provided to coordinate all the locations of the points to be visited, reducing the possibility of errors and allowing the possibility of returning to the same new point collections for confirmation.

The samples were placed in plastic bags, identified and taken to the Rural Agronomy Laboratory Maringa for macro nutrient chemical analysis. The chemical elements analyzed were: calcium and magnesium (Ca + Mg) and potassium (K), using the methods developed by Embrapa (2010).

In order to analyze and compare the spatial distribution of attributes: Ca + Mg and K, showed the best regular sampling grid (50, 70.8, 100, 141.4, 173.3 and 200 m) from the set that best characterizes the spatial distribution of the attribute in the soil which faithfully portrays local conditions.

Statistical analysis

For each chemical attributes of the studied soil, descriptive statistical analysis and the comparison of average by the Tukey test at 5% significance were done, with the aid of the Statistica software. Descriptive statistics calculated the mean, median, minimum, maximum, variance, asymmetry, kurtosis, the coefficient of variation (CV), standard deviation (SD) and the type of distribution. The Lilliefors test (P-value) at 5% probability was used to test the hypothesis of normality.

The Ca + Mg and K attributes were normally distributed in all regular grids sampling, being an important feature for later perform geostatistical study. It was, in this work, that the data meets the intrinsic stationarity condition that occurs when hope (E) $Z(x_i)$ is constant, $\mu(x) = \mu$ and the variance (VAR) of the increment between $Z(x_i)$ and $Z(x_i + h)$ is finite and independent of the position in space, depending only on the separation distance h , since the data is symmetrical with respect to normal Gonçalves et al. (1997), Vieira et al. (1997) and Webster and Oliver (1990). This level of stationarity of data is sufficient for the application of geostatistics.

RESULTS AND DISCUSSION

To better understand the distribution of attributes in different sampling grids evaluated in the study area, the values of the arithmetic mean of the attributes for each grade were established, as shown in Table 1. According to EMBRAPA et al. (2010), the mean values of soil chemical properties in the layer 00 to 0.20 cm (Table 1),

Table 1. Arithmetic means and coefficient of variation (CV) of soil attributes obtained from the samples chosen for the different grids.

Attributes	Grid						CV (%)
	50 m	70.8 m	100 m	141.4 m	173.3 m	200 m	
K	0.4	0.4	0.5	0.5	0.3	0.4	10.41
Ca + Mg	6.7	6.6	6.5	7.0	7.1	6.9	3.33

*Calcium and magnesium (Ca+Mg) and potassium (K) given in cmolc.dm^{-3} .

Table 2. Descriptive statistics of Ca + Mg values for the different sampling grids.

Grid ¹ (m)	N ²	Min	Median	Max	Mean	Kurtosis	Skewness	CV% ³	σ^4	SD ⁵	P ⁶
50	203	3.4	6.7	13.2	6.8	2.2	0.8	0.2	2.3	1.5	0.0*
70.8	103	3.4	6.6	11.4	6.6	0.7	0.5	0.2	2.2	1.5	0.5
100	48	3.7	6.6	13.2	6.5	4.6	1.3	0.3	2.7	1.6	0.1
141.4	26	3.9	7.2	9.7	7.0	-0.6	-0.1	0.2	2.2	1.5	0.7
173.3	16	3.6	7.4	9.7	7.1	-0.6	-0.3	0.3	3.1	1.8	0.8
200	13	5.1	6.9	8.5	6.9	-0.2	-0.1	0.1	0.9	0.9	1.0

¹Regular grid in meters; ²Number of sample points; ³Coefficient of variation (%); ⁴variance; ⁵standard deviation; ⁶test of Lilliefors; **, *, significant at 1 and 5%, respectively.

Table 3. Descriptive statistics of K values for the different sampling grids.

Grid ¹ (m)	N ²	Min	Median	Max	Mean	Kurtosis	Skewness	CV% ³	σ^4	SD ⁵	P ⁶
50	203	0.1	0.5	1.0	0.5	-0.7	0.2	43.9	0.0	0.2	0.1
70.8	103	0.1	0.5	1.0	0.5	-0.8	0.3	45.3	0.0	0.2	0.0
100	48	0.1	0.6	1.0	0.5	-0.6	0.1	42.0	0.1	0.2	0.9
141.4	26	0.1	0.5	1.0	0.5	-0.7	0.2	46.9	0.1	0.2	0.5
173.3	16	0.1	0.4	0.7	0.4	-1.2	0.1	47.8	0.0	0.2	0.5
200	13	0.2	0.4	0.9	0.4	-0.9	0.6	53.1	0.1	0.2	0.2

¹Regular grid in meters; ²Number of sample points; ³Coefficient of variation (%); ⁴variance; ⁵standard deviation; ⁶test of Lilliefors; **, *, significant at 1 and 5%, respectively.

was used to classify their fertility as high for Ca + Mg and K,

According Vanni et al. (1998), if the coefficient of variation is less than 35%, the data series can be regarded as a homogeneous medium and can present significant, can be used as representative of the series from which it was obtained.

For all the regular grids, CV's presented lower values probably due to the same soil management and cultural practices (fertilization) established for the area. The results of the descriptive analysis of soil chemical properties are shown in Tables 2 and 3 separately. The application of the normality test to the data set reveals that the attributes: Ca + Mg and K normal distribution. Analyzing the results obtained in the descriptive statistics (Table 2), it is observed that the values of Ca + Mg and K demonstrated and maintained low CV in all the regular

grids sampling (<12%), according to the criteria proposed by Warrick and Nielsen et al. (1980). The attribute K (Table 3) also showed normal distribution, CV and SD low on different grids, given normal, as reported by Nanni et al. (2011). However, different results were obtained by Cavalcante et al. (2007). The variogram analysis indicated that soil attributes analyzed (Figures 3 and 4) separately in different sampling regular grids spatial correlation, except for Ca + Mg attribute in 200 m grid.

The Ca + Mg attribute maintained a greater distance between the nugget and semivariance values, with moderate spatial dependence structure, with a range of about 290-700 m in the sampling grid (Table 4). Values of Ca + Mg (200 m grid) showed that the data sets in grids of lower sample intensities tend to behave where spatial dependence cannot be quantified, and the information that best represents the data set in these regular grids is

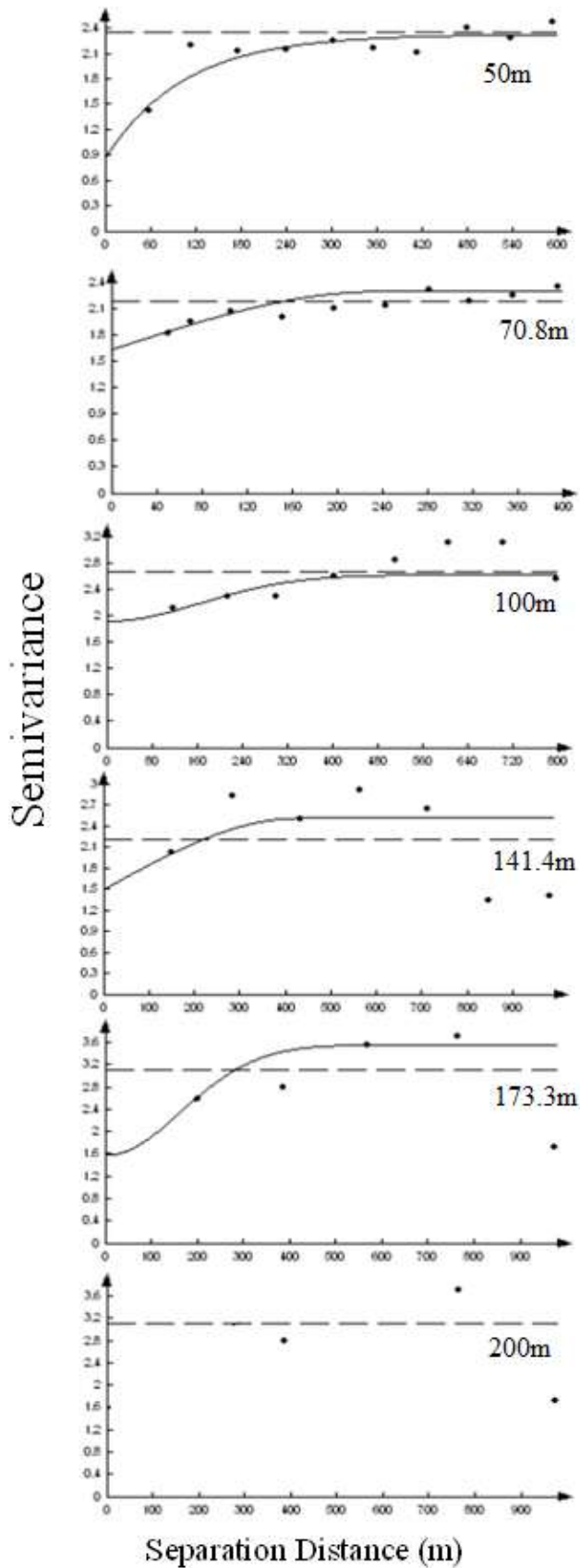


Figure 3. Semivariogram different sampling grids for Ca + Mg attributes.

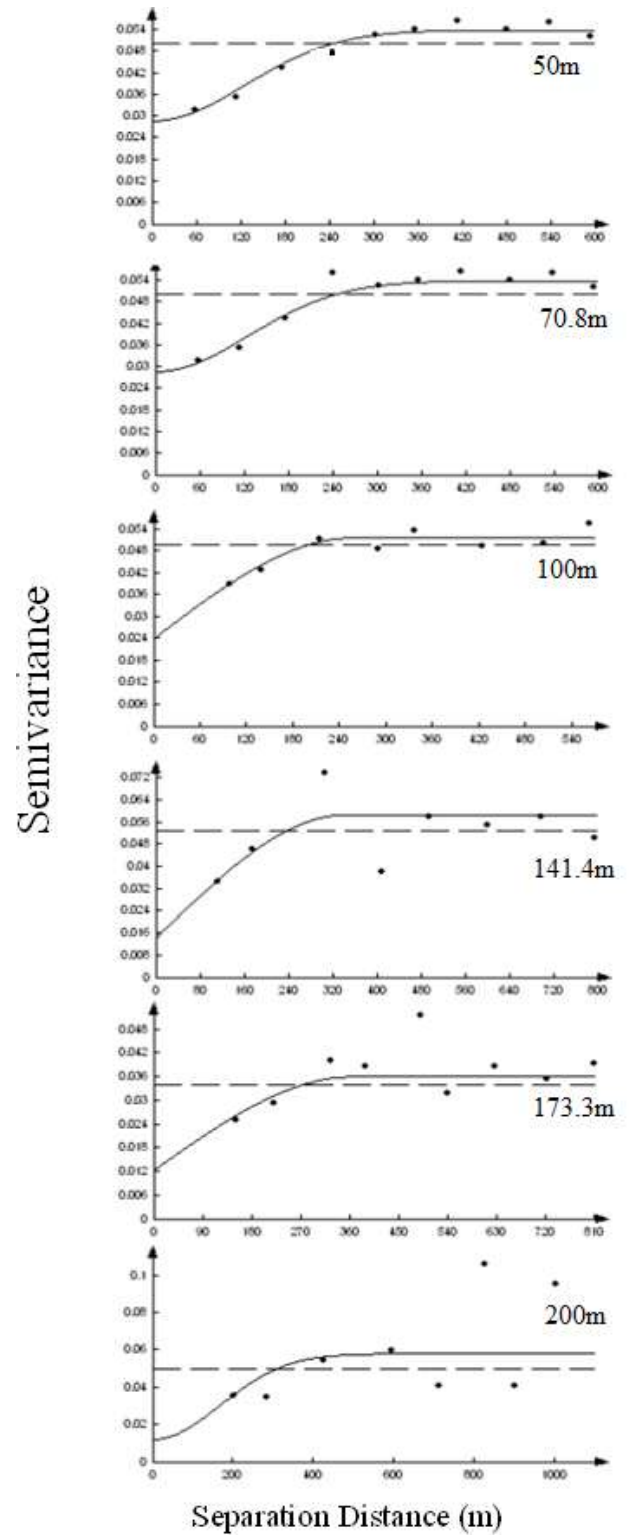


Figure 4. Semivariogram different sampling grids for K attributes.

the arithmetic mean, as also observed by Souza et al. (2014).

Table 4. Semivariogram of Ca + Mg values for different sampling grids.

Semivariogram		Nugget	Sill	Range (m)	IGF
Grid (m)	Model	Co	(Co + C)	A0	
50	Exponential	1.19086	2.43286	290	2.39E-03
70.8	Spherical	1.64465	2.30465	240	3.73E-03
100	Gaussian	1.93302	2.63502	400	1.09E-02
141.4	Spherical	1.23165	2.63465	480	7.17E-02
173.3	Gaussian	2.28511	3.49411	700	3.79E-02
200	Pure nugget effect				

IGF¹ Indicate goodness of fit.

Table 5. Semivariogram of K values for different sampling grids.

Semivariogram		Nugget	Sill	Range (m)	IGF ¹
Grid (m)	Model	Co	(Co + C)	A0	
50	Exponential	0.022673	0.054173	240	2.72E-03
70.8	Gaussian	0.028984	0.054184	240-300	6.38E-03
100	Spherical	0.024378	0.051878	240-300	3.19E-03
141.4	Spherical	0.014706	0.059106	240-300	8.10E-02
173.3	Spherical	0.012669	0.036269	240-300	4.45E-02
200	Gaussian	0.012673	0.059796	700	1.79E-02

IGF¹ Indicate goodness of fit.

The attribute Ca + Mg showed moderate spatial dependence structure, with reach corresponding to the zone of influence of the spatial dependence around 700 m in sampling grids (Table 4).

The K attribute presented structure of the semivariogram with moderate spatial dependence in all established regular grids (Table 5), in agreement with results obtained by Salviano et al. (1998) and Souza et al. (1998).

The K presented a range around 240-700 m, with spatial continuity greater than the other attributes of the study area. Some authors attribute the spatial variability of Ca + Mg and K to their soil mobility. In this case, this condition is probably due to the form of fertilizer distribution (K) which, in the case of sugarcane, occurs in the planting line, that is, in a localized way, stabilizing the values with the Ca and Mg, which is distributed over a total area.

The semivariogram of Ca + Mg and K, spherical model best fitted the experimental semivariograms for the soil chemistry parameters measured. Similar results were found by Barbieri et al. (2008). The range of values for the Semivariograms play a significant role in determining the limit of the spatial dependence can also be indicative of the interval between soil map units (Grego and Vieira, 2005), and moderate spatial dependence of the class can be attributed to intrinsic factors (mineralogy and texture), whereas extrinsic (soil management) is attributed to weak

dependence.

The moderate spatial dependence would be due to soil homogenization, confirmed this hypothesis when analyzing the range of variation of the chemical attributes Ca + Mg and K that have low CV, a similar situation was observed by Cavalcante et al. (2007) studying the use and management systems soil. Spatial distribution maps of the chemical attributes Ca + Mg and K were generated from the kriging interpolation bars that had spatial dependence Figures 5 and 6. Analyzing the results obtained the details of patterns of map variations become increasingly degraded as the decrease in sampling intensity. Similar results were observed by Kerry and Oliver (2008) and Nanni et al. (2010, 2011).

When using kriging with variograms calculated from much spaced samples, as in grids above 1 sample per 2 ha, thematic maps of the soil used to determine the classes of the attribute in space do not reflect the main patterns of variation present (Kerry and Oliver, 2008).

Conclusions

Descriptive statistics of the study area attributes analyzed together with different regular grids sampling showed chemical homogeneity, in other words, if the option is the central tendency, all the grids showed very similar results, regardless of the sampling rate. In the

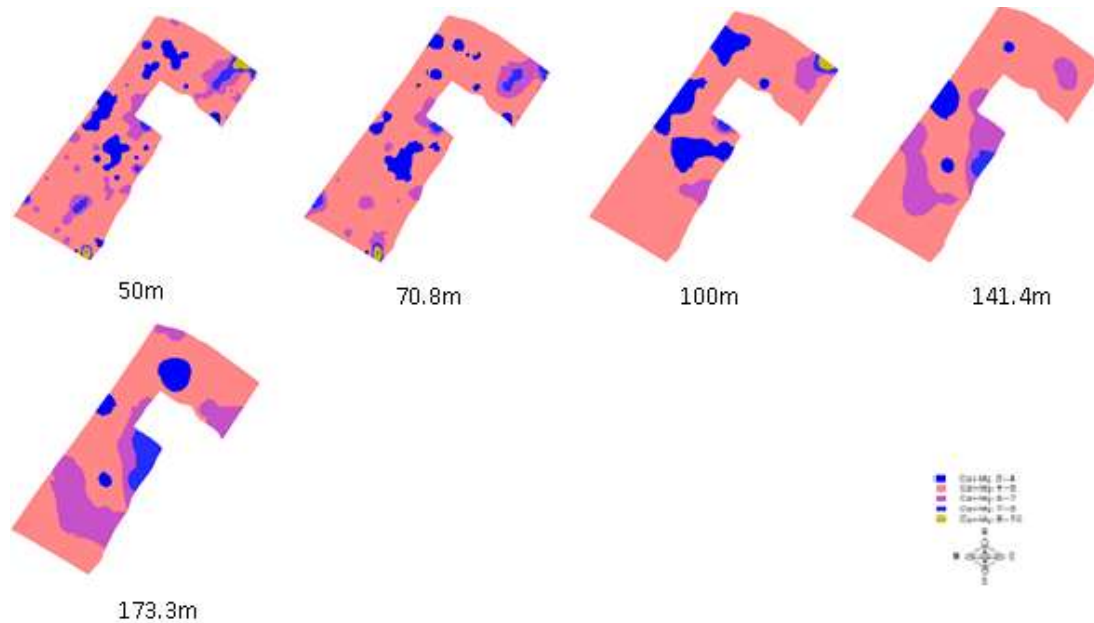


Figure 5. Spatial distribution maps attributes Ca + Mg.

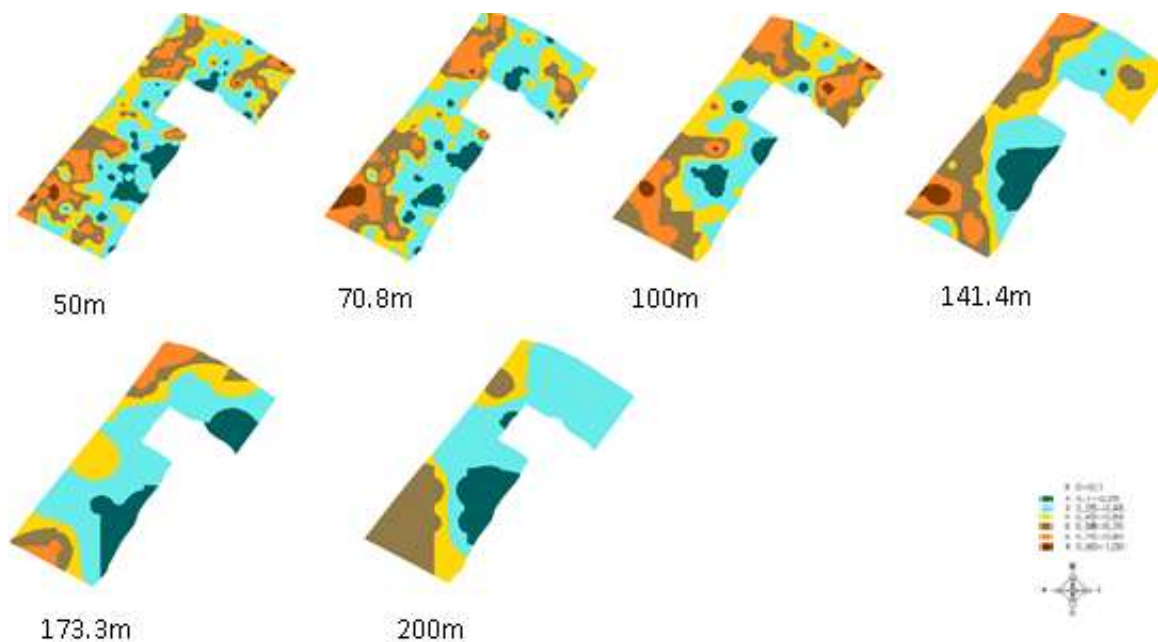


Figure 6. Spatial distribution maps attribute K.

semivariogram analyzes, all the attributes presented spatial dependence: Ca + Mg and K with exceptions: Ca + Mg 200 m grid.

The results obtained in separately semivariogram for each attribute in their regular grids sampling established regular grid with lower density samples, the attribute can be characterized in a satisfactory way and representative

geostatistics: Ca + Mg regular grids of 173.3 m (1 sample in 3 hectares) and K 173.3 m regular grids or 200 m (1 sample in 3 hectares or 1 sample in 4 hectares).

Conflict of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Quality of mechanized peanut digging in function of the auto guidance

Santos A. F.*, Kazama E. H., Ormond A. T. S., Tavares T. O. and Silva R. P.

Department of Rural Engineering, São Paulo State University (UNESP), School of Agricultural and Veterinarian Sciences, Jaboticabal, Brazil.

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Within the context of precision agriculture, the use of automatic guidance is without a doubt one of the most popular tools among farmers, however, are few producers of peanuts using this technology, the benefits from this technology can bring significant gains for culture even more when thinking about reducing the indices of losses in the digging. Thus, it objective was to evaluate the variability of quantitative losses of peanut mechanized digging with use the autopilot, using the Statistical Process Control. The treatments consisted of absence of autopilot use in sowing and digging, pilot's absence at sowing and presence in the digging, pilot use at sowing and absence in the digging and the pilot use in sowing and digging. In each treatment, 15 points of each variable was collected from distance of 50 m apart. Visible, invisible and total losses in the digging and parallelism were evaluated. The reduction of the plant material on the vibratory mat affected the levels of visible losses. Total losses are strongly correlated with the invisible losses. The use of the autopilot allows the operator to pay more attention to the digging operation improving the quality of the operation. The average error found between passes of the mechanized set using autopilot was 0.35 m. The variability of the losses as well as of parallelism was reduced when using the autopilot in two operations, providing a higher quality process.

Key words: RTK (Real Time Kinematic), automatic guidance, precision agriculture, statistical process control.

INTRODUCTION

South central region of Brazil is a place where peanuts are mostly sown, especially, São Paulo is the foundation where approximately 110 thousand hectares of peanut are grown. The state is the largest producer with about 81% production.

However, even in small and less expressive form, crop production extends to other regions. Tocantins is the only state in the northern region that has areas with the peanut crop, with productivity forecast of 3.9 t ha⁻¹ for 2014/2015, showing highly competitive production

*Corresponding author. E-mail: adaofeliped@gmail.com.

conditions, seeing that the average national production is 3.0 t ha^{-1} and it is 1.6 t ha^{-1} in the world (Conab, 2015).

Independent of region, the production results are directly affected by losses during the dug up, in most cases due to excess maturation caused by harvest delay, which encourages the weakening of gynophore and consequently the pods are retained in the soil. Ince and Guzel (2003) reported that soil water content at the time of digging contributes to gynophore weakening, resulting in an exponential increase in losses, since the extent of decrease of the soil water content reduces the tear resistance of the gynophore and consequently increase the total losses of harvest.

