African Journal of Agricultural Research

Volume 12 Number 6 9 February 2017
ISSN 1991-637X

Academic Journals

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Vol. 12(6), pp. 377-381, 9 February, 2017
DOI: 10.5897/AJAR2016.11860
Article Number: 5C3272D62667
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Review

Wheat blast research: Status and imperatives

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Received 21 October, 2016; Accepted 3 January, 2017

Wheat blast is relatively a new disease of wheat that first appeared in Brazil in 1985. It did spread to some other neighbouring countries in the following years and owing to its predisposing factors, was feared to be capable of moving across continental boundaries. The disease has now been reported from Bangladesh. Wheat blast at best can be described as poorly understood as both pathogen and its pathogenicity as well as host and its ability to resist need to be investigated before breeders could confidently field varieties with sufficient levels of genetic resistance. In the meantime, chemical protectants and management strategies need to be worked out to tackle this menace that has already been impoertant in rice.

Key words: Wheat, blast, *Magnaporthe*, disease, research.

INTRODUCTION

Literally speaking, blast means explosion. Wheat blast directly strikes wheat ear and renders grains shrunken, shrivelled and deformed within a week of initial symptoms giving no time to farmers to react. Climatic conditions viz., hot and humid climate play a crucial role in disease development. The blast pathogen shows various infection abilities and is known to infect many grasses like rice, wheat, barley, etc. In fact, rice blast has been one of the most important and damaging rice diseases, whereas wheat blast is of relatively recent occurrence (Maciel, 2016). First sighted in 1985 in Brazil, it soon spread to other iso-climatic neighbouring countries of South America. It is now a serious production constraint in the tropics and sub tropic regions, including Brazil, Argentina, Bolivia and Paraguay causing yield losses of up to 100% (Peng et al., 2011). Most current wheat varieties are blast susceptible, pathogen is highly variable, epidemiology as well as genetics of resistance is poorly understood. All this makes wheat blast a formidable wheat enemy. Since wheat blast requires concurrent heat and humidity to develop, experts had earlier warned about a possible movement of blast from Latin America to similar regions of Africa and Asia. The detection of blast in early 2016 in Bangladesh (Callaway, 2016) confirmed the fear. The blast in Bangladesh was most likely caused by a wheat-infecting South American lineage of the blast pathogen, *Magnaporthe oryzae* (Islam et al., 2016). If blast fungus continues to show similar migratory capacity, it could soon spread to other hot and humid wheat growing regions in South Asia and beyond. The situation perhaps is even more demanding as fungicides at best offer only a partial defence (CIMMYT, 2016). A spread of wheat blast in South Asia could jeopardize food security of 300 million inhabitants of this region as they consume over

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100 million tonnes of wheat each year. It is already reported that blast affected 16000 hectares of wheat crop in Bangladesh and consequent poor harvest led to Bangladesh importing extra 400,000 tonnes of wheat as compared to previous year (New Age, 2016). This article attempts to review the available information on wheat blast research and also identify gaps to be addressed.

PATHOGEN, DISEASE DEVELOPMENT AND HOST VARIATION

Literature now accepts *M. oryzae* pathotype *Triticum* as the correct name for wheat blast pathogen (Maciel, 2016; Castroagudin et al., 2015, Perello et al., 2015; Maciel et al., 2014) although recently, a new species named *Pyricularia graminis-tritici* was proposed to cause wheat blast by Castroagudin et al. (2016). Ever since its first report, blast pathogen was variously named by researchers for example, *Pyricularia oryzae* (Araujo et al., 2016; Oliveira et al., 2015; Cruz et al., 2015a; Silva et al., 2015), *Pyricularia grisea* (Filha et al., 2011; Kohli et al., 2011; Rocha et al., 2014), *Magnaporthe grisea* (Urashima and Kato, 1994; Peng et al., 2011; Pagani et al., 2014) and *M. oryzae Triticum* (Cruz et al., 2015a). Blast pathogen has shown capability to evolve fast to adapt to new climates. Peng et al. (2011) reported that isolates of blast pathogen from different species displayed differential infection abilities and host parasite specificity between wheat cultivars and pathogen isolates was observed. Triticale (*Secale* X *triticum*) and barley (*Hordeum vulgare*) have also been reported to be infected by *M. grisea* (Urashimae et al., 2004). Cross infectivity studies among hosts revealed that blast pathogen from triticale and barley could infect triticale, barley, wheat, oat and rye but not rice, sorghum, maize, common millet, sugarcane and *Brachiaria brizantha* (Urishama et al., 2004). Ever since its detection in 1985, blast had been observed only on wheat and black oats in Brazil. The disease did spread to some other *Gramineae* species but white oat remained resistant till 2012 when cultivar IAC 7 was severely attacked in Sau Paulo (Marangoni et al., 2013). It is worth mentioning that first detection of blast in US in 2011 was reported to be a case of host jumping by blast pathogen (Tosa et al., 2016). Urashima and Kato (1994) screened 43 wheat lines from Brazil, Japan, USA, Bulgaria, seven *Triticum* spp., and 18 *Aegilops* lines against *M. grisea* inoculation under greenhouse conditions. They found only two *Aegilops* accessions resistant and all others screened were susceptible. Attempting to differentiate between young and adult stage resistance, Cruz et al. (2010) challenged 70 wheat genotypes in young stage to 18 isolates of blast pathogen. They found BRS229, BRS179, CNT8, BRS120 and BRS Buriti with better resistance levels. 12 of the 70 genotypes were inoculated at adult stage and they found CNT8, NE 20156-B, PF 844001, PF 964009 and PF 804002 having less leaf and head area affected by blast. Blast pathogen has also evolved to acquire resistance to fungicides extensively used to manage the disease. Oliveira et al. (2015) compared resistance presented by two groups of *Pyricularia oryzae* isolates from wheat to two fungicides viz., azoxystrobin and pyraclostrobin, both of which are quinone oxidoreductase inhibitors or QoI fungicides. They concluded that high level of resistance to QoI fungicides may be the result of high selection pressure exerted by consecutive years of strobilurin application for the management of wheat diseases in Brazil.

Blast is still spreading in South America and now covers large geographic regions. Maciel et al. (2014) found no subdivision among isolates collected from wheat fields of central-western, southwestern and southern Brazil, indicating high level of gene flow across a large geographic expanse. They proposed that populations of wheat blast pathogen exhibited a mixed reproductive system in which sexual reproduction is followed by local dispersal of clones. Based on seedling virulence assays with local wheat cultivars, they reported 14 pathotypes in the current population; however, detached head virulence assays differentiated only eight virulence groups on the same set of wheat cultivars, and there was no correlation between seedling and head reactions.

Epidemiology, distribution and quantification

First detected in Brazil in 1985, wheat blast soon spread to other neighbouring countries like Bolivia, Paraguay (Kohli et al., 2011) and was detected in Argentina in 2012 (Perello et al., 2015). The blast causing fungal pathogen *M. oryzae* can spread through seed and can also survive on crop residues. The blast mainly affects grains; however, leaf lesions are also observed. The leaf lesions and/or sporulation on leaves does not precede spike blast and therefore importance of inoculum originating from leaves in severely affected fields is disputed, even though it was observed that conidia production coincided with spike emergence under both green house and field conditions (Cruz et al., 2015b). However, Goulart et al. (1995) reported that infected rachis (black point infection in rachis) did pass on pathogen to harvested seed. They found BH 1146 with least infection index and consequently no BH 1146 seed carried infection. On the contrary, variety Anahuac had highest infection index (99.5%) and 26.7% of its seeds carried wheat blast pathogen. They reported a significant positive correlation between field incidence of wheat blast and percentage of seed with wheat blast pathogen across varieties. Cytological investigations revealed that in case of compatible reactions (host resistance) viz., rice blast pathogen on rice (r_b_p_r) or wheat blast pathogen on wheat (w_b_p_w) fungal hyphae penetrated and colonized the epidermal cells and also invaded many neighbouring cells. On the other hand, in the case of incompatible reactions (non-host resistance) of the type w_b_p_r and r_b_p_w fungal hyphae were not able to neither penetrate nor colonize the epidermal cells. Interestingly, in the case of non-host resistance if penetration did occur, the hyphae remained restricted to the first invaded epidermal cell (Araujo et al., 2016). Additionally, unsuccessful penetration occurred with high frequency in incompatible interactions as compared to compatible ones. Correct and uniform scoring of disease symptoms is a critical perquisite to comparative studies, understanding and reporting. Visual scoring like that for glume blotch and fusarium head blight can be an efficient and useful tool. Maciel et al. (2013) employed a software 'ImageJ' to propose a diagrammatic scale to record varying severity of the disease symptoms on wheat spikes. Similarly, Rios et al. (2013) developed a standard area diagram sets (SADs) to quantify wheat blast severity on wheat leaves. Severity estimates were more reliable even with inexperienced scorers when SADs were employed.

Resistance mechanism

Interaction studies of 27 wheat cultivars with two ear pathogens viz., *Magnaporthe* wheat blast (WB) and *Fusarium* head blight (FHB) revealed that most of the 27 cultivars displayed inverse disease response to two diseases. The cultivar 'Milan' displayed resistance (R) to blast and susceptible (S) reaction to FHB. The reactions were reversed when cultivar 'Sumai 3' was inoculated with these two pathogens. Microscopic studies revealed that MWB similarly colonized spikelets in both the cultivars and FHB infected anthers of the susceptible cultivar earlier. Interestingly, both the pathogens grew much faster in the rachilla of the susceptible cultivars indicating that resistance mainly expressed in this part connecting spikelet with rachis (Ha et al., 2016). Gene expression patterns confirmed differential disease phenotypes, fungal spread in the rachis and colonization patterns. The differential response of resistant and susceptible cultivars rules out availability of common resistance genes at least in the material investigated. Cellular investigations revealed that resistance to non-adapted *Magnaporthe* isolates was due to formation of appositions beneath pathogen penetration sites that adapted virulent isolates were able to breach (Tufan et al., 2009). They also reported differential transcription post infection between adapted and non-adapted isolates. Five major genes for wheat blast resistance viz., *Rmg1, Rmg2, Rmg3, Rmg4* and *Rmg5* have been reported (Peng et al., 2011). It is interesting however, to note that wheat leaf rust resistance gene *Lr34* confers resistance to blast in rice (Krattinger et al., 2016). A word of caution on resistance that even complete resistance may break down due to nitrogen induced susceptibility (NIS). Ballini et al. (2013) reported that NIS is a general phenomenon affecting resistance to blast fungus in both wheat and rice.

BLAST MANAGEMENT

Peng et al. (2011) reported absence of effective method for control of wheat blast and emphasized that efforts should be focused to prevent pathogen dispersal to protect wheat production, a warning that came true when blast was detected in Bangladesh (Callaway, 2016). Blast pathogen has also evolved to acquire resistance to fungicides extensively used to manage the disease (Oliveira et al., 2015). Similar findings of widespread distribution of QoI (group of fungicides used for controlling blast) resistance in *M. oryzae* populations sampled from wheat fields and Poaceous hosts across central and southern Brazil were reported by Castroagudin et al. (2015). This resistance is a result of mutation of G143A which led to evolution of cytochrome b gene. Since strobilurins are widely used to manage wheat blast in Brazil, there has been a surge in frequency of the G143A mutation in the wheat infecting population of *M. oryzae* from 36% in 2005 to 90% in 2012 (Castroagudin et al., 2015).

Pagani et al. (2014) advocated integrating several options for efficient management of wheat blast. In a two year study, they found that phosphite treated plots increased yield by 9 to 80%, silicon (Si) treatment by 26 to 92% and synthetic fungicides by 90 to 121%. Rocha et al. (2014) however, concluded that control of wheat blast by means of fungicides application was effective for flag leaves but not for ears. Positive contribution of Si in augmenting the resistance to blast was confirmed by Cruz et al. (2015a). They reported limited colonization of +Si plants by pathogen and that this was associated with the deposition of phenolic compounds. They also observed that expression of all defence related genes was significantly increased on infection but expression level was two to three times higher for +Si plants as compared to -Si counterparts. Similar results of increased Si concentration causing reduced fungal growth were reported by Silva et al. (2015). They found that at histochemical level, Si is involved in the potentiation of the biosynthetic pathway of flavonoids that increases wheat resistance to blast. Silicon application reduced area under blast progress curve by 31% in an experiment reported by Filha et al. (2011). Several substances like jasmonic acid (JA), deacetylated chitosan (DC), potassium silicate (PS), potassium phosphate (PP), tebuconazole (TE) etc. have been experimented to manage wheat blast (Cruz et al., 2011). They found that PP was the best treatment that most reduced severity in the three cultivars tested. TE and PS when added to the culture medium gave lowest values for mycelial growth.

They concluded that PP and TE increased the potentiation of wheat resistance to blast which was also dependent on the inherent level of resistance of the cultivar. According to Urashima and Kato (1994), probenazole and tricyclazole gave good control of blast, except at heading stage. They also reported that new products containing blacin and acetamide gave good protection of the wheat head. Some combinations of earlier reported fungicides viz., tricyclazole and tebuconazole were reported (Goulart and Paiva, 1993) to give best yield increase if followed by thiophanate-methyl+ mancozeb. However, Goulart et al. (1996) reported only mancozeb application to be economically viable. Even though the disease is new and is a subject of detailed investigations worldwide, it is a disease of serious consequences and therefore early warning or disease forecasting can be of great help for farmers and administrators. Development of wheat blast requires simultaneous occurrence of both temperature and spike-wetness. Cardoso et al. (2008) reported highest blast intensity at 30°C which increased with duration of wetting period, while the lowest severity was at 25°C with 10 h of spike wetness. Irrespective of temperature, a wetting period of less than 10 h caused no disease, whereas at 25°C and 40 h wetting period, intensity exceeded 85%. Authors developed a model that shows blast intensity as a function of temperature and spike wetness. The model has then been used to prepare tables to predict blast. Rios et al. (2016) recommended combining both genetic resistance and fungicide treatment for most effective blast management. With 70 and 90% control of final incidence and severity, they found that effect of resistance and fungicide was additive of incidence as well as severity control.

There have been reports on agronomic management (Oliveira et al., 2016) and biological control (Singh et al., 2012; Gnanamanickam and Mew, 1992) of rice blast having potential implications for integrated management of wheat blast. Sowing date significantly affected disease incidence and yield of 14 wheat varieties in Brazil (Oliveira et al., 2016). The strain F0142 of *Chaetomium globosum* isolated from barnyard grass showed potent disease control efficacy against *M. grisea* and also wheat leaf rust (Park et al., 2005). The methanol extract from stems of a tree of Chinese origin, *Catalpa ovata* exhibited potent antifungal activity against several fungal pathogens including *M. grisea* (Cho et al., 2006). The fungus, *Trichoderma harzianum* (Singh et al., 2012) and bacteria viz., *Pseudomonas* spp. and *Bacillus* spp. (Gnanamanickam and Mew, 1992) were also observed to control rice blast. The results hold promise and warrant further investigations to integrate agents of biological origin in a wheat blast management strategy.

CONCLUSION

Wheat blast is a poorly understood emerging threat with potential to be of catastrophic magnitude. There is need to investigate all the parties involved viz., pathogen, host and predisposing factors that would enable stakeholders to manage the disease. Research imperatives on pathogen side include pathogen range, evolution, patterns of variation, effect of climatic factors, epidemiology, virulence patterns, etc. There is need to study variation in pathogen vis a vis, its geographical spread to deploy genetic resistance accordingly. Some research in South America has identified resistance sources; however, this needs to be undertaken in all wheat growing areas where blast favouring conditions prevail. Establishing distinctness of resistance and any relationship with growth stage and/or environmental factors need to be investigated. Since a commercial product needs to have all the features including yield, therefore resistance to blast has to be an integral feature of breeding programmes targeting regions with blast favouring climate. Last but not the least, predisposing factors, chemical protectants, agronomic manipulations and biological agents need to be studied so as to devise management strategies till usable genetic resistance is available in commercial cultivars.

Conflict of Interests

The authors have not declared any conflict of interests.

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Vol. 12(6), pp. 382-388, 9 February, 2017
DOI: 10.5897/AJAR2016.11897
Article Number: 398099662671
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Evaluation of nonlinear econometric models to estimate the wood volume of amazon forests

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Received 1 November, 2016; Accepted 18 January, 2017

Effective timber extraction from primary managed forests requires accurate estimates of the annual volumes of wood. Unlike other studies, this paper uses dummy variables to capture the effects of atypical observations and to estimate the volumetric equations using nonlinear least squares. The results show that the artificial variables are important for the model's specification, and that the use of nonlinear least squares estimates provides more robust results for timber volumes than those generated by the ordinary least squares method. This methodology can be adopted to estimate the volume of wood in the primary Amazon forests that are selected for forest concessions.

Key words: Forest management, volume equation, timber company.

INTRODUCTION

The timber industry in the state of Pará, Brazil is currently going through an important restructuring process, in which the main requirement is managed wood extraction from primary forests for industrial processing (Santana et al., 2016). To maintain their competitiveness, timber companies need to apply rational technologies for the extraction and processing of wood; hence, there is a need to improve the techniques used in estimating the volume of timber to be harvested in each annual production unit (APU), as part of a sustainable forest management plan determined by the companies.

In this context, as we aim to generate data with high statistical significance (Silva et al., 2011; Santos et al., 2014), quantitative methods are used to estimate the volume of timber to be removed from each APU, which depends directly on the forest inventory applied in areas defined by representative samples.

The models used to estimate the volume of wood from primary forests follows those traditionally applied to data from planted forests. Along these lines, several studies conclude that the logarithmic model of the timber volume (dependent variable), and diameter of logs and tree height (independent variables), also known as the Schumacher-Hall (1933) model, has proven to be most

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adequate (Silva 1984; Milk and Regazzi, 1992; Rolim et al., 2006; Thaines et al., 2010; Silva et al., 2011). In primary forests with a high diversity of species, especially in the Amazon, many atypical values (outliers) can be observed; this considerably impairs the samples as a whole and their impact cannot be simply removed from the dataset (Santos et al., 2014). These atypical values, according to Silva et al. (2011), can introduce problems of heteroscedasticity in the residuals of the equation that, as Gujarati (2003) indicates, make parameter estimates of the volume equation inefficient and the model inadequate for making accurate inferences regarding the estimated volume.

Several alternative techniques can be adopted to mitigate this statistical problem. One of these techniques is the correction of heteroscedasticity via White's generalized method, as in Silva et al. (2011), the only known study that has applied this technique. Another way to avoid heteroscedasticity problems is to conduct logarithmic transformation of the equation (Gujarati, 2003) in order to reduce the difference in the measurement scale of the variables. This technique, however, cannot eliminate the problem when heteroscedasticity is produced by outliers. Moreover, it should be noted that the homoscedasticity hypothesis is commonly violated in samples of cross-sectional data (*cross-section*), and due to the problems caused to the estimators generated by the ordinary least squares (OLS) method, should be tested and, if necessary, corrections must be made prior to the model estimation.

The simple removal of trees that generate atypical values can introduce errors in specifying models. As a result, the residuals may not have a normal distribution and the statistics (R^2 and the standard error of the regression) used to measure the performance of the adjustment of equations may present bias. In this case, an efficient technique to solve the problem is the use of dummy variables (DVs) to isolate the effects of the error variance generated by the observations with values above or below the average of the samples.

The differential of this method in relation to those used previously is that the DV captures the magnitude of the effects that such information causes in the volume estimates, thereby correcting the errors in the model specification. Additionally, before considering the DV as relevant in the model, a test should be conducted to assess its contribution (Gujarati, 2003).

Finally, estimation using the Schumacher-Hall (1933) model is conducted via OLS, after the original equation has been linearized within the parameters via log application; the model is conventionally specified in logarithmic form according to the data sample characteristics in the form of an inverted "J". This model, however, entails inconvenience with respect to the requirements for calculating the antilogarithm of the variables to estimate its volume and respective inference. Thus, application of a correction factor to the data is required, as indicated by Leite and Regazzi (1992). In this model, due to the application of a logarithm to the dependent variable, the R^2 cannot be directly compared to models in which this convention is not applied (Gujarati, 2003). Nevertheless, we find that these issues are often neglected in volumetric studies, thereby contributing to the production of spurious and unfavourable economic results for lumbermen.

As a novel alternative to parameter estimation of the original equation without a logarithmic transformation, this paper proposes applying the nonlinear least squares (NLS) method to the original functional form of the equation, which is not linear in the parameters, in order to prevent the direct application of OLS and thus minimize the sum of squared residuals.

In this context, the objective of the study is to specify atypical values using the DV to estimate the equation using NLS and OLS, and to compare the results between models with and without DV. Furthermore, the paper verifies the performance between the estimated OLS and NLS models in generating more precise estimates of timber volumes for the forest species in the inventoried area.

MATERIALS AND METHODS

The data used in estimating the volume equations were obtained from trees harvested in a timber logging area of 95.91 ha of the APU (APU No. 11, work unit—UT No. 4, located in a dense forest Ombrófila) of the River Capim, in the Cikel in Brazil, with headquarters in the municipality of Paragominas, State of Pará, Brazil. The climate and soil characteristics of the study area can be observed in Silva et al. (2011).

The species were selected based on their economic importance to the company Cikel. The data collected for each sample tree harvested were the actual volume, based on the measurement of the circumference of the sections for every 2 m; diameter at breast height (DBH), calculated from equation 01; and commercial real bole height.

$$DBH = \frac{CAP}{\pi} \; (\pi = 3{,}141592) \qquad (1)$$

In total, 234 trees were used as a sample, and the real volume (in m^3) was determined using equation 2 (Silva et al., 1984):

$$Vol = \sum_{i=1}^{k} \frac{g_i + g_{i+1}}{2} l_i \qquad (2)$$

Where: *Vol* = total volume; g_i is basal area in the *i*-th position; and l_i is the length of the section in the *i*-th position. The trees' distribution by diameter class can be found in Smith et al. (2011).

Nonlinear regression model

The estimation of linear regression and nonlinear models applied to cross-sectional data is subject to the normality hypothesis of the error term, homoscedasticity and multicollinearity, being met. The first hypothesis is directly dependent on the R^2 and standard error regression statistics. The second, when violated, affects the efficiency property of the OLS estimators and makes the inference of data analysis spurious. The third, in turn, compromises the isolated contribution of each independent variable to the dependent variable, in addition to providing unreliable estimates of the volume intervals.

In this study, the normality hypothesis is evaluated using the Jarque and Bera (1987) test, the homoscedasticity hypothesis is tested via the White (1980) generalized test, and the multicollinearity hypothesis is checked using the variance inflation factor. Further description of the tests applied can be found in Gujarati (2003), Stata12 (2011) and Schwert (2009).

Following the incorporation of atypical values through DVs, the Chow (1960) test was applied to assess their relevance in the model specification, and the *t* statistic was used to confirm the importance of its effects on the OLS and NLS estimators. The formula is as follows:

$$F_c = \frac{(SQR_r - SQR_i)/m}{SQR_i/(n-k)} \tag{3}$$

Where F_c is the adapted Chow test; SQR_r and SQR_i are the sum of squared residuals of the restricted (without dummy) and unrestricted (with dummy) regressions, respectively; *m* is the number of DVs; *n* is the number observations; and *k* is the number of estimated parameters.

Finally, comparison between the estimated models is given by the standard error of regression, applying the Furnival Index (FI) (Furnival, 1961), as follows:

$$FI = antln\left(\frac{\sum lnVol_i}{n}\right).EP_r.\exp\left(\frac{n-k}{2n}\right) \tag{4}$$

Where EP_r is the standard error of the regression.

The applying a nonlinear generalized estimation method of volumetric equations requires special treatment. For this purpose, a description of the general process of estimating a nonlinear regression using NLS is presented. Thus, Equation 5 is as follows:

$$y_i = f(x_i, \beta) + \varepsilon_i, \text{ whit } \varepsilon_i \sim iidN(0, \sigma^2), (i = 1, ..., n) \tag{5}$$

Where *f* is the overall function of the x_i variables and β parameters. The method of OLS estimates the value of the parameters that minimize the sum of the squared residuals, given that the model is specified in a linear form within its parameters. In this case, the derivative of *f* with respect to the parameters does not depend of β. Therefore, the process of estimating the β parameters is intended to minimize the sum of squared residuals, given by Equation 6.

$$SQR(\beta) = \sum_i [y_i - f(x_i, \beta)]^2 \tag{6}$$

The variable y_i is the timber volume of the tree *i* (Vol_i); x_i is a vector of independent variables formed by the diameter to the height of the tree chest *i* (Dap_i) and the tree height (H_i). The model specified in loglinear form, known in the volumetric analysis literature as the Schumacher-Hall logarithmic model, is given by Equation 7.

$$lnVol_i = \beta_1 + \beta_2 lnDap_i + \beta_3 lnH_i + \varepsilon_i \tag{7}$$

The linear parameters found in the model can then be estimated by OLS.

On the other hand, when the derivative is a function of β, it is said that the model is nonlinear in the parameters, and may be specified in the form given by Equation 8.

$$Vol_i = \beta_1 Dap_i^{\beta_2} H_i^{\beta_3} + \varepsilon_i \tag{8}$$

It follows that, in this model, the derivatives depend on the β vector. Therefore, the OLS estimation method cannot be used to minimize the sum of squared residuals. In this case, the NLS method should be applied, which minimizes the sum of squared residuals with respect to the choice of β parameters. Thus, a better linear approximation of the population parameters can be obtained, with the estimation based on expanding the function $f(x, \beta)$ around the β_0 estimator, and applying the OLS to the final model. Throughout this iterative process of parameters estimation, in seeking the optimal solution, the first-order condition expressed in Equation 9 is satisfied.

$$[g(\beta)]'[y - f(x, \beta)] = 0 \tag{9}$$

Where $g(\beta)$ is the matrix of the first derivatives of $f(x, \beta)$ with respect to β. The expansion of the Taylor series for the optimal solution, in special cases, can be found in Pindyck and Rubenfield (2004).

Specification and adjustment of the volumetric model

One of the difficulties of multiple regression adjustment for estimation of the Amazon rainforest timber volume is the presence of atypical information. However, simply removing these observations can compromise the result. The characteristic of primary forests (native forests) to present commercial trees with higher-than-average value and with large volumetry.

To leave such observations in the sample dataset without adequately capturing their effects on the efficiency of the parameters, and with inadequate model specification, may incur violation of the homoscedasticity assumption (Santana, 2003); this tends to generate biased estimates of the average volume of wood.

To solve the problem, DVs are included in the equation to capture the effects of atypical values (values statistically positioned well above or well below the average of the data), due to the volume variation of the trees.

In this work, a high atypical observation (IA_i) is considered to be one that reaches a value greater than or equal to $IA_i = Q_3 + 3(Q_3 - Q_1)$, while a low observation is $(IB_i) = Q_1 - 3(Q_3 - Q_1)$. Here, Q_1 and Q_3 are, respectively, the first and third quartiles. Thus, the nonlinear model used in this study to estimate the volume of primary forest trees can be specified as in Equation 10:

$$Vol_i = \beta_1 Dap_i^{\beta_2} H_i^{\beta_3} e^{\beta_4 Vda_i + \beta_5 Vdb_i} + \varepsilon_i \tag{10}$$

Where Vol_i is the volume of the tree *i*, in m^3; Dap_i is the diameter of tree *i,* measured at breast height in m; H_i is the height of the tree bole *i* in m; Vda_i is the DV for an atypical high value of volume; Vdb_i is the DV for an atypical low value of volume well below the average; *e* is the base of the neperian logarithm; and ε_i is the error term normally distributed, independent and identically distributed *iid* $N(0, \sigma^2)$. The model specified in this way can only be estimated by NLS, generating nonbiased estimates and efficient parameters.

The nonlinear estimation process is determined by the iterative linearization method through the Taylor series expansion, which allows the function to be linearized around an initial set of values for the parameters, called β_0. In the sequence, the equation is estimated by OLS, generating new values for the parameters. In the second iteration, the nonlinear equation is linearized again around the new values estimated by OLS, and the process continues until it reaches convergence, or until the values of the parameters no longer change.

To illustrate this process, the Davidson and MacKinnon (2004) derivation is adopted. For this, the second-order expansion of the Taylor series is used, centred on the values of the vector β (Equation 11):

$$SQR(\beta) \approx SQR(\beta_0) + g'(\beta_0)(\beta - \beta_0) + \frac{1}{2}(\beta - \beta_0)H(\beta_0)(\beta - \beta_0) \tag{11}$$

Table 1. Volumetric models with and without DVs, estimated by NLS.

Dependent variable: *VOL=* β_0*(DAP^β_1)*(HA^β_2)*exp(β_3*VDa+β_4*VDb)				
Variable	**NLS with *dummy***		**NLS without *dummy***	
	Coefficient	**t-Statistic**	**Coefficient**	**t-Statistic**
Intercept - β_0	0.00012*	3.292598	6.09E-05*	7.18430
DAP - β_1	1.95425*	30.04372	2.09429*	78.8056
HA - β_2	0.79580*	23.19888	0.83039*	27.1666
VDa - β_3	0.08448*	2.837419		
VDb - β_4	-0.24604*	-4.929588		
R-squared	0.96387		0.96125	
Adjusted R-squared	0.96324		0.96091	
Sum squared resid	57.3815		61.5462	
Akaike info criterion	1.47501		1.52799	
Schwarz criterion	1.54884		1.57228	
Heteroskedasticity: Hw	0.952^{ns}		0.087^{ns}	
Multicollinearity: FVI	1.866^{ns}		1.015^{ns}	
Normality: Jb	4.812^{ns}		6.062**	
Durbin-Watson stat	2.132^{ns}		2.039^{ns}	
Chow Test F	8.3103 *	0.000327		

Source: Research data. *Significant at 1%; **Significant at 5%; ^{ns}not significant.

Where *g'*(β_0) is the transpose matrix of the first differences of *f*(x, β) with respect to β; and *H*(β_0) represents the Hessian matrix (k x k) of *SQR*(β), defined around β_0.
The first-order condition for a minimum is given by Equation 12.

$$g(\beta_0) + H(\beta_0)(\beta - \beta_0) = 0 \qquad (12)$$

Which gives the origin to the iterative process, given by Equation 13.

$$\beta_{j+1} = \beta_j - \alpha H^{-1}(\beta_j)g(\beta_j) \qquad (13)$$

Where α is a coefficient of adjustment, utilized in an iterative process, in order to improve the parameters' convergence to the true values. This is the nonlinear estimation process used by Stata12 software (2011) and Schwert (2009).

RESULTS

As shown in Table 1, the R² statistic indicates that there was a good fit of the model, in which 96.32% of the variation in the volume of trees was explained by the independent variables. Equally important is the observation that all independent variables had the expected signs and were statistically significant, based on the *t* statistic. The results agree with the theoretical assumptions for the commercial tree timber volume function of the Amazon forest, where the volume is a direct function of diameter and tree height.

The estimates of the parameters associated with these variables presented positive signs and significant values at 1%. The dependence relationship between these variables and the volume show that the diameter had a higher impact than did height in explaining changes in the volume of trees. Thus, for each 1% increment in the diameter value, the volume is expected to vary 1.95% in the same direction; therefore, variation in diameter produces a more than proportional influence on the volume of wood. Regarding height, each increase of 1% led to a 0.796% variation in the volume, that is, a less than proportional change.

The trees presented a volumetry that was well above or below the average of the sampled trees, which significantly influenced the estimated value of the volume of the trees' timber, as revealed by the significance of the *t*-statistics associated with the DVs. In this study, with the average volume of 4.43 m^3 as a reference point, the 13 atypical trees with a higher volume showed an average of 12.95 m^3, and an average of 1.65 m^3 for the six atypical trees with a smaller volume; that is, the values were 2.9 times higher and 2.7 times lower than the average, respectively.

The adapted Chow F test indicated the relevance of the two DVs included in the model; when absent, errors were found in the model specification, as was a bias in the volume estimates (Table 1). The Akaike and Schwarz criteria, by presenting lower statistical values for the model with DVs relative to the no-dummy model, also presented the best model specification. Finally, the Durbin–Watson statistic reflecting the result of the test for autocorrelation of residuals indicated the absence of this problem. This result was in line with expectations, since in cross-sectional samples for just one year this typical problem of time series data was not present.

The results of hypothesis tests for normality, hetero-

Table 2. Volumetric models with and without DVs estimated by OLS.

Dependent variable: $lnVOL = \beta_0 + \beta_1 lnDAP + \beta_2 lnHA + \beta_3 VDa + \beta_4 VDb$				
Variable	OLS with *dummy*		OLS without *dummy*	
	Coefficient	t-Statistic	Coefficient	t-Statistic
Intercept - β_0	-8.930925*	-40.74628	-9.508421*	-52.87361
lnDAP - β_1	1.905115*	40.46376	2.013940*	51.38402
lnHA - β_2	0.836789*	26.01590	0.878799*	26.72688
VDa - β_3	0.099373*	2.650997		
VDb - β_4	-0.225023*	-4.914108		
R-squared	0.948066		0.941702	
Adjusted R-squared	0.947159		0.941197	
Sum squared resid	2.502277		2.808908	
Akaike info criterion	-1.657508		-1.559007	
Schwarz criterion	-1.583676		-1.514708	
Heteroskedasticity: Hw	0.748^{ns}		0.952^{ns}	
Multicollinearity: FVI	1.629^{ns}		1.014^{ns}	
Normality: Jb	15.876*		18.639*	
Durbin-Watson stat	2.071^{ns}		1.933^{ns}	
Chow Test F	14.0311*	1.785E-06		

Source: Research data. *Significant to 1%; ^{ns}not significant.

scedasticity and multicollinearity confirmed that the model with the DV did not violate these assumptions, and that the restricted model without the incorporation of such variables displayed specification error, since the DVs were found relevant according to the significance of the test of normality and the *t*-statistics (Table 1).

From the results presented in Table 1, it can be observed that the atypical values (VDa and VDb) generated by trees influence significantly and in the opposite direction to the estimated volume of wood in logs. Additionally, the trees with lowest volume were found to cause a higher impact on estimates than the trees that produced larger atypical volumes, when compared to the average sample volume.

The results of the OLS for the logarithmic Hall–Schumacher model are shown in Table 2. It is noted that the DVs were relevant for specification of the logarithmic model, since the parameter estimates associated with such variables differed from zero at 1%. Likewise, the Chow F adapted test was also significant, ratifying the importance of including the variables in the equation. Moreover, the Akaike and Schwarz statistics showed lower values for the model with DVs, indicating a more adjusted model.

Regarding the assumptions of the regression model to be estimated by OLS, it was observed that the normality test was not met, demonstrating that R^2 statistics and regression standard deviation did not serve as parameters and analysis.

Finally, the estimated equations by NLS were compared with those estimated using OLS. The statistical adjusted R^2 of the equations estimated by NLS was higher by 2.3 and 2.01% for the equations with and without DVs, respectively. Given the improvement of accuracy through the model adjustment, and also due to the fact that the algorithm for estimating nonlinear equations is available in the primary software, it is worth making the effort to estimate the NLS equations.

DISCUSSION

To date, no study on volumetric equations of primary forests has referred to the treatment of atypical values of data samples through DVs. This gap also includes problems pertaining to violation of assumptions of the OLS heteroscedasticity model (or not) due to atypical values and multicollinearity were considered.

In this study, the Jarque and Bera (1987) test was applied to evaluate the normality of the residuals. The null hypothesis of normality of errors was accepted for the distribution of errors of the nonlinear model and rejected for the linear model estimated by OLS (Tables 1 and 2). This means that the Schumacher-Hall logarithmic model, which is considered as one having the best performance in volumetric studies (Souza and Jesus, 1991; Silva, 1984; Leite and Regazzi, 1992; Rolim et al., 2006; Thaines et al. 2010; Silva et al., 2011), should not be used without proper caution in the statistical evaluation, which directly influences the statistics and indicators used to select the “best fit” model. Indeed, the estimated NLS model met these assumptions, thereby validating the results.

Regarding the violation of the homoscedasticity hypothesis, Batista et al. (2004) and Silva et al. (2011) identify its infringement and correct the problems using weighted least squares and generalized least squares methods. In fact, some authors, such as Batista et al. (2004) and Silva et al. (2011), state that the variable volume tends to generate heteroscedasticity problems by causing different variance estimates in cross-sectional data.

Moreover, the disregard or unfamiliarity with the effects that violation of this hypothesis cause to the properties of estimators is found to be widespread. Indeed, many studies have included graphics between the error terms and the independent variables that show a distribution in the form of a funnel, as in Thaines et al. (2010), thereby indicating that the variance of the errors is not constant.

Furthermore, Rolim et al. (2006) identify a growing trend among the regression errors and independent variables that reveals the presence of heteroscedasticity. However, it is surprising that nothing is mentioned about correcting the problem, with results published and faults going unnoticed in published journals. This absence of care in evaluating the regression analysis assumptions is a serious issue related to abandon the rigor that should be given to the use of statistical tools and the disservice this causes to those who use these results to make decisions.

The multicollinearity hypothesis is tested by Silva et al. (2011). In other studies (Batista et al., 2004; Rolim et al., 2006), this hypothesis is only mentioned in passing, at most, which also reflects the lack of concern regarding the high correlation between the independent variables. This ratifies the importance of understanding the many problems that multicollinearity causes, including the instability of the estimated parameters, which directly affects projections of estimated values of the dependent variable. In fact, polynomial models that use the squared variables and their combinations make the partial and/or multiple correlations between them very high and generally transformed, presenting a high level of multicollinearity. As a result, though the statistical R^2 presents high value, significant parameters are not found and signals are exchanged (Santana, 2003; Pindyck and Rubinfeld, 2004; Gujarati, 2003). Due to this problem, and especially the nonhomogeneity of the residuals, these models are rejected in favour of the of Schumacher-Hall logarithmic model, which does not violate these assumptions.

With respect to the use of DVs, some studies apply this technique to explain the influence of different regions on estimating the average volume of wood (Mc Tague et al., 1989; Batista et al., 2004). Nevertheless, no record has been found that applies DVs to capture the effects of atypical information on estimation of the average volume of wood.

However, in the case of samples of primary forests, especially the Amazon forest, atypical observations provide desirable information because they represent species of high commercial value and, for the most part, are regarded as the most valuable data observations. As these observations exert desirable influence on the parameters, they must be directly incorporated into the model specification using dummies in order to test their relevance, regardless of the form of the volumetric equation. This study applied this technique in a pioneering way and the results were significant for the adjusted NLS and OLS models (Tables 1 and 2). The adapted Chow F test, together with the Akaike and Schwarz criteria, confirmed that the atypical observations were well specified in both models via the use of DVs. Thus, in addition to eliminating the specification error of the models, we were able to incorporate a significant influence of these observations. In the case of primary forests, it is important for future studies to observe the analysis of atypical observations and their specification for the evaluation of normality assumptions, the estimation of NLS models, and heteroscedasticity and multicollinearity, in the case of cross-sectional data.

With respect to the estimation method, some studies have applied the Schumacher-Hall general model or nonlinear model (Mc Tague et al., 1989; Batista et al., 2004) via NLS and concluded that some models show better adjustment. In addition, it is not necessary to correct the variables used to estimate volume. The difference between this work in relation to others is the use of the NLS generalized method to estimate the correction of heteroscedasticity using White's method, as it generates consistent results for the variance and covariance matrix, and provides asymptotically valid statistical tests, while the weighted methods used in other studies do not guarantee a good adjustment for the model (Pindyck and Rubinfeld, 2004).

Finally, it is emphasized that, following the adjustment made via application of the Furnival Index, the comparison between the standard errors of the NLS (0.50057) and OLS (0.73787) estimated models showed the former to have a standard error that was 32.16% lower than that of the OLS. The comparison via adjusted R^2 between the NLS (adjusted R^2 = 0.9632) and OLS (adjusted R^2 = 0.9287) models, after correction for comparison purposes (Gujarati, 2003), allowed us to demonstrate that the nonlinear model showed a 3.71% superiority in the adjustment. These results confirm that the Schumacher-Hall nonlinear model allows for better adjustment compared to the logarithmic model.

Conclusion

The inclusion of dummy variables to capture the effects of relevant atypical observations made the specification of models more appropriate and generated better estimation and adjustment of parameters using OLS and NLS. Failure to incorporate the effects of atypical observations in specification of the models necessarily implies a specification error and over- or underestimation of the timber volume for the company. In addition, it distorts economic results, such as profit, and the productivity factors of labour and capital. Due to the good performance of the wood volumetric model for trees grown in primary forests, in which atypical values were represented by DVs and estimation was performed using NLS, it is suggested that the model be tested in cases of Amazon's public areas, which are intended as forest concessions by the Brazilian Forest Service, and also in Federal and State public areas, particularly the protected areas selected for sustainable use, such as the National Forests (Flonas) and State Forests (Flotas).

Conflicts of Interests

The authors have not declared any conflict of interests.

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Vol. 12(6), pp. 389-396, 9 February, 2017
DOI: 10.5897/AJAR2016.11515
Article Number: BE76AA562673
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Tomato Leafminer, *Tuta absoluta* (Meyrick 1917), an emerging agricultural pest in Sub-Saharan Africa: Current and prospective management strategies

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Received 3 August, 2016; Accepted 30 November, 2016

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop for income and nutrition of small-holder farmers in sub-Saharan Africa. However, it is attacked by many insect pests that cause high economic losses. This review focuses on one insect pest, namely *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae). Many studies have shown that chemical pesticides have failed to control tomato leafminer in many parts of the world including America, Europe, Asian and Sub-Saharan Africa, where the pest is impacting significantly the tomato value chains as farmers were unaware of the pest and unprepared to control it. The review has also evaluated current approaches used to manage *T. absoluta* in different countries and proposes areas for future investment in research for effective and affordable management to prevent further losses caused by *T. absoluta* in tomato production is Sub-Saharan Africa.

Key words: *Tuta absoluta*, agricultural pest, pesticides resistance, pheromone trap, biocontrols

INTRODUCTION

Tomato leaf miner, *Tuta absoluta* (Meyrick, 1917; Lepidoptera: Gelechiidae) is a devastating pest of tomato and other Solanaceous crops in many areas of the world causing severe damage and yield loss (Cifuentes et al., 2011; Zappala et al., 2012, 2013; El-Arnaouty et al., 2014; Tonnang et al., 2015; Bawin et al., 2015). It is a native of South America and known to cause substantial loses (Urbaneja et al., 2013; Zucchi et al., 2009). *T. absoluta* has been–reported to be common in tomatoes growing in altitudes not exceeding 1000 m above sea level (Tonnang et al., 2015). It spreads mainly by natural dispersal means, such as through winds (Gontijo et al., 2013; Sridhar et al., 2014). Tomato leafminer was recorded first in 1917 and as tomato pest in 1960s in Peru (Seplyarsky et al., 2010; Guedes and Picanço, 2012). Then, it crossed borders to Europe, where for the first time it was reported in 2006 in Spain (Desneux et al., 2011). Later on, the pest extended its invasion to France, Italy, Greece, Malta and Bulgaria (Harizanova et al., 2009; Roditakis et al., 2010; Braham et al., 2012). In Africa, *T. absoluta* was reported first in Algeria and Morocco in 2008 and in 2009, it was reported in Libya

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(Harbi et al., 2012). *T. absoluta* continued to spread in Africa and invaded Egypt in 2010 (Moussa et al., 2013) then reached Sudan and South Sudan in 2011 (Pfeiffer et al., 2013; Brevault et al., 2014), then Ethiopia in 2012 (Goftishu et al., 2014). Other countries in Africa reported to be invaded by tomato leafminer are Kenya (2013) *(*Mohamed et al., 2015*),* Tanzania (2014) (Biondi et al., 2015) and Senegal (2014) (Tonnang et al., 2015). *T. absoluta* cannot easily be controlled by chemical sprays due tothe fact that coontact toxicity annot reach larvae inside the leaves (Ayalew, 2015). The pest has a physiological ability to adapt and survive in harsh environments such as cold temperate and hot tropical regions (Cuthbertson et al., 2013; Ponti et al., 2015). Tonnang et al. (2015) reported that the pest can survive temperature as high as 49°C in summer in Sudan. In another report by Van Damme et al. (2015), *T. absoluta* adults have been reported to survive at temperatures below 5°C. The pest can also tolerant dryness, making it flourish well in hot and dry areas (Miranda et al., 1998). *T. absoluta* larvae feedby mining leaves, stems and fruits. It can attack tomato plants at all developmental stage causing up to 100% loss in tomato fruits, if not controlled (Desneux et al., 2010). It has high reproductive ratewithin a short period of time and capable of producing up to 12 generations per year at favorable temperature (Mollá et al., 2011).

Several chemical pesticides are used to control the pest, but none is suitably adapted for control of the tomato borer due to larvare feeding stratergy inside plant tissues and foliar spray easily washed out by wind and rain (Abbes and Chermiti, 2011; Guedes and Picanço, 2012; Guedes and Siqueira, 2013). Additionally, most chemical pesticides have adverse impacts to both humans, non targeted organisms and environment as well (Abdel-Raheem et al., 2015). It is always agreed that, pest control using resistant tomato varieties is the best and sustainable option (Oliveira et al., 2012). Many accessions have been reported to be good source of germplasm resistant to pests including *T. absoluta* (Rodrigues et al., 2011). The resistance by host tomato plant can be attributed to acylysugar, a substance that was reported to provide resistance against *T. absoluta* (Resende et al., 2006). However, use of resitant variety is a long term approach for that would take time to attain a suitable one for SubSaharan Africa. Hence there is a need to develop a short and long term pest control strategies that will avert losses caused by *T. absoluta* in SubSaharan Africa.

There are efforts to reduce use of insecticides in tomato fields, including cultural control methods such as controlled irrigation, crop rotation argumentative biological control (Van Lenteren and Bueno, 2003) and destruction of infested plant material the environment (Abbes et al., 2012). Cultivation of resistance tomato varieties has been reported in other countries (Guedes and Siqueira, 2013). but not common to Sub-Saharan Africa. Other methods include biological control, such as use of natural enemies including parasitoids predators and entomopathogenic microbes (Guedes and Picanço, 2012). Abbes and Chermiti (2011) reported that use of insect's sex pheromones to control *T. absoluta* in open fields. Similarly, the pheromones are reported to perform well in greenhouses (Cocco et al., 2013). Although these methods are applied, they are not guaranteed to reduce this pest and may be costly and not readily available, especially for small holder tomato farmers in sub-Saharan Africa. There is need to propose a systematic, sustainable and integrated pest management stratergy to control this invasive pest in Subsahan Africa. Therefore, this review comprehensively describes the economic importance of *T. absoluta*, control methods that exist and finally proposes an IPM strategy that can be applied to manage the pest in Sub-Saharan Africa.

Economic importance of ***Tuta absoluta***

Tomato is the major horticultural crop in Tanzania where it is estimated that 17.5 Mt/ha is produced per year (Materu et al., 2016). However, invasion of tomato borer has declined production by 50% (Materu et al., 2016). *T.absoluta* is a new pest in sub-Saharan Africa. It is greatly damaging tomato crop to levels that farmers are giving up production due to costs and losses it causes in tomato production (Muniappan and Heinrichs, 2015). It is well known that small-holder farmers rely on tomato for income in many parts of sub-Saharan Africa (Oerke et al., 2012), due to its high nutritive value and role in small-scale trade (Cetin and Vardar, 2008). Tomato is cultivated throughout the year in varied range of environments from valley, mountains, in arid and semiarid areas as long as environmental conditions favors (Calatrava et al., 2011; Laube and Awo, 2012). During rainy season, farmers work out to control diseases whereas dry season is highly susceptible to pest including tomato borer. The two varying seasons increases infestation pressure to the pest causing economic losses of to up to 100% in some countries in sub-Saharan Africa (Ayalew, 2015). It has been reported that, farmers in Tanzania increase pesticides use by misusing, doubling doses and wrong application for the purpose of protecting their crops from demage (Materu et al., 2016). However, little succes has been archieved, but would increase the problem such as development resistance among pest populations (Muniappan and Heinrichs, 2015). Moreover, in Tanzania where the pest was noticed in farmers' fields recently, it seemed doubtlessly that tomato growers were not prepared for the pest thus they never had any appropriate control against it (Materu et al., 2016). Considering time of entry to Africa of *T .absoluta* being less than ten years, it is again probably that tomato growers in the sub-Saharan Africa are unable to grow the crop due to fear of loses. There is need therefore to impose immediate attention and practical solutions in favor of tomato production within its value chain in sub-Saharan Africa.

Use of chemical pesticide

Chemical pesticides are common in pest control. Common chemicals are pyrethroids (Guedes and Picanço, 2012), organophosphates, spinosad, emamectin benzoate and abamectin (Campos et al.,2014), chloride channel activators, benzoylureas (Haddi 2012) and diamide (Roditakis et al., 2015). Application of these chemicals against *T. absoluta* has been reported with little success, mainly because of pest resistance and to some point could be utilized by plant as well (Siqueira et al., 2000). Tomato borer resistance has been reported widely used chemicals such as spinosad Cartap and Abamectin, creating further threat to farmers (Siqueira et al., 2000; Reyes et al., 2011; Haddi et al., 2012; Campos et al., 2015; Guedes and Siqueira, 2013).