Apart from these main factors, the incidence of weeds at the time of digging, maintenance of knives, displacement speed, vibration in the shaking conveyor and maturation, should also be given special attention because it can contribute to increase in loss (Bragachini and Peiretti, 2008), as well as the digging line deviations of the mechanized set during the operation, fact related to the operator's experience (hours worked in the digging operation), being that higher experience, lowers deviations and consequently lowers total losses coming from the factor manpower.

However, with technology advancement and easy access to the application of precision agriculture in various sectors of production, mainly at harvest, has become a viable alternative, but without much study of the peanut crop when compared with sugarcane in which 39% of mills uses the automatic guidance (Silva et al., 2011).

The use of this kind of technology can be fundamental to reducing losses in the peanut harvest, especially when you have an alignment of sowing with the digging operation, because the operator has difficulty maintaining the tractor aligned with culture. Balkcom et al. (2010) emphasize that this fact is due to the high production of biomass that covers the soil and impedes vision of the operator. To Sun et al. (2010) when using the guidance system with RTK signal accuracy of 2.5 cm, it is possible to make a precise adjustment for subsequent operations, besides increasing the operational capacity provided by the use of this system (Oliveira and Molin, 2011) and improvements in the quality of operation.

Thus, considering that the process has the quality as the final objective, Montgomery (2009) affirms that a definition which will be well accepted as the term quality is to reduce the variability and therefore lower the variation and increase the reliability and acceptance of the product or service. The evaluation of the quality of agricultural operations mechanized through the SPC (Statistical Process Control) can bring improvements to the process.

Several studies used the SPC as a tool to assess the quality of the mechanical harvesting process and demonstrate a potential tool to be applied in agriculture (Noronha et al., 2011; Chioderoli et al., 2012; Bertonha et

al., 2014; Voltarelli et al., 2015), mainly because of the possibility of correcting failed points, which considerably increases the final quality of the process, as well as the net return to agricultural activity.

From that exposed, it presupposes that the losses in mechanical harvesting of peanuts have temporal variability that can be reduced with the use of automatic guidance, which is aimed at evaluating the quality of digging mechanized peanuts with and without the use of autopilot at sowing and digging, using the losses as quality indicators through statistical process control techniques.

MATERIALS AND METHODS

The experiment was conducted on the farm of Córrego do Meio, in the municipality of Alvorada-TO, located in the geographical coordinates $12^{\circ}28'48'' \text{ S}$ and $49^{\circ}07'29'' \text{ O}$, with an altitude of 289 m. The cultivar was IAC 503, vegetative runner group, creeping size, indeterminate growth habit, sown in the spacing of 0.90 m between rows, sowing density of 21 seeds by meter, in soil predominantly sandy texture (Embrapa, 2013).

The sowing for all areas was performed by a tractor John Deere brand, model 6110 J to 149.5 kW of engine power (110 cv) and seeder PHT4 Supreme. The digging up was carried out by mechanized set, which was a digger/inverter BM Dumont 4×2 (4 lines and 2 windrows) pulled by tractor JD 6145J (145 hp). Mechanized sets were equipped with electric autopilot with RTK correction, precision 2.5 cm antenna StarFire™ and GreenStar™ monitor. These were activated in the treatments with pilot and disabled to perform the pilotless treatments, both in sowing, as the digging, and the guidance in sowing done by the line marker and the digging by the vision and experience of the operator to perform the operation.

The design followed the standard adopted by statistical process control, in which samples are collected over time, consisting of four treatments in different areas, as follows:

- Absence of autopilot use in sowing and at dug up (S/S pilot);
- Pilot use at sowing and absence at dug up (C/S pilot);
- Pilot Absence at sowing and presence at dug up (S/C pilot); and
- Pilot use at sowing and dug up (C/C pilot).

For each treatment, up to 15 points distance was collected from one another by 50 m, totaling 60 sample points.

The variables used to assess the quality of the process were visible digging losses (VDL), invisible (IDL) and the total digging losses (TDL) that correspond to the sum of visible and invisible losses. To collect the loss manually, a metal frame of approximately 2 m^2 ($3.9 \times 0.5 \text{ m}$) was placed across the windrow, and the visible and invisible losses were collected with a hoe at a depth of 0.15 m. The definition of the width of the frame corresponds to the working width of the digger-inverter. After collection, the pods were packed in plastic bags, weighed and identified.

The samples were sent to the Machines and Agricultural Mechanization Laboratory (LAMMA) of Unesp/Jaboticabal, where they were placed in an electric oven at 105°C for 24 h until they reached constant mass (Brasil, 2009). After drying, the mass of the pods was determined again, getting the values of the losses which were extrapolated kg ha^{-1} , with subsequent correction for 8% water content value used for peanut storage in hulling (Martins and Lago, 2008). The loss values were calculated in kg ha^{-1} and percentage in relation to productivity.

For sampling productivity in the four areas, the same frame of approximately 2 m^2 previously described was used. It was placed

on the windrows at a different sample point where the losses were determined. After this, cutting and bagging of all materials contained within the frame of the area and from the pods found within the sampling area was done with productivity of 8% water content calculated, and adding it to the productivity of harvest with the total losses from the digging up in this area (gross productivity).

For evaluation of the maturation, 100 pods were withdrawn randomly from the samples used to estimate the yield; next, the colour of the mesocarp was exposed through the Hull Scrape method through jet pressure water (Williams and Drexler, 1981).

Parallelism was measured after the digging operation, taking into account the working width of the digger/inverter (3.60 m) between the past tractor-digger set, obtained from the center of a windrow to the center of another windrow.

The water content was obtained by reading the probe of a TDR (Time Domain Reflectometer) which was used to determine the water quantity in the soil; TDR determines the dielectric constant of the soil by measuring the time (t) it takes for an electromagnetic pulse emitted in parallel conductive bar length L , fixed in the soil to reach its final level and return to the point of emission (Silva and Gervasio, 1999).

The analysis of the variability of peanut mechanical digging process was performed using SPC with the help of Minitab® software. The tools used were the control charts for variables. The selected control chart model was the Single Mobile Amplitude (I-MR: Single-Moving Range), which contains two graphs: the top, corresponding to the individual values sampled at each point and the lower obtained by amplitude calculated between the two successive observations. The control limits were established considering the variation in the data due to uncontrolled causes in the process (special causes), and was calculated based on the standard deviation of the variable, as demonstrated in Equations 1 and 2.

$$UCL = \bar{x} + 3\sigma \quad (1)$$

$$LCL = \bar{x} - 3\sigma \quad (2)$$

where UCL is the upper control limit; \bar{x} is the general mean of the variable; σ is the standard deviation; LCL is the lower control limit.

The best estimator of σ for R graph is given by: MR / d_2 , d_2 being one tabulated value and MR is the mean of the amplitudes. For the preparation of control charts, it is assumed that the data of a process under control are stationary and uncorrelated, providing graphics that can be planned in a way with predictable and reasonable performance and detecting points off reliably control. When the data is auto correlated, dependencies were observed between them, and this leads to an above average value which tends to be followed by an above average value, the same happening for trends below average. This means that as a condition in which there is little difference in each consecutive pair of points, reducing mobile range, which implies lower limits, increasing the rate of false alarm is important (Montgomery, 2009; Vaccaro et al., 2011).

The normality of the data is a fundamental supposition for development of \bar{x} and R graphics. This approach can be difficult in some cases and many analysts would probably prefer to use the standard procedure based on the assumption of normality, since it is known that the effect of the removal of such a supposition is not very serious (Montgomery, 2009), so there was analysis of normality by Ryan-Joiner test at 5% and if necessary the transformation of the data.

RESULTS AND DISCUSSION

The following were analyzed in the data: visible digging

losses (VDL), invisible digging losses (IDL), total digging losses (TDA), parallelism and the soil water content present with absence of autocorrelation, as observed in the figures that the bars do not extend beyond the dotted line in red (Figure 1).

Data normality was also observed for the variables, except for the total losses in the treatment C/S (with autopilot at sowing and absence at digging) getting 0.027, an amount close to 5% (normality), being considered by the assumption that the data follow a normal distribution according Montgomery (2009) (Table 1). From the confirmation of basic assumption for the use of control charts, the statistical process control was used as a tool to analyze the digging processes of peanuts.

Individual control charts and the mobile range for the visible losses, invisible and total, were stable for all treatments (Figure 2).

The visible loss showed quality similar process for treatments S/S, C/S and C/C. It was observed that the S/C treatment showed higher variability in the visible losses. This process can be related to the fact that the green peanut mass was substantially lower (27.765 kg ha⁻¹) compared to treatment S/S, C/S and C/C (37.437, 53.700, and 39.125 kg ha⁻¹, respectively).

Whereas the green mass dampens the vibration of peanuts on the vibrating mat, reducing the detachment of gynophore even when the pods have a high percentage of maturation. This fact is proved when analyzing maturation in the treatments, where the mean maturation values were 83, 84, 79, and 83% for S/S, S/C, C/S, and C/C, respectively, so even when the treatment S/C presenting a lower percentage of maturation, there was a higher detachment of fruit due to less dampening pods in the vibratory mat.

Thus, taking into account that the maturation is the main indicative for the start of management of peanut crop, Sanders et al. (1980) point as the ideal time for the pull-off when the pods present values between 70 and 75% maturation physiological (mesocarp after scraping presents color from light brown to black). However, according Onemli (2005), the maturation of the pods may be influenced by climatic factors, especially, cloudiness and precipitation factors that can increase the flowering period of peanut plants, a fact that decreases proportionally to the maturity of pods, retarding the start of the harvest.

Similarly, processes for the invisible loss (Figure 2B) are under control. It is noted that the process variability is reduced as the autopilot system is used; so, the best quality is obtained by C/C system, followed by use of the pilot in at least one of the operations (C/S, S/C) and finally, only the experience of the operator (S/S).

In this way, when using autopilot in only one of the operations (C/S) reduction of variability in invisible losses is noted compared to using only the autopilot operation in the digging (S/C). The lower variability obtained when sowing was performed with autopilot is justified

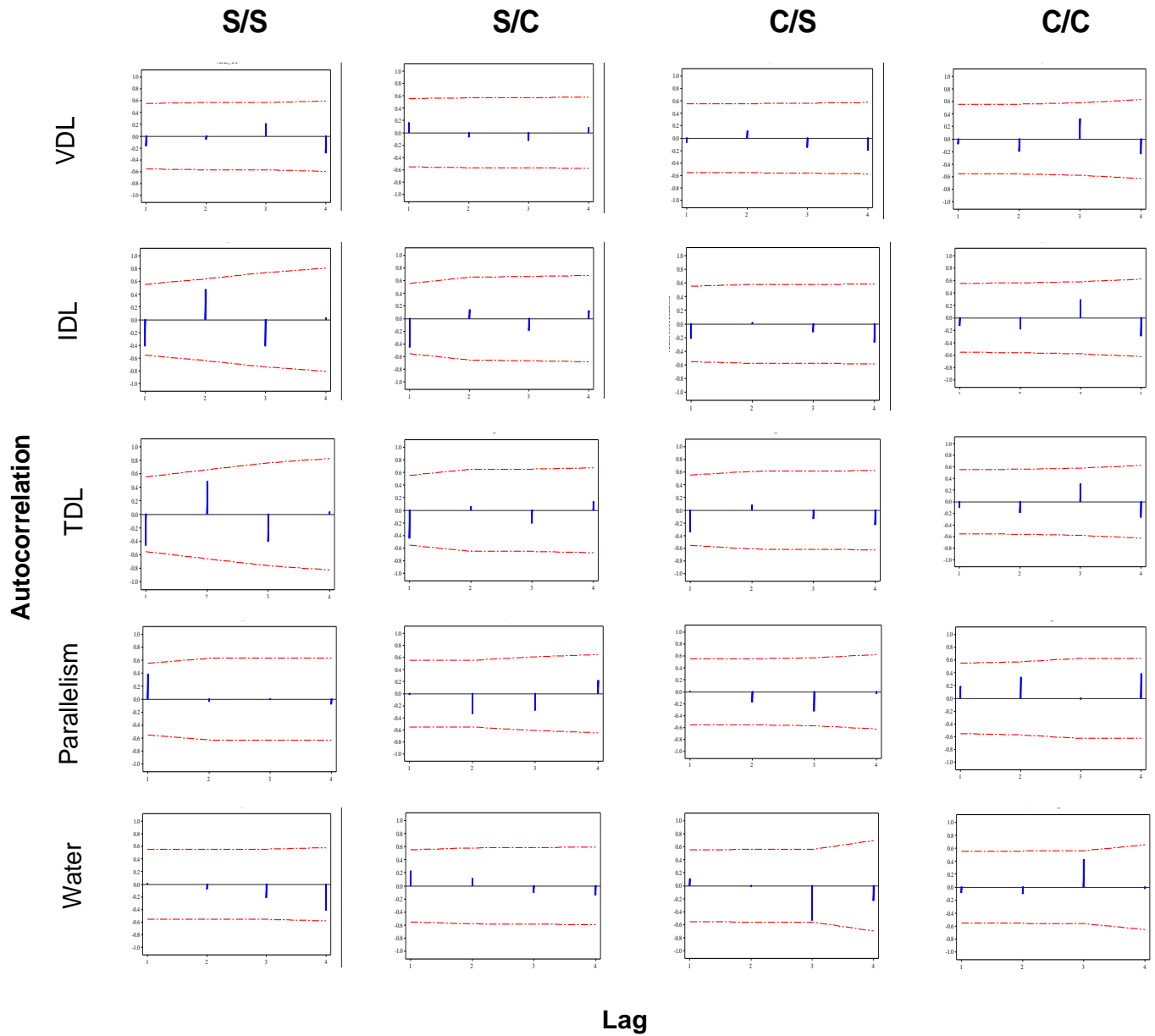


Figure 1. Autocorrelation function of visible loss in digging, 5% significance limit due to the absence of autopilot at sowing and digging up (S/S), absence of autopilot at sowing and presence at digging up (S/C), presence of autopilot at sowing and absence at digging up (C/S) and presence of autopilot at sowing and digging up (C/C).

Table 1. Normality test at 5% by the Ryan-Joiner test (similar to Shapiro-Wilk) due to the absence of autopilot at sowing and digging up (S/S), absence of autopilot at sowing and presence at digging up (S/C), presence of autopilot at sowing and absence at digging up (C/S) and presence of autopilot at sowing and digging up (C/C).

Variable	S/S	S/C	C/S	C/C
VDL	>0.100	>0.100	>0.100	0.054
IDL	>0.100	>0.100	>0.100	0.079
TDL	0.074	>0.100	0.026	0.054
Parallelism	>0.100	>0.100	>0.100	>0.100
Water content	>0.100	>0.100	>0.100	>0.100

*Values higher than 0.05 are considered normal to test.

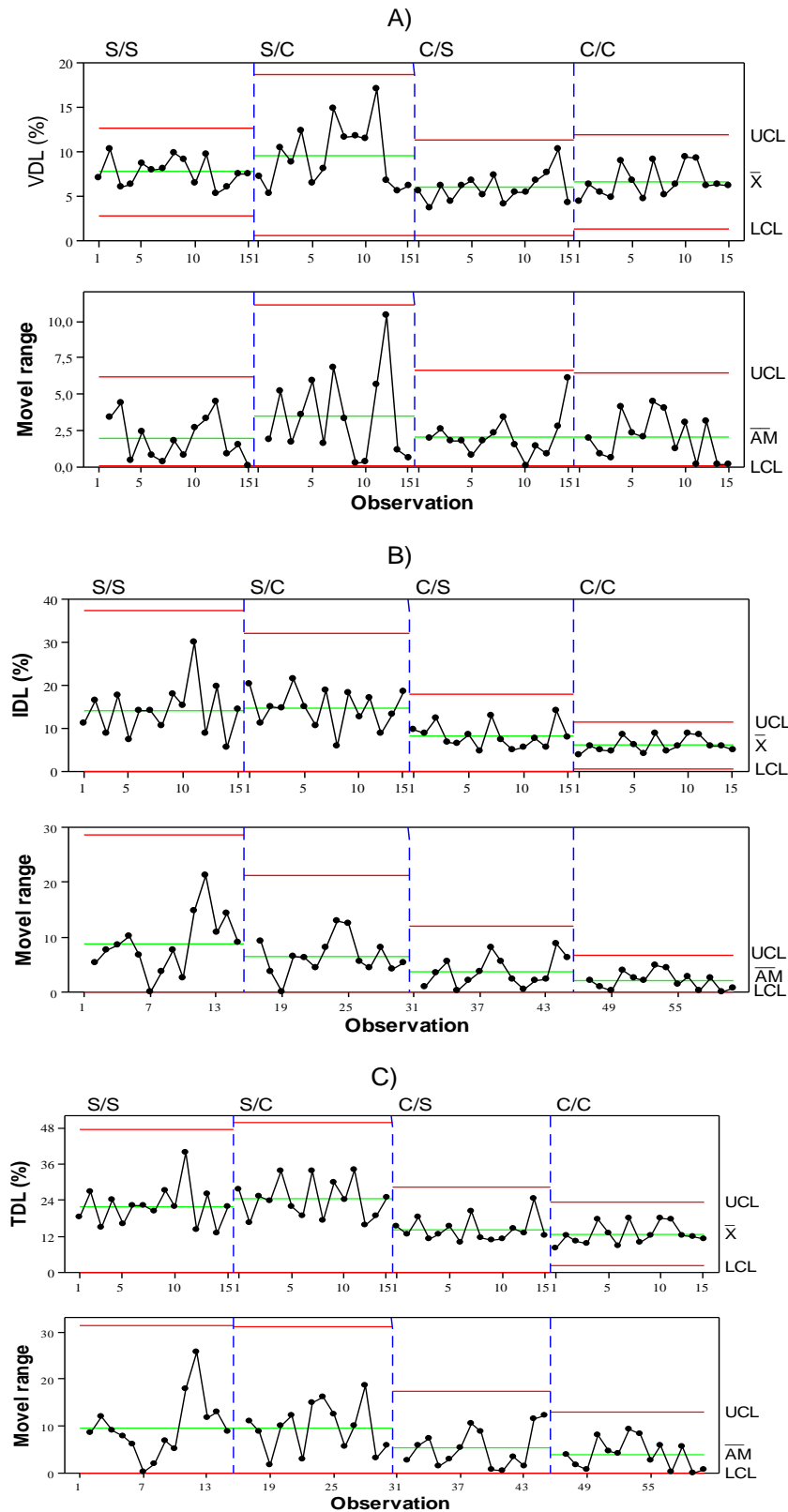


Figure 2. Control charts for losses in the digging due to the absence of autopilot at sowing and digging (S/S), no autopilot at sowing and presence in the digging (S/C), autopilot presence at sowing and absence in the digging (C/S) and presence of autopilot at sowing and digging (C/C). Visible digging losses (a) invisible digging losses (b) and total digging losses (c).

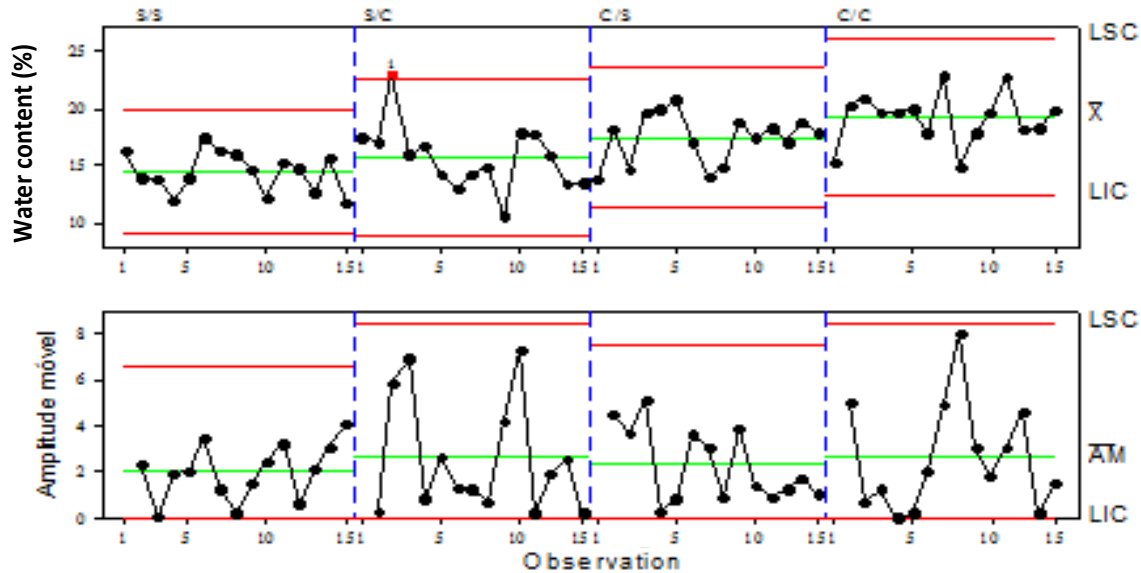


Figure 3. Control charts of soil water content due to the absence of autopilot at sowing and digging (S/S), no autopilot at sowing and presence in the digging (S/C), autopilot presence at sowing and absence in the digging (C/S) and presence of autopilot at sowing and digging (C/C).

by the fact that the sowing lines maintain a uniform standard throughout the operation, which facilitates digging operation, even when this is done with the help of the operator (pilotless). Furthermore, there is a better use of inputs and higher economic yields per sown area (Holpp, 2007).

Based on the moving range, charts (Figure 2B) confirm that the variability was reduced when sowing aligned with the digging using the autopilot (C/C). The reduction of variability in this process was due to the precise positioning of the tractor-digger set over peanut rows coming from the sowing operation. With the alignment of the two operations, the operator is not concerned with having to keep aligned tractor with row crop, and then you can give attention to possible faults in the digger, as straw accumulation and depth of work, ensuring reduction in the invisible loss rates and consequently the total.

It is noteworthy that the total losses (Figure 2C) are mainly influenced by the invisible losses. Presenting correlation of these variables of 0.96, correlation coefficient is considered strong and positive. The obtained relations from the invisible loss on total losses were 65, 61, 58 and 48% of total losses for treatments S/S, S/C, C/S and C/C, respectively, indicating that even in sandy soil, 60% of total losses, on average, comes from the invisible losses.

Thus, the use of the autopilot at sowing, aligned with the digging, can be a good tool in reducing losses in the pull-off, without letting pods retained in the soil, for alignment error.

These results are in accordance with those found by Zerbato et al. (2014a) that studying the use of autopilot

(RTK signal) in peanut digging concluded that its use can reduce 24.9% of invisible losses, regardless of displacement speed. In the same way, Jackson et al. (2011) found a reduction in losses of 26% of the peanut pods productivity in crops sown and digging without autopilot in southern Georgia, USA.

For the digging performed without a pilot (S/S), average of invisible losses around 14.2% was obtained; this high rate of loss may have been influenced by the water content in the soil (14.39%, Figure 3). This value is below that recommended by Santos et al. (2010) that establish a range of 18 to 20% in clayey soil.

However, in sandy soils, commonly found in the state of Tocantins, can be inferred that based on the results, water content in the soil below 20% may represent significant increase in the rates of total losses in the digging. The water content in the soil has great variability in space and time, even when it belongs to the same pedological unit (Ávila et al., 2010).

In this sense, Zerbato et al. (2014b) affirms that higher soil water content can reduce the losses in the digging, but when it is too high it hinders the performance of the machines. In corroboration, Kad et al. (2008) in the India, report that the water content in the soil is near 25% at the time of digging difficult operation for soil of the region.

Regarding the average productivity, it can be considered as good, 5070, 6143, 5842, and 6294 kg ha⁻¹ for treatment S/S, S/C, C/S and C/C, respectively at 135 days after sowing. Being that values found corroborate those observed by Santos et al. (2013), 6041.5 to 7020.9 kg ha⁻¹ using the cultivar runner, digged between 120 and 140 days after sowing. Still, Ortiz et al. (2013) evaluated the use of autopilot in two sowing systems and found

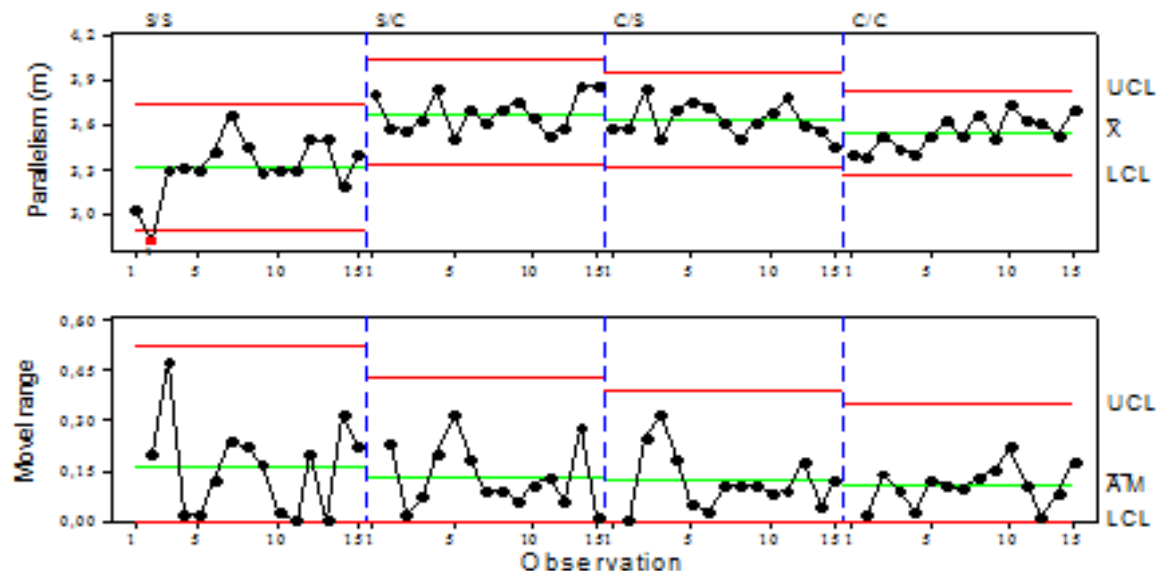


Figure 4. Parallelism control charts due to the absence of autopilot at sowing and digging (S/S), no autopilot at sowing but present in the digging (S/C), autopilot presence at sowing and absence in the digging (C/S) and presence of autopilot at sowing and digging (C/C).

productivity ranging from 3690 to 4324 kg ha⁻¹, while Assunção et al. (2008) obtained 4400 kg ha⁻¹ in irrigated conditions.

The lowest yield was found in treatments S/S and C/S can be attributed to the occurrence of weeds, even making periodic control areas, these interfere in the development of peanut plants, with accentuated reduction in these two treatments. Everman et al. (2008) emphasize that one of the factors that affect the growth and development of peanut crops are weeds, and may occur up to 80% reduction in productivity. Gunri et al. (2014) point out that the weeds grow faster than peanuts, and competition in the early stage reduces the development of crops reflecting a reduction in productivity.

Parallelism demonstrated instability (Figure 4), with a point out of control in treatment S/S, caused probably by manpower factor, where the operator even with experience (eighth season) deviated attention to the digger and caused slipping the longitudinal axis of the tractor with the culture.

This carelessness resulted in reduction between the windrows formed by the digger, making them closer to one another (2.82 m) between the past of set, which should pass 3.60 m. This error of 7.8 cm justifies the increased variability of the total losses in this treatment.

For the other treatments, the process can be considered stable, not showing points out of control, that is, the causes of variation are intrinsic in the process. The use of autopilot in the two operations (C/C) showed lower variations with respect to amplitude, when compared with treatment (S/C and C/S).

It was expected that the guidance error in this

treatment was only 0.03 m, but it presented a deviation from of 0.035 m, because the distance from the rover to the fixed base. However, when comparing the positioning error when autopilot (S/S) is not used, the average error was 0.084 m. Baio (2012) evaluating the average error of the autopilot in sugarcane harvest in two periods of work, found an average error of 0.030 m, while the manual system of this value increased significantly to 0.183 m.

The quality of the operation in relation to reducing the overlap of past tractor-digger system, reduced with the use of autopilot, following the same pattern of reduced variability presented in the total losses graphics. In this way, it is presumed that the use of the autopilot reduces variability in total losses in peanut digging and increases the quality of the operation, by reducing the parallelism errors. This fact is most evident when using the autopilot at sowing and digging due to positioning precision of the machines, and synchronization of operations.

Vellidis et al. (2013) in the same conditions of soil of the present work, also found lower losses in peanut using mechanical digging autopilot, and these results justified by the smaller error deviation tractor-digger system, provided by the accuracy of the RTK signal. Ortiz et al. (2013) also using RTK signal, emphasized that the use of automatic guidance with error 2.5 cm, can give net return of 94 and 404 US\$ ha⁻¹ for producers, against deviation of 18 cm operated manually.

Conclusions

It can be inferred that the alignment of sowing with peanut digging with the autopilot use provides reduction

of variability in total losses and consequently a better quality process.

The use of autopilot maintained the parallelism of mechanized set in digging the closest of regulated, with less variability and less positioning error.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Farmers' knowledge, attitude and perceptions on the use of locally available plant material to prevent rodent damage to maize crop in Eastern Tanzania

Mdangi M.^{1, 2, 3*}, Sibuga P. K.¹, Massawe A. W.³, Magadula J. J.^{4†} Ngowo V.⁵, Mrosso F. P.⁶, Mkangwa Z. C.⁶, Kilonzo B. S.³ and Mulungu L. S.³

¹Crop Science and Production, Sokoine University of Agriculture, P. O. Box 3005, Morogoro – Tanzania.

²Ministry of Agriculture Training Institute - Ilonga, P. O. Box 66, Kilosa, Morogoro – Tanzania.

³Pest Management Centre, Sokoine University of Agriculture, Box 3110, Morogoro– Tanzania.

⁴Muhimbili University of Health and Allied Sciences, Institute of Traditional Medicine, P. O. Box 65001, Dar es Salaam – Tanzania.

⁵Ministry of Agriculture, Livestock and Fisheries, Rodent Control Centre, P. O. Box 3047, Morogoro, Tanzania.

⁶Ministry of Agriculture, Livestock and Fisheries, Rodent Control Centre, Agricultural Research Institute - Ilonga, P. O. Box 33, Kilosa, Morogoro – Tanzania.

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A quantitative study was conducted in the Eastern zone of Tanzania, from May to September 2012 to assess farmers' knowledge, attitude and practice on the use of locally available plant materials for controlling rodent damage in maize fields and stores. Three villages in three districts were purposively selected with a total of 270 farmers randomly selected for the interview. A semi structured questionnaire was used to assess maize production constraints. Rodent pests were ranked higher (56%) than other pests with their crop losses estimated to be 64 and 36% in fields and stores, respectively. Use of rodenticides for rodent control was reported as the common single method. However, 85% of farmers use rodenticides with inadequate knowledge on application and their effects on the environment and health. It was further revealed that only 15% of the respondents reported to have attained training on how to apply rodenticides. With regard to the use of locally available plants, 4% of respondents reported to use them for rodent control, while 96% were not aware of any plant that was effective against rodents. However, most (97%) respondents expressed their willingness to use plant materials if provided with evidence that they are effective. Therefore, evaluation of plant materials and consequent development of plant products which can be safely used by poor resource farmers and subsequently reduce health and environmental risks associate with chemical rodenticides was recommended.

Key words: Rodents, plant materials, maize, Tanzania.

INTRODUCTION

Maize (*Zea mays* L.) is cultivated in the tropical, subtropical and temperate regions of the world and is the most important staple food reported to be the 5th agricultural commodity in The United Republic of Tanzania (Anna, 2014). According to FAOSTAT (2013), maize represented five percent of total agricultural imports in The United Republic of Tanzania during the period 2005 to 2010. In Tanzania, maize is grown all over the country in more than 20 regions where approximately 65 of maize grown by poor smallholder farmers (Barreiro-Hurle, 2012). It has been also reported that maize is predominantly used for multiple purposes largely for human consumption and animal feeds (William et al., 2012). It provide main energy source in the diet accounting for 25 percent of total caloric intake (FAOSTAT, 2013). According to Jeffrey and Maria (2014), 60 to 70% of maize production Worldwide is used domestically as livestock feed and the remaining 30 to 40% used for production of items for human consumption. It is reported that maize for human food involves boiling or roasting the green fresh maize on its cob or milling into flour for preparation of stiff porridge (“*ugali*” in Swahili). Additionally in some areas of Tanzania, example in Iringa region however, green maize stems are occasionally used as sugar cane whereby residents chew and suck the sugary juice in the stems (Kilonzo, pers. Observation). In some areas maize cobs has many agricultural and industrial applications including using them as fodder for ruminants despite their low nutritive value (Jansen, 2012). They (cobs) are also used as fuel for cooking or heating purposes, especially in traditional households and small scale farms. In other parts of the world, e.g German, strong incentives were set to produce biogas from dedicated energy crops of which the prominent plant was maize (Herrmann, 2013; Britz and Delzeit, 2013). In Tanzania, maize is the most staple food for the majority of Tanzanians grown for both subsistence and as a cash crop (Trevor and Lewis, 2015). It has been reported that 80% of maize production have been under small-scale farmers (Trevor and Lewis, 2015). However, according to Trevor and Lewis (2015), the maize yields in Tanzania is hampered by several problems including uncertain land tenure, little access to affordable finance, poor rural infrastructure, periodic bans on cereal exports, corruption, local taxes on farm production, the limited availability of improved seed, weak business skills and inadequate institutional and technical capacity.

Additionally, like other crops soil infertility, drought, weed

infestation, crop diseases and pest attack has been reported as a factor for reduced maize crop yield (Min et al., 2013). Vertebrate pests, especially rodents are most important contributing to maize crop damage during seedling stage and in stores resulting to a serious threat for reduction of income and widespread of food shortage (Mohammed, 2013). However, in their endeavor to reduce the rodent infestations, most small-scale farmers in many places of Tanzania use acute rodenticides so that dead bodies of the pests are seen shortly after application (Mulungu et al., 2015). However, according to the authors the use of synthetic rodenticides may facilitate development of bait shyness (toxiphobia) among the target species. This will then require surplus baiting to ensure that most of the rodents have access to the bait and can consume adequate dose of the same. Additionally, rodenticides are hazardous to environment or cause risks to non-targeted organisms including humans and livestock. Therefore, appropriate rodent control programs relying on ecologically based approaches which require minimal or none chemical dependence should be thought. It is reported that the awareness and use of pesticidal plants in developing countries is growing over time following the scientific proof of damages caused by synthetic pesticides (Mkindi et al., 2015). According to the authors, pesticidal plants are preferred because of their non-cytotoxicity, easy of biodegradability and simulator nature of host metabolism and hence more environmental friendly compared with synthetic compounds. In recent time across Africa, there is a massive availability of plants which have been identified for their pesticidal effects particularly for insect pest control with little effort in rodent management. This study therefore, aimed to investigate and provide information on the knowledge of Tanzanian small scale farmers on the use of locally available pesticidal plants for rodent control.

MATERIALS AND METHODS

Study areas

The study was carried out in Handeni, Mvomero and Kilosa districts in the Eastern zone of Tanzania between May and September 2012. In these districts, agriculture is the major economic activity which provides the main source of income for the entire population where by maize is the main food and cash crop for the majority of farmers. Three villages in each district were purposively selected basing on the history of rodent damage in maize crop. Handeni district is located at 5°30' 00" S and 38°0'00" E and an elevation of

*Corresponding author. E-mail: mesha78m@yahoo.com.

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581 meters above sea level. It is one of eight districts of Tanga region bordered to the west by the Kilindi district, to the north by Korogwe and Muheza districts, East by Pangani district and to the South by Pwani Region. There are two rain seasons, i.e short rains which fall from October to December, and the long rains from mid-March to June. The dry season is between July and September. The mean annual precipitation is 800 to 1500 mm in the lower altitude areas and rain shadowed areas in the lee ward side of the mountains in the Northern and north-western areas may have about 400 mm only and a single rainfall season. This amount of rainfall supports the growth of crops such as cassava, maize, beans, ground nuts, citrus fruits, millets and sorghum. Maize is a staple crop grown largely by small-scale farmers and stored in roof and sacks after harvest for future use (Shabani et al., 2015). With regard to Mvomero district, it is located at 6°15' S and 38°40' E and an elevation of 506 meter above sea level. It is one of the six districts of the Morogoro region of Tanzania bordered to the north by Tanga region, to the northeast by Pwani region, to the east and southeast by Morogoro rural and Morogoro urban, respectively, and to the west by Kilosa district. The approximately mean annual rainfall in the area is about 800 to 1000 mm (Mkonda, 2014). Mvomero district has various type of soil ranging from sandy clay loams, sandy clays and sandy loams. The major food crops grown in Mvomero districts in small-scale farming are maize, sorghum, cassava, cowpeas, pigeon peas, lablab, sweet potatoes and rice. Crop storage practices in the area vary from crop type where the maize and rice crops stored using sacks. Similarly, Kilosa (6°55' S and 36°59' E at an elevation of 604 meter above sea level) is one of the six districts of the Morogoro region of Tanzania bordered to the North by Manyara region, to the Northeast by Tanga Region, to the East by Mvomero district, to the Southeast by Morogoro Rural, to the South by Kilombero district, to the Southwest by Iringa Region and West by Dodoma Region.

Kilosa District comprises mostly flat lowland that covers the whole of the eastern part called Mkata Plains. Kilosa district soil differ very little between villages from sandy to sandy loam. The district experiences an average of eight months of rainfall (October to May), with the highest levels between February and March. The rainfall distribution is bimodal in good years, with short rains (October to January), followed by long rains (mid-February to May). Mean annual rainfall ranges between 1,000 and 1,400 mm in the southern flood plain, while further north (Gairo Division) has an annual rainfall ranging from 800 to 1,100 mm. The mean annual temperature in Kilosa is about 25°C and is famous for cultivating a variety of crops due to its good environmental conditions. However, maize is a dominant crop grown by almost every household. Other crops include rice, millet, bananas, tomatoes, cassava, sunflower, pigeon peas, sweet potatoes, beans and a variety of vegetables. A few households also cultivated coconuts and cashew nuts. Most crops are used for both own consumption and trade (Wassena et al., 2013). All of the studied districts have a bimodal rainfall pattern with maize crop produced twice a year under short and long rains. The first cropping season (short rain) from late November to February and the second (long rain) March to June.

Sampling procedure

In this study, multistage sampling technique was employed and the sampling frame was the district, village, and finally a household. Purposive sampling was used to select the districts and villages with rodent infestation. In each of three selected districts three villages were selected for survey, making a total of 9 villages. In each selected village, the list of farming households growing maize was used as a sampling frame from which respondents were randomly selected. Thirty farmers were sampled in each village

giving a total sample size of 270 farmers (90 in each district).

Data collection

Information regarding farmers' knowledge, attitude and perception on the use of botanicals for controlling rodent pests was collected using semi-structured questionnaire containing both closed and open ended questions. The questionnaires were designed to seek information on socio-economic characteristics (age, education, farmer's experience on farming, major source of income, the farm size at household level, rodent control measures used, knowledge, altitude and perception on the use of pesticidal plants for rodent control. A question on the ranking of maize production constraints was also addressed.

Statistical analysis

The questionnaires were checked and edited for completeness and internal consistency. They were then sorted, numbered and coded before entry into access software. Quantitative data processing involved categorization, reorganization, editing, coding and entered in a computer using Statistical Package for Social Sciences (SPSS) program volume 16. A substantial part of the analysis in this study was based on descriptive statistics analysis using SPSS computer software based on t-test, frequency analysis and percentages. Data were presented in form of texts, histograms and tables to illustrate findings.

RESULTS

Sex ratios and socio-economic characteristics of respondents

Out of the 270 respondents interviewed in the three districts, 62.7% were males and 37.3% females. As regard to age structure, most respondents (96.3%) were above 25 years old while only 3.7% were below this age and majority of respondents (76.3%) were single (Table 1). In all districts most of the respondents (36, 32 and 32% in Handeni, Mvomero and Kilosa, respectively) had primary school education. The proportion of respondents with secondary school education was higher (75%) in Mvomero than in Handeni and Kilosa (17%) and 8% respectively). When asked on the sources of income, 58% of respondents in all three districts mentioned agriculture as their major source, while 42% mentioned non-agricultural activities (small business and salaries) as their source of income (Table 1). With regard to experience in farming, most of the respondents (86.3%) reported that they have been in farming for more than 5 years while some farmers (13.7%) said that they had farming experience for less than 5 years (Table 1). As regard to cultivated farm size, it was shown that majority 24, 13 and 42% of the farmers in Kilosa, Mvomero and Handeni district, respectively cultivate 3 and above acres. The response outnumbered those farmers 8, 10 and 3% from Kilosa, Mvomero and Handeni district, respectively who cultivate smaller areas below 3 acres (Figure 1).

Table 1. Sex ratios and socio-economic characteristics of respondents in the study districts (N = 270).

Variable	Category	Percent Respondents in each district			All districts
		Handeni	Mvomero	Kilosa	
Age	< 25 Years	7	1	3	3.7
	≥ 25 Years	93	99	97	96.3
Gender	Male	70	51	67	62.7
	Female	30	49	33	37.3
Marital status	Single	83	61	86	76.7
	Married	6	18	8	10.7
	Divorced/Separated	11	19	4	11.3
	Widow/Widower	0	2	2	1.3
Education level	None	6	0	12	6
	Primary	91	79	79	83
	Secondary	2	20	5	9
	Post-secondary	1	1	4	2
Experience in farming	≤ 5 years	21	0	20	13.7
	> 5 years	79	100	80	86.3
Major farming season	Short rains	0	3	3	2
	Long rains	30	11	75	38.7
	Both	70	86	22	59.5
Major source of income	Farming alone	70	53	51	58
	Business& salaries	30	47	49	42

Maize production constraints

Results show that in all three districts, rodents cause substantial damage to maize both in the field and home stores and that they, together with storage insects and lack of farm inputs, comprise the major constraints to production of the crop in the area (Table 2). When asked whether the farmer could differentiate various species of rodents, 80% of them (farmers) showed ability to differentiate the animal by color and 20% differentiated them (rodent) by morphological, body size, mouth structure and residence that is, (house or field rodents). When respondents were asked about the development stage at which maize was most damaged by rodent pests, their responses indicated that rodents mostly damage maize soon after sowing (55%) followed by damage at germination stages (35%) (Table 3). However, some few respondents 6 and 4% claimed that their crops were being damaged during flowering and at maturity stage, respectively (Table 3). Most of farmers (100%) reported that the rodent damage after sowing and at seed germination forces them to re-sow the seeds a situation

that doubles the production costs.

Rodent control methods used by farmers

As regards to rodent control measures, respondents reported that they use different control techniques against rodent infestations (Figure 2). Results show that rodent control methods mostly mentioned by respondents were chemical rodenticides (35%), traditional methods including snap and wire traps, pitfall traps, excavation of rodent burrows (8%) and bush fires (4%), keeping of cats (4%), and use of rodenticide in combination with traditional methods (49%). The contributions of each district in each control method are as shown in Figure 2. Regarding time of applying rodent control measure using rodenticides, majority of respondents (73%) reported that they start after observing rodent movement in their fields and the remaining 27% claimed to start after being instructed by extension officers, but also part of them undertake the activity as routine farming practices. Of all the respondents interviewed, 53, 62 and 55% in Kilosa,

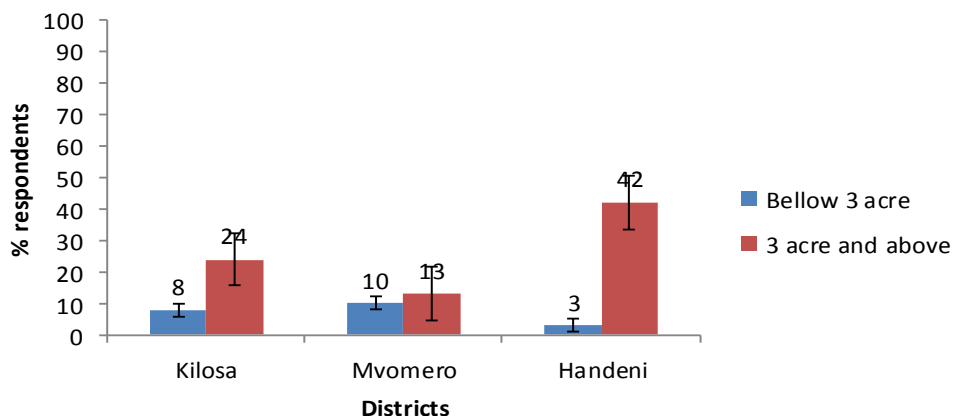


Figure 1. Size of land cultivated by farmers in the three studied districts (N = 270).

Table 2. Constraints in maize production in Handeni, Mvomero and Kilosa districts (N = 270). *Score for ranking order = 1 – 8; 1 is highest and 8 lowest.

Type of constraint	*Ranking order in each district		
	Handeni	Mvomero	Kilosa
Storage insects	4	4	4
Field insects	6	-	5
Weeds	7	5	-
Crop diseases	-	-	7
Rodents in store	2	1	3
Rodents in field	1	3	1
Lack of farm inputs	3	2	2
Drought	5	-	1
Poor soil fertility	8	-	6

Table 3. Level of rodent damage to maize at different crop development stages (N = 270).