Pest resistance has been reported to cause increased use of chemical pesticides applications against *T. absoluta* in many parts of the world (Consoli et al., 1998; Siqueira et al., 2000; Lietti et al., 2005). In Spain, about 15 applications and in Brazil up to 30 applications have been reported (Guedes and Picanço, 2012; Silva et al., 2011). The pest resistance against spinosad chemical reached up to 180,000 resistances within seven further generations in Brazil (Campos et al., 2014). In countries such as Tunisia, more than 18 chemicals were introduced during 2009-2011 for the control of tomato borer but none of them seemed efficient in solving the pest problem (Abbes et al., 2012). Failure of these chemicals in controlling *T. absoluta* opened a new window for development of other methods including biopesticides, pheromone traps, and parasitoids (Regnault-Roger, 2012; Cherifet al., 2013; Zappala et al., 2013). Though chemical pesticides are economically and environmentally unaffordable, farmers still seek them for their agricultural uses because is the only easily accessible option. Thus introduction of IPM strategies in Sub-Saharan Africa will promote sustainable horticultural farming.

Bioactive compounds from plant against *T. absoluta*

Botanicals have been reported to play a great role in controlling pests (Isman, 2006; Sharma and Bhandari, 2014; Zekeya et al., 2014). Many laboratory studies revealed the efficacy of plant compounds against insect pests including *T. absoluta* (Castillo et al., 2010; Senthil-Nathan, 2013). For instance, extracts from neem plants were reported to be efficient against *T. absoluta* under laboratory condition (Durmusoglu et al., 2011). Valchev and Markova (2014) reported that Neem plant contains a number of active metabolites such as alkaloids which can control insect pests. These compounds have been reported to have control efficacy against tomato borer (Yankova et al., 2014). Other plants which are promising in management of *T. absoluta* include Piper (Brito et al., 2015) whereas compounds from *Acmella oleracea* were revealed to be active against *Tuta absoluta* (Moreno et al., 2012). Though biochemical pesticides have been cited as promising for pest control, their application in the sub-Saharan Africa is limited and none of the compounds have been registered commercially to help farmers. Hence more researches and validation of these natural resources is highly demanded to protect crop damage and loss including those by *T. absoluta* (Cork et al., 2009). Plant based pesticides have been documented to be better than synthetic chemical pesticides as they are biodegradable, naturally available and environmentally friend to none targeted organisms.

Management *T. absoluta* by entomopathogenic microbes

Use of microorganism as biopesticides for management of pests has increasingly gained popularity in recent years (Mollá et al., 2011). Bacteria and fungi have been used for a long time in management of tomato borer in America and Europe (Trottin-Caudal et al., 2012; Parra, 2009). The microbes have been reported to attack pests by their pathogenic effects (İnanli et al., 2012; Pires et al., 2009). Currently there are many commercially available bacterial and fungal formulations for controlling pests including *T. absoluta* in America and Europe (Sabbour, 2014). The formulations are either by foliar spray or by drenching the roots (Amizadeh et al., 2015). One of the best and successful formulations was that of *Metarhizium anisopliae* (fungus) and *Bacillus subtilis* (bacteria) which have been reported to reduce the population of *T. absoluta* on tomato at all developmental stages in America and Europe (İnanli et al., 2012). Other formulations reported to be tested against include that of *Metarhizium anisopliae* and *Beauveria bassiana* (İnanli et al., 2012; Kaoud, 2014). Most of these reports however were all based on screen house studies (González-Cabrera et al., 2011; Sabbour and Nayera, 2014) and only a few have been tested on field conditions and thus they may not be readily available for small-holder farmers. Nematodes have been reported as biocontrols of *T. absoluta* in some countries and depicted high insect mortality (Batalla-Carrera et al., 2010). The nematodes were reported to be effective against larvae, pupae and adult *T. absoluta* (Garcia-del-Pino et al., 2013). Unfortunately, none of these strategies have been reported to be effective in Sub-Saharan Africa, thus this review highlight the potential of native entomopathogens and endophytes in management of *T. absoluta* with respect to environmental conservation in Sub-Saharan Africa.

Pheromone traps for scheming *T. absoluta*

Sex pheromone traps have been cited as among environmentally accepted pest management strategy (Kılıç, 2010; Witzgall et al., 2010; Gacemi and Guenaoui, 2012). They have been reported to play a significant role in monitoring *T. absoluta* abundance (Harizanova et al., 2009; Reddy and Guerrero, 2010; Van der Straten et al., 2011). The traps are used prior to other control strategies so as to determine the presence and abundance of insects so as to decide on appropriate control measure to apply (Cocco et al., 2013; Witzgall and Cork, 2010). Although these traps are designed to control only adult male moth, they have been reported to be effective in managing tomato borer (Cocco et al., 2013; Reddy and Guerrero, 2010; Braham, 2014b; Cocco et al., 2012; Vacas et al., 2011). For effective application in the field, the sex pheromone traps are to be properly hanged at right positions depending on the height of tomato varieties and wind direction (Kılıç, 2010; Soliman et al., 2013). Another factor reported to be important is the color of the trap which, affects and influences the movement of the pest towards it, thus enhancing trapping efficiency (Braham, 2014a; Megido et al., 2013; Mwangi, 2015). Shining colors especially red has been reported to be the most attractive to *T. absoluta* (Taha et al., 2012). Combination of these factors have been reported to improve traps efficiency in the field (Kılıç, 2010; Lobos et al., 2013; Speranza and Sannino, 2012), especially when they are combined with insect killing ingredients. Use of killing agent in combination with sex pheromones is has minor effect however when the pheromone traps used are only for disrupting mating system (Mafra-Neto et al., 2013; Gacemi and Guenaoui, 2012).

Although pheromone traps in combination with active insect killing agent is reported to be used against *T.absoluta*, no study has reported the efficacy of pheromone traps when synergized by active plant compounds. Due to the current *T. absoluta* situation in sub-Saharan Africa, in particular Tanzania, it is evident that a pheromone trap baited with active compound could be developed and deployed in fields to improve monitoring and control of *T. absoluta.*

Parasitoids for management of *T. absoluta*

Natural enemies play a geat ecological role in controlling pests in natural settings (Chailleux et al., 2013; Ferracini et al., 2012; Sánchez et al., 2009; Ghoneim, 2014). A study by Megido et al. (2014) showed that the larvae of *T. absoluta* search for and acquires some biological characteristics and thermal requirements from host plants that can attract a parasitoid as well. *T. absoluta* host plants have ability to emmit volatile compounds that attract either pest predator or parasitoid toward it that also favor the parasitoid indirectly (Proffit et al., 2011; De Backer et al., 2015). One of suscessiful used parasitoids include *Trichogramma pretiosum* which, can parasitise a number of species including *T. absoluta* (Abbes et al., 2014; Zappala, 2012).

Other reports showing application of parasitoid principles in controlling *T.absoluta* are for instance from oder Hymenoptera (Balzan and Wäckers, 2013; Ferracini et al., 2012). The most important *T. absoluta* egg parasitoids are originated in the family Trichogrammatidae, Encyrtidae and Eupelmidae. Several Trichogrammatid species parasitizes eggs of different insects orders, especially Hymenoptera, Neuroptera, Diptera and *Trichogramma* (Ghoneim2014a). There are about 210 species of *Trichogramma* that have been signaled as natural enemies of a variety of agricultural and forest pests in many regions of the world and some species are used commercially in biological control programs (Ghoneim, 2014a; Zouba et al., 2013). This is due to their good records in controlling pests and ability to be produced quickly and affordably relative to other parasitoids (Zouba et al., 2013). Of practical use, *Trichogramma achaeae* Nagaraja and Nagarkatti, has a worldwide distribution and was reported to parasitize on *T. absoluta* eggs (Chailleux et al., 2012; Steiner and Goodwin, 2015). This parasitoid especially female has high ability in parasitising both eggs and larvae of the pests (Jervis et al., 2008). *T. achaeae* is known to be genetically compatibile with many pest insects as successful partasitoids (Michel and Whitfield, 2004). Further investigation on use of *Trichogramma* parasitoids in insect pest management is drawing an attention of some authors for other insect pests to date (Cabello et al., 2015; Luna et al., 2015). One of other successful parasitoid in the literature include; *Pseudapanteles dignus* (Hymenoptera) which, has been reported have ability to parasitize *T. absoluta* larvae (Sánchez et al., 2009). Larvae of other species reported to parasitize *T. absoluta* include *Neochrysocharis Formosa*, *Pnigalio* (Ratzeburgiola) *cristatus* (Ratzeburg), and *Braconosculator* (Ferracini et al., 2012). However little or none of native microbes have been used for management of the pest in the region. Hence screening and application natural enemies such as microbial parasitoids could be a potential management strategy in Sub-Saharan Africa.

Although parasitoids are very promising in management of pest, there are no any parasitoids of *T. absoluta* that have been reported from Sub-Saharan African countries including Tanzania. Hence, there is an urgent need to identify and assess parasitism rate in sub-Saharan Africa and include in IPM programs.

Cultivation of resistant tomato varieties

Plant and herbivore pests have coexisted since ancient time and each part played a role in development of resistance inorder to survive (VanDoorn and de Vos, 2013). Plant resistance to pests is influenced by genetic and phenotypic traits such as morphological and chemicals released (Antonio et al., 2011). Tomato is known to have narrow genetic base due severe breeding and domestication of wild varieties (Do et al., 2009; Melo et al., 2008; Gharekhani and Salek-Ebrahimi, 2014). However, its variation has a role to play in resistance against pests (Hartman and St Clair, 1998). The source of resistance against *T. absoluta* has been reported (Resende et al*.,* 2006; da Silva et al., 2008; Rodrigues et al*.,* 2011). The role of tomato chemical including acyl sugars in resistance againt *T. absoluta* have been documented (Oliveira et al., 2012). Maluf et al. (2010) revealed the importance of tomato resistance against T. absoluta. However, these sources have not been exploited yet in sub-saharan Africa, also calling for imediate managerial strategy *T. absoluta*.

Several studies recommend use of Integrated Pest Management (IPM) strategy for effective management of *T. absoluta* (Miranda et al., 2005; Arnó et al., 2009). A combination of physical and biological agents such as parasitoids, predators (Chailleux et al., 2013; Mollá et al., 2014) and traps (Michereff et al., 2000) can create an effective IPM (Mollá et al., 2011). The use of pheromone traps together with entomopathogenic fungi and bacteria is common in IPM programs (Abbes et al., 2012). Parasitoids and predators have been used and are commecially available as part of IPM programs in America and Europe (Abes et al., 2014; Al-Jboory et al., 2012; Cely et al., 2010; Zappala et al., 2013).On other hand, chemical pesticides are common in management of pest, but are not suitable when integrated with other management strategies especially biological ones (Arnó et al., 2009). Chemical pesticides have been reported to cause severe side effects to natural enermies (Zappalà et al., 2012), thus ad. Arnó and Gabarra (2011) reported that conventional pesticides have great effects on natural enemies of parasitoids whereas the use of organic pesticides is also uncertainty (Biondi, 2012).Thus coming up with an effective IPM strategy is challenging but not impossible. Hence development of sustainable and affordable IPM is crucial to rescue tomato production as well as raising income of farmers in Sub-Saharan Africa.

Potential management strategy in Sub Saharan Africa

Tomato is one of the major horticultural crops for income of small holder farmers in Africa. Invasion of tomato borer has led to decline of tomato market. Hence this paper reviews current managerial options against tomato leafminer in tomato growing in sub-Saharan Africa so as to highlight the current situation and future prospects. Pheromone traps are important and best for detection and monitoring of insect population but could not be used as management option. Use of chemical pesticides is common in Sub-Saharan Africa; however, alternation of classes of compound would reduce the problem of insect resistance to pesticides. On the other hand, entomopathogenic fungi and bacteria such as *Metarhizium anisopliae* and *Bacillus subtilis* are commercially available in the region, validated to be used at early stage of plant development for control of the pest. Conversely, none of parasitoid and resistant tomato variety has been identified for management of *T. absoluta* in Sub-Saharan Africa. This calls for researches to search for best option suitable for the region. However, no single control method or approach has been reported for sub-Saharan Africa, thus this review highlighted potentials strategies that would be adopted immediately to sustainably control *T. absoluta* in sub-Saharan Africa, where cultivation is solely rely on open fields making it more susceptible to pest. The prospective IPM strategy based on native microbial biocontrols, pheromone trap, compounds from plants and some moderate synthetic pesticides would be relevant and environmentally affordable solution for small holder farmers in Sub-Saharan Africa.

Conflict of Interests

The authors have not declared any conflict of interests.

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academicJournals

Vol. 12(6), pp. 397-405, 9 February, 2017
DOI: 10.5897/AJAR2016.11794
Article Number: 8D0217762677
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Performance variation among improved common bean (*Phaseolus vulgaris* L.) genotypes under sole and intercropping with maize (*Zea mays* L.)

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Received 5 October, 2016; Accepted 8 November, 2016

Periodic assessment of released common bean cultivars is essential to screen genotypes that offer superior intercropping advantage to farmers when grown in association with maize. Thus, comparative performance of improved genotypes representing commonly used growth habit and market classes were investigated under sole and intercropping system at Halaba special district, Southern Ethiopia. Treatments consisted of a factorial combination of seven common bean genotypes and two cropping systems, which were arranged in a split plot design replicated three times. Cropping system and genotype were assigned as main and sub plot factors, respectively. Cropping system by genotype interaction was significant for bean grain yield and two of the yield components causing moderate changes in ranking. Relative yield reduction due to association with maize varied from 26% for genotype Sari-1 (Type II) to 67% for Awash Melka (Type III), while maize suffered a smaller reduction, 7%. The total Land Equivalent Ratio (LER) values under intercropping with maize ranged from 1.34 for the improved Hawassa Dume (Type II) to 1.01 for the local cultivar, Red Wolayita (Type III). Genotypes with greater LER were not necessarily all top yielders under sole cropping, because of the genotype by cropping system interaction. Bush and semi bush (Type I and II) types produced the highest intercropping advantage, as a group. The two export bean types, which have a semi climbing (Type III) growth pattern, had the lowest LER values among the improved genotypes. Genotypes such as Hawassa Dume and Sari-1 are preferred to the conventionally used cultivars for maximizing intercropping advantage. Developing bush type export genotypes may help broaden their expansion outside their traditional zones since better performance under intercropping could attract more farmers to adopt them.

Key words: Bush types, genotype, interaction, intercropping efficiency, semi climbing types.

INTRODUCTION

Intercropping, the agricultural practice of cultivating two or more crops in the same space at the same time is an old and commonly used cropping practice which aims to match efficiently crop demands to the available growth

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resources and labor (Lithourgidis et al., 2011). Intercropping has been found to be advantageous in maximizing land use efficiency through efficient use of resources like moisture (Coll et al., 2012), nutrients and light (Awal et al., 2006) and also reduced pest and disease problems (Theunissen and Schelling, 1996). It is also a viable strategy to stabilize yield through risk minimization of crop failure from unfavorable environmental conditions. Intercropping has been shown to produce higher and more stable yields in a wide range of crop combinations, while the system is characterized by minimal use of inputs such as fertilizers and pesticides, emphasizing the production of healthy, safe, and high quality food in the context of environmentally sound production (Lithourgidis et al., 2011). Intercropping may contribute to reduction of greenhouse gas emissions thereby allowing a more sustainable production system by mitigating climate change. Reduced greenhouse gas emissions have been reported from cereal-legume intercrops compared to their sole counterparts (Dyer et al., 2012; Huang et al., 2013). Thus, intercropping can be considered as one of the strategies of climate smart agriculture to achieve nutrient and food security under changing climate particularly to those small farmers constrained by land scarcity.

Intercropping for food grain production is widely practiced by small farmers who significantly contribute to food security but constrained by land and inputs in Africa (Dakora, 1996; Tsubo et al., 2005). Intercropping is a common practice in many areas of Africa as part of traditional farming systems commonly implemented in the area due to declining land sizes and food security needs (Dakora, 1996). In Ethiopia, it is a familiar practice of crop production in densely populated areas such as southern Ethiopia. Arable land scarcity is an acute problem in southern Ethiopia due to high population pressure where 49% of farmers have an average land holding of 0.1 to 0.5 ha with a further 21% having 0.51 to 1 ha (CSA, 2015). Two of the popular component crops for intercropping in the region are maize and common bean as principal and subsidiary crops, respectively.

The advantages of intercropping can easily be constrained depending on various factors such as suitability of cultivars for intercropping, soil moisture levels, component interactions and competition for resources (Dakora, 1996). The choice of compatible cultivars would be very important in a crop like common bean where there is great variation in the growth habit and morphology of cultivars (Worku, 2008). According to Davis et al. (1986), bush bean is less competitive, easy to harvest and suitable for both sole and intercropping while climbers are more aggressive and reduce maize yield.

Many studies have shown yield reduction when beans are grown with maize under intercropping (Gebeyehu et al., 2006; Tana et al., 2007; Worku, 2008). On the other hand, the magnitude of intercropping efficiency depends largely on the performance of the associated beans. Thus, it is necessary to screen and select suitable bean genotypes in order to maximize advantage from intercropping. In southern Ethiopia, a semi climbing red seeded local bean cultivar has been the favorite component among farmers for intercropping with maize. More than 30 improved bean genotypes of diverse growth habit have been released in the country. Adoption of some of the varieties has been gaining momentum under sole cropping while the local cultivar is still widely used for intercropping. It is, thus, important to investigate how the improved varieties perform under sole and intercropping environments in order to screen for compatible genotypes. As is common in most breeding programs, the cultivars have been tested and selected for their performance under sole cropping environment. Plant genotypes are rarely developed for mixed cropping systems despite the potential of these systems to provide multiple ecosystem services (Isaacs et al., 2016). Significant cropping system by genotype interactions have been reported from maize-bean intercropping (Hauggaard-Nielsen and Jensen, 2001; Atuahene-Amankwa et al., 2004; Gebeyehu et al., 2006) whereas Worku (2008) has not observed a significant interaction. Differences in growth habit and morphology of the component bean genotypes involved may have contributed to reported differences in the response of genotypes to cropping systems (Worku, 2008). Thus, this investigation was conducted to assess the response of released common bean genotypes to component performance and intercropping efficiency and identify suitable genotypes, under intercropping with maize.

MATERIALS AND METHODS

Description of the study site

The experiment was conducted on a farmer's field at Halaba special district, during the 2013 cropping season under rainfed condition. The site is located at 7° 3" N latitude and 38°10"E longitude with an elevation of 1788 m above sea level. The mean annual rainfall of the area ranges from 857 to 1085 mm while annual mean temperature varies from 17 to 20°C.The experimental crops received a well distributed total rainfall of 780 mm, which was greater by 38% against the long term average (Table 1). As a result, the season was conducive for the growth of both crops in terms of moisture and temperature. Analysis of soil sample before planting indicated that the soil has clay loam texture with a pH of 6.4, which are not limiting for growth of the component crops.

Treatments and experimental design

The treatments were made from a combination of two factors: cropping systems and common bean genotypes. Cropping systems consisted of intercropping and sole cropping while the genotypes included six improved varieties and one popular local variety (Red Wolayita) and consisted of determinate and indeterminate bush and indeterminate semi climber types (Table 2). A late maturing maize hybrid variety, Shone Pioneer, and the seven common bean genotypes were factorially combined under the two cropping

Table 1. Weather condition and mean rainfall of the experimental site during the crop growth period[(a).]

Month	Temperature (°C)		Rainfall (mm)	
	Minimum	Maximum	2013	2003-2012
April	15.1	29.9	132.3	129.5
May	14.6	28.0	123.1	98.2
June	15.4	26.1	167.4	92.0
July	16.6	24.6	131.4	125.2
August	17.6	24.9	178.1	118.5
September	17.4	28.2	138.8	112.8
October	16.7	29.0	118.9	49.3

[(a)]The crop growth period was from 27 April to 07 October 2013.

systems. The experiment was laid out in a split plot design with three replications. Cropping systems and common bean genotypes were assigned as main plot and sub-plot factors, respectively. Also, sole maize crop was included for standardization under each replication.

Experimental procedures and crop management

Both maize and common bean crops were planted together on 27th of April 2013. Common bean seeds were obtained from Hawassa Agricultural Research Centre except the local variety which was obtained from farmers in the study site. The maize variety was obtained from Halaba Agriculture and Rural Development Office. Maize seeds were sown at 0.8 m inter-row and 0.3 m intra-row spacing under intercropping and sole cropping systems. Common bean varieties were planted at 0.4 and 0.1 m inter-row and intra-row spacing, respectively under both cropping systems. The spatial arrangement was 1:2, where two rows of common bean were planted between successive rows of maize. The two components were associated with their full sole density, which were, 41,666 plants ha^{-1} for maize and 250,000 plants ha^{-1} for common bean. The distances that separated sub plots, main plots and blocks were 0.5, 1 and 1.5 m, respectively. The plot sizes for intercrop and sole crops were 4.8 m wide and 3 m long (14.4 m^2).

Intercropped and maize sole crop plots received nitrogen and phosphorus fertilizers recommended for sole maize production. The common bean component did not receive any additional fertilizer. Intercropped and sole maize plot received phosphorus fertilizer at a rate of 20 kg P ha^{-1} just before planting. Also, nitrogen was applied at the rate of 64 kg ha^{-1} as split application: 18 kg ha^{-1}at planting and the remaining 46 kg ha^{-1} at knee height. Sole common bean plots received 20 kg ha^{-1} P and 18 kg ha^{-1} N as a single dose during sowing. Urea (46-0-0) and Di-ammonium phosphate (18-46-0) were used as sources of N and P nutrients. Weeds were removed as often as required. Stalk borer infestation of maize was controlled by spraying Lambda Cyhalotrin (karate) 5% EC at the rate of 16 g a.i. in 300 L water ha^{-1}, twice at fifteen days interval before tasseling.

Data collection and analyses

Yield and yield components

Common bean: Average number of mature pods was counted at harvest from six randomly taken plants. Number of seeds per pod was determined from 15 randomly selected pods. Hundred randomly taken seeds were used to determine seed weight. Grain yield was determined from eight central rows (3.2 m × 3 m = 9.6 m^2) and was adjusted to 10.5% seed moisture content.

Maize: Number of ears per plant, number of seed rows per ear and number of seeds per row were recorded from six randomly taken plants from the central harvested rows. Hundred randomly taken seeds were used to determine grain weight. Four central rows (3.2 m × 3 m = 9.6 m^2) were used to determine grain yield, which was adjusted to 12.5% seed moisture content.

Intercropping efficiency

The land equivalent ratio (LER) method was used to assess the efficiency of the intercropping system (Mead and Willey, 1980).

Total LER = Yim/Ysm + Yib/Ysb

where *Yim* and *Yib* are intercrop yields of maize and common bean, respectively and *Ysm* and *Ysb* are yields of maize and common bean grown as sole crop, respectively.

Land equivalent ratio indicates relative land area under sole crop required to produce the same yield as obtained under intercropping system at the same level of management. To minimize unwanted variation among the ratios and identify the most productive association, yield of the best sole crop bean genotype was used as standardization factor instead of individual sole crop yields of genotypes (Mead and Willey, 1980; Oyejola and Mead, 1982; Gebeyehu et al., 2006).

The main and interaction effects of genotypes and cropping systems on yield, yield components and intercropping efficiency of component crops were determined by analysis of variance using SAS Software (SAS, 2008). Least significant difference (LSD) test was used to separate the means when the analysis of variance indicated presence of significant differences (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Common bean

Grain yield

Both main effects and interaction between genotype and cropping system significantly influenced grain yield

Table 2. Agro-morphological characteristics of common bean genotypes used in the experiment.

Genotypes	Year released	Growth habit[(b)]	Days to maturity	Purpose of production	Seed size	Seed color
Sari-1	2011	Indeterminate bush (Type II)	85-95	Domestic consumption	Small	Dark red
Hawassa Dume	2008	Indeterminate semi bush (Type II)	85-90	Domestic consumption	Small	Dark red
Ibbado	2003	Determinate bush (Type I)	85-90	Domestic consumption	Large	Speckled red
Omo-95	2003	Indeterminate semi climber (Type III)	90-120	Domestic consumption	Small	Dark red
Awash Melka	1998	Indeterminate semi climber (Type III)	90-100	Export	Small	White
Awash-1	1990	Indeterminate semi climber (Type III)	90-100	Export	Small	White
Red Wolayita (Local)	1974[(a)]	Indeterminate semi climber (Type III)	90-100	Domestic consumption	Small	Red

[(a)]Recommended; [(b)]Based on Singh (1982).