Crop phenology	Farmers' observation (%)			All districts (Total)
	Handeni	Mvomero	Kilosa	
After sowing	26	11	18	55
During germination	5	15	15	35
During flowering	1	5	0	6
During maturation	2	2	0	4

Mvomero and Handeni, respectively had used poison to protect their crops from being damaged by pests. Likewise, 43% of respondents in the three districts claimed to have applied rodenticides both in field and stores. It was further revealed that farmers applying rodenticides separately in fields and stores comprised 37 and 20%, respectively. Investigation on frequency of rodenticide application per farming season showed that

30, 46 and 24% of farmers apply once, twice and thrice, respectively. Although farmers in the study area applied rodenticides as one of the rodent control measures, most of them (85%) claimed that they had never attended any training on handling and application of such chemical (Figure 3) and that they depend on their experience in undertaking such activity. Furthermore, 63% of the farmers reported that they provide verbal information to

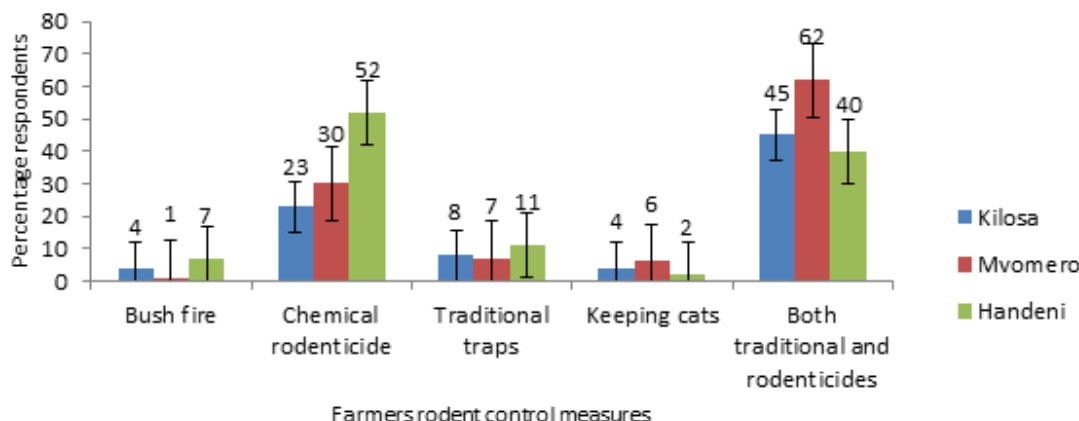


Figure 2. Techniques used to control rodents by farmers in the three studied districts (N = 270).

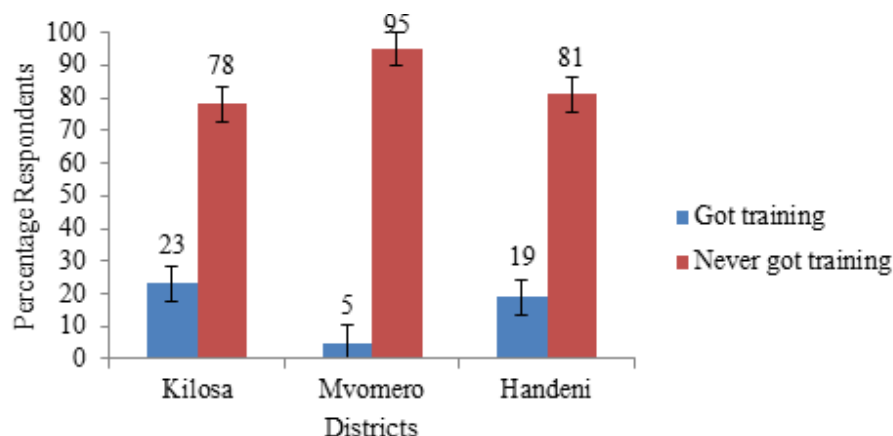


Figure 3. Percentage of farmers in three studied districts without training on rodenticide application (N = 270).

their neighbours prior to application so as to caution the latter on the activity. With regard to the source and availability of rodenticides, most farmers (51%) responded that they obtain the chemical from local markets and that they are available at such places.

Effectiveness of rodenticides

When asked about effectiveness of rodenticides they use, farmers had different perceptions ranging from excellent (36%), very good (24%), good (21%) to fair (18%). Only few farmers (1%) replied that the rodenticides used do not work at all (Figure 4).

Farmers’ awareness on the use of pesticidal plants for rodent control

When asked if they had ever used pesticidal plants for

controlling rodent, majority (96%) of farmers replied that they had never done so. However, they reported that most known pesticidal plants were used for controlling insect pests. Such plants mentioned in local languages and later on translated to English and botanical names included Aloe (*Aloe vera*), Neem (*Azadirachta indica*), Pepper (*Capsicum spp*), Mimosa (*Mimosa pudica*) and Tobacco (*Tabacum spp*). In response to inquiry as to whether farmers had any information regarding plants which can be used for controlling rodents, most (96%) respondents contended that they were not aware and, the remaining (4%) of the respondents reported to have used some pesticidal plants including *Tabacum spp*, *Mimosa pudica* and *Strychnos henningsii* for rodent control. Despite the lack of awareness on the use of pesticidal plants for controlling rodents, most (97%) farmers expressed their willingness to use such botanicals if and when informed about such plants and their capability of controlling rodents (Figure 5).

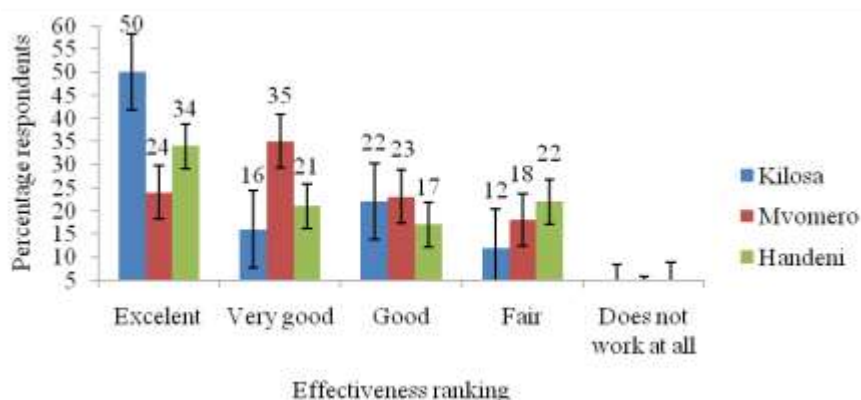


Figure 4. Effectiveness of rodenticides used to control rodents in the three studied districts (N = 270).

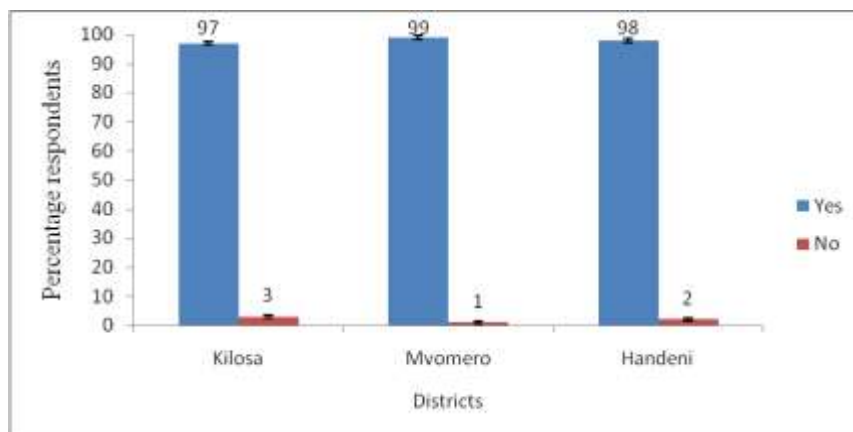


Figure 5. Willingness of farmers to use pesticidal plants for rodent control in three districts (N = 270).

DISCUSSION

Constraints to maize production

The current report by farmers that rodent pests, storage insects and lack of farm inputs are the major factors hindering maize crop production in the three districts are partly consistent with observations by Min et al., (2013) that maize yields are hampered by problems such as soil infertility, drought, weed infestation, crop diseases and pest attack. Similarly, a survey by Mulungu et al. (2015) reported that in Mvomero district of Tanzania maize and rice which caused a losses ranging from an average of 20 to 80%. Furthermore, the report by the majority of farmers in the current study that maize is most damaged by rodents soon after sowing are similar to observation in Ethiopia reported by Mohammed (2013) who reported that rodent cause a great damage by eating the seed

before and after its germination stage with 1 to 2 leaves which then forces farmers to replant the field with other seed. In general, rodent associated problems together with other constraints including storage insects, lack of farm inputs, drought, crop diseases and poor soil fertility have been major obstacles for maize productivity in many areas of Tanzania.

Rodent control methods used by farmers

The current findings that rodent control measures applied by farmers in the study areas and their ranking vary from one location to another and the use of rodenticides was the commonest method reported by most (84%) farmers followed by the use of other control measures reported by 15% farmers indicated that rodenticides is more used by Tanzanian farmers as crop protectants against rodent

pests. However, it was observed that most of the farmers were not familiar with the name of the rodenticides they use. The study revealed that small number of famers mentioned Zinc phosphide while the majority of them described the chemicals on the basis of the latter's colour and other physical features.

Based on farmer's descriptions, the rodenticides were identified as Zinc phosphide (Zn_3P_2) and Temic, and were being used by 53 and 21% farmers, respectively. The observation that majority (85%) of farmers did not have any training on the use and handling of rodenticides was interpreted to suggest improper application of rodenticides by farmer. Indeed, 63% of farmers reported to use zinc phosphide in their houses an undertaking which is highly dangerous to human and animal health. Zinc phosphide is very poisonous and should be used under control of the government especially in rodent outbreaks.

Likewise in Tanzania, the chemical is only allowed to be used under strict supervision by well trained personnel and its use in plague endemic area is strictly forbidden (Tesha, 2016, Personal communication). It has been reported that zinc phosphide and temic reportedly pose hazards to wildlife species up to 4th and 7th consumer level, respectively, (Ngowo, 2012, Personal communication). On the basis of the rodenticide – associated risks therefore, search for and use of alternative rodent control measures that have no or limited risk to farmers is advised. With regard to rodenticides (Ratox, bait powder made in Kenya) costs in Tanzania is about one thousand Tanzania shillings for a packet of one gram (Personal observation). This kind of rodenticides is sold at vendors of which are uncontrolled markets. It is reported that the amount of 27 to 40 mg zinc phosphide is needed to kill a rat at acute oral LD₅₀ of mg/kg. However, base on lack of training to farmers it happen that more rodenticides improperly applied to fields and causing possible effect to nontargeted organisms. Therefore, there is a need to reduce this contamination by finding alternative methods of rodent control.

Farmer's awareness on the use of pesticidal plants for rodent control

Pesticidal plants have been used by African farmers for generations and are of importance to poor, small-scale farmers for effective, low-cost pest control. However, in this study the use of pesticidal plants constituted a smaller portion of the rodent control options in all the study districts. Of all respondents, only 4% reported to have used pesticidal plants for rodent control compared to 96% who used acute poisons. This study shows that the use of pesticidal plants by Tanzanian farmers is concentrated largely on insect pest control. However,

although farmers in the study areas knew different kinds of plants with insecticidal effects, most of them were not aware of any plant with rodenticidal effect. Therefore, there is a great need to search for pesticide of rodenticidal effects to be used in reducing the crop damage caused by rodent pests.

Conclusion

On the basis of the current studies together with earlier observation reported elsewhere, it can be justifiably concluded that rodents are the most important constraints to maize production in Morogoro and Tanga regions and that they occur almost every month. It is also conclusive from these findings that lack of farm inputs is the next important constraint causing significant reduction in maize crop production.

Furthermore, it can be concluded that most farmers in Handeni, Mvomero and Kilosa districts use rodenticides for controlling rodent pests despite lack of training on the proper application of such chemicals. Additionally, it is conclusive from the study that most farmers are unaware of potential use of botanicals for controlling rodents but are willing to adopt the method if and when informed about appropriately effective pesticidal plants. A need to evaluate and develop useful pesticidal plants product as a rodent control strategy that can be adopted by farmers in rural areas to reduce rodent damage to sown maize seeds and other stages in maize crop production, is strongly recommended.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of Crambe-based products (*Crambe abyssinica*) on the control of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) in stored maize

Ana Paula Morais Mourão Simonetti^{1,2*}, Viviane Prata Dall'oglio², Tais Regina Strieder², Hingrit Mazurek Siqueira², Silvia Renata Machado Coelho¹ and Divair Christ¹

¹UNIOESTE/CASCAVEL/CCET/PGEAGRI – State University of West Paraná. Rua Universitária, 2069, CEP: 85.819-110 - Bairro Faculdade, Cascavel, Paraná, Brazil.

²Centro Universitário Assis Gurgacz, Av. das Torres, 500, CEP: 85806-095 Bairro FAG, Cascavel, Paraná, Brazil.

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Maize is one of the most consumed cereals in the world, but its consumption is not always immediate. Thus, its storage is an important logistical factor. During the storage period, the grains may be exposed to several pests, including *Sitophilus zeamais*. The aim of this study was to test different *Crambe abyssinica*-based products as an alternative control of this pest. The experiment was conducted in the Laboratory of the Assis Gurgacz University Center in Cascavel, PR, Brazil and divided into three stages (survival, emergence and mortality), all arranged in a completely randomized design in a 2×5 factorial scheme. Factor 1 was the type of crambe-based product (crambe powder or aqueous extract) and factor 2 was the product concentration (0, 1, 2, 3 and 4%). The attractiveness, repellency and insecticidal effect were evaluated in the three treatments (control, crambe powder and aqueous extract). It was concluded that between the crambe-based products assessed, the aqueous extract was the one that caused the lowest survival and emergence of *S. zeamais* and the lowest consumption of maize, proving to be repellent at first contact with the insect.

Key words: Maize weevil, plant extract, brassicas.

INTRODUCTION

Brazil is one of the largest producers of maize in the world. In the country, it is cultivated in two crop seasons. Data published by Conab (2016) revealed that the area sown for the 2015/2016 season was equivalent to 15,215,900 hectares, with an estimated yield of 82,327,400 tons of grains and an average production of

5,411 kg per hectare.

Not all harvested grains are used immediately and several tons of grains are stored after harvesting. Improper storage conditions lead to severe pest attacks on stored grains, making them unsuitable for consumption (Michelraj and Sharma, 2006) or for

*Corresponding author. E-mail: anamourao@fag.edu.br. Tel: (55) 45 -99115949.

marketing in Brazil when more than 4% of the grain samples present weevils, as stated in the IN No. 60 (Botelho et al., 2013).

Among the many pests that attack stored grains, *Sitophilus zeamais* stands out for being responsible for the physical deterioration of the stored batch (Lorini et al., 2010). Adult and immature insects feed on the grain and cause large losses of mass, germinating power, seed vigor, as well as nutritional and commercial values of the grain (Santos, 2008).

S. zeamais is considered an internal primary pest, as it attacks whole grains, perforating them and developing within them, and may present cross infestation, that is, infest both the seeds in the field and in the grain storage (Gallo et al., 2002; Lorini et al., 2010).

According to Benhalima et al. (2004), *S. zeamais* control is performed chemically by the application of contact insecticides, which may cause intoxication to applicators and the selection of resistant populations, besides leaving toxic residues on the grains. Kljajic and Peric (2005) also highlighted the increasing cases of resistance developed by some insect species to certain formulations.

Krinski et al. (2014) stated that the use of plant-based products, such as extracts and essential oils, against insects has increased in Brazil. Thus, numerous studies on the alternative control of *Sitophilus* species with the use of plant-based extracts, powders and oils have been developed (Guimarães et al., 2014; Almeida et al., 2014a, b; Fernandes and Favero, 2014; Silva et al., 2013).

Crambe abyssinica Hochst belongs to the botanical family of brassicas or cruciferous. It is native to the Mediterranean region, but is well adapted to different climatic conditions (Souza et al., 2009). Crambe is highly tolerant to pests, which attack the plant only during the seedling stage. Some of these pests are the Cucurbit Beetle (*Diabrotica speciosa*) and *Agrotis* species (Knights, 2002; Bezerra et al., 2011).

Several cruciferous plants have been studied for being sources of chemical protectors, such as glucosinolates, which are capable of synthesizing (Fahey et al., 2001). Chew (1988) states that crambe (*C. abyssinica* Hochst) produces glucosinolate, which is a secondary metabolite that helps plants defend against insects and fungi.

The objective of this study was to assess the repellent and insecticidal effect of *C. abyssinica* Hochst powder and aqueous extract, as well as their effects on the survival, emergence and mortality of weevils (*S. zeamais*) in maize (*Zea mays*).

MATERIALS AND METHODS

This experiment was conducted at the Entomology Laboratory of the Assis Gurgacz University Center in Cascavel, Paraná State, Brazil, at a temperature of $25 \pm 2^\circ\text{C}$, relative humidity of $60 \pm 5\%$. The insects used in the experiment were obtained from the insect farm kept in the laboratory in containers measuring 8 cm of

diameter by 6 cm of height containing maize grains (hybrid AM 4003), which were obtained from the company Melhoramento Agropastoril. *C. abyssinica* grains were obtained from experimental fields of FAG's School Farm in the 2014 season and stored away from light and heat.

The crambe grains were ground in a mill (IKA A11 Basic 2500 1/min IP43) to obtain powder. The liquid crambe extract was obtained by grinding the crambe grains in a blender and then mixing 100 ml of distilled water at certain concentrations, being 1 g of grains in 100 ml of distilled water to obtain the concentration of 1%, 2 g in 100 ml of distilled water to obtain the concentration of 2%; 3 g to obtain the concentration of 3% and 4 g to obtain concentration of 4% followed by storage in a beaker with plastic film and aluminium foil for light protection for 48 h.

Effects of the crambe-based products on *S. zeamais* survival, emergence and mortality

The experiments were conducted in a completely randomized design in a 2x5 factorial scheme. Factor 1 was the type of crambe-based product (crambe powder or aqueous extract) and factor 2 was the concentration of the products (0, 1, 2, 3 and 4%). Eight replications were performed of each treatment, totalizing eighty experimental plots.

The treatments were performed with 400 g of maize, which were exposed to 10 ml of the aqueous extract in different concentrations and homogenized in a plastic bag for 2 min. The volume of aqueous extract was based on preliminary tests with dyestuff in different amounts to achieve the maximum coating of the maize grains. The same was performed for setting the number of grams of crambe powder to be used.

The plastic containers were used in the experiment had a diameter of 8 cm and a height of 6 cm. Their covers were perforated for aeration and protected by a tissue to prevent the escape of insects. Each container kept 50 g of maize, weighed in analytical balance, and 20 non-sexed inoculated insects aged up to 15 days.

The number of dead insects was observed daily until the seventh day of experiment. At 40 days of exposure of insects to the grains containing the products, the number of dead and live insects and the mass (g) of the remaining grains were obtained. After these assessments, all insects were discarded and the containers with the grains were kept and analyzed after 60 days of experiment to investigate the number of hatched insects.

Effects of repellency/attractiveness on *S. zeamais* insects

To assess the repellency of the crambe-based products on *S. zeamais*, two feeding stations made of MDF were used, measuring 45x45x3 cm with a central hole with a diameter of 8 cm and four side holes with a diameter of 6 cm each, symmetrically connected by four paths connecting the central and lateral holes with a length of 10 cm each, all with a depth of 2 cm, lined with contact paper and covered with plastic film perforated to allow aeration.

The experiment was conducted in a completely randomized design (CRD) with 3 treatments (T1 - maize grains, T2 - maize grains mixed with crambe powder, and T3 - maize grains mixed with aqueous extract of crambe at 4% concentration) with 10 replications.

Each treatment was tested separately from the control. Ten grams of maize grains were placed in each container of the station. Containers 1 and 2 (control treatments) had only maize grains, and containers 3 and 4 had maize grains mixed with 0.5 g of crambe powder. Just as in the other station, containers 3 and 4 were filled with 10 g of maize grains mixed with 0.5 ml of aqueous extract of crambe, whereas containers 1 and 2 were the control treatments.

Table 1. Number of dead *Sitophilus zeamais* insects, number of emerged insects and mass of maize grains (g) at 40 days; and number of emerged insects at 60 days of exposure to different concentrations of crambe powder and aqueous extract of crambe – Cascavel, PR.

Treatments	Number of dead insects at 40 days	Number of emerged insects at 40 days	Mass of grains (g)	Number of emerged insects at 60 days
Crambe-based product				
Powder	0.75	18.87 ^a	48.81 ^b	4.59 ^a
Aqueous extract	0.95	14.92 ^b	49.68 ^a	3.02 ^b
Concentration				
0%	0.44	15.94	49.66	3.66
1%	0.44	17.12	49.16	3.98
2%	1.62	15.19	48.75	3.99
3%	0.75	17.87	49.25	3.94
4%	1.00	18.37	49.41	3.46
CV (%)	17.92	18.70	2.02	27.79
F-Test				
Type of product × Concentration	n.s	n.s	n.s	n.s
Type of product	n.s	*	*	*
Concentration	n.s	*	n.s	n.s

n.s: Not significant. *Significant at 5% probability by Tukey's test.

Ten non-sexed *S. zeamais* insects were released into the central container of each station. After 1 and 48 h, the number of insects per container was counted.

The Preference Index (PI) for each of the times (1 and 48 h) was calculated using the data obtained in the tests, based on the formula proposed by Procópio et al. (2003): $PI = (\text{percentage of insects in treated container}) - (\text{percentage of insects in non-treated container}) / (\text{percentage of insects in treated container}) + (\text{percentage of insects in non-treated container})$; where $PI = -1.00$ to -0.10 indicating repellent plant; $PI = -0.10$ to $+0.10$ indicates neutral plant; and $PI = +0.10$ to $+1.00$ indicates attractant plant.

Contact toxicity assay

The evaluation was carried out in Petri dishes, in a completely randomized design with three treatments: T1 – control (distilled water), T2 – aqueous extract of crambe, and T3 – crambe powder; with 10 replications each, totaling 30 plots.

Each Petri dish was lined with two sheets of germination paper and either 1 ml of distilled water, 1 ml of extract of crambe at 4% concentration or 0.4 g of crambe powder was added. Then, each dish was infested with 10 non-sexed adult *S. zeamais* insects. Dishes were sealed with plastic film perforated for aeration. The 30 dishes were subsequently accommodated in a B.O.D incubator, at $25 \pm 2^\circ\text{C}$ temperature, photoperiod of 14 h and relative humidity of $60 \pm 5\%$. At 12 and 24 h, the number of dead insects was recorded.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) and the averages were compared by Tukey's test at 5% significance level in the statistical software ASSISTAT® version 7.7 (Silva and Azevedo, 2009).

RESULTS AND DISCUSSION

Survival, emergence and mortality of *S. zeamais*

According to the number of dead and live insects at 40 days of exposure to different amounts of crambe-based products (Table 1), there was no significant interaction between factor 1 (type of crambe-based product) and factor 2 (concentration). The number of dead insects was also not significantly influenced (at 5% probability) by the type of product or concentration. In a study by Lima-Mendonça et al. (2013), adult *Sitophilus* spp. insects had 89 and 100% mortality when subjected to powders of *Piper nigrum* L. and *Chenopodium ambrosioides*, respectively. However, the number of live insects after exposure to crambe powder was significantly superior (18.87) to the number of live insects after exposure to the aqueous extract of crambe (14.92), regardless of the concentration, what indicates that insects lived longer in maize mixed with crambe powder than in maize mixed with aqueous extract. Such results agree with those by Silva et al. (2013), who achieved a high mortality rate (95.83%) using hydroalcoholic extract of *Cinnamomum zeylanicum* in a study on the control of *Sitophilus* with different vegetable extracts.

The mass of the maize grains was also significantly higher (49.68 g) when they were mixed with aqueous extract than when mixed with crambe powder (48.81 g), which means that the insects consumed less maize grains mixed with aqueous extract than those mixed with crambe powder. Fazolin et al. (2010) also reported

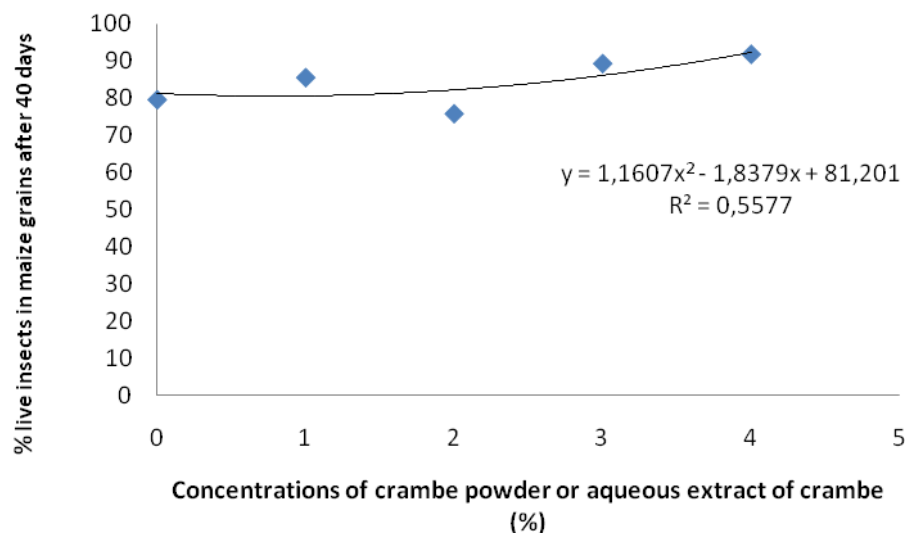


Figure 1. Percentage of live insects in maize grains after 40 days of exposure to different concentrations of crambe powder or aqueous extract of crambe – Cascavel, PR.

significant differences in the mass of maize grains treated with *Tanaecium nocturnum* and exposed to *Sitophilus* in comparison to other treatments.

The coefficient of variation (CV) of the mass of maize grains was 2.02%. According to Pimentel-Gomes (2009) coefficients are low when below 10%, medium when between 10 and 20%, and high when between 20 and 30%.

The number of emerged insects at 60 days was higher in maize grains mixed with crambe powder (4.59) than in maize grains mixed with aqueous extract (3.02), thus, a better condition for egg and larvae development was observed in the treatment with crambe powder.

Coitinho et al. (2010) studied the effects of oils from different vegetable species on stored maize exposed to *Sitophilus* and also reported lower emergence of this insect in maize mixed with *Piper marginatum* than in other treatments.

Figure 1 shows that the percentage of live insects at 40 days was lower in the treatment with 2% concentration (T3) and in the control (T1) than in the other treatments. Therefore, the regression fitted a second order polynomial, with the lowest number of dead insects at 2% concentration.

When using crambe powder, the highest mortality rate at the seventh day of exposure was found with the concentration of 2% (T3), followed by the concentrations of 4% (T5), 3% (T4), 1% (T2) and control (T1). When using aqueous extract of crambe, the highest mortality rate was found with the concentration of 1%, followed by the concentrations of 4, 3 and 2% and control (Figure 2).

Siqueira and Simonetti (2015) obtained 97.5% mortality when *Sitophilus* adults were exposed to maize grains mixed with crambe for 15 days, whereas only 5%

mortality was observed for the insects in maize grains without treatment.

Repellency/Attractiveness on *Sitophilus* spp. insects

Only the aqueous extract of crambe after 1 h of exposure provoked repellency on *Sitophilus* adults (Table 2). Crambe powder after 1 and 48 h of exposure as well as the aqueous extract after 48 h of exposure were considered neutral, as their preference indices ranged from -0.10 to +0.10 (Procópio et al., 2003).

Initial repellency superior to that assessed after 48 h was also observed in a study by Pedotti-Striquer et al. (2006) on *Sitophilus* control with vegetable powders of *Ocimum gratissimum* and *Mikania glomerata*, in concentrations of 100 and 400 ppm. However, several different vegetable powders assessed in other researches did not cause repellency on *Sitophilus* spp., such as powders of *Azadirchta indica*, *Melia azedarach*, *Ricinus communis*, *C. ambrosioides* (Procópio et al., 2003), *P. nigrum*, *Anadenanthera colubrina*, *Annona muricata*, among others (Lima-Mendonça et al., 2013).

Gott et al. (2010) concluded that the repellent effect of *Curcuma longa* on *Sitophilus* spp. disappears with time probably due to the evaporation of its compounds in charge of the repellent activity. Such evidence backs up the result of this study, which showed that after 48 h of exposure the crambe extract went from repellent to neutral.

Insecticidal effect

Figure 3 shows the insecticidal effect. The statistical

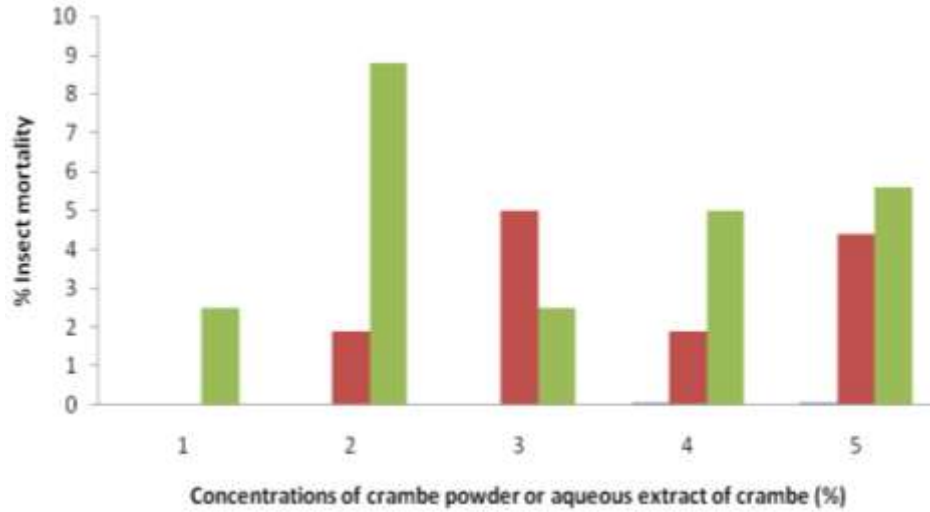


Figure 2. Insect mortality at the seventh day of exposure to different concentrations of crambe powder or aqueous extract of crambe – Cascavel, PR.

Table 2. Comparison of the effect of the repellency of the different crambe-based products on *Sitophilus* sp adults through the Preference Index (PI) and percentage of adults attracted, calculated in free-choice tests with two different exposure times.

Treatment	PI (1 h)	Classification	PI (48 h)	Classification
Crambe powder Control	0.01	N	0.1	N
Aqueous extract of Crambe Control	-0.26	R	0.02	N

PI: Preference index; Classification: N: Neutral, R: Repellent.

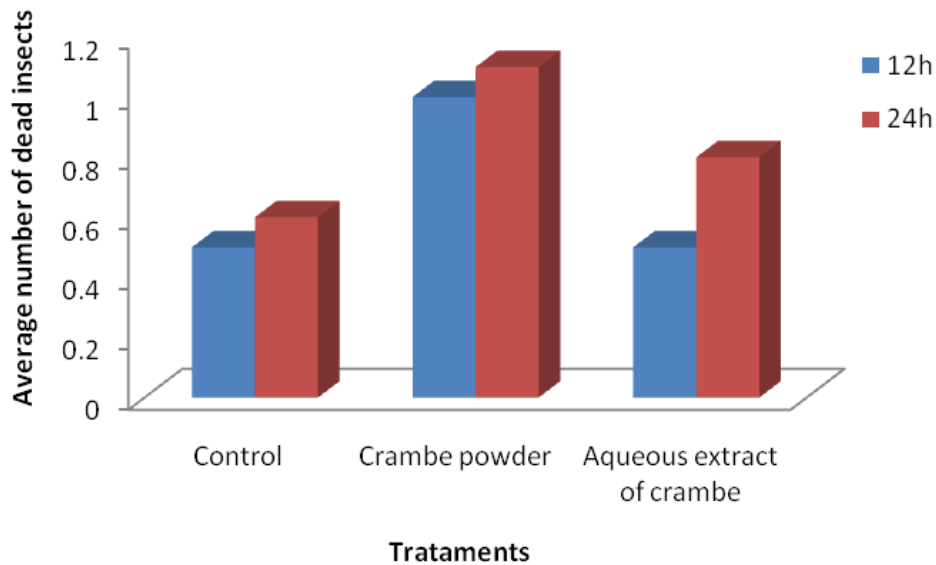


Figure 3. Average number of dead insects after 12 or 24 h of exposure to crambe powder or aqueous extract of crambe, at controlled temperature and photoperiod, Cascavel – PR. 12 h of exposure: CV= 9.67%; 24 h of exposure: CV = 8.86%. n.s: Non-significant at 5% probability by Tukey's test.

analysis did not present significant differences between the control and treatments with crambe powder and aqueous extract of crambe at 5% significance by Tukey's test. The treatment with crambe powder was slightly superior to the others at 12 and 24 h of exposure to the insect.

Krinski et al. (2014) states that several plants have insecticidal capability and can be considered as alternatives in insect control, which was not the case of crambe in the forms of powder or aqueous extract.

Conclusion

It was concluded that between the crambe-based products assessed, the aqueous extract was the one that caused the lowest survival and emergence of *S. zeamais* and the lowest consumption of maize, proving to be repellent at first contact with the insect.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Use of additives in combination with UV-C for the conservation of minimally processed 'Fuji Suprema' apples

Caroline Farias Barreto^{1*}, Marines Batalha Moreno Kirinus¹, Pricila Santos da Silva¹, Roseli de Mello Farias¹, Marcelo Barbosa Malgarim¹ and Carlos Roberto Martins²

¹Department of Plant Science, Universidade Federal de Pelotas, City of Capão do Leão, State of Rio Grande do Sul, Brazil.

²Brazilian Agricultural Research Corporation (EMBRAPA), Cascade Station, City of Pelotas, State Rio Grande do Sul, Brasil.

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Minimally processed fruits need to be treated with techniques to keep their quality, and lower the incidence of their pulp and rots becoming black. In this context, this work aims to evaluate the efficiency of the use of UV-C radiation and different additives in preventing browning and conserving 'Fuji Suprema' apples that are minimally processed. The experimental design was completely randomized with factorial scheme of 5x2x3 (5 additives x 2 UV-C applications x 3 storage periods). The apple slices were placed in solutions containing the following: control; ascorbic acid (1%); sodium isoascorbate (1%); ascorbic acid (0.5%) + sodium isoascorbate (0.5%); citric acid (0.5%) + sodium isoascorbate + 0.5%. It was used with and without UV-C radiation in minimally processed apples, the intensity of the radiation emitted was 2.71 kJ.m⁻². Then the trays were stored in a cold room at 4±1°C temperature and a relative humidity of 85-90%. They were stored for periods of 0, 6 and 12 days. The parameters assessed were: mass loss, pulp color, soluble solids, titratable acidity, rot incidence, total phenolic compounds and antioxidant activity. The use of ascorbic acid, sodium isoascorbate and associate compounds contributes to the keep of the pulp color of the minimally processed apples on 12th day of storage. UV-C reduces rot incidence, and increases the soluble solids, phenolic compounds and antioxidant activity, when compared without the use of UV-C radiation on 12th day of storage. The ascorbic acids keep the total phenolic concentration in the minimally processed apples.

Key words: *Malus domestica*, storage duration, phytochemical content.

INTRODUCTION

The minimally processed fruits sector is expanding due to changes in the patterns of fruits consumption, consumers' want, ease of preparation and consumption. However, minimally processed fruits preparation requires the use of techniques which are able to keep their quality

with low incidence of both pulp browning and rot. In this context, minimum processing is a way of using surplus production and adding value to the product (Villas-Boas et al., 2009), besides meeting the new demands of the consumer market.

Some steps are involved in minimal processing: sanitization, peeling and cutting, ease of consumption (Perera et al., 2010), and reduction of post-harvest life. Minimal processing operations not only cause mechanical damage to fruit tissues but also accelerate senescence and deterioration, thus, leading to discoloration and loss of nutritional value (Kluge et al., 2014), fast pulp browning (Perera et al., 2010), texture loss and microbial growth (Fontes et al., 2008), besides changes in physico-chemical characteristics and variation in the contents of specialized metabolism compounds. Therefore, some of the major challenges of minimal processing are to enhance the shelf life and preserve the quality of fruits.

Minimally processed apples are highly perishable products as a result of the acceleration of the respiratory metabolism and maturation stage. Injuries caused in plant tissues, as a result of manipulation processing which promotes increased contact between the enzymes and substrates, induce undesired enzymatic reactions (Fontes et al., 2008) and cause pulp browning. Fast browning happens due to the production of melanin which results from reactions catalyzed by enzymes, such as peroxidase and polyphenol oxidase (Tomás-Barberán and Spín, 2001).

Therefore, new preservation techniques must be developed in order to keep the quality of minimally processed foods so as to increase their useful life. Antioxidant compounds, such as ascorbic acid, citric acid (Kluge et al., 2014) and sodium isoascorbate (Martins et al., 2011). Associated with these techniques, UV-C radiation can be used in minimally processed products, which have germicidal effect and lowers rot incidence. The application of UV-C in minimally processed apples has been tested (Gómez et al., 2010; Chen et al., 2016). However, the reported effects are quite diverse, depending on the cultivar and applied doses.

In this context, it proposed to assess the effectiveness of the use of UV-C light and different additives in preventing browning and conserving minimally processed apples 'Fuji Suprema'.

MATERIALS AND METHODS

The apple cultivar used by this study was 'Fuji Suprema'. The fruits were grown in a commercial orchard, about 15 km from São Joaquim, a city located around 1350 m above sea level in Santa Catarina state, Brazil (28°17'38" S and 49°55'54" W) and harvested in the season 2014/2015.

The fruits were pre-selected based on the following criteria: absence of injuries and visual disease incidence. After fruits selection, these were sanitized with sodium hypochlorite at 200 mg.L⁻¹ for 10 min at room temperature. The selected apples were

cut into six core format slices, with the help of sanitized stainless steel knives.

The experimental design was completely randomized with factorial scheme of 5x2x3 (5 additives x 2 UV-C applications x 3 storage periods), with 4 repetitions consisting of 9 slices of minimally processed apples. The apple slices were dipped for 2 min in solutions containing the following treatments: control (distilled water); ascorbic acid (AA), 1% (w/v); sodium isoascorbate (SI), 1% (w/v); ascorbic acid, 0.5% (w/v) + sodium isoascorbate, 0.5% (w/v); citric acid (CA), 0.5% (w/v) + sodium isoascorbate + 0.5% (w/v). Then the pieces were drained for 2 to 3 min in order to remove the excess of solution and then slices were dried in a refrigerated environment (10±1°C) for 15 min.

Apple pieces were placed on 300x230x33 millimeter expanded polystyrene trays and wrapped in 9 µ stretchable PVC film. The mean weight of every tray was 250 g. UV-C Phillips® 30 W was used in minimally processed apples. The distance between the lamps and trays were approximately 50 cm and the intensity of the radiation emitted by the lamps was measured with a digital UV light meter (RS-232 MRUR-203 Model, Instrutherm). It results in an intensity of 2.71 kJ.m⁻² per two minutes application. Then the trays were stored in a cold room at 4±1°C temperature, with a relative humidity of 85-90%, and stored for periods of 6 and 12 days.

The parameters assessed were: a) mass loss: obtained by the difference between the total mass before and after the storage, data expressed in percentage of total mass (%); b) pulp color, measured with colorimeter Minolta CR-300® brand, with tridimensional color system (CIE L a b). The results were expressed by L, which represents color lightness (0 = black and 100 = white), by the a* value, which is ranged from green (-a) to red (+a), by the b*-value axis, which is ranged from blue (-b) to yellow (+b), and hue angle and hue; c) soluble solids (SS): obtained by refractometry, results expressed in °Brix; d) titratable acidity: determined by titration of a solution that contained 10 mL of juice diluted in 100 mL of distilled water, with a solution of NaOH 0.1 N, results expressed in percentage of malic acid; e) the rot incidence was considered in the fruits with lesions with diameter greater than 0.1 cm, the results were expressed as percent (%); f) total phenolic compounds, determined by the method based on reaction with the Folin-Ciocalteu reagent according to the adapted method of Singleton et al. (1999), with the results expressed in mg equivalent of gallic acid in 100 g sample (EGA 100 g⁻¹); g) antioxidant activity, determined by DPPH radical method adapted from Brand-Williams et al. (1995), with the results expressed in Trolox mg equivalent. 100 g⁻¹ of fruits.

The analysis of variance (ANOVA) was performed for all the parameters evaluated. Significant parameters averages were compared through Tukey's test (p < 0.05).

RESULTS AND DISCUSSION

Through the data in Table 1, it is observed that the variables weight loss and antioxidant activity had significant effects with the different additives and UV-C applications. The storage periods x UV-C applications showed significant interaction for the variable parameter soluble solids, titratable acidity, phenolic compounds, antioxidant activity and rot. The additives and storage

*Corresponding author. E-mail: carol_fariasb@hotmail.com. Tel: +555599090689.

Table 1. Weight loss (WL), parameter brightness (L*), soluble solids (SS), titratable acidity (TA), phenolic compounds (PC), antioxidant activity (AA) and rots (R) of minimally processed 'Fuji Suprema' apple.

Parameter	Mean square														
	GL	WL	L*	SS	TA	PC	AA	R							
U	1	0.60441	ns	27.46754	**	0.0278	ns	0.0023	*	194.1432	*	13167.25	**	1.6000	*
A	4	89.333	**	27.23851	**	2.49128	**	0.00277	**	669.9087	**	868.1086	ns	0.5722	ns
P	2	45.30738	**	5.05219	ns	1.29478	*	0.00428	**	3519.950	**	141742.8	**	23.6444	**
UxA	4	0.04114	*	4.95189	ns	0.19194	ns	0.00015	ns	48.90998	ns	1937.222	*	0.12778	ns
UxP	2	0.39987	ns	6.9501	ns	1.26144	*	0.0026	**	1949.337	**	9167.084	**	0.93333	**
AxP	8	1.59569	**	10.87857	**	0.92436	*	0.00213	**	176.706	**	3796.387	**	0.33889	ns
UxAxP	8	0.88644	ns	6.673	**	0.52353	ns	0.00053	ns	31.784	ns	903.3557	ns	0.12778	ns
T	29	4.12442	**	11.05677	**	0.9459	**	0.00169	**	540.5489	**	12545.05	**	1.97548	**
R	60	0.5167		20.4042		0.253		0.0005		4.225.998		746.1266		0.28880	
Total	89	-		-		-		-		-		-		-	

UV-C applications (U), additives (A), storage periods (SP); ns = not significant by F test; *,**Significant respectively at 5 and 1% probability.

Table 2. Average values of the L* coordinate for minimally processed 'Fuji Suprema' apples, subjected to UV-C radiation and different additives, stored at 4±1°C and 85-90% RH for up to 12 days.

Additive		L*					
		Day 0	Day 6	Day 12			
Without UV-C	Control	75.73	aA	70.01	bB	68.78	cC
Without UV-C	AA	75.81	aA	74.61	aA	73.80	abB
Without UV-C	SI	75.87	aA	74.54	aA	74.40	aA
Without UV-C	AA+SI	75.21	aA	74.72	aA	74.37	aA
Without UV-C	CA+SI	75.52	aA	74.31	aA	74.16	aA
With UV-C	Control	75.73	aA	72.41	aB	70.17	cC
With UV-C	AA	75.81	aA	74.33	aAB	73.85	abB
With UV-C	SI	75.87	aA	74.17	aA	74.10	aA
With UV-C	AA+SI	75.21	aA	74.91	aA	74.88	aA
With UV-C	AC+SI	75.52	aA	74.53	aA	74.34	aA

Aascorbic acid (AA), sodium isoascorbate (SI) ascorbic acid + sodium isoascorbate (AA+SI), citric acid + sodium isoascorbate (CA + SI). Means followed by equal letters, lowercase in the columns and uppercase in the lines, do not differ by Tukey's test, at 5% probability ($p \leq 0.05$).

periods showed significant interaction for the entire variable. In fruits coloring, the L* parameter (brightness) represents lighter fruits (highest L* value) or darker fruits (lower L*). For this parameter, there was interaction between additives, application of UV-C and periods of cold storage factors in minimally processed 'Fuji Suprema' apples.

Additives associated with UV-C radiation showed promising results in maintaining the color in both storage times, keeping the apples lighter in the control without and with UV-C (Table 2). The treatments with additives were more effective in preventing the surface browning of apples. The brightness results corroborate with Perez-Gago et al. (2006), who also found in 'Golden Delicious' apples the inhibitory effect of enzymatic browning by the

use of antioxidants, after storage for 14 days at 5°C.

On the other hand, the control without additives showed lower L* values, a fact that implied pulp browning. There was more intense pulp browning in the control without UV-C after the 6th storage day whereas it happened after the 12th day in the control treatment with UV-C. These results agree with the ones reported by Fontes et al. (2008), whose study showed that the control treatment in minimally processed apples had high browning index. Pulp browning is one of the main problems related to minimally processed products since it affects the color of the surface of the fruit, which is an important quality attribute to the commercialization of the product (Jang and Moon, 2011).

In the control treatment, mass loss increased in the

Table 3. Weight Loss and antioxidant activity in minimally processed 'Fuji Suprema' apples under different additives, with and without the use of radiation UV-C and stored to 12 days.

Activity	Without UV-C		With UV-C	
	Weight Loss (%)			
Control	1.36	abB	1.91	aA
AA	0.98	bA	1.12	bA
SI	1.72	aA	1.37	abB
AA+SI	1.07	abB	1.32	abA
CA+SI	0.91	cB	1.14	bA
Antioxidant Activity (Trolox mg equivalent.100 g ⁻¹)				
Control	201.96	abA	186.53	aA
AA	232.21	aA	171.40	aB
SI	213.38	abA	193.26	aA
AA+SI	193.93	bA	180.11	aA
CA+SI	207.41	abA	196.66	aA

Ascorbic acid (AA), sodium isoascorbate (SI), ascorbic acid + sodium isoascorbate (AA+SI), citric acid + sodium isoascorbate (CA+S). Means followed by equal letters, lowercase in the columns and uppercase in the lines, do not differ by Tukey's test, at 5% probability ($p \leq 0.05$).

minimally processed apples with UV-C radiation, by comparison with apples with no UV-C radiation (Table 3). Minimally processed apples without application of UV-C radiation had less mass loss in CA+SI, whereas it happened with AA and CA+SI when UV-C radiation was applied. The use of UV-C associated with citric acid contributed to reduce weight loss in minimally processed apples during storage (Chen et al., 2016). UV-C radiation may develop a protective film on minimally processed fruits. However, long exposure to U-VC radiation may break cell membranes of apples and favor fruit dehydration and increase in mass loss (Chen et al., 2016). Rupture of cell membranes may also increase the contact between enzymes and substrate, thus, favoring browning (Gómez et al., 2010).