(Table 3). As a result, there were moderate changes in performance rankings of genotypes under sole and intercropping systems (Table 4). The genotype Hawassa Dume was the top yielder followed by Ibbado and Awash-Melka, with the latter two having similar yields, under sole cropping. Performance of Hawassa Dume was equivalent to Sari-1 under intercropping and this was followed by Ibbado and Omo-95. The least performers rank included Sari-1, Awash-1 and Red Wolayita for sole cropping while Awash-Melka, Awash-1 and Red Wolayita were the lowest for the intercropping system. The genotype that showed exceptional characteristic was Sari-1, which had a top yield under intercropping in spite of its place in the lower group of genotypes under sole cropping. Relative yield losses under intercropping compared to sole cropping varied from 26% for Sari-1 to 67% for Awash Melka. The observed yield loss could be attributed to the severe impact of shading by the taller maize plant. The favorable environment in terms of one of the vital resources, moisture, may have contributed to the vigorous maize growth leading to severe shading. For instance, Tsubo and Walker (2003) reported that the taller maize canopy at a density of 6.67 plant m^{-2} reduced incident radiation on the top of intercropped bean canopies by up to 90% decreasing total dry matter of beans by 67% at the end of the growing season.

Distribution of growth habit groups among the performance rankings showed variation between the two cropping systems. There was a more equitable distribution of genotypes from the different growth habit groups under sole cropping while some patterns were observed under intercropping. Accordingly, the bush and semi bush types dominated the top and medium performance ranks while the poor performers cluster was made from semi climbing types under intercropping. Similarly, Worku (2008) has observed that bush types were better than semi climbing types and suggested that their improved performance could be attributed to better light distribution throughout their canopy as a result of their upright growth. Moreover, semi climbing types tend to twine on maize when intercropped and this makes them grow beneath the maize leaves where shading is at its severest. Also, Davis et al. (1986) observed that bush beans are less competitive, easy to harvest and suitable for both sole and intercropping while climbers are more aggressive and reduce maize yield.

Genotype by cropping system interactions have been reported in maize-groundnut (Tefera and Tana, 2002), maize-common bean (Davis and Gracia, 1983; Atuahene-Amankwa et al., 2004; Gebeyehu et al., 2006) and barley-pea (Hauggaard-Nielsen and Jensen, 2001) intercropping systems. Padi (2007) and Worku (2008) in sorghum-cowpea and maize-bean intercropping have not observed significant interaction respectively. Differences in growth habit and morphology of the component cultivars involved may have contributed to reported differences in the response of genotypes to cropping systems. Genotype by cropping systems interactions may basically indicate the necessity of screening bean cultivars specifically for the intercropping environment though it is necessary to examine how large and important the interaction is.

Yield components

Number of pods per plant, number of seeds per pod and seed weight varied significantly among genotypes but only number of pods per plant and seed weight have been significantly influenced by cropping systems and its interaction with

Table 3. Analysis of variance on yield and yield components of common bean genotypes under sole and intercropping with maize at Halaba.

Source of variation	DF	Grain yield (t ha^{-1})	Pod no. plant^{-1}	Seed No. pod^{-1}	Hundred seed weight (g)	Total biomass (t ha^{-1})
Replication	2	0.0532^{ns}	0.880^{ns}	0.285^{ns}	2.590^{ns}	0.30^{ns}
Cropping syst. (CS)	1	18.586***	814.8***	1.928^{ns}	104.02*	138.2**
Error a	2	0.0332	0.1666	0.2857	1.63	0.377
Genotype (GEN)	6	1.272***	31.706***	2.261***	1085.78***	3.81***
CS×GEN	6	0.299***	41.88***	0.039ns	4.78*	6.36***
Error b	24	0.0295	2.496	0.2579	1.72	0.48

*, **, ***Indicate significance at 5, 1 and 0.1% probability levels, respectively; ns, non-significant.

Table 4. Grain yield (t ha^{-1}) of common bean genotypes under sole cropping and intercropping with maize.

Cropping system	Genotypes						
	Hawassa Dume	Sari-1	Ibbado	Omo-95	Awash Melka	Awash-1	Red Wolayita
Sole	3.60	2.09	2.82	2.48	2.78	1.97	1.95
Intercrop	1.83	1.55	1.29	1.25	0.92	0.85	0.68
% Reduction	49	26	54	50	67	57	65
Lsd$_{5\%}$ = 0.34	-	-	-	-	-	-	-

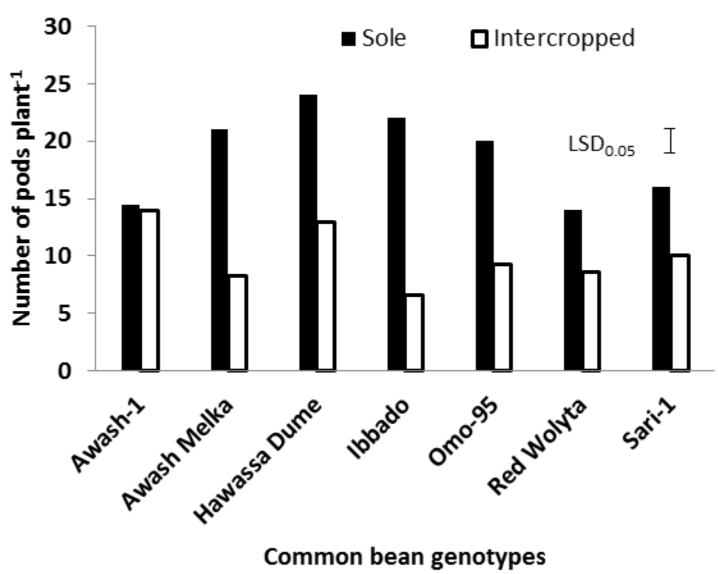

Figure 1. Interaction effect of common bean genotypes and cropping system on number of pods plant^{-1}.

genotype (Table 3). All genotypes except Awash-1, suffered a significant reduction in number of pods per plant when grown under intercropping ranging from 38% for Sari-1 to 70% for Ibbado (Figure 1). The relationship between grain yield and number of pods per plant was significant under sole cropping (r = 0.86***), while it was not under intercropping. Thus, rankings for pod number per plant followed mostly that of grain yield under sole cropping.

The determinate bush genotype, Ibbado, had the smallest seed number and the heaviest seed weight (Data not shown). The other genotypes produced

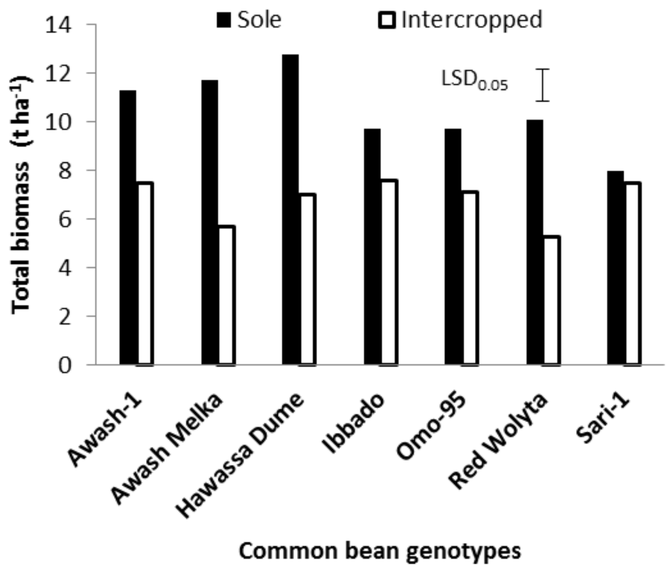

Figure 2. Effect of genotype by cropping system interaction on total biomass of common bean.

similarly greater number of seeds per pod but smaller seed size. Intercropping slightly depressed seed weight compared to sole cropping, though the extent varied among genotypes (Data not shown). The variation among common bean genotypes for number of seeds per pod and seed weight could be attributed to genetic differences. Both seed weight and seed number per pod were less influenced by intercropping when compared with number of pods per plant.

Total biomass

Total biomass was significantly influenced by genotype, cropping systems and their interaction (Table 3). Greater biomass was obtained from genotypes Awash Melka and Hawassa Dume under intercropping while the lowest came from Red Wolayita (Figure 2). The other genotypes gave an intermediate amount of biomass under a similar cropping system. All genotypes suffered loss of biomass when intercropped except Sari-1. However, the magnitude of the effect varied remarkably differing from 51% loss for Awash Melka to 22% for Ibbado. Overall, those cultivars with better productivity under sole cropping suffered a much severe loss when intercropped.

Maize

Grain yield and yield components

Maize grain yield was reduced significantly due to its association with common bean (Table 5). The mean yield loss amounted to 7%. The yield loss was related with a concomitant drop in yield components such as number of seeds per row and seed weight (Table 6). The influence of the associated bean on maize yield did not vary significantly among the genotypes.

All the genotypes showed a moderate impact on maize performance with absence of either over-aggressive or non-competitive types. Reports on the impact of intercropping on maize performance are mixed. The result agrees with the findings of Worku (2014) who recorded a 16% yield loss from simultaneous intercropping with bean in a sub-humid environment. David and Gracia (1983) reported a 15% loss in a wetter area while the decline was as much as 30% in a drier area for a similar simultaneous intercropping. Muraya et al. (2006) and Worku (2008) did not observe significant yield reduction from a maize-common bean simultaneous intercropping. The bean component may not have exerted much competition on the maize component either because of the competitiveness of the maize hybrids and/or the less aggressive nature of the bean genotypes (Muraya et al., 2006). In other studies, maize yield did not suffer from intercropping when the bean was planted a month after maize emergence (Gebeyehu et al., 2006) and from relay planting (Davis and Gracia, 1983; Worku, 2014). The long growth duration of maize and its dominant nature provided by its architecture may have lessened a strong competition from common bean. Absence of severe maize yield loss under intercropping might be attributed to the favorable growth environment especially in terms of a well distributed and adequate rainfall. The magnitude of maize yield loss may vary depending on the competitive ability of the associated

Table 5. Mean square values for yield and yield components of maize grown as sole and intercropped with common bean genotypes at Halaba, in 2013.

Source of variation	DF	No. of ears plant^{-1}	No. of rows ear^{-1}	No. of seeds row^{-1}	100 seed weight (g)	Grain yield (t ha^{-1})
Replication	2	0.001^{ns}	0.320^{ns}	2.725^{ns}	0.438^{ns}	0.218^{ns}
Genotype	7	0.002^{ns}	1.246^{ns}	9.236*	2.752*	0.593**
Error	14	0.003	0.683	2.547	0.975	0.131

*, **Significant at 5 and 1% probability levels, respectively; ns, non-significant.

Table 6. Grain yield and yield components of maize under sole and intercropping with maize at Halaba.

Associated bean genotype	Grain yield (t ha^{-1})	No. of ears plant^{-1}	No. of rows ear^{-1}	No. of seeds row^{-1}	100 seed weight (g)
None (sole maize)	8.02^{a}	1.0^{a}	17.4^{a}	36.1^{a}	38.3^{a}
Hawassa Dume	6.70^{b}	1.1^{a}	15.7^{a}	31.1^{b}	35.2^{b}
Ibbado	7.09^{b}	1.2^{a}	16.4^{a}	31.9^{b}	36.5^{b}
Sari-1	7.11^{b}	1.0^{a}	16.7^{a}	31.9^{b}	36.5^{b}
Omo-95	7.01^{b}	1.0^{a}	16.4^{a}	31.6^{b}	36.5^{b}
Awash-1	6.82^{b}	1.0^{a}	15.4^{a}	30.7^{b}	35.8^{b}
Awash Melka	6.93^{b}	1.0^{a}	16.1^{a}	31.4^{b}	36.2^{b}
Red Wolayita	6.55^{b}	1.1^{a}	15.8^{a}	30.7^{b}	35.4^{b}
$LSD_{5\%}$	0.63	0.14	1.44	2.79	1.73
CV	5.1	5.0	5.1	4.9	2.7

Means within a column followed by different letters are significantly different at $p<0.05$.

bean and maize varieties, the bean introduction time and the availability of growth resources. Fininsa (1997) indicated that earlier planting of the associated bean components depressed maize yield while it favoured that of the bean yield. It seems safe to say that it is possible to limit maize yield loss from intercropping by choosing less aggressive bean genotypes and through agronomic management such as adjusting the bean planting date and avoiding stress for main growth resources.

Intercropping efficiency

Partial and total land equivalent ratio

Partial LER of maize did not vary when it was grown with the different common bean genotypes (Table 7). A mean partial LER of 0.86 was obtained for maize (Table 8). The partial LER gives an indication of the relative competitive abilities of the components of an intercropping system. The species with higher partial LER is considered to be more competitive for growth limiting factors than the species with lower partial LER (Willey, 1979). Thus, the high partial LER value recorded for maize in all treatments indicated the presence of greater competitive capacity of maize against common bean.

The various common bean genotypes had significantly different partial LER values (Table 7). The highest partial LER (0.51) was recorded from genotype Hawassa Dume followed by Sari-1 (0.43) while lower values were obtained from Awash-1 (0.23) and Red Wolayita (0.19) (Table 8). Bush and semi bush types had greater partial LER values compared to semi climbing ones. This may be related to their capacity to intercept more light because of their erect growth. The semi climbing types could use the maize stalk for support but this puts most of their leaves directly underneath the maize canopy where available light is at its lowest thus leading to poor performance. Comparison of the genotypes in terms of their utility had showed that none of the two genotypes used for export had a partial LER in the top group. This might be related to their growth habit, which is semi climbing type. Performance under sole cropping did not reflect their competitive ability under intercropping for more than half of the varieties tested because of genotype by cropping system interaction for grain yield.

Total LER had showed significant difference among common bean genotypes (Table 7). The top intercropping advantages were obtained from associations with genotypes Hawassa Dume and Sari-1 (Table 8). The yield advantage of the intercrop over sole crop for genotype Hawassa Dume was 34%, Sari-1 (32%),

Table 7. Mean square values of partial and total LER from a maize-common bean intercropping at Halaba, in 2013.

Source of variation	DF	Partial LER		Total LER
		Maize	Common bean	
Replication	2	0.0108*	0.0005[ns]	0.0078[ns]
Genotype	6	0.0020ns	0.0389***	0.0469***
Error	12	0.0021	0.0009	0.0029

*, **, ***Indicate significance at 5, 1 and 0.1% probability levels, respectively; ns, non-significant.

Table 8. Partial and total land equivalent ratio from a maize-common bean intercropping at Halaba, in 2013.

Genotype	Partial LER		Total LER
	Maize	Common bean	
Hawassa Dume	0.83[a]	0.51[a]	1.34[a]
Ibbado	0.88[a]	0.36[c]	1.24[bc]
Sari-1	0.89[a]	0.43[b]	1.32[ab]
Omo-95	0.87[a]	0.34[c]	1.22[c]
Awash-1	0.86[a]	0.23[de]	1.08[de]
Awash Melka	0.85[a]	0.25[d]	1.12[d]
Red Wolayita	0.82[a]	0.19[e]	1.01[e]
Mean	0.86	0.33	1.19
$LSD_{5\%}$	0.08	0.05	0.09
CV	5.4	9.2	4.5

Means within a column followed by different letters are significantly different at p<0.05.

Ibbado (24%), Omo-95 (22%), Awash-1 (8%), Awash Melka (12%) and 1% for Red Wolayita. This means that sole cropping requires more land than intercropping to produce equal yields indicating the greater land use efficiency from intercrops. Between the two genotypes that recorded the highest total LER only one is the top yielder under sole cropping while the other was one of the poor yielders. Thus, intercropping advantage from genotypes may not necessarily reflect performance under sole cropping indicating the need for evaluating genotypes under intended cropping systems. Yield advantages from maize-bean associations have been reported in several studies (Gebeyehu et al., 2006; Muraya et al., 2006; Worku, 2008, 2014; Workayehu and Wortmann, 2011). Though most of the contribution was derived from the dominant component, maize, differences in intercropping advantage appeared due to variability among the associated bean genotypes.

In this maize-bean association, while the bean is strongly and negatively affected, the effect on maize was slight. This type of association would be important in southern Ethiopia and elsewhere where the maize component is considered as the principal crop and the associated bean is used as a subsidiary crop. The intercropping advantage in such systems could be maximized by selecting appropriate bean genotypes that would not be aggressive on maize but strong enough to perform well under intercropping. Above all, such relationships could be maintained as long as severe shortages for moisture and nutrients are avoided because such environments tend to favor the dominated species (bean) at the expense of the dominant species (maize).

Conclusion

The genotype by cropping system interaction caused a moderate reranking of genotype performance between the two cropping systems leading to differences in choice. The genotype Hawassa Dume is the best choice followed by Ibbado and Awash-Melka under sole cropping while genotypes like Hawassa Dume and Sari-1 are equally good choices under intercropping. The traditionally used local cultivar did not perform well either in sole or intercropping systems suggesting the need for its replacement. Moreover, the more recent releases were found to be more efficient under intercropping than the variety identified previously (Ibbado), indicating the need for periodic assessment. Given the costly nature of plant breeding, the modest ranking changes observed for productivity between the two cropping systems do not warrant a separate variety development program for intercropping since there are genotypes with overlapping performance. Bush and semi bush types had better compatibility under intercropping while performance under sole cropping did not fall to a specific growth habit category. Though, one of the two export genotypes has showed good performance under sole cropping, none performed well under intercropping. This may be related to their growth habit since both are semi climbing types. Developing bush type export genotypes may help broaden their expansion outside their traditional zones since better performance under intercropping could attract more farmers to adopt them.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The financial grant received from the International Development Research Center and Department of Foreign Affairs, Trade and Development, Canada is gratefully acknowledged.

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Vol. 12(6), pp. 406-414, 9 February, 2017
DOI: 10.5897/AJAR2016.11808
Article Number: F18AC3F62679
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Validation of a phenological model for coffee tree productivity in Southern State of Minas Gerais, Brazil

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Received 7 October, 2016; Accepted 18 January, 2017

There are studies on the current state of understanding productivity models, focusing on the applicability of different estimation models for coffee tree productivity; the majority involving a considerable level of complexity. Thus, when searching for a simple and direct association between phenological characteristics and coffee productivity, doing research on this hypothesis is necessary. In this study, we aimed to validate a phenological model for coffee tree productivity by using phenological indices, under given edaphoclimatic conditions of Southern State of Minas Gerais, Brazil. We used 10 sample plots obtained from the municipalities of Lavras, Varginha, Carmo de Minas, Ijaci and Santo Antônio do Amparo. Plots were chosen based on the existing history about coffee productivity, which is over 40 sacks ha^{-1}. Phenological data were collected in September-October, December-January and March to April of the harvesting seasons 2012/2013 and 2013/2014. The number of flowers and fruits were obtained at the fourth and fifth productive nodes of coffee plagiotropic branches sampled at the middle third of each coffee plant. Forty plants were sampled in each plot for the measurement of plant height and estimates of productivity phenological indices. Data regarding the observed production were obtained for models comparison and validation and, then, statistical tests were run. Results showed that these models are suitable for the coffee crop in the region under study. In addition, productivity phenological indices showed good correlation with the observed productivity.

Key words: Coffee phenology, *Coffea arabica* L., prediction of productivity, agrometeorological modeling.

INTRODUCTION

Cultivation of coffee tree, usually done in large commercial plantations, is influenced by variation of climate elements, occurrence of adverse weather conditions such as frost and dry spell, as well as the

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Table 1. Location and cropping characteristics of sampling plots (SP) in coffee plantations assessed in the Southern of the State of Minas Gerais.

SP	Municipality	Geographical coordinates*			Cultivar	Plant spacing (m)	Area (ha)**
		Elevation (m)	South latitude	West longitude			
1	Lavras	1003	21º 18’ 33’’	45º 01’ 33’’	Acaia	3.8 × 0.7	4.0
2	Lavras	989	21º 19’ 07’’	44º 57’ 49’’	Catucaí	3.8 × 0.7	5.7
3	Varginha	1125	21º 32’ 49’’	45º 19’ 38’’	Catuaí	3.8 × 0.8	6.4
4	Varginha	1014	21º 33’ 22’’	45º 16’ 07’’	Catucaí	3.5 × 0.7	5.0
5	Carmo de Minas	1117	22º 09’ 02’’	45º 07’ 31’’	Catucaí	3.0 × 0.5	1.6
6	Carmo de Minas	1193	22º 10’ 43’’	45º 10’ 41’’	Catuaí	3.0 × 1.0	5.2
7	Carmo de Minas	1037	22º 08’ 24’’	45º 09’ 01’’	Acaia	3.0 × 1.0	4.6
8	Carmo de Minas	990	22º 06’ 45’’	45º 07’ 13’’	Acaia	3.0 × 0.5	8.2
9	Ijaci	932	21º 10 04’’	44º 58’ 40’’	Catuaí	3.6 × 0.5	21.0
10	Santo Antônio do Amparo	1093	21º 00’ 32’’	44º 53’ 07’’	Catuaí	2.5 × 0.6	18.5

*Data were obtained at the centre of the sampling plots. ** The estimate of area was provided by the farmers.

effect of plant physiology (bienniality). Besides, the coffee productivity forecast is found to be rather complex due to the intricate physiological mechanisms, crops diversity, and management conditions associated with the crop.

Coffee is a commodity, whose prices around the world are set in merchant exchanges. These prices depend on the expectations created regarding the availability of the commodity and expected demand. Thus, in order to ensure financial viability of the activity, a detailed planning of the application of resources or not, and necessary operations to ensure a given production level are found to be indispensable.

According to Sette et al. (2010), the relevance of performing costs-of-production forecasts is highlighted, especially coffee tree productivity estimates. This foresight is carried out to identify the best inputs combination, aiming to optimize economical outcomes.

Various productivity estimation models have been used, for example, agrometeorological, a model proposed by Picini et al. (1999) and Santos and Camargo (2006). Besides, there are many other models already tested in different producing regions, as well as in different edaphoclimatic and crop management conditions (Silva et al., 2011; Camargo et al., 2007). Such models have also been used to determine the onset and duration of phenological stages for coffee trees (Zacharias et al., 2008; Nunes et al., 2010; Carvalho et al., 2011).

There are some limitations regarding the use of agrometeorological models because it depends on the availability of meteorological data, specialized professionals for data interpretation, and the disregard of influence of factors such as soil fertility and plant sanitation activities.

The agrometeorological-spectral model has also been used for crops production forecasting (Rosa et al., 2010). This model uses satellite imagery obtained by means of the MODIS sensor. It also uses agrometeorological data obtained from the regional model used for weather forecasting as input variable in coffee growing areas of the Southern State of Minas Gerais, Brazil. However, besides difficulties mentioned above, the use of this model is limited by the need for the acquisition of images at the desired frequency for a given locality.

The third estimation model developed for the same purpose was described by Carvalho et al. (2005) and uses the harmonic analysis based on Fourier series. This model involves 33 variables; however, results obtained by using this model were not satisfactory due to the high level of complexity found in coffee production forecast.

In the limitations mentioned above, and considering that the assessment of phenological characteristics, determining of coffee tree production, can be a tool for the establishment of crop forecast models with significant level of simplicity, studies were performed as outlined in Fahl et al. (2005) and Sáenz et al. (2008).

In this study, we tested the hypothesis that phenological characteristics of coffee tree can be used as indicators of productivity in spite of edaphoclimatic and physiological conditions, the cultivar under crop, and agrotechnical management practices. We aimed to validate an estimation model for coffee tree productivity by using two phenological indices, under cropping conditions of Southern State of Minas Gerais, Brazil.

MATERIALS AND METHODS

Sampling plots were established in the municipalities of Lavras, Varginha, Carmo de Minas, Ijaci and Santo Antônio do Amparo, located in the Southern State of Minas Gerais, Brazil. These locations were chosen as representatives of edaphoclimatic characteristics and crop management practices for coffee plantations in the region under study.

Table 1 show ten sampling plots clustered according to municipalities, cultivars, plant spacing, and time after planting greater than 8 years. These parameters were considered because we sought to perform the experiment in plantations already established and with some history with regard to coffee productivity.

The sequential climatic water balance (CWB) was estimated as outlined in Thornthwaite and Mather (1955), seeking to characterize the prevailing climate conditions during the experimental period in the region under study, especially in terms of the effect caused by the hydric deficiency with regard to the coffee productivity.