Without the application of UV-C radiation in minimally processed apples, the highest concentrations of antioxidant activity were observed in AA, control, SI, CA+SI. However, when applied UV-C radiation in minimally processed there were no differences between the additives. Application of UV-C enhanced of antioxidant activity in fresh-cut mangoes (González-Aguilar et al., 2007) and UV-C radiation with heat in broccoli (Lemoine et al., 2010).

The application of UV-C in minimally processed apples interfered in the rot percentage, soluble solids, phenolics concentration and antioxidant activity during cold storage periods (Table 4). On the 12th day of storage the use of UV-C reduced the rot percentage in minimally processed apples. Use of radiation alone or in combination with other techniques optimizes the conservation of minimally processed apples. Radiation resulted in an efficient control of microbial contamination in other fruits, such as

minimally processed mango (Vieites et al., 2004) and melon (Manzocco et al., 2011).

The soluble solids from the minimally processed apples showed higher values with the application of UV-C on the 12th day of cold storage. However, the rise of the sugar concentration of the fruit occurs with the evolution of fruit maturation (Jie et al., 2013).

The total phenolics concentration in minimally processed apples was higher with the use of UV-C at 6th and 12th day. The increase of the phenolic compounds is a way of protecting cells from UV-C radiation (De Wit, 2007; Erkan et al., 2008), as an adaptation response to stress (Keutgen et al., 2011).

Antioxidant activity was higher on the 12th day of refrigerated storage for treatment with UV-C radiation when compared to the treatment without radiation. The use of UV-C increased the content of phenolic compounds and antioxidant activity in strawberry, because the UV-C radiation may cause different types of stress and activate defense responses in fruits (Erkan et al., 2008).

There was interaction between additives and storage periods for the total phenolic concentration in minimally processed apples (Figure 1). Decrease in total phenol contents in minimally processed apples during the cooled storage period as a result of the metabolism of fruit maturation and senescence was observed. It led to the oxidation of these compounds by polyphenol oxidases (Mishra et al., 2012). On the 12th day, the reduction of phenols content was higher in the control apples, in relation to other additives. The use of AA kept the total phenolic content in minimally processed apples on the 12th day. The preservation of the total phenolic

Table 4. Rots, soluble solids, phenolic compounds and antioxidant activity of minimally processed 'Fuji Suprema' apple, with and without the use of radiation UV-C, stored at $4\pm 1^\circ\text{C}$ and 85-90% RH for up to 12 days.

Activity	Day 0		Day 6		Day 12	
	Rot (%)					
Without UV-C	0.00	aC	6.66	aB	15.96	aA
With UV-C	0.00	aC	5.18	aB	9.55	bA
Soluble Slids ($^\circ\text{Brix}$)						
Without UV-C	12.38	aB	12.51	aA	12.70	bA
With UV-C	12.25	aB	12.60	aA	12.98	aA
Phenolic Compounds ($\text{EGA } 100 \text{ g}^{-1}$)						
Without UV-C	82.45	aA	69.41	bA	55.46	bB
With UV-C	82.55	aA	80.73	aB	66.98	aB
Antioxidant Activity ($\text{Trolox mg equivalent. } 100 \text{ g}^{-1}$)						
Without UV-C	265.12	aA	205.37	aB	95.58	bC
With UV-C	266.10	aA	196.08	aB	119.85	aC

Means followed by equal letters, lowercase in the columns and uppercase in the lines, do not differ by Tukey's test, at 5% probability ($p \leq 0.05$).

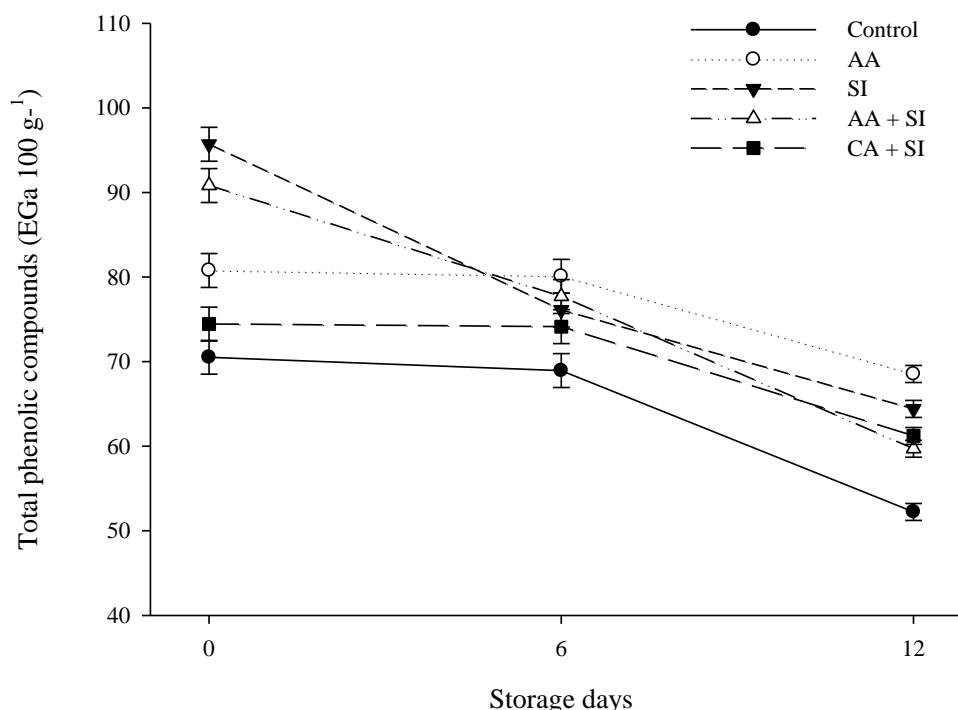


Figure 1. Average of total phenols in minimally processed 'Fuji Suprema' apples under different additives, stored at $4\pm 1^\circ\text{C}$ and 85-90% RH for up to 12 days. Ascorbic acid (AA), sodium isoascorbate (SI), ascorbic acid + sodium isoascorbate (AA+SI), citric acid + sodium isoascorbate (CA+S). Significant difference ($p \leq 0.05$).

compounds by the AA, probably occurs because this acid can sequester free oxygen and prevent oxidation action

Table 5. Weight loss, titratable acidity, soluble solids and antioxidant activity of minimally processed 'Fuji Suprema' apples under different additives, stored at 4±1°C and 85-90% RH for up to 12 days.

Activity	Weight Loss (%)					
	Day 0		Day 6		Day 12	
Control	0.00	aC	1.55	aB	3.94	aA
AA	0.00	aB	1.24	aA	1.93	bA
SI	0.00	aC	1.52	aB	2.55	bA
AA+SI	0.00	aB	1.41	aA	2.18	bA
CA+SI	0.00	aB	1.49	aA	2.59	bA
Titratable acidity (% of malic acid)						
Control	0.30	aA	0.26	aB	0.22	bC
AA	0.28	aA	0.26	aAB	0.23	bB
SI	0.28	aA	0.26	aB	0.25	aB
AA+SI	0.27	aA	0.25	aA	0.22	bB
CA+SI	0.28	aA	0.25	aAB	0.23	bB
Soluble Solids (°Brix)						
Control	12.06	bB	12.38	aB	13.43	aA
AA	12.78	abA	12.95	aA	13.33	aA
SI	13.01	aA	12.93	aA	13.11	bA
AA+SI	12.00	bA	12.58	aA	12.83	bA
CA+SI	12.43	abA	12.70	aA	12.96	bA
Antioxidant Activity (Trolox mg equivalent.100g ⁻¹)						
Control	270.40	aA	190.56	bB	117.73	bC
AA	259.69	aA	218.78	aB	126.94	abC
SI	274.57	aA	188.10	bB	127.28	abC
AA+SI	250.26	aA	215.93	aA	144.87	aB
CA+SI	280.66	aA	197.72	bB	121.76	abC

Ascorbic acid (AA), sodium isoascorbate (SI), ascorbic acid + sodium isoascorbate (AA+SI), citric acid + sodium isoascorbate (CA+SI). Means followed by equal letters, lowercase in the columns and uppercase in the lines, do not differ by Tukey's test, at 5% probability ($p \leq 0.05$).

of polyphenoloxidase (Rico et al., 2007).

The additives affected the weight loss, titratable acidity, soluble solids and antioxidant activity of minimally processed apples in relation to cold storage periods (Table 5). There was increase in the mass loss during cold storage period in all treatments. There was no statistical difference in weight loss on the 6th day; however, on day 12th weight loss was higher in the control apples. Mass loss in the control treatment was also higher in minimally processed 'Royal Gala' apples, reaching 8.78% after a 15 day cooled storage period (Pizato et al., 2013).

There was no difference in total acidity among the additives on the day the experiment was installed (day 0). Titratable acidity was high in minimally processed apples treated with SI on the 12th day. In this study, variations in mean values of titratable acidity in the storage period ranged from 0.27 to 0.30% malic acid on the day the experiment was installed (Day 0), from 0.25 to 0.26% on the 6th day and from 0.22 to 0.25% on the 12th day, among the treatments under study. Titratable acidity of

minimally processed apples treated with edible films ranged from 0.26 to 0.56% malic acid (Fontes et al., 2008).

On the 12th day of cold storage, the control and AA increased the concentration of soluble solids in minimally processed apples. Pizato et al. (2013) observed that the control treatment got a high increase in soluble solids in minimally processed apples with edible coatings in a 15 day storage period. Increase in soluble solids observed in the storage period, regardless of the use of additives in minimally processed apples, may be related to sugar accumulation due to humidity loss.

Additives used by this study affected antioxidant activity of apples; the treatments with AA and AA + IS led to the highest concentrations on the 6th day of cold storage; while on the 12th day, they were AA, SI, AA+SI and CA+SI. However, the control showed had the lowest antioxidant capacity and did not differ statistically from AA, SI and CA+SI at the 12th day of cold storage. Oms-Oliu et al. (2008) achieved high levels of antioxidant activity and the maintenance of this compound in pears

minimally processed and coated with polysaccharides.

Conclusion

The use of ascorbic acid, sodium isoascorbate and associates contributes to keep the color of minimally processed 'Fuji Suprema' apples under refrigeration, for up to twelve days. The use of UV-C in minimally processed apples mitigated the incidence of rot and increased their contents of soluble solids and total phenols, besides their antioxidant activity on the 12th day of storage. Ascorbic acid contributed to the total phenol content in minimally processed apples on the 12th day.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Bioactive compounds, antioxidant activity and minerals of 'Cajuí' (*Anacardium humile* St. Hill) during the ripening

Rayssa Gabriela Costa Lima Porto¹, Roseane Fett², José Alfredo Gomes Arêas³, Amanda de Castro Amorim Serpa Brandão¹, Marcelo Antônio Morgano⁴, Rosana Aparecida Manólio Soares³, Marcos Antônio da Mota Araújo⁵, and Regilda Saraiva dos Reis Moreira-Araújo^{6*}

¹Post-graduation Program in Food and Nutrition, Federal University of Piauí – UFPI, Campus Minister Petrônio Portela, Ininga SG 13, CEP: 64049-550. Piauí, Teresina, Brazil.

²Department of Food Science and Technology, Centre of Agro-Sciences, UFSC- Federal University of Santa Catarina, Rod. Admar Gonzaga 1346 Itacorubi 88034-001, Florianópolis, Santa Catarina, Brazil.

³Department of Nutrition, Faculty of Public Health, University of Sao Paulo, Brazil.

⁴ITAL- Institute of Food Technology, Center of Foods Science and Quality, Av. Brasil, 2880, Jardim Chapadão, 13070-178 Campinas, São Paulo, Brazil.

⁵Statistician of the Health Municipal Foundation, R. Gov. Raimundo Artur Vasconcelos, 3015 - Primavera, 64002-595, Teresina, Piauí, Brazil.

⁶Department of Nutrition, Health Sciences Centre, UFPI- Federal University of Piauí, Department of Nutrition, Campus Minister Petrônio Portela, Ininga SG 13, CEP: 64049-550. Piauí, Teresina, Brazil.

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The present study aimed to determine the content of minerals, bioactive compounds and the antioxidant activity of 'Cajuí' (*Anacardium humile* St. Hill) during the ripening. The fruits were collected in three maturity stages. The content of the minerals, total phenolics, proanthocyanidin and carotenoids contents as well as the antioxidant activity, ABTS (2,2-azinobis-3-ethylben-zothiazoline-6-sulphonic acid), DPPH (2,2-diphenyl-1-picrylhydrazyl) and FRAP (ferric reducing antioxidant power) were determined, with results expressed on Trolox equivalent antioxidant capacity (TEAC). The Student's t-test was employed to analyse the data, based on a significance level of $p < 0.05$. The total phenolic contents were determined as 1424.33 ± 28.62 , 991.16 ± 21.52 and 867.08 ± 28.56 mg GAE.100 g⁻¹ for the immature, semi-mature and mature stages, respectively. Regarding the carotenoid content, 18.05 ± 1.01 was obtained for the immature stage, 8.62 ± 0.96 was obtained for the semi-mature stage, and 8.32 ± 0.97 mg-β-carotene.100 g⁻¹ was obtained for the mature stage. Regarding the antioxidant activity; it was particularly relevant for the fruits in the immature stage in the three methods used: DPPH (30399.63 ± 27.06 μM TEAC.100g⁻¹), ABTS (40860.62 ± 9.32 μM TEAC 100 g⁻¹) and FRAP (6118.22 ± 83.04 μM TEAC.100 g⁻¹). The 'cajuí' exhibited high antioxidant activity and content of bioactive compounds, especially for the immature stage. Among the minerals, 'cajuí' showed high levels of K (potassium), P (phosphorus), and Mg (magnesium). Thus, the cajuí presents itself as a good source of antioxidant compounds which can be exploited by the food industry as an ingredient for the development of a food with functional properties and the pharmaceutical industry, as phytochemical.

Key words: Minerals, phenolic compounds; maturation stages; antioxidant activity.

INTRODUCTION

The Cerrado's flora comprises a variety of fruit tree species with great potential for agricultural use, which are traditionally used by the local population, who consume them *in natura* or processed as juice, liquor, ice cream, jams and sweets (Silva et al., 2008). Among the compounds present in foods with functional properties, antioxidants have received special attention because they protect the human body against oxidative stress, thus avoiding a great number of chronic non-communicable diseases (Canuto et al., 2010; Yahia, 2010).

Anacardium humile St. Hill. (Anacardiaceae) is commonly known as 'cajuzinho-do-cerrado' or 'cajuí' (Hoehne, 1979). This pseudo-fruit can be consumed in the form of juice, sweets and wine. The 'cajuzinhos' ("small cashews") are popularly recognised as having excellent taste and low astringency. The high sugar and total soluble solids contents, which influence the level of sweetness of these small cashew apples, are apparently responsible for the good sensory acceptance (Agostini-Costa et al., 2004).

During fruit maturation, physical, chemical, biochemical and physiological changes occur, which result in detectable transformations in the colour, flavour, aroma and texture (Romojaro et al., 1996). Some authors have demonstrated the existence of significant differences in the levels of bioactive compounds and in the antioxidant capacity of other tropical fruits at different maturation stages (Park et al., 2006; Zhang et al., 2006). Therefore, the present study aimed to determine the influence of the maturation stage on the bioactive compounds content and the antioxidant activity of the 'cajuí' fruit.

MATERIALS AND METHODS

Samples preparation

The *A. humile* St. Hill fruits were provided in two lots in the months of August and September of 2012 by the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária – Embrapa), located at latitude 05°05'21" and longitude 42°48'07" in the city of Teresina, capital of the State of Piauí, Brazil. The fruits were collected directly and were in three different maturation stages (immature, semi-mature and mature), as determined by physical characteristics such as fruit colour and shape (immature - green fruit and firm texture; semi-mature - yellowish green fruit and soft texture; and ripe - yellow fruit and soft texture) with the satisfactory integrity of the samples based on the fruit conservation state. Once sanitised, the pulp of the fruit was removed, and the fruits were dried in a ventilated oven at 45°C for 12 h. After drying, the fruits were ground in a mill and stored in

plastic bags at -20°C for later analysis of the levels of bioactive compounds and the antioxidant properties.

Reagents

The Folin-Ciocalteu phenol reagent, catechin, β -carotene, 2,2-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), 1,1-diphenyl-2-picrylhydrazyl (DPPH), 2,4,6-tris(2-pyridyl)-s-triazine (TPTZ) and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) were purchased from Sigma Chemical (St. Louis, MO, USA). Gallic acid, sodium carbonate (Na_2CO_3), hydrochloric acid (HCl), anhydrous ferric chloride (FeCl_3), methanol, ethanol, hexane and acetone were purchased from Vetec (Rio de Janeiro-RJ, Brazil). All of the reagents used were of analytical degree, and deionised water was used.

Procedure

The bioactive compounds analyses were performed in the Food Chemistry Laboratory of the Federal University of Santa Catarina (Florianópolis - SC), and minerals analyses in Institute of Food Technology (Campinas – SP).

Preparation of extracts

The extracts were prepared with a dry sample according to Rufino et al. (2010). Two solvents were used: 80% acetone and a methanol/acetone/water mixture (4:4:2 by volume). The extraction was conducted with an ultrasound device (USC-1400-Original ®) for a period of 60 min, followed by centrifugation at 4000 rpm. Subsequently, the supernatant was used to determine the total phenolic and proanthocyanidin contents and the antioxidant activity.

Determination of total phenolics content

For this analysis, 2 ml of deionised water was added to a 10 ml flask, 100 μl of sample (extract) was pipetted with an automatic pipette, and the sample was transferred to a 10 ml volumetric flask. Next, 0.5 ml of the Folin-Ciocalteu reagent was added, followed by vigorous agitation. After 5 min, 1.5 ml of sodium carbonate at 20% m/v was added, and the mixture was well agitated and diluted with deionised water to a volume of 10 ml. After a 2 h rest at room temperature with the sample kept in the dark, the absorbance was measured at 765 nm with a spectrophotometer Hewlett-Packard model HP 8452A (Cheadle Heath, Stockport Cheshire, UK) in a 10 mm cuvette (Singleton and Rossi, 1965). The total phenolic content was expressed in mg gallic acid equivalent (GAE) per 100 g of sample. Each determination was performed in triplicate and repeated at least three times.

ABTS method

The ABTS (2,2-azinobis-3-ethylbenzothiazoline-6-sulphonic acid)

*Corresponding author. E-mail: regilda@ufpi.edu.br. Tel/Fax: +55 86 3237 2062.

method used was previously described by Re et al. (1999). The ABTS⁺ cation was produced by mixing ABTS (7 mM) with 2.45 Mm potassium persulphate (final concentration) and keeping the mixture in the dark and at room temperature for 16 h. For analysis, the reagent was diluted in ethanol until the absorption at 734 nm reached the value of 0.700 ± 0.02 . The absorbance was measured in a Hewlett-Packard 8452A spectrophotometer 7 min after (kept at room temperature and in the dark) the addition of the extract. The results were expressed in μM Trolox equivalent antioxidant capacity (TEAC) per 100 g of sample. Each determination was performed in triplicate and repeated at least three times.

DPPH (2,2-diphenyl-1-picrylhydrazyl) method

For this analysis, 0.0394 g of the radical was weighted and dissolved in 10 ml of methanol. After this procedure, the solution was diluted 1:100 in 80% methanol v/v, adjusting the initial absorption to 0.800. Once the solution was prepared, 2.9 ml of the radical was pipetted into a 10 mm cuvette. The initial absorption was then measured. A 100 μl sample of extract was added, and a reaction time of 30 min was allowed at room temperature with the sample kept in the dark with the spectrophotometer Hewlett-Packard model HP 8452A. The results were compared to the standard antioxidant Trolox and expressed in μM TEAC 100⁻¹g of sample. The method was conducted according to Kim et al. (2002). Each determination was performed in triplicate and repeated at least three times.

FRAP (ferric reducing antioxidant power) method

For the sample, 200 μl of the 3 M ferric chloride solution was pipetted into 10 ml test tubes in triplicate. Next, 200 μl of the sample extract was added to each test tube, followed by homogenisation with a vortex agitator. At this point, a chronometer was started to time the reaction. The reaction occurred for 30 min in a water bath at 37°C. The sample was then removed from the water bath, and 3.6 ml of the previously prepared TPTZ (2,4,6-tris(2-pyridyl)-s-triazine) solution was added. Ten min after the addition of TPTZ (kept at room temperature and protected from light), the absorbance was measured at 620 nm with a spectrophotometer Hewlett-Packard model HP 8452A in 10 mm cuvettes. The results were expressed in μM TEAC per 100 g of sample, according to the methodology described by Benzie and Strain (1999), with modifications by Arnous et al. (2002). Each determination was performed in triplicate and repeated at least three times.

Determination of total carotenoid content

The carotenoid content was determined according to the methodology by Alvarez-Suarez et al. (2011) and Ferreira et al. (2009). In brief, 1 g of sample was weighed in a 30 ml beaker, and 10 ml of the acetone/hexane (4:6) solvent, which was kept under agitation for 10 min, was added. Next, the content was filtered, and the absorbance was determined at 450 nm with a spectrophotometer Hewlett-Packard model HP 8452A. The results were expressed in mg of β -carotene per 100 g of sample, for comparison with the standard β -carotene curve previously constructed. Each determination was performed in triplicate and repeated at least three times.

Determination of proanthocyanidin content

The level of proanthocyanidin (condensed tannins) was determined

by colorimetry using the vanillin method and using catechin as a standard (Price et al., 1978). For this procedure, 5.0 ml of the vanillin reagent (0.5 g of reagent and 200 ml of methanol HCl at 4%) was added to 1.0 ml of the methanol/acetone extract. After 20 min of reaction in the dark and at room temperature, the reading was taken at an absorbance of 500 nm. Measurements were performed in triplicate, and the results were expressed in mg of catechin equivalent (CE) per 100 g of dry sample. Each determination was performed in triplicate and repeated at least three times.

Determination of minerals

To determine the mineral, all glassware used after washing with soap Extran (Merck) previously remained immersion in nitric acid (HNO₃) 25% (v/v) for 24 h. Then, the glassware was rinsed with distilled water and demineralized (M Ω resistivity of 18.2 cm⁻¹). To determine the role of calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), sodium (Na), potassium (K), phosphorus (P) and zinc (Zn) in the samples, we used as a method of sample preparation by dry digestion, according to Horwitz and Latimer (2005) were weighed in a porcelain capsule 2.5 g sample in triplicate. Then, the samples were pre-calcined in the heating plate and incinerated in a muffle furnace at 450°C until formation of ash-free black dots. The ashes were quantitatively transferred to a volumetric flask with 25 ml of hydrochloric acid 5% (v/v) and the solution was filtered through quantitative filter paper before reading on emission spectrometer with inductively coupled plasma (ICP-OES). Analytical blanks were prepared by omitting the samples. The quantification of inorganic elements was performed using an emission spectrometer (ICP-OES) of Varian (Mulgrave Victoria, Australia) model Vista MPX axial view, equipped with a source of radio frequency (RF) of 40 MHz, one simultaneous multi-element detector solid state type Charge Coupled Device (CCD), a peristaltic pump, a spray chamber and nebulizer sea spray. The system is fully controlled by the ICP Expert software using the plasma gas liquid argon with purity of 99.996% (Air Liquid, SP, Brazil).