Data about rainfall and mean air temperature required for the estimation of the representative CWB in the region were obtained in the Principal Climatological Station, under the agreement established between the Federal University of Lavras (UFLA) and the Brazilian National Institute of Meteorology (INMET). This station belongs to the network of surface meteorological observations of the INMET located in the Campus of the UFLA, at the following geographical coordinates: 21º 14' South latitude, 45º 00' West longitude and 918.8 m elevation.

Phenological data about coffee tree productivity were collected in three different agricultural seasons as follows: Flowering (September-October), appearance of berries (December-January) and graining (February-March) of the crop seasons 2012/2013 and 2013/2014.

Four sampling points were randomly selected for each of 10 plots. These points consisted of eight planting lines clustered at pairs to form a planting space given by the spacing within parallel lines. Five plants per planting line were alternately taken in each planting space, at about 10 m from each other, totalizing 10 plants per planting space and 40 plants per sampling plot. Plagiotropic branches sampled at the third middle position of each coffee plant were directed to the center of the planting space.

Plants and planting spaces were randomly sampled within each plot, so that there was no need to identify plants in order to use always the same for data collection in different crop seasons. The following parameters were obtained: Number of flowers, berries and grain fruits found at the fourth and fifth productive nodes of each plagiotropic branch sampled in the study.

The fourth and fifth productive nodes were counted from the tip of the plagiotropic branch to the orthotropic branch, from the first node containing a flower or fruit. We counted all productive nodes in the sampled branches, represented by nodes containing flowers and/or fruits. Nodes with no flowers or fruits in the branches were also counted. These nodes consisted of spaces from which the abscission of flower and/or fruits occurred mainly due to the prevailing local meteorological conditions.

The height of sampled plants (meters) was measured using a graduated scale, and considering the vertical distance from the soil surface to the apical meristem at the tip of the plant.

A representative model for productive vegetal areas (PVA), given by the Equation 1, was used to obtain phenological indices:

$$\mathrm{PVA} = \left(\frac{100}{\mathrm{SWL}} \times 100\right) \times 2 \times \mathrm{MPH} \quad (1)$$

Where PVA is the productive vegetal area ($m^2.ha^{-1}$), SWL is the spacing within lines (meters), and MPH is the mean plant height (meters).

Equation 2 provides the Productivity Phenological Index #1 (PPI_1):

$$\mathrm{PPI}_1 = \mathrm{PVA} \times \mathrm{AF45} \quad (2)$$

Where PPI_1 is the productivity phenological index #1 (number of fruits × m^2), and AF45 is the average number of flowers and/or fruits found at the fourth and fifth productive nodes of all plagiotropic branches sampled in the plot.

Equation 3 provides the PPI_2 obtained as product of PPI_1 by number of flowers and/or fruits found at the productive nodes of the plagiotropic branch.

$$\mathrm{PPI}_2 = \mathrm{PPI}_1 \times \mathrm{NPN} \quad (3)$$

Where PPI_2 is the productivity phenological index #2 [number of fruits × m^2 × number of productive internodes]; and NPN is the number of productive nodes of the plagiotropic branch.

The coffee tree productivity per sampling plot, measured by sacks of benefitted coffee per hectare ($sacks.ha^{-1}$), was obtained by means of consultation to owners and/or growers responsible for coffee farms.

Linear regression models were fitted to pairs of data about the observed productivity as function of productivity phenological indices (PPI_1 and PPI_2).

Three sampling plots were taken as reference to develop, by using a linear regression, and test statistically equations to estimate productivity phenological indices #1 and #2 best suited to the growing conditions of the Southern State of Minas Gerais, Brazil.

The initial assessment of the coefficient of determination (r^2) allowed the testing of some combinations. However, the estimate of coffee tree productivity was obtained for combinations in which the coefficient of determination was greater. This estimate was obtained by using data collected in other seven sampling plots.

This process, known as cross validation, was performed as outlined in Mariano et al. (2014), who stated that data used in this process are randomly clustered in two distinct sets known as training and validation data sets.

The phenological models of productivity #1 and #2 were assessed using independent data of productivity collected in sampling plots during the experimental period. Results were evaluated by a regression based on the coefficient of determination (r^2) and concordance index (CI) described in Willmott et al. (1985). The correlation coefficient (r) and the C index described in Camargo and Sentelhas (1997), obtained as product of r by CI, were also used.

The following parameters were also used to define the statistical quality of the model as described in Mariano et al. (2014): Mean error (ME), mean absolute deviation (MAD), mean absolute percentage error (MAPE), and mean square error (MSE). These parameters described measurements of the prediction error obtained from the existing difference between observed and predicted values.

RESULTS AND DISCUSSION

Figure 1 shows the extract of the sequential climatic water balance (CWB) estimated for the three years comprised in the crop seasons 2012/2013 and 2013/2014. Estimates referring to hydric deficiency of 123 and 75 mm respectively for the years of 2012 and 2013 were kept within limits considered normal to attain water requirements for coffee tree, as outlined in Meireles et al. (2009). Regarding the year 2012, however, there was no rainfall record in August and September. The rainfall was only recorded from October 2012, what contributed to the delayed onset of the main flowering (Figure 1A).

A low rainfall index of 80 mm was recorded from February to March, either for 2013 or for 2014 (Figure 1B and C), while we expected the occurrence of hydric excess about 90 mm, an amount considered normal for these months. However, an excess less than 50 mm was

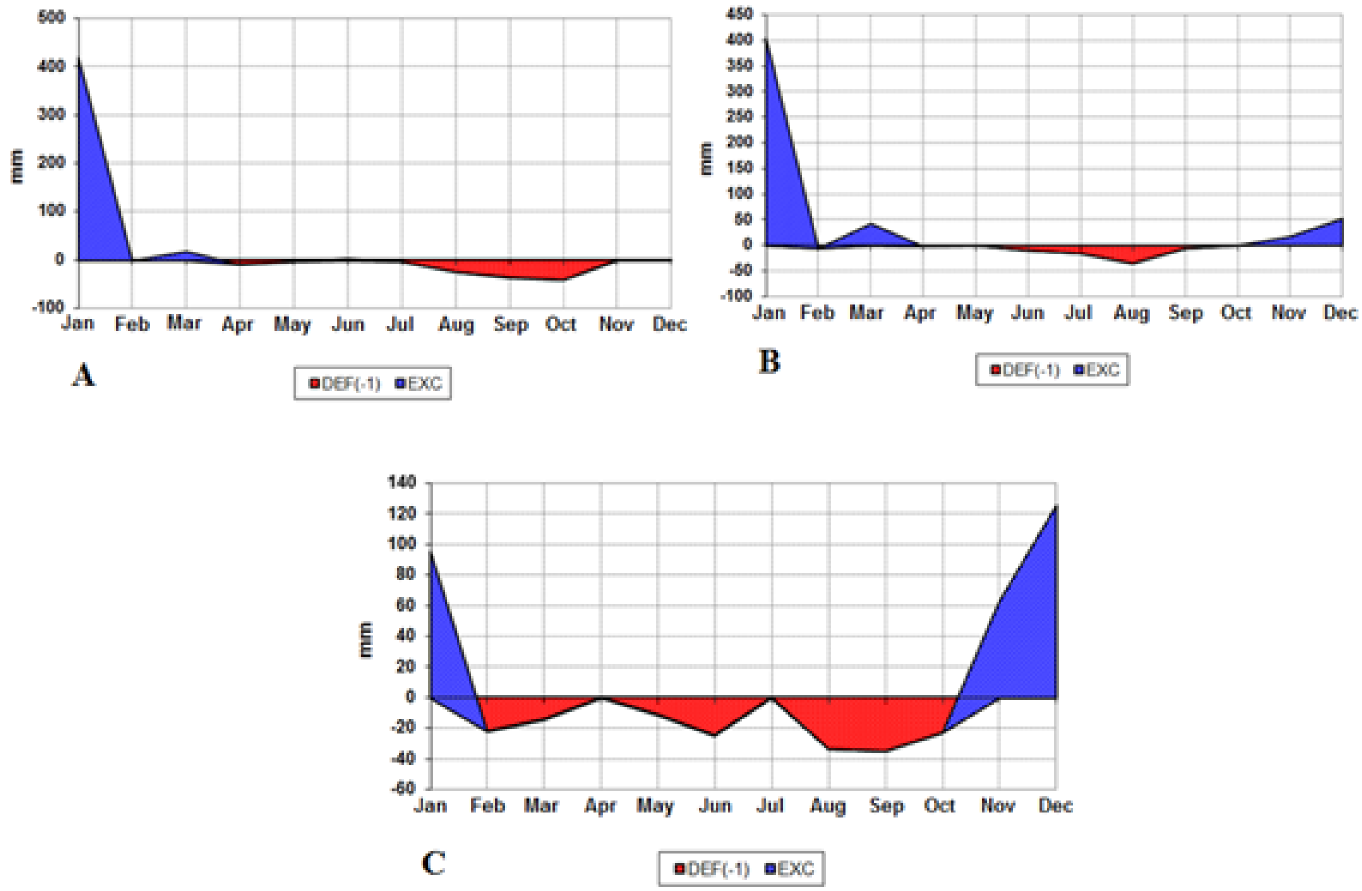

Figure 1. Extract of climatic water balance for Lavras, State of Minas Gerais, referring to 2012 (A), 2013 (B) and 2014 (C).

recorded in 2013 and, a hydric deficiency around 20 mm was recorded in 2014. These records were less than the expectation, what affected the graining stage. This resulted in malformed fruits, low yields, and need for greater volume of farm coffee to fill up a sack with benefitted coffee.

In this context, we realized that rainfall is a limiting factor for a more consistent performance of this productivity estimation model because physical and chemical properties of coffee fruits were not considered in the study. Instead, were only considered the presence or absence of flowers and fruits in the coffee branches.

The hydric deficiency recorded in the year 2014 was 164 mm; however, greater than the limit considered acceptable (150 mm) according to the magnitude condition outlined in Camargo (1977). This deficiency was recorded from February to October, what is considered atypical for the region under study. In addition, the temperature remained up to 2°C above the mean (21.6ºC) normally recorded from January to March. This pattern caused an increase in the potential evapotranspiration on the period during which the fruits expansion would occur and, consequently, when the hydric demand was high.

Although high temperatures occurred in the period under study, the mean annual temperatures ranged within limits that characterize the aptitude for coffee growing as outlined in Pereira et al. (2008), since mean temperatures were 20.8, 20.3 and 21.0°C respectively for years 2012, 2013 and 2014.

Productivity levels recorded in the plots remained high for both crop seasons, with average of 36 sacks.ha^{-1}. However, a remarkable variability was found, with data ranging from 15.2 to 60.1 sacks.ha^{-1}. Thus, by analyzing data referring to these years, we could realize that there is an alternation between high and low production, that is, the coffee tree shows a bienniality for each plot and each cultivar.

Table 2 shows estimates of Productivity Phenological Index #1 (PPI_1) and Productivity Phenological Index #2 (PPI_2) obtained from Equations 2 and 3 for sampling plots under study. These estimates highlight the decreasing of the PPI_1 and PPI_2 from the stage of appearance of berries to the graining stage.

Similar results were described by Alfonsi (2008), who found a decreasing trend for PPI_1 when analyzing data in the chronological order of their collection. This author

Table 2. Estimates of productivity phenological index #1 (PPI_1) and productivity phenological index #2 (PPI_2) obtained in three different agricultural seasons of the crop seasons 2012/2013 and 2013/2014.

SP	Productivity phenological index 1 (PPI_1)					
	Flowering		Appearance of berries		Graining	
	2012/2013	2013/2014	2012/2013	2013/2014	2012/2013	2013/2014
1	37623	22798	81626	67537	46656	58428
2	52366	21433	53720	46066	33152	52597
3	10896	77092	19484	56002	11601	40718
4	45729	---	59611	16109	40055	21435
5	---	75000	21897	39574	15768	40864
6	21457	27383	52668	32595	33138	32597
7	12290	39958	46700	37549	47534	66900
8	30554	47600	35980	80467	24367	45333
9	50771	51970	72318	39276	33547	38920
10	24820	25800	62876	56657	46142	70115
SP	Productivity Phenological Index 2 (PPI_2)					
	Flowering		Appearance of berries		Graining	
	2012/2013	2013/2014	2012/2013	2013/2014	2012/2013	2013/2014
1	493806	238810	1071344	707453	573871	565287
2	400600	197187	410960	423805	445062	451017
3	168344	969433	301031	684628	137766	455019
4	840263	---	1095357	145783	488670	198808
5	---	804375	244698	346274	136784	405575
6	271435	277941	666250	325132	386052	317003
7	165909	436545	630456	389574	690435	868028
8	491927	441490	579278	887145	314330	429533
9	572439	521003	815384	393747	381599	382389
10	300322	288315	760803	633143	561782	676609

described examples recorded in Graça/Marília and Campinas, regions of the State of São Paulo, Brazil. In these regions, he obtained greater records in December than in March for the same parameters.

In this study, we found an increasing of PPI_1 and PPI_2 from flowering to the appearance of berries. This result is contrary to that described in Alfonsi (2008), who found greater estimate in October than in December and, then, greater than that recorded in March. This decrease was because data collected in October reflect the potential of the first flowering. Then, due to climatic phenomena such as high temperature and hydric deficiency in the post-flowering period, the abortion and abscission of flowers can occur. This phenomenon can result in lower quantity of berries in December than the quantity of flowers produced in productive nodes.

In the physiological context, and considering that we were expecting a decrease of estimates of PPI_1 and PPI_2, we might infer that this decrease did not occur in this study because of the fall of too many flowers during data collection in different sampling plots. In addition, the irregular succession of flowering as function of time and localities may have contributed to the inadequate data collection in this phenological stage.

Equations 4 to 6 are related to the PPI_1 and they resulted from linear regressions for three data sets referring to the best response for the interaction in the whole dataset. Estimates described above were obtained from these equations, which are considered to be models applied for each phenological stage.

1. Flowering

$$P = 0.0002 \times PPI_1 + 23.67 \tag{4}$$

2. Appearance of berries

$$P = 0.0005 \times PPI_1 + 5.74 \tag{5}$$

3. Graining

$$P = 0.0006 \times PPI_1 + 10.08 \tag{6}$$

Estimates obtained from these equations were equally

Table 3. Output data generated from statistical analysis for phenological models.

				Crop season 2012/2013					
Model	**Phenological stage**	**r^2**	**r**	**CI**	**C**	**ME**	**MAD**	**MAPE**	**MSE**
	Flowering	0.03	0.16	0.45	0.07	13.67	14.93	31.04	296.97
PPI_1	Appearance of berries	0.81	0.90	0.73	0.65	12.81	10.98	29.52	178.79
	Graining	0.54	0.73	0.65	0.48	13.11	11.24	28.18	226.34
	Flowering	0.01	-0.08	0.41	-0.03	11.84	14.28	30.61	277.21
PPI_2	Appearance of berries	0.30	0.55	0.64	0.35	11.19	12.40	33.38	237.22
	Graining	0.35	0.59	0.67	0.39	12.15	12.43	33.16	240.32
				Crop season 2013/2014					
Model	Phenological stage	r^2	r	CI	C	ME	MAD	MAPE	MSE
	Flowering	0.15	0.39	0.55	0.22	1.85	4.88	14.10	43.83
PPI_1	Appearance of berries	0.004	0.07	0.44	0.03	5.41	10.76	38.25	171.95
	Graining	0.28	0.53	0.66	0.35	-6.97	7.55	30.40	120.85
	Flowering	0.23	0.48	0.61	0.29	1.81	4.64	13.24	39.56
PPI_2	Appearance of berries	0.01	0.10	0.46	0.05	9.45	11.53	38.97	210.53
	Graining	0.54	0.74	0.78	0.57	-2.30	7.78	28.60	87.20

similar to that found by using Equation 7 proposed by Fahl et al. (2005) to estimate the productivity in the graining stage as follows:

$$P = 0.0005 \times PPI_1 \quad (7)$$

Miranda et al. (2014), aiming to develop a simple and accurate method to estimate the coffee production, also developed similar equations, inclusively with an angular coefficient equal to 0.00053 for the fruits expansion period.

Estimates of r^2 obtained in this study were 0.1874, 0.8199 and 0.5274, respectively for flowering, appearance of berries and graining. These estimates were less than those found by Fahl et al. (2005) [0.989] and Miranda et al. (2014) [0.8683]. This difference was estimated based on the significant hydric deficiency recorded in January and March 2013, which limited the performance of the model.

Regarding the PPI_2, estimates of r^2 obtained in this study were greater than those found by Alfonsi (2008) for flowering [0.2137], appearance of berries [0.8357] and graining [0.709]. This effect suggests a great PPI_2 potential for the estimation of coffee productivity in conditions under study.

Equations 8 to 10 describe models used in this study to estimate the coffee tree productivity, given the PPI_2:

1. Flowering

$$P = 0.00002 \times PPI_2 + 23.47 \quad (8)$$

2. Appearance of berries

$$P = 0.00004 \times PPI_2 + 6.42 \quad (9)$$

3. Graining

$$P = 0.00006 \times PPI_2 + 5.65 \quad (10)$$

Models resulting from regressions established as function of the observed productivity and Productivity Phenological Indices #1 and #2 were tested with data obtained from other seven sampling plots (SP). Table 3 shows output data generated from statistical analysis for the assessment of phenological models.

PPI_1 was highlighted by showing performance better than PPI_2 in the crop season of 2012/2013. This evidence can be better shown by comparing estimates of r^2, r, CI and C, once statistical indices related to the difference between the observed and estimated values showed very similar patterns.

Regarding the existing similarity between PPI_1 and PPI_2, we found that both indices were unable to predict the productivity in the flowering stage. This was because of the long period recorded from the flowering to harvesting. Besides, the flowering was not found to be good parameter to describe the coffee tree productivity with good accuracy, due to factors related to the plant physiology, interference of climate factors, and difficulties for data collection.

Table 3 shows the performance of models for PPI_1 and PPI_2 estimated for the crop season 2013/2014. This performance did not come up to the estimate found in the previous crop season, probably because of adverse and atypical weather conditions recorded in the region during the experimental period.

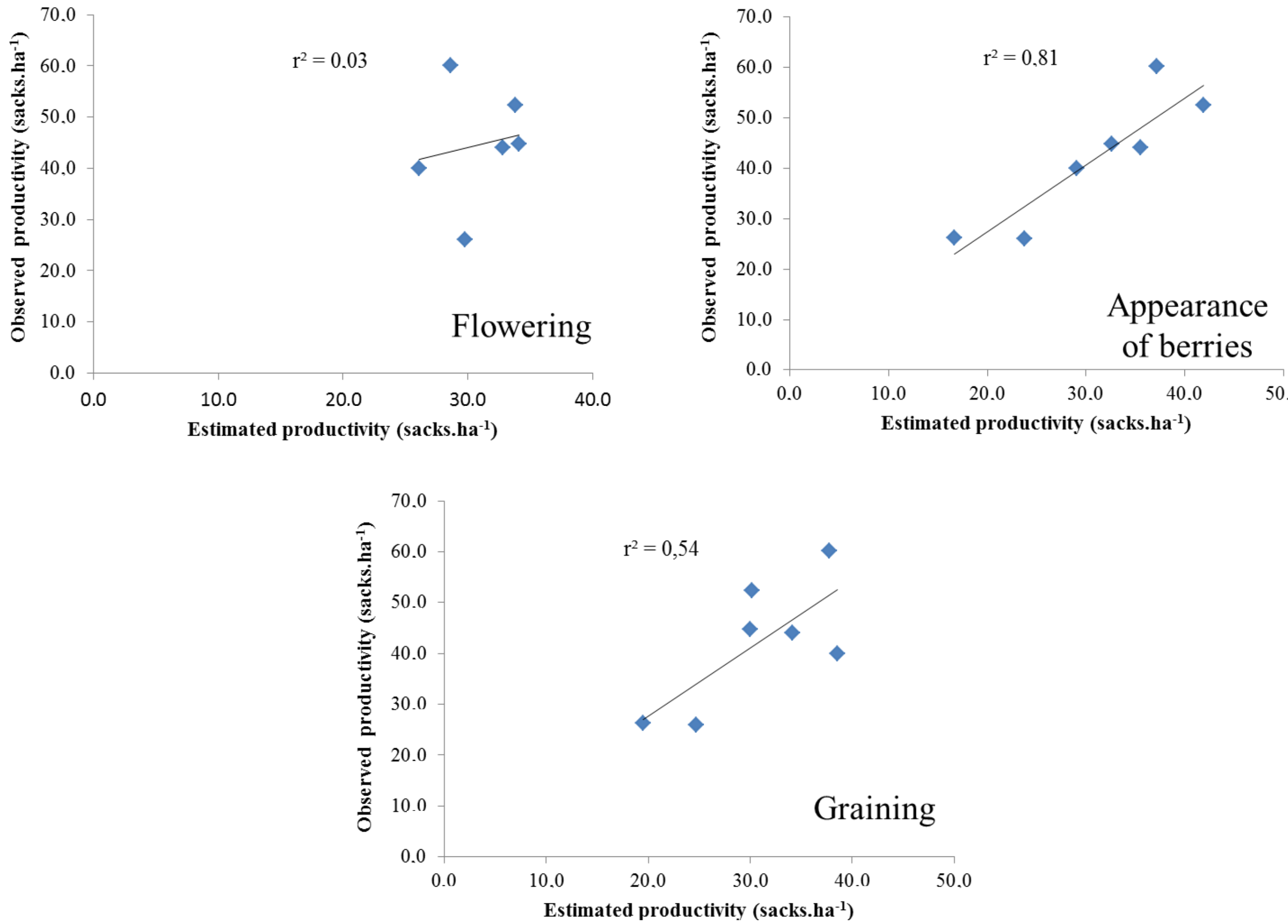

Figure 2. Correlation between observed and estimated productivity by means of the model for the crop season 2012/2013 used for PPI_1.

Figure 2 shows regressions developed as function of observed and estimated productivity, with respective values of r^2 for each phenological stage of the crop in the crop season 2012/2013, by using PPI_1. This was because results found in this crop season were greater than those found in the crop season 2013/2014.

The performance of the model for the stage of appearance of berries was even greater than that referring to the graining stage. This result was not expected due to the existing proximity between the graining stage and harvesting. However, this can be explained by the excessive rainfall, about 499.7 mm, recorded in January 2013 as provided by the Principal Climatological Station, under the agreement established between the UFLA and the INMET. Thus, this rainfall may have probably intensified the abscission of berries in some localities. In addition, it might have caused damages on plants, thus, limiting the possibility of success to complete the crop production cycle, with adequate maturation of fruits.

Regarding the crop season 2013/2014, the atypical weather conditions recorded in the region during the experimental period caused an increased data dispersion, suggesting that the model is inaccurate in these conditions. However, differently from previous situation, the performance of the estimate was found to be worse in the stage of appearance of berries.

Alfonsi (2008) points out that these variations can be attributed to the sample size, which can have great variation during the extrapolation process from a small sample size to a larger size sample.

Figure 3 shows the regression developed as function of observed and estimated productivity, with respective values of r^2 observed for each phenological stage of the crop in the crop season 2013/2014, by using PPI_2. This figure also shows that the PPI_2 showed a moderate performance in the prediction of productivity when used in the graining stage. This effect suggests a great PPI_2 potential for the estimation of coffee productivity in the graining stage, as well as in adverse weather conditions. In fact, this was the only moment in which the r and CI indices were approximately equal to one.

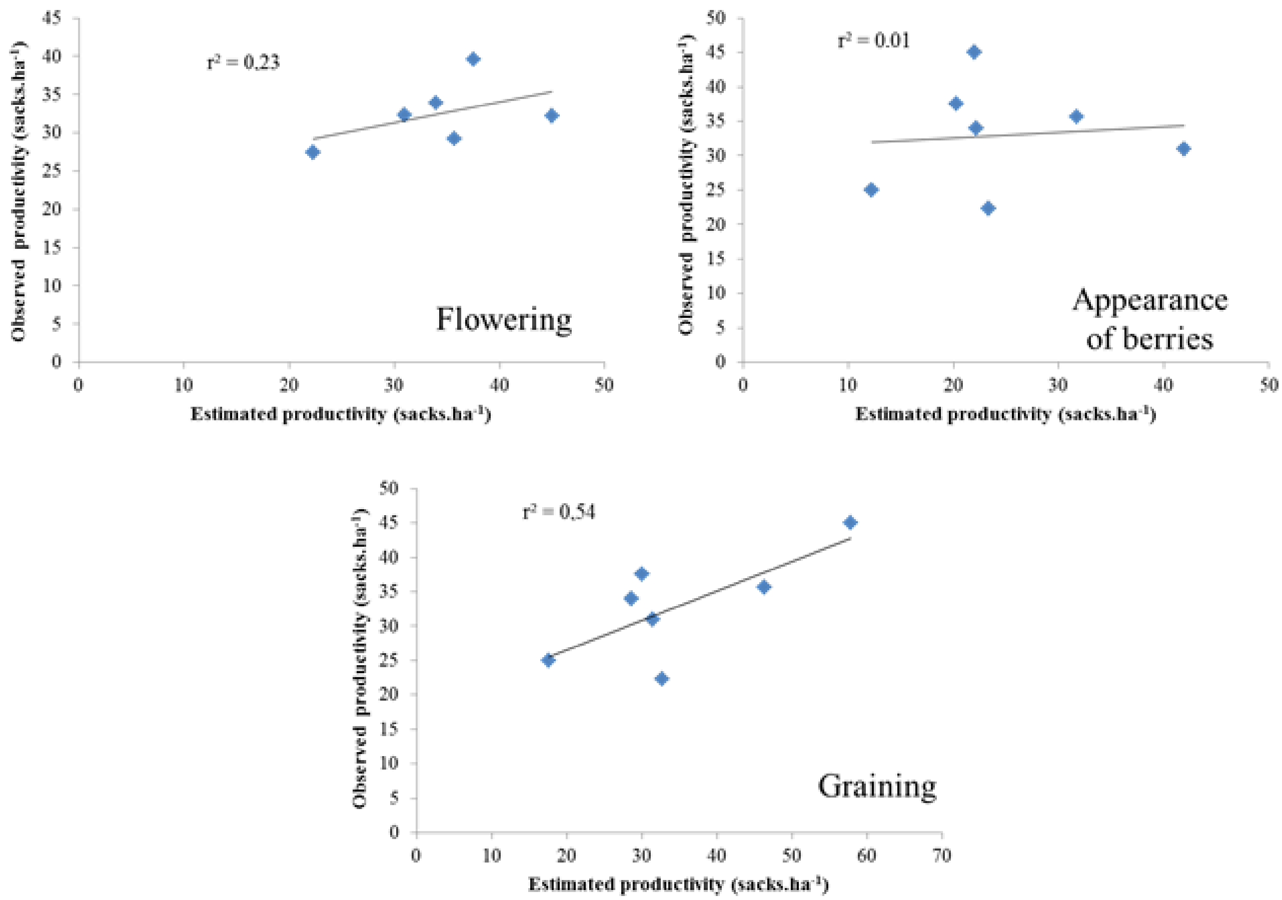

Figure 3. Correlation between observed and estimated productivity by means of the model for the crop season 2013/2014 used for PPI_2.

However, the quality of this idea should be improved along with the possibility of inserting an index related to the penalization of productivity, resulting from the effect of adverse weather phenomena.

Therefore, we can infer that none of crop seasons under study allowed obtaining a high performance model as those described in Oliveira (2007), which were obtained by using the equation P = 0.0004×PPI for the month of December, and P = 0.0005×PPI for the month of March. This author found estimates of r^2 ranging from 0.95 to 0.99. In addition, he found that the estimated productivity was always equal to the observed productivity for 93 plots under study.

Conclusion

The model validated in this study was found to be suitable for crop management conditions, cultivars and edaphoclimatic conditions of the region under study. However, the performance of the model was affected by adverse weather conditions recorded in the region during the experimental period. The estimate of coffee tree productivity obtained by counting flowers of productive nodes did not allow obtaining satisfactory results for any situation. Thus, these results did not suggest any possibility of recommending the use of this method. Predicting the productivity of coffee plots with good confidence level, up to six months in advance, is found to be possible, since phenological data are collected in the stage of appearance of berries. Productivity Phenological Indices #1 and #2 showed good correlation with crop productivity therefore these indices are considered to be good indicators for coffee productivity estimation processes.

Conflicts of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The doctoral scholarship was provided by the Coordination for the Improvement of Higher Education Personnel (CAPES) to the first author. The productivity grant was provided by the National Council for Scientific and Technological Development (CNPq) to the second author, by means of the process n^{o} 306204/2012-6. The project was funded by the Research Support Foundation of the State of Minas Gerais (FAPEMIG), by means of the process n^{o} CAG-APQ 01670/13.

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Vol. 12(6), pp. 415-423, 9 February, 2017
DOI: 10.5897/AJAR2016.11814
Article Number: 770FDF462683
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Basic experimental unit and plot sizes with the method of maximum curvature of the coefficient of variation in sunn hemp

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Received 10 October, 2016; Accepted 3 January, 2017

The influence of the basic experimental unit size on the plot size estimation determined by the method of maximum curvature of the coefficient of variation model is unknown in sunn hemp. This study aimed to verify the influence of the basic experimental unit (BEU) size in the estimate of the optimum plot size obtained by the method of maximum curvature of the coefficient of variation model for the evaluation of fresh matter of sunn hemp (*Crotalaria juncea* L.). Fresh matter of sunn hemp at the flowering was evaluated in uniformity trials in two sowing dates. In each sowing date, 4,608 BEU of 0.5 × 0.5 m (0.25 m^2) were evaluated and 64 BEU plans were formed with sizes from 0.25 to 64 m^2. In each evaluation period for each BEU plan, the first order spatial autocorrelation coefficient, variance, standard deviation, mean, coefficient of variation of the trial and the plot size were determined with the fresh matter data. For each BEU plan, the optimum plot size was determined by the method of maximum curvature of the coefficient of variation model. The estimate of optimum plot size depends on the basic experimental unit size. Determining the plot size to assess the fresh matter in basic experimental units as small as possible is recommended in order to prevent overestimation of the plot size and to contemplate all existing variability.

Key words: *Crotalaria juncea* L., experimental design, basic experimental unit.

INTRODUCTION

The sunn hemp (*Crotalaria juncea* L.) is a cover crop option for soil protection due to its hardiness, high dry matter production and nitrogen fixation (Silva and Menezes, 2007), improving and maintaining soil quality,

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raising to considerable levels of soil organic matter and nutrients (Leite et al., 2010). The crop rapid development enables the use of sunn hemp in cropping systems with rotation and crop succession. It is the legume with greatest dry matter production in comparison with gray velvet bean (*Mucuna nivea*), jack bean (*Canavalia ensiformis*), velvet bean (*Mucuna* aterrina), lab-lab (*Dolichos lablab*), showy crotalaria (*Crotalaria spectabilis*), and dwarf pigeon pea (*Cajanus cajan*) (Teodoro et al., 2011); in a study carried out by Andrade Neto et al. (2010), the fresh matter of aerial part values of sunn hemp were 13.9 t ha^{-1}.

One aspect to be considered is the inferences made in agricultural research representing experimental reality which is the use of an optimum plot size to minimize the experimental error. The optimum plot size can be calculated based on data obtained from uniformity trials in which treatments are not applied (Ramalho et al., 2012; Storck et al., 2016). In order to evaluate traits of the studied crop, the experimental area is divided into basic experimental units (BEU) with the smallest possible size. Therefore, based on this information, the plot size is determined.

The influence of the BEU size in estimating the optimum plot size is still an area with few studies but Oliveira et al. (2005) verified in potato (*Solanum tuberosum* L.) the BEU size effect on the optimum plot size estimated by the method of the modified maximum curvature (Meier and Lessman, 1971). These authors also concluded that the BEU size interferes with estimating the optimum plot size. In maize (*Zea mays* L.), Storck et al. (2006a) identified the causes of variation in the estimates of the optimum plot sizes obtained by different methods and concluded that estimate of variance among plots of one BEU and the soil heterogeneity index interfere with optimum plot size. Thus, the optimum plot size depends on the BEU size.

In white lupine (*Lupinus albus* L.) and forage turnip (*Raphanus sativus*), the BEU size affects the estimate of the plot size, which evaluate the fresh matter in BEU as small as possible in order to be used in the estimation of the optimum plot size (Cargnelutti Filho et al., 2016a, b). Several methodologies are used to estimate the optimum plot size. The method of maximum curvature of the coefficient of variation model (Paranaíba et al., 2009a) is considered appropriate to obtain the optimum plot size of wheat and cassava (Paranaíba et al., 2009b). This method presents the advantage of dispensing the grouping of adjacent BEU, that is, the researcher should only get estimates of first order spatial autocorrelation coefficient, variance and mean based on a plot with size equals to one BEU.

Estimates of the plot size by the method of Paranaíba et al. (2009a) were performed for several crops, such as the study of fresh matter of forage turnip (*Raphanus sativus* L.) (Cargnelutti Filho et al., 2014b); fresh matter of black oat (*Avena strigosa* Schreb) (Cargnelutti Filho et al., 2014a); fresh matter of pods, fresh matter of aerial part without pods, and fresh matter of aerial part of jack bean (*Canavalia ensiformis*) (Cargnelutti Filho et al., 2014c); fresh matter of canola (*Brassica napus* L.) (Cargnelutti Filho et al., 2015); fresh matter of pigeon pea (*Cajanus cajan* (L.) Millsp.) (Santos et al., 2016); fresh matter of lettuce (*Lactuca sativa*), and fresh matter of pepper fruits (*Capsicum annuum*) (Schwertner et al., 2015).

Studies on the influence of the BEU size in estimating plot size obtained by the method of maximum curvature of the coefficient of variation model (Paranaíba et al., 2009a) for sunn hemp crop were not found in literature. Therefore, the hypothesis that the BEU size influences the determination of plot size is unknown for the sunn hemp crop.

Thus, this study aimed to verify the influence of the basic experimental unit (BEU) size in the estimate of the optimum plot size obtained by the method of maximum curvature of the coefficient of variation model for the evaluation of fresh matter of sunn hemp (*C. juncea* L.).

MATERIALS AND METHODS

Two uniformity trials were carried out with sunn hemp (*C. juncea* L.) in an experimental area of 50 × 52 m located in southern Brazil at 29°42'S lat, 53°49'W long, and 95 m of altitude. According to Köppen climate classification, the climate is *Cfa*, humid subtropical, with hot summers and no dry season defined (Heldwein et al., 2009) (Figure 2). The soil is classified as sandy loam typic Paleudalf (Santos et al., 2013).

The experiment was performed during the 2014/15 agricultural year in two sowing dates. In the first sowing date, the sowing procedure was held on 22 October, 2014 and in the second sowing date, the sowing procedure was held on December 03, 2014 (Figure 2). The sowing for both sowing dates was performed in rows with spacing of 0.50 m, with plant density of 20 plants per linear meter in an area of 50 × 26 m (1,300 m^2). The basic fertilization was 15 kg ha^{-1} of N, 60 kg ha^{-1} of P_2O_5 and 60 kg ha^{-1} of K_2O. The uniformity trials were carried out with cultural practices performed homogeneously throughout the experimental area, as suggested by Storck et al. (2016).

In each sowing date, an area of 48 × 24 m (1,152 m^2) was demarcated in the central part of the uniformity trial. The area of each sowing date was divided into 4,608 BEU of 0.5 ×0.5 m (0.25 m^2), forming a matrix with 96 rows and 48 columns. In the first sowing date at 110 days after sowing (DAS) and in the second sowing time at 97 DAS, the plants were cut close to the ground and the fresh matter was weighed, in grams, in each BEU when the crop was at the flowering stage.

In each sowing date with the data of fresh matter of 4,608 BEU, 64 plans of BEU with sizes $X = X_R \times X_C$ (X = 0.25, 0.50, 0.75, 1, 1.5, 2, 2.25, 3, 4, 4.5, 6, 8, 9, 12, 16, 18, 24, 32, 36, 48, and 64m^2) were formed (Tables 1 and 2). The abbreviations X_R, X_C and X stand for respectively, the number of BEU adjacent to the row, number of BEU adjacent to the column, and BEU size, in number of BEU or in square meters. Thus, the 64 BEU plans were formed between 0.5 × 0.5 m (1BEU = 0.25 m^2) and 16 ×16 m (256BEU = 64 m^2) and the

Table 1. Plans of basic experimental units (BEU) with sizes of $X = X_R \times X_C$ in BEU and in m^2 and their respective estimates of first order spatial autocorrelation coefficient (ρ), standard deviation (s), mean (m), coefficient of variation of the trial (CV, in %), optimum plot size (Xo, in BEU), and optimum plot size (Xo, in m^2) for fresh matter of sunn hemp (*C. juncea* L.), in g 0.25 m^{-2} evaluated at 110 days after sowing (DAS) (sowing date 1) in uniformity trial with 4,608 BEU of 0.5 × 0.5 m (0.25 m^2).

Plan	X_R	X_C	X (BEU)	X (m^2)	n	ρ	s	m	CV (%)	Xo (BEU)	Xo (m^2)
1	1	1	1	0.25	4,608	0.08	563.98	1,078.28	52.30	8.16	2.04
2	1	2	2	0.5	2,304	0.16	838.63	2,156.55	38.89	6.65	3.33
3	1	3	3	0.75	1,536	0.22	1,070.26	3,234.83	33.09	5.93	4.45
4	1	4	4	1	1,152	0.26	1,294.33	4,313.11	30.01	5.51	5.51
5	1	6	6	1.5	768	0.32	1,700.47	6,469.66	26.28	4.99	7.48
6	1	8	8	2	576	0.34	2,080.39	8,626.22	24.12	4.68	9.37
7	1	12	12	3	384	0.28	2,846.89	12,939.33	22.00	4.46	13.39
8	1	16	16	4	288	0.23	3,519.46	17,252.43	20.40	4.28	17.14
9	2	1	2	0.5	2,304	0.11	812.48	21,56.55	37.68	6.54	3.27
10	2	2	4	1	1,152	0.17	1,220.70	4,313.11	28.30	5.38	5.38
11	2	3	6	1.5	768	0.25	1,588.39	6,469.66	24.55	4.83	7.25
12	2	4	8	2	576	0.37	1,892.96	8,626.22	21.94	4.36	8.72
13	2	6	12	3	384	0.42	2,530.72	12,939.33	19.56	3.98	11.94
14	2	8	16	4	288	0.43	3,159.73	17,252.43	18.31	3.79	15.17
15	2	12	24	6	192	0.36	4,357.29	25,878.65	16.84	3.67	22.00
16	2	16	32	8	144	0.25	5,591.30	34,504.87	16.20	3.66	29.30
17	3	1	3	0.75	1,536	0.08	993.40	3,234.83	30.71	5.72	4.29
18	3	2	6	1.5	768	0.18	1,458.78	6,469.66	22.55	4.61	6.92
19	3	3	9	2.25	512	0.29	1,871.87	9,704.49	19.29	4.08	9.19
20	3	4	12	3	384	0.36	2,281.10	12,939.33	17.63	3.78	11.35
21	3	6	18	4.5	256	0.43	3,012.91	19,408.99	15.52	3.40	15.28
22	3	8	24	6	192	0.44	3,746.90	25,878.65	14.48	3.23	19.38
23	3	12	36	9	128	0.40	5,102.66	38,817.98	13.15	3.07	27.64
24	3	16	48	12	96	0.19	6,695.72	51,757.30	12.94	3.18	38.19
25	4	1	4	1	1,152	0.09	1,150.86	4,313.11	26.68	5.21	5.21
26	4	2	8	2	576	0.11	1,709.72	8,626.22	19.82	4.27	8.53
27	4	3	12	3	384	0.18	2,186.02	12,939.33	16.89	3.81	11.42
28	4	4	16	4	288	0.35	2,553.33	17,252.43	14.80	3.37	13.49
29	4	6	24	6	192	0.42	3,359.00	25,878.65	12.98	3.03	18.20
30	4	8	32	8	144	0.41	4,184.31	34,504.87	12.13	2.91	23.25
31	4	12	48	12	96	0.32	5,661.62	51,757.30	10.94	2.78	33.34
32	4	16	64	16	72	0.16	7,358.50	69,009.74	10.66	2.81	44.93
33	6	1	6	1.5	768	0.14	1,462.01	6,469.66	22.60	4.65	6.97
34	6	2	12	3	384	0.21	2,215.26	12,939.33	17.12	3.83	11.48
35	6	3	18	4.5	256	0.31	2,867.25	19,408.99	14.77	3.40	15.30
36	6	4	24	6	192	0.41	3,486.74	25,878.65	13.47	3.12	18.71
37	6	6	36	9	128	0.48	4,625.00	38,817.98	11.91	2.80	25.18
38	6	8	48	12	96	0.47	5,781.85	51,757.30	11.17	2.69	32.32
39	6	12	72	18	64	0.40	7,823.62	77,635.95	10.08	2.58	46.36
40	6	16	96	24	48	0.12	10,571.02	103,514.60	10.21	2.74	65.74
41	8	1	8	2	576	0.16	1,757.76	8,626.22	20.38	4.33	8.65
42	8	2	16	4	288	0.20	2,685.52	17,252.43	15.57	3.60	14.38
43	8	3	24	6	192	0.30	3,486.13	25,878.65	13.47	3.21	19.26
44	8	4	32	8	144	0.45	4,196.65	34,504.87	12.16	2.86	22.91
45	8	6	48	12	96	0.51	5,569.15	51,757.30	10.76	2.58	30.91
46	8	8	64	16	72	0.45	7,196.78	69,009.74	10.43	2.59	41.38

Table 1. Contd.

47	8	12	96	24	48	0.38	9,668.45	103,514.60	9.34	2.46	59.13
48	8	16	128	32	36	0.11	13,027.99	138,019.47	9.44	2.60	83.27
49	12	1	12	3	384	0.22	2,339.03	12,939.33	18.08	3.96	11.89
50	12	2	24	6	192	0.30	3,640.53	25,878.65	14.07	3.30	19.82
51	12	3	36	9	128	0.41	4,824.25	38,817.98	12.43	2.95	26.59
52	12	4	48	12	96	0.55	5,902.92	51,757.30	11.41	2.62	31.48
53	12	6	72	18	64	0.56	8,009.48	77,635.95	10.32	2.45	44.08
54	12	8	96	24	48	0.51	10,249.21	103,514.60	9.90	2.44	58.62
55	12	12	144	36	32	0.39	14,060.29	155,271.91	9.06	2.40	86.44
56	12	16	192	48	24	0.11	19,133.25	207,029.21	9.24	2.56	123.10
57	16	1	16	4	288	0.26	2,797.68	17,252.43	16.22	3.66	14.64
58	16	2	32	8	144	0.39	4,386.11	34,504.87	12.71	3.02	24.13
59	16	3	48	12	96	0.35	6,178.69	51,757.30	11.94	2.92	35.08
60	16	4	64	16	72	0.60	7,328.79	69,009.74	10.62	2.44	38.98
61	16	6	96	24	48	0.55	10,099.39	103,514.60	9.76	2.37	56.86
62	16	8	128	32	36	0.47	13,047.54	138,019.47	9.45	2.41	76.97
63	16	12	192	48	24	0.30	18,143.33	207,029.21	8.76	2.41	115.64
64	16	16	256	64	18	0.01	24,560.49	276,038.94	8.90	2.51	160.70

X_R: Adjacent BEU to the row; X_C: adjacent BEU to the column; n: number of BEU with size of X BEU (n=4,608/X).

fresh matter values of X_R BEU adjacent to the row and the X_C BEU adjacent to the column were added for its composition.

For each BEU plan with the fresh matter data, the first order spatial autocorrelation coefficient (ρ), the variance (s^2), the standard deviation (s), the mean (m), and the coefficient of variation of the trial (CV=100s/m, in %) were determined. The estimate of ρ was obtained in the row sense according to the methodology of Lessman and Atkins (1963), adapted by Paranaíba et al. (2009a). Based on the method of maximum curvature of the coefficient of variation model proposed by Paranaíba et al. (2009a), the optimum plot size (Xo) in BEU was determined by $Xo = \left(10\sqrt[3]{2\,(1-\rho^2)\,s^2 m}\right)\big/ m$. The optimum plot size (Xo) in m^2 was determined by the multiplication of Xo in BEU, with the BEU area in m^2.

Statistical analyzes were performed with the support of Microsoft Office Excel® application.

RESULTS AND DISCUSSION

Based on fresh matter of sunn hemp data, there was variability in the estimates of first order spatial autocorrelation (ρ), standard deviation (s), mean (m), coefficient of variation of the trial (CV), values of the optimum plot size Xo (BEU) and Xo (m^2) (Figure 1) among the distinct sizes of planned BEU and between the two sowing dates. In general, the first order spatial autocorrelation coefficient (ρ) oscillated between 0.01 and 0.60 at the sowing date 1 and between 0.13 and 0.52 at the sowing date 2. This variability of ρ values between 64 BEU plans with sizes $X = X_R \times X_C$ (X = 0.25, 0.50, 0.75, 1, 1.5, 2, 2.25, 3, 4, 4.5, 6, 8 9, 12, 16, 18, 24, 32, 36, 48 and 64 m^2) demonstrates a possible dependence of ρ regarding the BEU sizes (Tables 1 and 2). The values of ρ indicate whether a BEU is independent (ρ=0) or dependent (ρ=|1|) of the adjacent BEU, that is, absence of correlation or presence of positive or negative perfect autocorrelation, respectively. The Xo calculated by the math expression $Xo = \left(10\sqrt[3]{2\,(1-\rho^2)\,s^2 m}\right)\big/ m$, Paranaíba et al. (2009a) with fixed values of variance (s^2) and mean (m) is maximum when there is independence between the adjacent BEU.

In the two sowing date evaluation of fresh matter of sunn hemp, there was a linear increase in standard deviation (s) and mean (m) with an increase of BEU sizes (X, in BEU) (Tables 1, 2 and Figure 1). The standard deviation (s) values increased in a lower proportion than the mean (m) and the values of the coefficient of variation of the trial (CV=100s/m, in %) decreased with a power model pattern. However, there was oscillation of ρ among the 64 BEU plans, being possible that the optimum plot size (Xo) was influenced by the BEU size due to the variation of standard deviation (s) and mean (m).

The coefficient of variation (CV) values ranged from 8.76 to 52.30% for the sowing date 1 and from 7.56 to 44.65% for sowing date 2 (Tables 1 and 2), decreasing with power model pattern as there was an increase of BEU sizes (X, in BEU). Lorentz et al. (2007) found similar behavior with wheat, where the coefficient of variation decreased with increasing size of planned plots. As the CV values decreased, a decrease in the same power model pattern occurred for the plot size values in BEU.

Table 2. Plans of basic experimental units (BEU) with sizes of $X = X_R \times X_C$ in BEU and in m^2 and their respective estimates of first order spatial autocorrelation coefficient (ρ), standard deviation (s), mean (m), coefficient of variation of the trial (CV, in %), optimum plot size (Xo, in BEU) and optimum plot size (Xo, in m^2) for fresh matter of sunn hemp (*C. juncea* L.), in g 0.25 m^{-2} evaluated at 97 days after sowing (DAS) (sowing date 2) in uniformity trial with 4,608 BEU of 0.5 × 0.5 m (0.25 m^2).