Statistical analysis

For the statistical analysis, a database was created with the statistical package for the social sciences (SPSS, 2010) software, version 17.0. The results are presented in tables with their respective means and standard deviations for each variable studied. To determine if there was a significant difference between means, Student's t-test and Tukey's test of means were used, Analysis of variance (ANOVA) and normality Kolmogorov Smirnov test were also applied. The significance level adopted for all the tests was $p < 0.05$ (5%) (Andrade and Ogliare, 2010).

RESULTS AND DISCUSSION

These results (Table 1) indicate that the total phenolics content decreased throughout the maturation process. Lopes et al. (2012) studied the antioxidant potential of the *A. occidentale* from different early dwarf clones during their ripening and obtained values lower than those in the present study, varying from 26.70 to 375.79 mg GAE.100 g⁻¹. Rocha et al. (2013) obtained sequential extraction values of 51.15 and 11.58 mg GAE.100 g⁻¹ in alcoholic and aqueous extracts, respectively. This inconsistency

Table 1. Total phenolic content, Carotenoids content and proanthocyanidins content in 'cajuí' (*Anacardium humile* St Hill) at three maturation stages, expressed on a dry basis.¹

Maturation Stages	Total Phenolics (mg.GAE.100 g ⁻¹) ²	Carotenoids (mg-â-carot.100 g ⁻¹)	Proanthocyanidins (mg CE.100g ⁻¹) ³
Immature	1424.33±28.62 ^a	18.05±1.01 ^a	37.41±0.00 ^a
Semi-mature	991.16±21.52 ^b	8.62±0.96 ^b	5.88±1.64 ^b
Mature	867.08±28.56 ^c	8.32±0.97 ^b	4.96±1.65 ^c

¹Data was expressed as average ± SD, n=3; ²Equivalent to gallic acid (GAE); ³Catechin Equivalent (CE); The same letters in the row represent non-significant difference between means according to Student's t-test p<0.05.

can be explained by differences in soil, climate, growing season, postharvest storage and extraction methods (Melo et al., 2006; Barreto et al., 2007; Rufino et al., 2010). Plants may also activate polyphenol synthesis in response to stress, such as injury, pathogens or low nutrients (Dixon and Paiva, 1995). Nevertheless, the variation between samples in different maturation stages is expected because maturation can be defined as a sequence of alterations in colour, flavour and texture of fruits and vegetables in general.

Rocha et al. (2011) obtained values of 170, 184 and 190 mg GAE.100 g⁻¹ for three 'cajuí' varieties using a 70% acetone extraction. The variation in the content of these compounds can be explained by climate and soil change, among other environmental factors, because the fruits used for the study by Rocha et al. (2011) were collected in the states of Goiás, Bahia and Federal District. There are no data in the literature concerning the total phenolic content in 'cajuí' at different maturation stages; however, studies have been conducted with other fruits. For instance, Lichtenthäler et al. (2003) and Pacheco-Palencia et al. (2009), demonstrated açai (*Euterpe oleraceae* Mart.) to be a fruit rich in phenolic compounds and with high antioxidant activity.

Gordon et al. (2012) obtained total phenolics contents of 12317 ± 264, 3039 ± 149 and 3437 ± 154 mg GAE 100 g⁻¹ for the immature, semi-mature and mature stages of açai, respectively. Those results were similar to the ones obtained in the present study. Using a comparison with other typical fruits from the Cerrado region, Almeida et al. (2011) obtained 98.8 ± 5.6 mg GAE 100 g⁻¹ for 'mangaba', 159.9 ± 5.6 mg GAE 100 g⁻¹ for 'murici' (or golden spoon), 83.8 ± 6.1 mg GAE 100 g⁻¹ for tamarind and 44.6 ± 2.7 mg GAE 100 g⁻¹ for 'umbu'(or Brazil plum). The contents obtained in the cited fruits were lower than the ones observed in the present study. The carotenoids content decreased significantly as the fruit matured (Table 1): the immature stage exhibited the greatest carotenoid content (18.05 ± 1.01 mg 100 g⁻¹), followed by the semi-mature (8.62 ± 0.96 mg 100 g⁻¹) and mature (8.32 ± 0.97 mg 100 g⁻¹) stages.

Lopes et al. (2012) obtained the a minimum of 0.09 mg

100 g⁻¹ and maximum value of 37.58 mg 100 g⁻¹ of carotenoids in *A. occidentale* when studying different early dwarf clones during their ripening. Therefore, the carotenoids content obtained in the present study was higher in the three maturation stages in comparison to the data from the literature, especially in the immature stage. Carotenoids are present in chloroplasts and are normally masked by the presence of other dominant chlorophyll pigments. Therefore, although they are present in greater amounts in the immature stage, carotenoids are not visually perceived because chlorophyll is the dominant pigment. As the fruit matures and chlorophyll degrades, the carotenoids become visible in colour shades varying from orange-yellow to red.

Regarding the proanthocyanidin content, the values obtained also differed statistically among the immature (37.41 ± 0.00 mg CE 100 g⁻¹), semi-mature (5.88 ± 1.64 mg CE 100 g⁻¹) and mature (4.96 ± 1.65 mg CE 100 g⁻¹) stages. Rocha et al. (2011) obtained higher values (186, 242 and 132 mg CE 100 g⁻¹) for the three varieties of 'cajuí'. The carotenoid and proanthocyanidin content in plants can vary according to the environment, cultivation system, solar incidence, type of soil and even the type of extraction and methodology employed for analysis.

Table 2 shows the results for antioxidant activity using three different methods (DPPH, ABTS and FRAP). The immature stage exhibited the highest antioxidant activity.

The antioxidant activity of 'cajuí' decreased with maturation (Table 2), becoming lower in the mature stage for all the methods in different extracts. Due to the complexity of the composition of foods, their antioxidant power depends on the synergistic effects and redox interaction between the different nutrient and "non-nutrient" molecules, which together contribute to the possible health benefits. Therefore, attention has been given to the antioxidant activity of fruits, a parameter that allows a real evaluation of the nutritional value of foods (Lenucci et al., 2006; Pellegrini et al., 2007).

In comparison to the present study, Gordon et al. (2012) obtained decreasing values throughout the maturation of açai when determining the antioxidant activity using the ABTS radical-scavenging method,

Table 2. Determination of antioxidant activity (DPPH, ABTS and FRAP) of 'cajuí' (*Anacardium humile* St Hill) at three maturation stages, expressed on a dry-weight.¹

Maturation stages	DPPH – TEAC ² µM.100 g ⁻¹	ABTS- TEAC µM.100 g ⁻¹	FRAP – TEAC µM.100 g ⁻¹
Immature	30399.63 ± 27.06 ^a	40860.62 ± 9.32 ^a	6118.22 ± 83.04 ^a
Semi-Mature	18647.86 ± 61.65 ^b	15107.08 ± 1.93 ^b	2882.20 ± 29.01 ^b
Mature	18498.16 ± 88.10 ^b	12171.12 ± 3.87 ^c	2125.48 ± 36.76 ^b

¹Results presented as mean ± SD, n=3; ² TEAC value (antioxidant activity equivalent to Trolox). The same letters in the row represent non-significant difference between means according to Student's t-test p<0.05.

Table 3. Mineral composition (mg.100⁻¹ g) of the *Anacardium humile* St Hill fruit in stage mature in relation DRI (Dietary Reference Intakes).

Minerals	DRI (mg/day;µg/day*)	Values**	%***
Calcium	1000	2.4 (± 0.2)	0.24
Copper	900	0.13 (± 0.01)	0.01
Iron	14	0.24 (± 0.01)	1.71
Phosphorus	700	27.0 (± 1)	3.85
Potassium	-	127.0 (± 5)	-
Sodium	-	8.1 (± 0.6)	-
Magnesium	260	9.8 (± 0.1)	3.77
Zinc	7	0.14 (± 0.01)	2.00

*Daily Intake: mg/day for calcium, magnesium, phosphorus, iron, zinc and manganese; mg / day for copper (Brasil, 2005); ** Results are expressed as averages ± SD (mg / 100 g); *** Percentage adequacy according to the IDR.

namely 17.0 ± 0.71, 4.04 ± 0.05 and 2.78 ± 0.10 µM TEAC 100 g⁻¹. Such values are lower than the ones obtained in this study. However, it is interesting to observe that the antioxidant activity decreased with a decrease in the total phenolics content, demonstrating once again that the presence of such compounds influences the antioxidant activity.

Bramorski et al. (2011) obtained similar values to the ones found in the present study for mature 'camarinha' fruit (*Gaylussacia brasiliensis* (Spreng) Meisn), with values of 2041.20 ± 4.03, 2110.62 ± 19.94 and 765.32 ± 2.60 µM TEAC 100 g⁻¹ for a methanol extraction using the ABTS, DPPH and FRAP methods, respectively. For an extraction with acetone, the results were 2054.72 ± 1.54, 2256.64 ± 92.50 and 851.77 ± 21.59 µM TEAC 100 g⁻¹ for ABTS, DPPH and FRAP, respectively. Thus, based on the higher values obtained in the present study, 'cajuí' exhibited high antioxidant activity.

Moo-Huchin et al. (2015) determined the antioxidant compounds, antioxidant activity and content of individual phenolic compounds of freeze-dried peel from three tropical fruits grown in Yucatan, México: purple star apple (*Chrysophyllum cainito* L.), yellow cashew and red cashew (*Anacardium occidentale*). The freeze-dried peels were good source of antioxidant compounds. ABTS and DPPH values in the peel from each fruit were

3050.95 to 3322.31 µM Trolox 100 g⁻¹ dry weight (DW) or 890.19 to 970.01 mg of vitamin C 100⁻¹g DW, and 1579.04 to 1680.90 µM Trolox 100⁻¹g DW or 340.18 to 362.18 mg of vitamin C 100⁻¹g DW, respectively.

Table 3 presents the contents of minerals (mg/100 g) and recommended daily intake (RDI) in the A. Humile (stage mature). The fruit is highlighted in the content K (127 mg 100⁻¹g), P (27.0 mg 100⁻¹g) and Mg (9.8 mg 100⁻¹g). Fruits in general are a good potassium source because this cation represents one of the most abundant minerals due to its diversity of functions in plants (Andola et al., 2011; Soares et al., 2004). Marc et al. (2011) conducted analysis in cashew apple juice (*A. occidentale*) and obtained values ranged from 2043.8 to 2189.5 mg L⁻¹ for K, 213.9 to 215.8 mg L⁻¹ for P, and 195.6 to 215.1 mg L⁻¹ for the mineral Mg. Among macro minerals analyzed, these were obtained in greater quantity similar to the present study. Trace elements do not provide calories but they play an important role in the metabolic processes of the human body.

Conclusions

'Cajuí' exhibited a high content of phenolic compounds, especially at the immature stage. The acetone solvent

performed the best for the extraction of such compounds. The proanthocyanidin content was greatest in the immature stage and decreased during the maturation process. The cajuí showed high levels of K, P and Mg. 'Cajuí' displayed a high total carotenoids content, with the highest content at its immature stage. The fruit exhibited high antioxidant activity as confirmed by the three methods tested (ABTS, DPPH and FRAP), especially at the immature stage. Thus, the cajuí presents itself as a good source of antioxidant compounds which can be exploited by the food industry as an ingredient for the development of a food with functional properties and the pharmaceutical industry, as phytochemical.

Conflict of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Agronomic response of arugula to green fertilization with rooster tree during two culture times

Ênio Gomes Flôr Souza^{1*}, Falkner Michael de Sousa Santana², Bruno Novaes Menezes Martins³, Manoel Galdino dos Santos⁴, Euvaldo Pereira de Cerqueira Júnior⁵, Aurélio Paes Barros Júnior⁴, Lindomar Maria da Silveira⁴, Francisco Bezerra Neto⁴, Hamurábi Anizio Lins⁴ and José Ricardo Tavares de Albuquerque⁴

¹Instituto Federal de Alagoas – IFAL, Brazil.

²Universidade Federal do Ceará – UFC, Brazil.

³Universidade Estadual Paulista “Júlio de Mesquita Filho” – UNESP, Brazil.

⁴Universidade Federal Rural do Semi-Árido – UFRSA, Brazil.

⁵Universidade Federal do Vale do São Francisco – UNIVASF, Brazil.

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The consumption of arugula is low compared to lettuce and coriander. However, it has been increasing, and there is a lack of information on fertilization and culture times. Growth and development characteristics of arugula were assessed. It was fertilized with different amounts of rooster tree biomass, at different times in the soil. It was cultured at two planting times (spring-summer and fall), in the municipality of Serra Talhada, PE, Brazil. The experimental design was randomized block, with treatments arranged on a 4 × 4 factorial, with three replications. The first factor is the amounts of rooster tree biomass (5.4, 8.8, 12.2 and 15.6 Mg ha⁻¹ on a dry base), and the second one is times of incorporating in the soil (0, 10, 20 and 30 days before the planting of arugula). The characteristics of arugula assessed were: Plant height, number of leafs per plant, yield of green and dry mass of the above-ground part. The maximum yield of arugula was obtained at a dose of 15.6 Mg ha⁻¹ of green fertilizer. Some synchronicity between the supply of nutrients (green fertilizer) and the period of maximum demand by the arugula plants was observed when they were incorporated 20 days before planting. The culture increased the cycle of arugula during the fall, offering greater green and dry mass yields to the culture.

Key words: *Calotropis procera* (Ait.) R. Br., *Eruca sativa* L., green fertilizer, meteorological conditions, organic fertilization.

INTRODUCTION

The production of vegetables in the Northeast Region of Brazil is done with mineral and organic fertilization, highlighting the use of cattle manure. Animal manure, organic compounds and agro-industrial residues are the target of a series of restrictions as to their use on organic

agriculture (Silva et al., 2011), in relation to the nutritional and sanitarian management of the animals that provide these fertilizers. One of the alternatives to the supply of nutrients to vegetables, with increased safety to the consumers, would be through green fertilization. It

consists of adding non-decomposed vegetable material to the soil, produced in the location or brought from other areas. This is done with the purpose of preserving and/or restoring the organic matter contents and nutrients on the soil, and also improving it biologically (Calegari et al., 1993).

The use of spontaneous species from the *Caatinga* biome may be a sustainable strategy for the use of the green fertilization practice in the semi-arid region (Oliveira et al., 2011). These species usually adapt to the edapho-climatic conditions of the region, are easy to collect, and have a high production of dry mass, low susceptibility to attack by plagues and diseases, chemical composition with significant nutrient contents and C/N relationship inferior to 30/1 (Liberalino Filho, 2013; Giacomini et al., 2003).

Researchers conducted on the semi-arid region of the state of Rio Grande do Norte (RN), Brazil, have shown the agronomic and economic feasibility of the use of spontaneous rooster tree [*Calotropis procera* (Ait.) R. Br.], hairy woodrose (*Merremia aegyptia* L.) and oneleaf Senna (*Senna uniflora* L.) plants as green fertilizers for the production of leafy and root vegetables (Linhares, 2009; Bezerra Neto et al., 2011; Silva et al., 2011; Batista et al., 2013; Bezerra Neto et al., 2014). However, rooster tree has stood out in relation to the others due to its greater resistance to drought, and due to the fact that it may produce biomass even under severe drought conditions.

The rooster tree belongs to the Apocynaceae family and it has a wide geographic distribution, above all, under arid and semi-arid conditions (Souto et al., 2008; Carvalho Júnior et al., 2010). The plant remains green and exuberant during the entire year, originating a bush with quick growth and vigorous regrowth, and production capacity of 700 kg of dry mass ha⁻¹, within 60 days after cutting (Andrade et al., 2008). The corresponding nitrogen, phosphorus and potassium contents are at 17.4, 4.4 and 23.5 g kg⁻¹ of dry mass, respectively, and the C/N relationship is 25/1, favoring the mineralization process of the organic matter.

Batista et al. (2013) highlight the capacity of this spontaneous species in improving the chemical and biological conditions of the soil, with a consequent increase on the productivity of radish, when fertilized with 21 Mg ha⁻¹ of the green fertilizer, 21 days before sowing the culture. Linhares (2009), working with this green fertilizer for the fertilization of leafy vegetables (lettuce, arugula and coriander), observed an increase on the height of plants, number of leaves and green, and dry mass yields. Between the highest and the lowest amount of biomass, 6 and 45 Mg ha⁻¹, respectively, the

incorporation to the soil by the rooster tree increased 75% on the commercial productivity of carrot roots (Silva et al., 2013).

For the arugula culture (*Eruca sativa* L.), as well as for other leafy vegetables, the use of cattle manure and chemical fertilizers is a usual daily practice in order to meet the nutritional demands from these cultures (Björkman et al., 2011). However, for the arugula culture, green fertilization with spontaneous species has offered significant increases on the yield of green mass (Linhares, 2009; Linhares et al., 2009).

In that sense, the objective of the research is to evaluate the growth and development characteristics of arugula according to different amounts of rooster tree biomass and its times of incorporation to the soil, during two culture times (spring-summer and fall), under the conditions shown at Serra Talhada, PE, Brazil.

MATERIALS AND METHODS

The experiments were conducted in field, during two culture times: Spring-summer (November 15, 2011 to January 23, 2012) and fall (March 23 to June 04, 2012), at Universidade Federal Rural de Pernambuco (UFRPE), Unidade Acadêmica de Serra Talhada (UAST). It is located at 7°57'15" of South latitude and 38°17'41" of West longitude, with 461 m altitude, in the micro-region of Sertão do Pajeú, Northern Pernambuco, Brazil. The local climate, according to Köppen's classification, is Bwh, referred to as semi-arid, warm and dry; it has summer rains, annual thermal means of 24.7°C and average annual rainfall of 642.10 mm (SUDENE, 1990; Medeiros et al., 2005). The average meteorological data from the period in which the experiments were conducted are shown in Figure 1.

The soil of the experimental area showed a sandy loam texture. During the spring-summer, its chemical characteristics, at 0-20 cm depth are: pH at H₂O (1:2.5) = 7.2; M.O. = 12.8 g kg⁻¹; P = 14.0 mg dm⁻³; K⁺ = 0.5 cmol_c dm⁻³; Ca²⁺ = 3.9 cmol_c dm⁻³; Mg²⁺ = 1.2 cmol_c dm⁻³; Al³⁺ = 0.0 cmol_c dm⁻³; and its chemical characteristics during the fall are: pH at H₂O (1:2.5) = 6.5; M.O. = 12.7 g kg⁻¹; P = 20.0 mg dm⁻³; K⁺ = 0.4 cmol_c dm⁻³; Ca²⁺ = 3.4 cmol_c dm⁻³; Mg²⁺ = 1.1 cmol_c dm⁻³; Al³⁺ = 0.0 cmol_c dm⁻³.

The experimental design used in each experiment consisted of randomized blocks, with the treatments arranged on a 4 × 4 factorial, with three replications. The first factor was constituted by four amounts of rooster tree biomass (5.4, 8.8, 12.2 and 15.6 Mg ha⁻¹ on a dry base), and the second factor, by four times of incorporation in the soil by this green fertilizer (0, 10, 20 and 30 days before the sowing of arugula).

Each experimental plot had 1.44 m², with a useful area of 0.80 m². Six rows or planting lines were transversally arranged on each plot, with a distance of 0.20 m from each other, and 0.05 m between the plants on the row. The arugula cultivar that was planted was 'Cultivada', indicated for culture on the Northeast region. The soil preparation in each experiment consisted of the manual lifting of the plants using hoes.

The rooster tree was collected in locations near UAST, and then it was grinded on a conventional foraging machine, producing

*Corresponding author. E-mail: enio.souza@ifal.edu.br. Tel: +55 87 9 96371428.

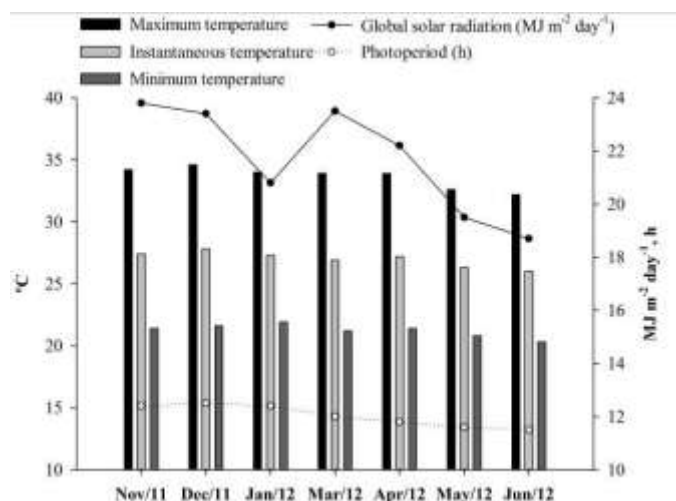


Figure 1. Average monthly values of instantaneous, maximum and minimum temperatures (°C), global solar radiation ($\text{MJ m}^{-2} \text{day}^{-1}$) and photoperiod (h) during the experiments. Serra Talhada, Pernambuco, Brazil, 2011-2012.

fragments between 2.0 and 3.0 cm. It was left to dry until it reach a hay-like condition (10% humidity). From samples of this material, the dry mass nutrient contents were determined (70°C): N = 17.4 g kg^{-1} ; P = 4.4 g kg^{-1} ; K = 23.5 g kg^{-1} ; Ca = 14.3 g kg^{-1} ; Mg = 23.0 g kg^{-1} ; B = 71.0 mg kg^{-1} ; Cu = 29.0 mg kg^{-1} ; Fe = 463.0 mg kg^{-1} ; Mn = 90.0 mg kg^{-1} ; Zn = 40.0 mg kg^{-1} ; Na = $1640.0 \text{ mg kg}^{-1}$; organic matter content = 764.0 g kg^{-1} ; C/N relationship = 25/1.

The green fertilizer was incorporated in the soil at 0-20 cm layer on the experimental plots, according to the treatments. The daily irrigations were conducted in the morning and afternoon, in order to favor the microbial activity of the soil on the mineralization process of the organic matter.

The planting of arugula during the first culture time (spring-summer) was conducted on December 15, 2011, while during the second time (fall), it was conducted on April 23, 2012. The no-tillage sowing was used, at a depth of 2.0 cm, sowing three seeds per hole. After ten days of the emergency, the thinning was conducted, leaving one plant per hole. The irrigations were conducted by a micro-aspersion system, providing a water blade of approximately 8 mm day^{-1} . Manual hoeing was conducted whenever necessary.

During the spring-summer, arugula was harvested 39 days after sowing (DAS), while, during the fall, it was harvested at 42 DAS. The harvesting point used consisted of the maximum vegetative development without the emission of floral stems. During the harvest, the following characteristics were evaluated: plant height, expressed in cm, obtained by measuring a sample of twenty plants with a ruler from the level of the soil up to the end of the highest leaf; the number of leaves per plant was determined on a sample of twenty plants, by counting directly the number of leaves over 3.0 cm in length, from the basal leaves up to the last open leaf; green mass yield, obtained from the fresh mass of the above-ground part of all plants on the useful area of the plot, expressed in Mg ha^{-1} ; and the dry mass of the above-ground part, estimated from the weight of the dry mass of twenty plants of the useful area, after drying in an oven with forced air circulation, with the temperature regulated at 65°C until a constant mass was reached, and expressed in Mg ha^{-1} .