Plan	X_R	X_C	X (BEU)	X (m^2)	n	ρ	s	m	CV (%)	Xo (BEU)	Xo (m^2)
1	1	1	1	0.25	4,608	0.15	394.74	884.11	44.65	7.31	1.83
2	1	2	2	0.5	2,304	0.22	593.63	1,768.22	33.57	5.99	2.99
3	1	3	3	0.75	1,536	0.29	769.51	2,652.33	29.01	5.37	4.03
4	1	4	4	1	1,152	0.33	935.98	3,536.44	26.47	5.00	5.00
5	1	6	6	1.5	768	0.32	1,247.38	5,304.66	23.51	4.63	6.95
6	1	8	8	2	576	0.33	1,544.63	7,072.88	21.84	4.40	8.80
7	1	12	12	3	384	0.33	2,086.03	10,609.32	19.66	4.10	12.29
8	1	16	16	4	288	0.29	2,599.53	14,145.76	18.38	3.96	15.83
9	2	1	2	0.5	2,304	0.13	586.84	1,768.22	33.19	6.01	3.00
10	2	2	4	1	1,152	0.20	875.10	3,536.44	24.75	4.90	4.90
11	2	3	6	1.5	768	0.27	1,126.76	5,304.66	21.24	4.38	6.56
12	2	4	8	2	576	0.28	1,374.23	7,072.88	19.43	4.11	8.23
13	2	6	12	3	384	0.31	1,817.25	10,609.32	17.13	3.76	11.27
14	2	8	16	4	288	0.29	2,213.82	14,145.76	15.65	3.55	14.21
15	2	12	24	6	192	0.31	2,984.44	21,218.64	14.07	3.29	19.75
16	2	16	32	8	144	0.30	3,700.17	28,291.51	13.08	3.14	25.15
17	3	1	3	0.75	1,536	0.17	759.08	2,652.33	28.62	5.42	4.06
18	3	2	6	1.5	768	0.19	1,150.51	5,304.66	21.69	4.49	6.74
19	3	3	9	2.25	512	0.27	1,492.18	7,956.99	18.75	4.02	9.05
20	3	4	12	3	384	0.29	1,810.00	10,609.32	17.06	3.76	11.28
21	3	6	18	4.5	256	0.29	2,406.52	15,913.98	15.12	3.47	15.64
22	3	8	24	6	192	0.33	2,924.16	21,218.64	13.78	3.23	19.39
23	3	12	36	9	128	0.38	3,997.96	31,827.95	12.56	3.00	27.01
24	3	16	48	12	96	0.40	4,953.57	42,437.27	11.67	2.84	34.10
25	4	1	4	1	1,152	0.15	870.34	3,536.44	24.61	4.91	4.91
26	4	2	8	2	576	0.15	1,285.78	7,072.88	18.18	4.01	8.02
27	4	3	12	3	384	0.23	1,642.98	10,609.32	15.49	3.57	10.70
28	4	4	16	4	288	0.27	1,979.54	14,145.76	13.99	3.31	13.24
29	4	6	24	6	192	0.31	2,607.00	21,218.64	12.29	3.01	18.05
30	4	8	32	8	144	0.45	3,062.59	28,291.51	10.83	2.66	21.26
31	4	12	48	12	96	0.40	4,266.97	42,437.27	10.05	2.57	30.86
32	4	16	64	16	72	0.44	5,245.03	56,583.03	9.27	2.40	38.46
33	6	1	6	1.5	768	0.19	1,160.61	5,304.66	21.88	4.52	6.78
34	6	2	12	3	384	0.18	1,757.91	10,609.32	16.57	3.76	11.28
35	6	3	18	4.5	256	0.30	2,239.05	15,913.98	14.07	3.30	14.85
36	6	4	24	6	192	0.28	2,755.40	21,218.64	12.99	3.15	18.88
37	6	6	36	9	128	0.35	3,592.20	31,827.95	11.29	2.82	25.37
38	6	8	48	12	96	0.45	4,313.68	42,437.27	10.16	2.54	30.50
39	6	12	72	18	64	0.41	5,948.10	63,655.91	9.34	2.44	43.97
40	6	16	96	24	48	0.49	7,316.55	84,874.54	8.62	2.25	53.92
41	8	1	8	2	576	0.22	1,421.07	7,072.88	20.09	4.25	8.51
42	8	2	16	4	288	0.18	2,120.38	14,145.76	14.99	3.51	14.06
43	8	3	24	6	192	0.27	2,749.93	21,218.64	12.96	3.15	18.89
44	8	4	32	8	144	0.27	3,357.60	28,291.51	11.87	2.97	23.74
45	8	6	48	12	96	0.35	4,351.73	42,437.27	10.25	2.64	31.72
46	8	8	64	16	72	0.48	5,197.48	56,583.03	9.19	2.35	37.65

Table 2. Contd.

47	8	12	96	24	48	0.43	7,196.32	84,874.54	8.48	2.27	54.56
48	8	16	128	32	36	0.46	8,959.49	113,166.06	7.92	2.15	68.68
49	12	1	12	3	384	0.27	1,907.57	10,609.32	17.98	3.91	11.74
50	12	2	24	6	192	0.23	2,923.34	21,218.64	13.78	3.30	19.82
51	12	3	36	9	128	0.38	3,754.72	31,827.95	11.80	2.88	25.88
52	12	4	48	12	96	0.28	4,787.48	42,437.27	11.28	2.86	34.33
53	12	6	72	18	64	0.36	6,196.34	63,655.91	9.73	2.54	45.77
54	12	8	96	24	48	0.51	7,436.41	84,874.54	8.76	2.25	53.97
55	12	12	144	36	32	0.45	10,270.23	127,311.81	8.07	2.18	78.65
56	12	16	192	48	24	0.49	12,840.42	169,749.08	7.56	2.06	98.66
57	16	1	16	4	288	0.30	2,441.42	14,145.76	17.26	3.79	15.15
58	16	2	32	8	144	0.28	3,757.95	28,291.51	13.28	3.19	25.56
59	16	3	48	12	96	0.39	4,939.36	42,437.27	11.64	2.85	34.14
60	16	4	64	16	72	0.31	6,293.07	56,583.03	11.12	2.82	45.06
61	16	6	96	24	48	0.38	8,277.47	84,874.54	9.75	2.53	60.75
62	16	8	128	32	36	0.52	9,980.21	113,166.06	8.82	2.25	72.05
63	16	12	192	48	24	0.47	13,943.53	169,749.08	8.21	2.19	105.10
64	16	16	256	64	18	0.48	17,523.77	226,332.11	7.74	2.10	134.21

X_R: adjacent BEU to the row; X_C: adjacent BEU to the column; n: number of BEU with size of X BEU (n=4,608/X).

In larger plots due to the increase of BEU sizes (X, in BEU), decrease of coefficient of variation (CV) values occurred and consequently improvements in the experimental inferences. Whereas with small increments in BEU size (X, in BEU), significant gains in precision occurs, that is, reduction of CV and a tendency to stabilize these gains with the increase in the BEU dimensions (Figure 1). In potato, the Xo obtained in uniformity trials is more influenced by the coefficient of variation value among the plots of one BEU than by the yield heterogeneity index (Oliveira et al., 2006).

With the increase of BEU sizes (X, in BEU), there was a reduction of the optimum plot size (Xo, in BEU) with power model pattern (Figure 1) oscillating between 8.16 and 2.37BEU for sowing date 1 and between 7.31 and 2.06 BEU for sowing date 2 (Tables 1 and 2). However, the optimum plot size (Xo, in m^2) increased linearly with the increase of BEU sizes (X, in BEU) (Figure 1) oscillating between 5.30 and 18.24 m^2 for sowing date 1 and between 16.34 m^2 and 4.60 for sowing date 2 (Tables 1 and 2).

Thus, it can be inferred that the optimum plot size for the evaluation of fresh matter of sunn hemp depends on the BEU size, in agreement with the study performed by Oliveira et al. (2005). These authors verified the effect of BEU size (1, 2, 3, 4, 6, 8, and 12 planting holes) on the optimum plot size estimated by the method of the modified maximum curvature (Meier and Lessman, 1971). For white lupine (*Lupinus albus* L.), fresh matter was evaluated in three sowing dates in 432BEU of 1 m^2 for each sowing date, with the formation of 16 plans with BEU sizes ranging from 1 to 16 m^2. In this way, the authors concluded that the estimate of the optimum plot size depends on the BEU size and indicated the evaluation of fresh matter in BEU size as small as possible to be used in the estimation of the optimum plot size (Cargnelutti Filho et al., 2016a).

In forage turnip, in order to verify the influence of BEU size on the estimate of the optimum plot size for fresh matter based on 3,456 BEU of 0.5 × 0.5 m, by the method of the maximum curvature of the coefficient of variation model, Cargnelutti Filho et al. (2016b) stated that the optimum plot size depends on the BEU size and the evaluation of fresh matter should be performed in basic experimental units as small as possible.

In these studies, the authors concluded that the BEU size affects the estimate of the optimum plot size. Thus, it can be concluded that the BEU size should be as small as possible for not overestimating the optimum plot size, as the optimum plot size is influenced by the uniformity trial size (Storck et al., 2006b). However, the uniformity trial size of potato measured in number of planting holes does not affect the estimate of the optimum plot size (Storck et al., 2006b).

Both the BEU size as the variation between plots and the experimental area heterogeneity are determining factors in estimating the optimum plot size by the method of Paranaíba et al. (2009a). The method is dependent on the BEU size and the variability existing among BEU. Therefore, it is important to consider these factors

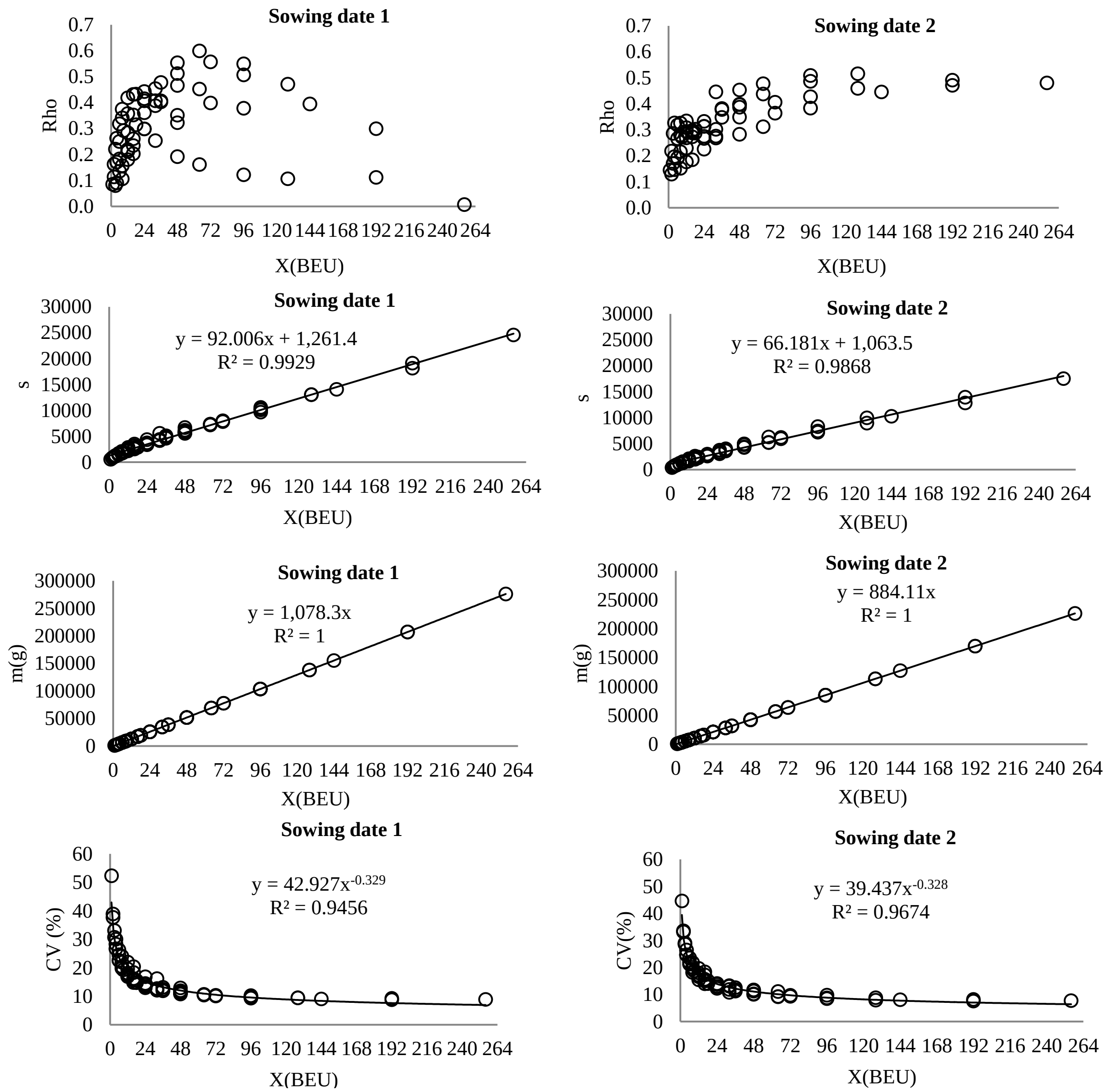

Figure 1. Relations between the dependent variables first order spatial autocorrelation coefficient (ρ), standard deviation (s), mean (m), coefficient of variation of the trial (CV, in %), optimum plot size (Xo, in BEU) and optimum plot size (Xo, in m^2) with the independent variable BEU size (X, in BEU) for fresh matter of sunn hemp (*Crotalaria juncea* L.) in g 0.25 m^{-2} evaluated in the first (Sowing date 1) and second (Sowing date 2) sowing date.

together, besides the possible limitations of the experimental area, financial costs for evaluations, and the definition of the plot size in X BEU for planning experiments with sunn hemp.

Conclusions

The estimate of the optimum plot size for the evaluation of fresh matter of sunn hemp (*C. juncea* L.) estimated by the method of maximum curvature of the coefficient of variation model depends on the size of the basic experimental unit. Determining the plot size to assess the fresh matter in basic experimental units as small as possible is recommended in order to prevent overestimation of the plot size and to contemplate all existing variability.

ACKNOWLEDGEMENTS

The authors thank the Brazilian National Council for

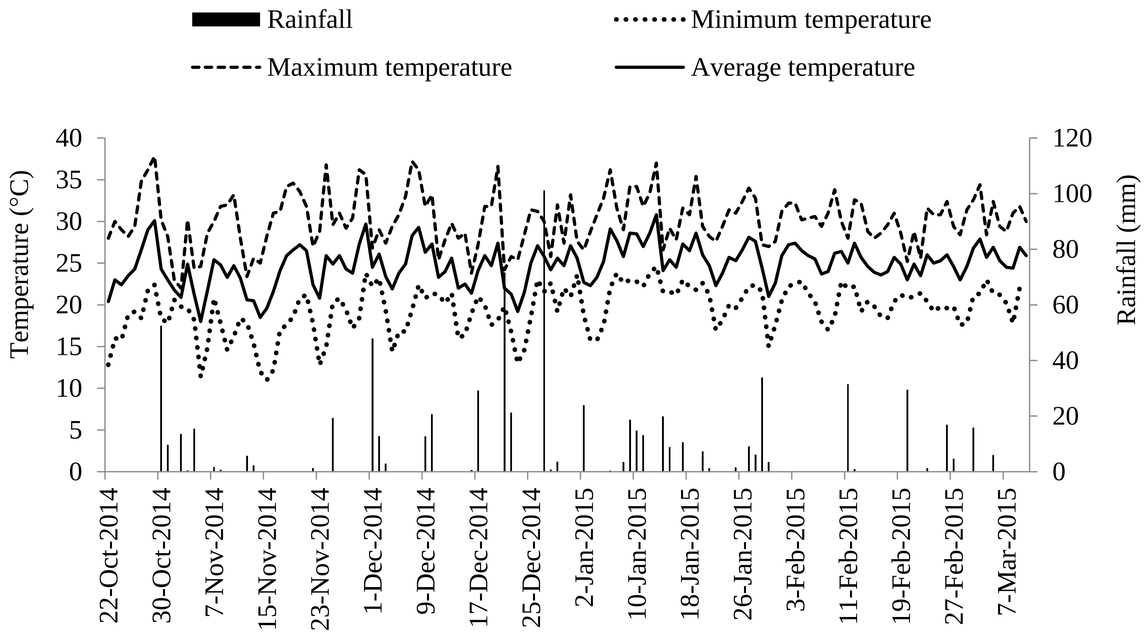

Figure 2. Minimum, maximum and mean daily air temperatures (°C) and rainfall (mm).

Scientific and Technological Development (CNPq) and the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting them scholarships. They appreciate the Rio Grande do Sul Research Foundation (FAPERGS) for the financial aid and the students for their help in data collection.

Conflict of interests

The authors have not declared any conflict of interest.

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academicJournals

Vol. 12(6), pp. 424-428, 9 February, 2017
DOI: 10.5897/AJAR2016.11565
Article Number: 2B6CD7C62687
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Climatization for scheduled ripening of caja-manga

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Received 16 August, 2016; Accepted 15 September, 2016

Being a climacteric fruit, the caja harvested still green has uneven ripening. Thus, the aim of this study was to evaluate the effect of ripening techniques aiming to promote a uniform ripening and reduction of quality loss in caja-manga fruits. The treatments resulted from the application of four ripening techniques (control, muffled, ethrel, and calcium carbide) and they were evaluated in 5 times, with 3 days intervals, for 12 days (0, 3, 6, 9, and 12 days). The fruits were evaluated physico-chemically with respect to soluble solids, titratable acidity, ratio, firmness, and color. Although, all treatments promoted the fruit ripening, ethrel showed homogenous and consistent fruit characteristics with ripening reactions in 6 days, being considered the best treatment. It showed intense yellow color (85 Hue), weight loss of about 5% compared to other treatments and tissue softening (29 N firmness) and increase in soluble solids (Brix 11°).

Key words: *Spondias mombin* L., exotic fruits, Ethrel, carbide.

INTRODUCTION

The caja-manga (*Spondias dulcis*) originating in French Polynesia and inserted in Brazil by the northeast region has attracted researchers and food processing industries, mainly because of its taste and innovative aspect, besides bioactive compounds as antioxidant capacity, presence of vitamins and carotenoids (Vanzela et al., 2011; Barreto et al., 2009).

This fruit is considered exotic, tropical, climacteric and it is mainly grown in the Brazilian North and Northeast. It has ellipsoid shape of drupe type with seeds provided with rigid and spinescent fibers that partially plunge in the pulp. The pulp is juicy, bittersweet and strongly aromatic, being highly appreciated in natura. It contains about 72.6 to 78% of moisture, 0.35 to 0.53% of fat, 0.25 to 1.2% of protein, 0.7% of ashes, 17.8% of carbohydrates, 1.5% of fiber, 1.2% of pectin, 9.3% of reducing sugar, and 5.0 to 13.1% of soluble solids (Vanzela et al., 2011; Donadio, 2000; Lorenzi et al., 2006). To supply the market demands, the climacteric fruits such as caja-manga should be harvested at physiological maturity, because

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when they are harvested at advanced maturity, it is hard to keep them conserved (Kader, 2002). However, when caja-manga is harvested before its point of consumption, it ripens unevenly and quickly and, in this case, there is also the possibility of significant losses. Aiming the lots homogenization and the scheduled ripening of the fruit, the climatization process has been adopted for post-harvest conservation of fruits and vegetables.

The fruit climatization can be performed with various active ingredients such as calcium carbide and exogenous ethylene. The moistened calcium carbide releases acethylene in the environment which is analogous to ethylene and can cause similar physiological effect on the plant tissues leading to a more uniform ripening (Bisognin et al., 2007). Another alternative is the use of ethephon (2-chloroethylphosphonic acid), which releases exogenous ethylene and increases the intensity and/or anticipate the fruit respiratory peak during the ripening (Nogueira et al., 2007). An effect that is biologically similar to the application of exogenous ethylene is the smothering technique of climacteric fruits. As it is a volatile gas, the ethylene released by the fruit is accumulated in the atmosphere. This high ethylene concentration will then act in the ripening of fruits which are muffled (Chitarra and Chitarra, 2005).

In view of what has been exposed, the aim of this study was to evaluate the effect of exogenous application of calcium carbide, ethrel and smothed technique on ripening of caja-manga and their effects in physical and chemical traits typical of fruit ripening.

MATERIALS AND METHODS

At Jabuticabal Farm and Winery, in Nova Fatima, Hidrolandia-GO, located at 16° 55'32.35 "south latitude and 49° 21'39.76 "west longitude, 180 unripe caja-manga fruits were harvested with about 56 cm and no imperfections. The fruits were washed and sanitized with sodium hypochlorite (200 ppm) for removing surface dirt and microbial contamination, and they were dried at room temperature.

The experiment was conducted in a completely randomized design (CRD) in split plot, with four ripening climatization techniques (control, muffled, fruit spraying with ethrel and ripening chamber with exposure to carbide), evaluated in 5 times, at 3 days intervals (0, 3, 6, 9, 12 days) for 12 days, at 20°C in a climatized room with four replications of three fruits.

For the treatment with Ethrel® (with Ethephon as the active ingrediente), fruits were sprayed with a mixture of 750 mg of the product and 100 L of water, 25 ml syrup were sprinkled to cover all parts of fruit. These fruits were dried at room temperature and armezandos in box. For the muffled treatment, the cardboard boxes containing fruits were wrapped in plastic bags (Polysack black polyethylene of 100 μ thick). The treatment with carbide was performed in a ripening chamber, solubilizing a portion of 160 $g.m^{-3}$ in water. The product was vaporized and a proper atmosphere within the chamber was created.

At the harvest day, experiment assembly and during 12 days with 3-day intervals, the fruits were analyzed for firmness, expressed in Newton (N) with the aid of texturometer using a probe which measured the penetration force in the fruit at a speed of 7 mm s^{-1} and 8 mm of penetration distance (those values were previously set and obtained by pre-testing). Regarding the soluble solids, readings of degrees Brix of the sample were made at 20°C in a digital refractometer (Atago N-1E). The total acidity was determined by titration with sodium hydroxide (NaOH) solution 0.1 N (AOAC, 2010). The soluble solids (SS) and titratable acidity (TA) were used to determine the maturation ratio-index (SS/TA). The color determination was performed at two equidistant points of the fruit, by reading three parameters defined by the CIELAB system, L*, a* and b* supplied by the colorimeter (Hunterlab, ColorQuest II). These parameters were used to calculate the Hue angle.

After being subjected to the test Cochran (homoscedasticity) and Lilliefors (data normality), the data were analyzed by variance analysis, Tukey test (qualitative factor) and regression (quantitative factor) at a significance level of 5% of probability.

RESULTS AND DISCUSSION

The ethrel treatment stood out regarding most parameters, which is an indicative of an uniform ripening, promoting lower firmness, higher TSS, higher brightness of the peel and consistente peel and pulp° h. The remaining climatization treatments had results that indicate uneven ripening treatment. Although, the carbide treatment resulted in a similar acidity to the ethrel treatment, and smaller weight loss, also resulted in lower soluble solids, and higher° h pulp. The smothering and control treatments resulted in very similar parameters and that also expresses an uneven ripening. The fruits remained firm, despite the weight loss was very representative (Table 1).

The time of storage (days) was significant for all parameters, which is very important since it is known that climacteric fruits such as caja suffer changes from the moment that they are detached from the mother plant. At twelve days, most parameters stood out and showed the best fruit ripening stage.

The interaction between time of storage and climatization ocurred for most parameters, with the exception of titratable acidity, ratio, and for pulp color. Evaluating the significant factors, it was observed that the firmness was influenced by the storage time and for climatization treatments. On average, at day 0, the fruits were with 87 N of firmness, which is typical for completely unripe fruits however, that during the experiment, fruits under ethrel effect lost firmness on the second day of evaluation before the other treatments (Table 2). After 12 days of evaluation, in all treatments, the fruits had the firmness reduced, fruits under the influence of carbide and muffled took longer to lose firmness, its happened from the 9th day on.

The firmness that is measured by a texturometer is based on the tissue collapse that is measured by the resistance to a force or stress. It is one of the most common physicochemical parameters to evaluate the progress of tissue softening that is peculiar of the fruit ripening process. In general, loss of firmness of the fruit during storage occurs primarily due to changes protopectins water-insoluble in water-soluble (Harker et al., 1997).

Table 1. Total titratable acidity (TTA), fruit firmness, weight loss (WL), totaloluble solids (TSS), Ratio, peel and pulp Angle Hue of caja manga fruits, due to climatization treatment and storage time.

Factor	TA (g/100 g citric acid)	Firmness (N)	WL (g)	SS (°Brix)	Ratio	Peel Hue (ºhue)	Pulp Hue (°hue)
Climatization(C)							
Control	0.72^{a}	77.62^{a}	5.37^{a}	9.50^{ab}	13.71^{b}	88.16^{b}	86.32^{bc}
Muffling	0.64^{b}	70.58^{a}	5.77^{a}	9.08^{bc}	14.37^{ab}	91.04^{ab}	88.11^{ab}
Calcium Carbide	0.64^{ab}	77.93^{a}	4.27^{b}	8.50^{c}	13.73^{b}	92.80^{a}	88.32^{a}
Ethrel	0.64^{ab}	47.27^{b}	5.31^{a}	10.24^{a}	16.68^{a}	87.74^{b}	85.43^{c}
F Climatization	3.45*	28.18**	7.92**	13.41**	4.22*	5.31**	5.05**
Periods							
0	0.65	87.74	0.00	8.27	12.74	98.16	85.29
3	0.47	91.43	1.84	8.22	17.75	98.13	88.27
6	0.60	71.08	4.04	8.97	15.17	92.53	87.33
9	0.72	53.37	7.90	9.86	14.07	83.43	86.44
12	0.85	40.15	12.08	11.32	13.39	77.40	87.91
F Periods (P)	37.45**	53.91**	36.71**	33.39**	6.60**	62.88**	5.05**
C×D	0.77^{ns}	4.26**	3.53**	6.33**	1.71^{ns}	5.72**	1.62^{ns}
CV (%)	12.01	15.43	17.03	8.33	12.13	4.49	2.13

Regression: Titrable acidity $y = 0.0048x^2 - 0.0364x + 0.6151$; $R^2 = 0.866$**; ratio $y = -0.0786x^2 + 0.8635x + 13.686$; $R^2 = 0.4898$; pulp Hue $y = -0.0057x^2 + 0.2572x + 85.363$; $R^2 = 0.7489$. C×D interaction among factors.