Analyses of variance were conducted for the evaluated characteristics, where corrections were applied for 70% of the effectively planted area, using the SISVAR 3.01 application

(Ferreira, 2003). A joint analysis of these characteristics was conducted. A procedure to adjust response curves was conducted among the evaluated characteristics and the quantitative factors using the SigmaPlot 12.0 program (Systat Software, 2011). Tukey's test ($p < 0.05$) was used to compare the means between the culture times.

RESULTS AND DISCUSSION

From the results of the joint analysis of the evaluated characteristics according to the time of culture, the rooster tree biomass amounts and the time of being incorporated in the soil, an interaction was observed between the amount of green fertilizer and the times of incorporation for the number of leaves per plant. In relation to the dry matter of the above-ground part, an interaction occurred between the amount of rooster tree biomass and culture time factors. The interaction among three factors was observed only for the yield of green mass for arugula. The plant height and the number of leaves per plant were influenced by the culture times (Table 1).

It may be observed that, for the planting of arugula during fall, the height and number of leaves per plant were superior to that planted during spring-summer (Table 2). This result is probably because the mean temperature is close to 26°C and the photoperiod is below 12 h during the fall (Figure 1). This favors the vegetative growth of the culture. On the other hand, at the end of spring and beginning of summer, a mean of maximal temperatures above 34°C and days with light lasting for over 12 h occurred (Figure 1), which possibly had a negative effect on the growth of arugula. The influence of the meteorological factors on the arugula plants also changed the harvesting period observed by the difference on the culture cycles during spring-summer (39 DAS) and fall (42 DAS).

Similar results were obtained by Tuncay et al. (2011), evaluating the effect of cattle manure (100 Mg ha^{-1}), calcium nitrate (150 kg ha^{-1} of N) and ammonium sulfate (150 kg ha^{-1} of N) on the productivity of arugula during different months of the year. The authors observed better results during the coldest months, since the growth cycle was larger, that is, with more than four weeks.

The height of the arugula plants increased linearly with the growing amounts of green fertilizer incorporated in the soil. For each ton added to the soil, an increment of 0.71 cm (Figure 2A) was recorded. The height of arugula increased in a quadratic manner with the times of incorporation of the green fertilizer in the soil, reaching a maximum value of 24.71 cm at 21.7 days, and then decreasing up to the last time of incorporation of the green fertilizer (Figure 2B). This positive result is probably due to the greater availability of macronutrients (N, P, K, Ca and Mg) on the soil after the green fertilization (Góes et al., 2011). Incorporating the arugula 22 days before sowing favored the mineralization of the green fertilizer constituents, promoting the improvement or maintenance of the fertility of the soil.

Table 1. Summary of the analysis of variance for the plant height (PH), number of leaves per plant (NLP), green mass yields (GMY) and dry mass of the above-ground part (DMAP) of arugula plants fertilized with rooster tree, on two culture times.

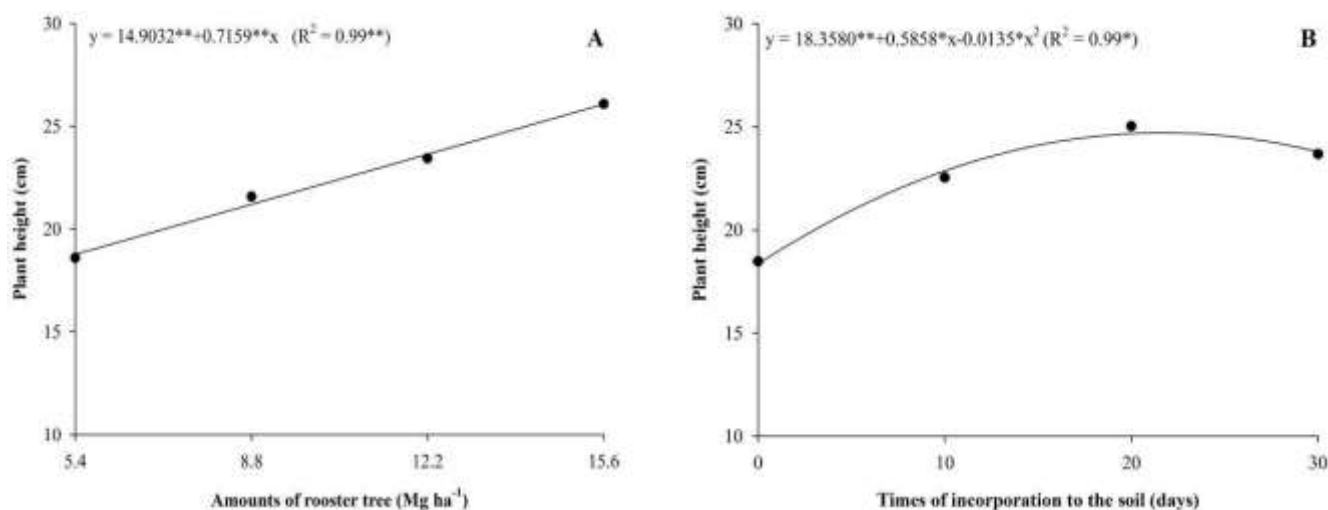
Sources of variation	d.f.	PH	NLP	GMY	DMAP
Seasons	1	11.10**	42.05**	83.98**	34.65**
Amounts	3	109.97**	336.65**	83.00**	129.98**
Times	3	88.06**	236.99**	17.36**	21.13**
Seasons × Amounts	3	0.63 ^{ns}	0.44 ^{ns}	6.58**	3.94*
Seasons × Times	3	0.66 ^{ns}	1.20 ^{ns}	1.91 ^{ns}	2.19 ^{ns}
Amounts × Times	9	0.64 ^{ns}	8.12**	1.12 ^{ns}	0.15 ^{ns}
Seasons × Amounts × Times	9	0.13 ^{ns}	1.50 ^{ns}	2.13*	0.39 ^{ns}
CV (%)		6.57	2.40	12.55	13.80

^{ns}, ** and *: non-significant, significant at 1 and 5% of probability, according to the F test, respectively.

Table 2. Mean values for the plant height and number of leaves per arugula plant fertilized with rooster tree, on two culture times.

Culture time	Plant height (cm)	Number of leaves per plant
Spring-summer	21.92 ^{b1}	14.00 ^{b1}
Fall	22.92 ^a	14.45 ^a

¹Means followed by the same letter on the column do not differ from each other according to Tukey's test at 5% of probability.

**Figure 2.** Height of arugula plants in relation to the amounts of green fertilizer, obtained from the rooster tree biomass (A), and to the times of incorporation to the soil (B) before planting.

Analyzing the rooster tree biomass amounts within each time of incorporation in the soil (0, 10, 20 and 30 days), it was observed that the number of leaves also increased with the growing amounts of the green fertilizer, reaching maximum values of 14.3, 15.0, 16.8 and 15.5 leaves per plant at an amount of 15.6 Mg ha⁻¹, respectively (Figure 3A). On the other hand, analyzing the times of incorporation within the amounts of green fertilizer (5.4, 8.8, 12.2 and 15.6 Mg ha⁻¹), it was observed that the

number of leaves reached maximum values of 13.4, 15.8, 16.6 and 17.0; on the respective times of 22.6, 23.7, 23.3 and 22.9 days, then, decreasing up to the last time (Figure 3B).

The chemical analyses of the soils of the experimental area revealed that the pH had favorable values for the availability of nutrients for the plants, as well as the C/N proportion (25/1) of the green fertilizer, which probably favored the mineralization of N in relation to the

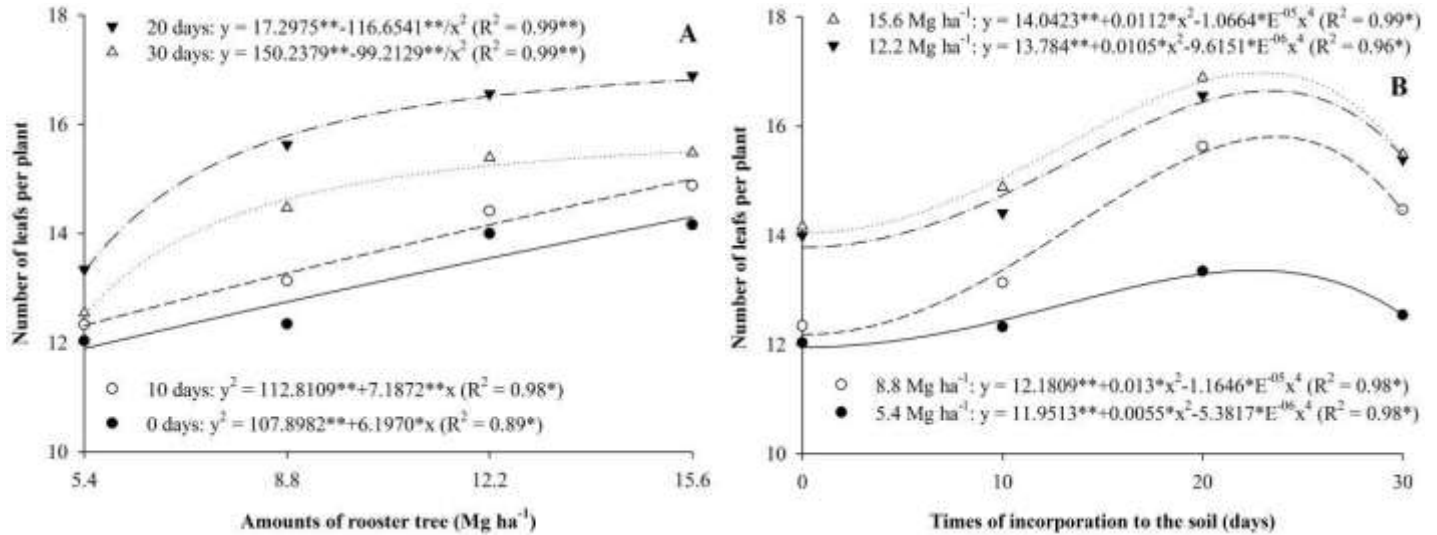


Figure 3. Number of leaves per arugula plant due to the unfolding of the interaction of amounts of green fertilizer, obtained from the rooster tree biomass, within times of incorporation in the soil (A) and its inverse unfolding (B).

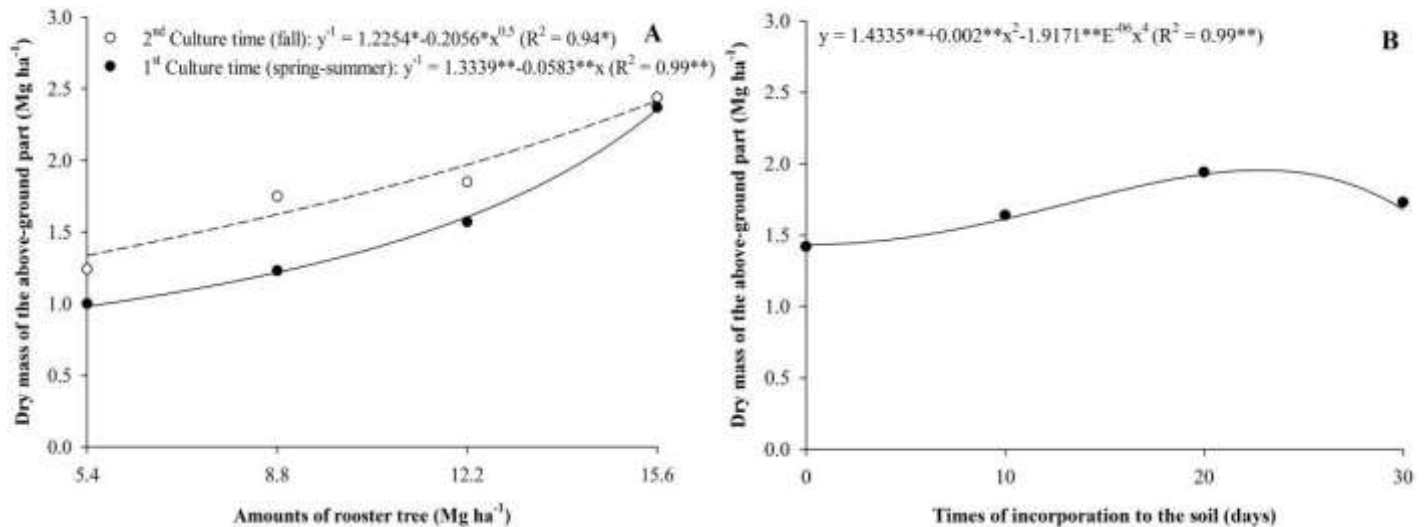


Figure 4. Dry mass of the above-ground part of arugula in relation to the unfolding of the interaction of amounts of green fertilizer, obtained from the rooster tree biomass, within culture times (A) and in relation to the times of incorporation in the soil (B) before planting.

immobilization process (Giacomini et al., 2003). In addition to the increase on the soil fertility, fertilization with vegetable species that occur spontaneously on the region also favors the microbiological aspects of the soil, with the increase on the amount of actinomycetes, fungi and bacteria that benefit the growth of plants, since they work for the solubilization of nutrients of the green fertilizer (Batista et al., 2013). Possibly, the constant irrigation and occurrence of mean temperatures above 26°C during the experiments (Figure 1) stimulated the microbial activity.

The dry mass of the above-ground part of arugula

increased with the growing amounts of fertilizer, reaching maximum values of 2.36 (spring-summer) and 2.42 Mg ha⁻¹ (fall) at a dose of 15.6 Mg ha⁻¹ (Figure 4A). On the other hand, analyzing the culture times within the amounts of rooster tree, significant differences are observed between the times only with 5.4, 8.8 and 12.2 Mg ha⁻¹, with greater dry mass of the above-ground part on the fall culture (Table 3).

The high temperatures associated with the long days during spring-summer (Figure 1) possibly contributed to damage the formation of leaves and the production of dry mass by arugula (Tables 2 and 3), since these

Table 3. Mean values of the dry mass of the above-ground part of arugula for the unfolding of the interaction of culture times according to the amounts of green fertilizer, obtained from the biomass of rooster tree.

Culture time	Dry mass of the above-ground part (Mg ha ⁻¹)			
	5.4 Mg ha ⁻¹	8.8 Mg ha ⁻¹	12.2 Mg ha ⁻¹	15.6 Mg ha ⁻¹
Spring-summer	1.00 ^{b1}	1.23 ^b	1.57 ^b	2.37 ^a
Fall	1.24 ^a	1.75 ^a	1.85 ^a	2.44 ^a

¹Means followed by the same letter on the column do not differ from each other according to Tukey's test at 5% of probability.

meteorological factors stimulate the synthesis of gibberellins, which are related to early bolting, growth of the stem and reduction on the number of leaves on leafy vegetables (Souza et al., 2008; Taiz and Zeiger, 2013).

For the dry mass of the above-ground part of arugula, a growing behavior was also observed with the times of incorporation in the soil of the rooster tree, up to 1.98 Mg ha⁻¹ within 23.1 days, then, decreasing up to the last evaluated time (Figure 4B). The study of the time of incorporation in the soil of the green fertilizer allows the identification of the synchronicity moment between the mineralization of the vegetable residue and the period of maximum nutritional demand of arugula (Myers et al., 1994); that is, the fertilization approximately 23 days before planting of the culture offered the ideal time to make the nutrients on its chemical composition available to the soil solution, thus, favoring the absorption and accumulation of the biomass by the plants.

For the green mass yield of arugula, by analyzing the interaction of the amounts of green fertilizer within times of incorporation in the soil and culture times, it was observed that the increase on the amount of rooster tree promoted an increase on the productivity of the culture, with maximum values of 36.79 Mg ha⁻¹ (spring-summer) and 44.83 Mg ha⁻¹ (fall) within 20 days (Figure 5A and B). The regressions related to the times of 30 days on the spring-summer culture and 10 and 20 days on the fall culture did not allow the adjustment of regression equations; however, the mean values obtained were 27.70, 33.69 and 40.22 Mg ha⁻¹, respectively (Figures 5A and B).

Analyzing the interaction of the times of incorporation in the soil according to the amounts of rooster tree biomass and the culture times, it was observed, on the spring-summer planting, a quadratic response for the fresh mass yield of arugula, considering the maximum value of 36.24 Mg ha⁻¹ at a quantity of 15.6 Mg ha⁻¹ of the fertilizer, at the incorporation time of 20.8 days before planting. For the amounts of 8.8 and 12.2 Mg ha⁻¹, there were no adjustments of regression equations on the first culture time; however, the productivity mean was 28.35 and 29.92 Mg ha⁻¹, respectively (Figure 5C).

From the same analysis, but for the fall culture, the largest yields of arugula green mass were observed within the incorporation time of 22 days, associated with the amounts of 12.2 and 15.6 Mg ha⁻¹ of green fertilizer.

Values were estimated on the order of 44.16 and 44.90 Mg ha⁻¹, respectively. For the same combinations of the factorial, it was observed that the productivity of fresh mass of the arugula cultivated during the fall was higher than the values observed for the spring-summer culture (Figure 5D).

According to Grangeiro et al. (2011), the largest demands for nutrients by arugula occur within the period between 25 and 30 days after sowing, therefore, with a greater demand occurring 45 days after the incorporation of the green fertilizer. It is highlighted that this recommended time did not change across the culture times, perhaps because the variation in temperature and solar radiation was unable to promote a change on the speed of the reactions between the microbiota and organic matter of the soil.

Torres et al. (2005) verified that the greater mineralization of N on cultures used as green fertilizers occurred on the first 42 days after being desiccated, relating it to the low C/N relationship of the vegetable material (20-25/1). This proportion is similar to the one observed on the chemical composition of the rooster tree (25/1).

Previous studies with green fertilization that originated from the rooster tree, on the production of arugula, revealed a green mass yield of only 7.9 Mg ha⁻¹ when using amounts of over 40 Mg ha⁻¹ of rooster tree, associated with the time of 20 days of incorporation to the soil, on the spring culture, in Mossoró, RN, Brazil (Silva, 2012). Such results were inferior to the ones found on this study, probably due to the low fertility of the soil before the implementation of the experiment Silva (2012).

Also in Mossoró-RN, Linhares (2009) obtained, on the spring culture, a fresh mass yield of arugula of 25.09 Mg ha⁻¹ when fertilized with 15.6 Mg ha⁻¹ of green fertilizer made from rooster tree, and incorporated in the soil 15 days before planting. The author observed that this fertilizer offered greater development for arugula, compared to the use of green fertilizer made from hairy woodrose (*Merremia aegyptia* L.) and one leaf Senna (*Senna uniflora* L.). This was attributed to the potassium content on the rooster tree, since this is the main element demanded by arugula (Grangeiro et al., 2011).

Considering the results, the fertilization of arugula using grinded rooster tree is recommended, on both culture times; however, the fall culture with 15.6 Mg ha⁻¹ of the

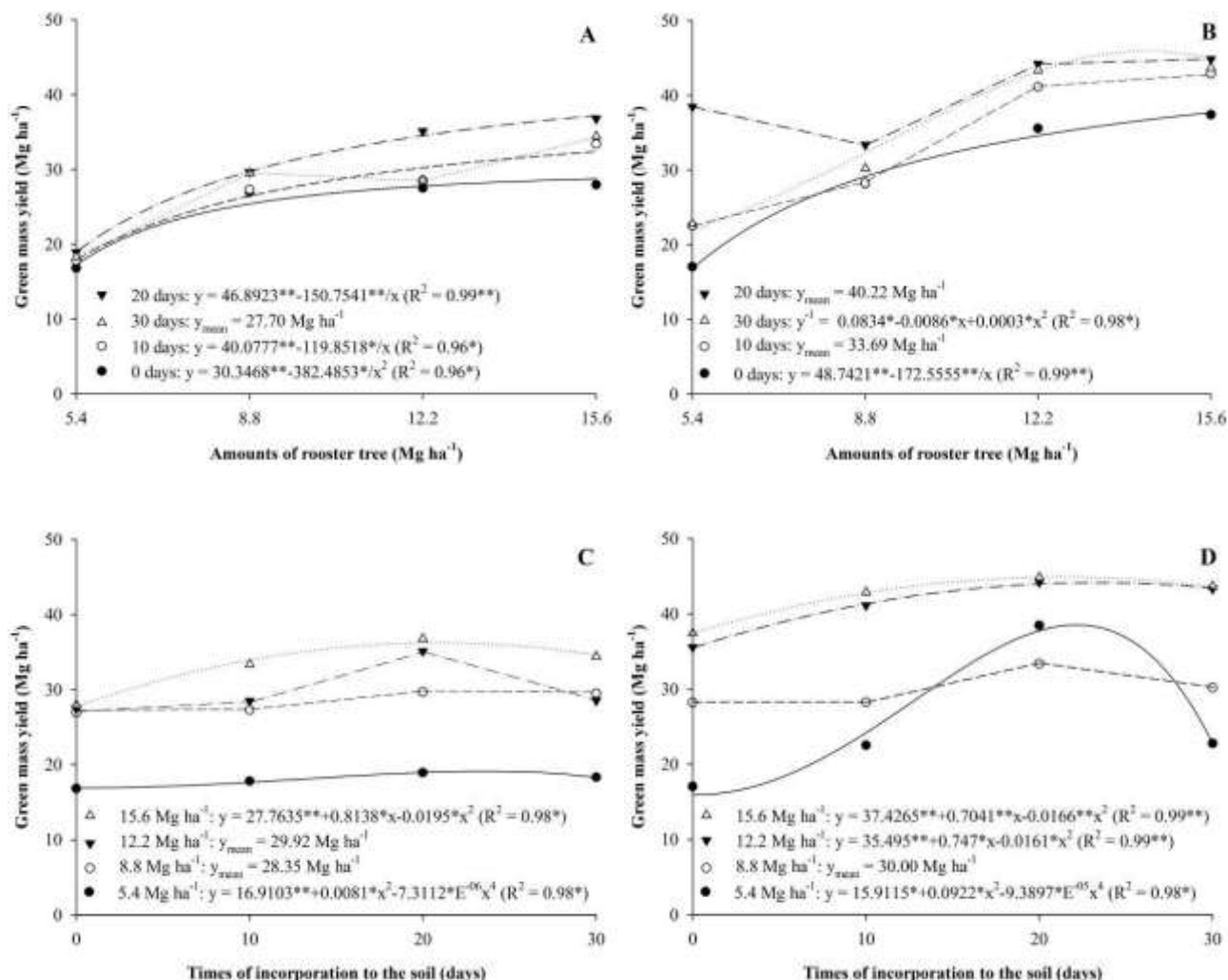


Figure 5. Yields of arugula green mass due to the unfolding of the interaction of amounts of rooster tree biomass, within times of incorporation in the soil (A. spring-summer; B. fall) and the inverse (C. spring-summer; D. fall), within each culture time.

green fertilizer, incorporated in the soil 20 days before sowing may offer 22% increment on the green mass yield in spring-summer culture.

Conclusion

1. Better growth and development of the arugula plants was obtained with the amount of 15.6 Mg ha^{-1} of green fertilizer, of grinded rooster tree plant.
2. The ideal time of incorporation of the green fertilizer in the soil is 20 days before sowing of the arugula.
3. Larger green and dry mass yields of arugula fertilized with rooster tree is obtained in culture produced during the fall season.

Conflict of interests

The authors have declared no conflict of interests.

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