Table 2. Total Soluble Solids, fruit firmness, weight loss, peel and pulp Hue angle of cajá-manga fruits due to climatization treatments and storage time.

	Total soluble solids				Firmness			
	Control	Muffling	Carbide	Etrhel	Control	Muffling	Carbide	Etrhel
0	8.28^{a}	8.28^{a}	8.28^{a}	8.28^{a}	87.74^{a}	87.74^{a}	87.74^{a}	87.74^{a}
3	8.00^{b}	7.33^{b}	7.53^{b}	10.03^{a}	102.05^{a}	95.34^{a}	98.98^{a}	69.34^{b}
6	8.33^{b}	7.67^{b}	8.57^{b}	11.33^{a}	87.22^{a}	88.34^{a}	75.70^{a}	33.06^{b}
9	9.50^{ab}	11.07^{a}	8.53^{b}	10.37^{a}	63.35^{bc}	50.52^{b}	75.33^{a}	16.29^{c}
12	13.40^{a}	11.07^{b}	9.60^{b}	11.23^{b}	47.77^{a}	30.95^{a}	51.92^{a}	29.93^{a}

Regressions (Total soluble solids):
Control $y= 0.0729x^2 – 0.4833x + 8.4645$, $R^2 = 0.9758$;
Muffling $y= 0.0393x^2 – 0.1613x + 7.9264$, $R^2 = 0.7674$;
Carbide $y = 0.1216x + 7.772$, $R^2 = 0.6047$;
Ethrel $y= -0.0321x^2 + 0.5937x + 8.4207$, $R^2 = 0.832$.

Regressions (Firmness):
Control $y= 0.5463x^2 + 2.6006x + 91.522$, $R^2 = 0.9257$;
Muffling $y= -0.6758x^2 + 2.8293x + 90.093$, $R^2 = 0.9472$;
Carbide $y= -0.3682x^2 + 1.2418x + 90.365$, $R^2 = 0.8649$;
Ethrel $y= 0.6634x^2 - 13.583x + 92.948$, $R^2 = 0.9322$

No.	Weight loss				Peel hue			
	Control	Muffling	Carbide	Etrhel	Control	Muffling	Carbide	Etrhel
0	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	98.16^{a}	98.16^{a}	98.16^{a}	98.16^{a}
3	3.26^{a}	1.16^{b}	1.07^{b}	2.01^{ab}	99.99^{a}	100.68^{a}	99.39^{a}	92.48^{a}
6	4.02^{a}	3.97^{a}	3.18^{a}	5.02^{a}	78.14^{b}	93.36^{a}	99.64^{a}	98.98^{a}
9	7.98^{ab}	9.27^{a}	6.81^{b}	7.55^{ab}	86.42^{a}	84.99^{a}	87.47^{a}	74.84^{b}
12	11.59^{b}	14.48^{a}	10.29^{b}	11.99^{b}	78.08^{a}	78.02^{a}	79.24^{a}	74.24^{a}

Regressions (Weight loss):
Control $y= 0.9301x – 0.2106$, $R^2 = 0.9656$;
Muffling $y= 1.2355x – 1.6382$, $R^2 = 0.942$;
Carbide $y= 0.8776x – 0.9954$, $R^2 = 0.9573$;
Ethrel $y= 0.9841x – 0.5916$, $R^2 = 0.9812$

Regressions (Peel hue):
Control $y= -1.7911x + 98.904$, $R^2 = 0.6487$;
Muffling $y= -1.8651x + 102.23$, $R^2 = 0.882$;
Carbide $y= -1.6582x + 102.73$, $R^2 = 0.7475$;
Ethrel $y= -2.182x + 100.83$, $R^2 = 0.7075$

^{a,b}Means followed by the same letter on the same line do not differ significantly.

The faster effect of ethylene compared to the other treatments, regarding firmness, can be attributed to the ethylene function in regulating the activity related to the tissue softening metabolism (Chitarra and Chitarra, 2005; Jeong et al., 2003). And this suggests an increase in the activity of softening enzymes, as celulase and polygalacturonase, also regulated by the action of ethylene (Chitarra and Chitarra, 2005; Lohani et al., 2004). However, all the treatments promoted fruit ripening.

Calcium carbide and ethephon anticipated changes and also unified the physicochemical characteristics of mangos, including pulp firmness (Zeitschriften, 2009). Firmness loss in cajá-manga fruits during storage and noted that at room temperature the rate of firmness loss is higher because there is a higher proximity to the optimum action temperature of pectinolytic enzymes, similar to this study that was performed at 20°C (Kohatsu et al., 2011).

Similar to the loss of firmness, the fruits under ethre treatment lost mass faster than the others; this loss was more intense from day 6 on (Table 2), showing that the storage time was a significant factor for firmness as well as the climatization. For the other treatments, the losses were more significant only in the last days of evaluation, from the 9th day on for the smothering treatment and from the 12th for the control and carbide treatments.

The weight loss of the fruit during storage is due to water loss, especially because of the transpiration promoted by the pressure deficit between the fruit and the environment, and in this case, due to the low natural humidity. Fruits have independent lives when they are removed from the mother plant and use their own reserves of substrates that were accumulated during their growth and maturation, with consequent progressive depression in accumulated dry matter reserves, thus causing weight losses (Taiz and Zeiger, 2009).

It was noted that the weight loss increased linearly after mango treatment with ethrel and carbide (Silva et al., 2012). Moisture losses for vegetables in the order of 3 to 6%, as occurred in this study are enough to cause a marked decrease in quality. However, in resistant products, such as caja-manga, they are still traded with up to 10% of moisture losses (Chitarra and Chitarra, 2005).

The loss of water by transpiration, besides causing weight loss can greatly contribute to the increase of the concentration (or apparent concentration) of other water-soluble compounds, such as total soluble solids. Initially, the average for the total soluble solids content in fruits was 8.27° Brix. After being treated with ethrel they had a significant increase in this content in the first six days (11.33° Brix) which confirms the relation water loss × apparent increase of soluble compounds which occurred concomitantly on this treatment (Table 2). Storage time and each climatization treatment were significant for the soluble solids.

The control treatment had an TSS peak only at the end of the experiment (13.40° Brix) when there was also the largest weight loss (Table 2). Regarding the beginning of the experiment, all treatments had an increase in TSS, which is a typical characterisctic of fruit ripening.

The TSS in fruits, however, does not increase the apparently during ripening, because the starch content converted into simple sugars provide the increase in levels of total sugars, non-reducing sugars and total soluble solids. In this process, the amylase enzyme is the main one responsible for the result of starch hydrolysis in oligosaccharides (Watada, 1986).

The soluble solids content is a critical factor in determining the quality and consumer acceptability in vegetables and fruits, because it is related to sweetness as has been reported by Crisoto and Crisoto (2005) and Lopez et al. (2011). In caja-manga, this factor is essential to balance the acidity of the fruit.

The acidity of all the fruits in all treatments increased until the end of the twelve days of experiment (Table 2) and was significant regarding the storage time and the climatization factor. Although, it is not very common, the titratable acidity values may increase, probably due to the formation of galacturonic acid that is derived from pectins degradation, which usually occurs when the fruits are harvested unripe, or more commonly, decrease due to the respiratory process or the conversion into sugar (Silva, 2009; Samson, 1986). These changes have important role in the fruit flavor characteristics. The Identity and Quality Standards (IQS) to cajá pulps stipulates minimum values of total acidity of 0.9 g 100 g^{-1}, consistent with the acidity results in this study (Brasil, 1999). The fruits from the control treatment had the highest values of acidity at the end of the experiment.

The ratio is the relation between the soluble solids (°Brix) and titratable acid content and it was significant for days and climatization factors. It is the indicator used to determine the stage of maturation, determining the balance of sweet: acid flavor. The ethrel treatment was the one that changed the ratio range during the evaluation period with an average of 16 compared to 13 of the other treatments.

Regarding the color, there are some authors who relate °*h* with firmness loss and the autocatalytic production of ethylene. It was noted that, in general, the color changed from a light yellow (whitish) for a more intense yellow, nearing 90° h at the end of the evaluations for all treatments (Table 2). In this study, there is also a correlation between the loss of firmness with the Hue angle. It was noted that for the ethrhel treatment, there was a more intense and uniform modification in color from the 6th day of evaluation, which was earlier than for the more other treatments. The same was observed for firmness loss. This change in coloration, demonstrates that the ripening reactions are not only catabolic. Some plant organs use the energy released by respiration to continue the synthesis of pigments, enzymes and other elaborate molecular structure materials as soon as they are detached from the plant. These syntheses are an essential part of many fruits ripening process, as in this study.

Conclusion

Conclusively, the ethrel treatment is the best option to promote uniform ripening in cajá-manga fruits. It is possible for caja-manga to be harvested unripe avoiding further damage and then be treated with ethrel to foster the development in the desired time.

Conflit of interests

The authors have not declared any conflict of interests.

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academicJournals

Vol. 12(6), pp. 429-434, 9 February, 2017
DOI: 10.5897/AJAR2016.11060
Article Number: 0029D1D62691
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Mathematical analysis of morphological traits and their effects on body weight in the red crab (*Charybdis feriata*)

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Received 29 March, 2016; Accepted 14 December, 2016

The red crab (*Charybdis feriata*) is one of most important fishery resource in China. In the present study, 17 morphological traits and body weight of *C. feriata* were first measured and 18 traits were characterized, and then, the effects of morphological traits on body weight were estimated by statistical methods including correlation coefficients, determination coefficients, path coefficients and regression equations. All correlation coefficients between each morphological trait and body weight reached an extremely significant level (*P*<0.01). Determination and path coefficients analysis revealed the real correlation between the independent variables and the dependent variable. Significant path coefficients were found between three morphological traits (stemum width, X_8; meropodite length of pereopod 3, X_{16}; meropodite length of pereopod 4, X_{17}) and body weight, suggesting these three traits were the key factors directly influencing body weight. Multiple correlation index (R^2) between the above three morphological traits and body weight was of 0.977, which indicated that the main independent variables influencing body weight had been found. Finally, a best-fit linear regression equation was established as $Y = 13.078\ X_8 + 7.048\ X_{16} - 4.902\ X_{17} - 576.635$, which provided an ideal model for better understanding of the feature of morphological traits and body weight of *C. feriata*.

Key words: *Charybdis Feriata*, morphological traits, correlation analysis, path analysis, regression analysis.

INTRODUCTION

Morphological trait is an essentially basic index for artificial breeding and seedling propagation. Body weight is a direct reflection of production performance, so it is always one of the main target traits for selection in aquaculture (Liu et al., 2004; Dong et al., 2007). However, the measurement of body weight not only needs special weighing apparatus, but also needs certain operating environmental condition. In contrast, it is easier to

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accurately measure the morphological traits. Recently, published literatures have already showed that the correlation between morphological traits and body weight can be clarified by multivariate analysis and path analysis in *Penaeus vannamei* (Liu et al., 2004), *Eriocheir sinensis* (Geng et al., 2007), *Micropterus salmoides* (He et al., 2009), *Charybdis japonica* (Song et al., 2010) and *Scylla paramamosain* (Ma et al., 2013). Accordingly, the goal of selective breeding could be reached through selection of morphological traits.

The red crab (*Charybdis feriata*) is a large size marine crab with high economic value, mainly distributed in coastal regions of southeastern sea of China (Wu, 2002; Yu et al., 2005; Huang, 2006). It is very popular in consuming market due to the growth speed, survival rate and flesh flavor. In the last decades, studies on *C. feriata* mainly focused on fisheries resources (Abello and Hispano, 2006; Sakthivel and Fernando, 2012), reproduction biology (Parado-Estepa et al., 2007; Josileen, 2011), and molecular phylogeny (Ma et al., 2015). Recently, multivariate analysis has been widely applied to scheme optimization of aquaculture and estimation of production (Liu et al., 2004; Song et al., 2010; Geng et al., 2007; Wang et al., 2008a; Gao et al., 2008; Yang et al., 2011; Deng et al., 2012). However, little information is available on the feature of morphological traits and their effects on body weight of *C. feriata* that has severely limited the understanding of growth characteristics and further studies such as conservation genetics and artificial selective breeding for *C. feriata.*

The morphological traits and body weight of *C. feriata* are important selective criteria for artificial selection and reproduction, of which, in practice, body weight is considered an essential trait for growth performance. Therefore, the purpose of this study was to characterize the morphological traits, and determine their effects on body weight of *C. feriata*, so that it could lay a foundation for better understanding of the morphological traits and body weight, and provide meaningful information for artificial selective breeding for *C. feriata*.

MATERIALS AND METHODS

Samples

Twenty-seven wild adults of *C. feriata* were randomly purchased from Tanmen Port Market, Hainan Province of China in November 2012. All of them were brought to Qionghai Research Center for measurement and analysis.

Measurement of morphological traits and body weight

A total of 17 morphological traits were measured by using a vernier caliper (accurate to 0.001 mm). These traits included body height (BH, X_1), carapace length (CL, X_2), carapace width (CW, X_3), internal carapace width (ICW, X_4), carapace width at spine 6 (6CW, X_5), carapace frontal width (FW, X_6), posterior carapace width (PWC, X_7), stemum width (SW, X_8), abdomen width (AW, X_9), fixed finger length of the claw (PL, X_{10}), fixed finger height of the claw (PD, X_{11}), fixed finger width of the claw (PW, X_{12}), dactylus length of the claw (DL, X_{13}), meropodite length of the claw (ML, X_{14}), meropodite length of pereopod 2 (2PML, X_{15}), meropodite length of pereopod 3 (3PML, X_{16}), and meropodite length of pereopod 4 (4PML, X_{17}). Body weight (Y) was measured using an electronic scale (accurate to 0.001 g).

Statistical analysis

The mean value and standard deviation of each trait were calculated using the software SPSS version 18.0. The coefficient of variation (CV) of each trait was estimated using the following formula: CV = (standard deviation/mean) × 100%. Path analysis was carried out as described by Du and Chen (2010). Correlation analysis and multiple regression analysis were also performed using SPSS 18.0. Multiple regression equation was constructed as follows: $Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3$, where Y is the dependent variable, X_1, X_2 and X_3 are the independent variables, b_0 is the constant, and b_1, b_2, and b_3 are the partial regression coefficients for Y. The determination coefficient was calculated using the alternative formulas: $d_i = P_i^2$ and $d_{ij} = 2r_{ij} \times P_i \times P_j$, where d_i is the effect of a single trait i on body weight, d_{ij} is the effect of traits i and j on body weight, P_i is the path coefficient of the single trait i to body weight, r_{ij} is the correlation coefficient between traits i and j, and P_j is the path coefficient of the single trait j to body weight.

RESULTS

Correlation relationships of 18 traits

The statistics of measured data of 17 morphological traits and body weight are listed in Table 1. Among 18 traits, the largest standard deviation (SD = 83.097) was detected in body weight, while the lowest one was present in morphological trait PW. The coefficient of variation of body weight was also the largest one (CV = 29.38%), whereas the lowest one was observed in morphological trait PWC.

The correlation coefficients of 18 traits in *C. feriata* are shown in Table 2. All phenotypic correlations between morphological traits and body weight reached an extremely significant level ($P < 0.01$) which indicated that the conduction of correlation analysis between morphological traits and body weight is practically meaningful. The size order of correlation coefficients (r) were as follows: $X_8Y > X_5Y > X_4Y > X_3Y > X_7Y > X_1Y > X_{10}Y > X_6Y > X_{16}Y > X_2Y > X_{12}Y > X_{17}Y > X_{14}Y > X_{15}Y > X_9Y > X_{11}Y > X_{13}Y$. Moreover, significant correlations were identified between morphological trait-pairs what suggested the existence of linear correlation among these traits.

Path analysis of morphological traits on body weight

Path coefficient of each morphological trait on body weight was calculated based on the principle of path

Table 1. The descriptive statistics of morphological traits and body weight in *C. feriata*.

Trait	Mean value	Standard deviation	Coefficient of variation (%)
BW (g)	282.819	83.097	29.382
BH (mm)	45.290	5.057	11.167
CL (mm)	73.302	9.513	12.978
CW (mm)	114.549	11.123	9.710
ICW (mm)	107.104	10.670	9.962
6CW (mm)	107.158	10.393	9.698
FW (mm)	39.683	3.729	9.398
PWC (mm)	37.563	3.467	9.231
SW (mm)	58.516	5.582	9.540
AW (mm)	42.523	9.051	21.284
PL (mm)	92.066	11.394	12.376
PD (mm)	28.315	3.706	13.090
PW (mm)	19.687	3.015	15.315
DL (mm)	45.691	7.404	16.205
ML (mm)	57.608	7.693	13.354
2PML (mm)	41.397	5.035	12.163
3PML (mm)	38.825	3.994	10.287
4PML (mm)	36.616	3.681	10.053

analysis. After a test of significance, three morphological traits including SW, 3PML and 4PML were retained, because their path coefficients reached a significant level (0.879, 0.339 and -0.217). Besides, those morphological traits with insignificant path coefficients were removed in the next analysis. Path coefficients reflected the direct influence of independent variables on dependent variables. Of the retained morphological traits, trait SW had the biggest direct influence on body weight, while 4PML had the negative effect on body weight.

Influence of morphological traits on body weight

According to composition effect, correlation coefficients can be divided into two parts including direct and indirect effects. From Table 3, we can see that three morphological traits showed effects on body weight. Trait SW, which had the largest correlation coefficient on body weight, also had the biggest direct effect (0.879) on body weight, whereas it had the smallest indirect effect (0.103) on body weight. The second biggest direct effect (0.339) on body weight was detected in trait 3PML, whose indirect effect was 0.517. Besides, direct effect of 4PML on body weight was negative (-0.217), but it has the largest indirect effect through other morphological traits (1.026) that has neutralized the negative effect. The multiple correlation coefficient (R^2) was 0.977 (higher than 0.85), indicating that morphological traits SW, 3PML and 4PML were the key factors influencing body weight in *C. feriata*. Table 4 shows the determination coefficients of morphological traits on body weight. Total sum of single determination coefficient and codetermination coefficient was 0.979; this number was equal to correlation coefficient (0.977) that indicated these three morphological traits are the main traits influencing body weight in *C. feriata*, while other traits had a relatively less influence on body weight. Data from Table 4 also showed that the determination degree of SW, 3PML and 4PML on body weight was 77.30, 11.50 and 4.70%, respectively. Further, SW and 3PML had the biggest codetermination coefficients (48.90%) on body weight.

Establishment of multiple regression equation

According to contribution rates of independent variables on body weight and the significance of standard partial regression coefficients, eight variables with insignificant influence on body weight and six variables (BW, CW, ICW, 6CW, PL and PWC) with colinearity to trait SW were excluded by using gradual regression method. Finally, a best-fit linear multiple regression equation, which took body weight as a dependent variable and SW, 3PML and 4PML as independent variables, was established as follows: $Y = 13.078 X_8 + 7.048 X_{16} - 4.902 X_{17} - 576.635$, where Y is body weight, X_8 is SW, X_{16} is 3PML and X_{14} is 4PML. The data listed in Table 5 indicated that the regression relation has reached an extremely significant level ($P < 0.01$). Meanwhile, significance tests showed that all partial regression coefficients have reached extremely significant level ($P<0.01$) (Table 6).

Table 2. The correlation coefficients among trait-pair in *C. feriata*.

Trait	BW (Y)	BH (X_1)	CL (X_2)	CW (X_3)	ICW (X_4)	6CW (X_5)	FW (X_6)	PWC (X_7)	SW (X_8)	AW (X_9)	PL (X_{10})	PD (X_{11})	PW (X_{12})	DL (X_{13})	ML (X_{14})	2PML (X_{15})	3PML (X_{16})	4PML (X_{17})
BW (Y)	1	0.927	0.847	0.972	0.975	0.979	0.861	0.943	0.981	0.765	0.907	0.757	0.825	0.72	0.782	0.774	0.855	0.809
BH (X_1)		1	0.83	0.924	0.919	0.922	0.847	0.938	0.914	0.794	0.82	0.793	0.817	0.659	0.728	0.644	0.747	0.682
CL (X_2)			1	0.865	0.868	0.87	0.768	0.827	0.844	0.697	0.787	0.675	0.747	0.719	0.635	0.659	0.692	0.695
CW (X_3)				1	0.996	0.996	0.885	0.96	0.978	0.812	0.922	0.795	0.838	0.77	0.769	0.742	0.813	0.796
ICW (X_4)					1	0.999	0.889	0.953	0.981	0.804	0.931	0.798	0.85	0.781	0.773	0.751	0.828	0.81
6CW (X_5)						1	0.892	0.954	0.981	0.801	0.931	0.793	0.845	0.775	0.774	0.757	0.835	0.808
FW (X_6)							1	0.853	0.844	0.739	0.82	0.868	0.714	0.701	0.646	0.653	0.77	0.709
PWC (X_7)								1	0.955	0.845	0.859	0.79	0.832	0.674	0.784	0.689	0.748	0.704
SW (X_8)									1	0.803	0.918	0.768	0.85	0.755	0.782	0.748	0.82	0.806
AW (X_9)										1	0.606	0.767	0.611	0.539	0.566	0.377	0.398	0.408
PL (X_{10})											1	0.743	0.877	0.814	0.8	0.807	0.908	0.893
PD (X_{11})												1	0.746	0.718	0.552	0.428	0.587	0.547
PW (X_{12})													1	0.702	0.749	0.669	0.748	0.721
DL (X_{13})														1	0.356	0.497	0.712	0.766
ML (X_{14})															1	0.793	0.732	0.677
2PML (X_{15})																1	0.856	0.779
3PML (X_{16})																	1	0.938
4PML (X_{17})																		1

DISCUSSION

Path analysis and selection of independent variables

Phenotypic correlation coefficient is a synthetical correlation between two morphological traits, which includes direct relation between them and indirect relation through other variables. Correlation analysis cannot comprehensively show the correlation relationship between variables, so the information it provides is only considered as a basis for multivariate analysis (Liu et al., 2004; Gao et al., 2008; Song et al., 2010). In this study, all phenotypic correlation coefficients between each morphological trait and body weight have reached significant or extremely significant level; nevertheless, it does not mean that each morphological trait has important effect on body weight. Similar phenomenon was observed in other animals such as *Strongylocentrotus intermedius* (Chang et al., 2012) and *Scylla paramamosain* (Jiang et al., 2014). This phenomenon is possibly because the interference of other variables was not excluded from the analysis. The essential independent variables which affect on body weight could not be identified only through phenotypic correlation analysis. So it is necessary to conduct path analysis to differentiate the effects of independent variables, and finally find out the main traits influencing body weight in *C. feriata*.

Path analysis can divide the total effects of independent variables on dependent variables into direct and indirect effects (De Rodriguez et al., 2001), and it can fully reflect the relative importance of independent variables on dependent variables. In general, an independent variable could be selected only when its phenotypic correlation coefficient reaches significant level to a dependent variable, otherwise, it should be excluded (Li et al., 2012).

Table 3. The effects of morphological traits on body weight in *C. feriata.*

Trait	Correlation coefficient	Direct effect	Indirect effect ($r_{ij} P_j$)			
			∑	SW	3PML	4PML
SW	0.981	0.879	0.103		0.278	-0.175
3PML	0.855	0.339	0.517	0.721		-0.204
4PML	0.809	-0.217	1.026	0.708	0.318	

Table 4. The determination coefficients of morphological traits on body weight in *C. feriata*.

Trait	SW	3PML	4PML
SW	0.773	0.489	-0.307
3PML		0.115	-0.138
4PML			0.047

Table 5. Analysis of variance of multiple regression equation in *C. feriata*.

Index	d.f.	Sum of squares	Mean squares	F value	*P* value
Regression	3	370708.190	123569.400	708.330	0.000
Residual	96	9071.492	174.452		
Total	99	379779.680			

Table 6. Partial coefficients test in *C. feriata*.

Parameter	Constant	SW (X_8)	3PML (X_{16})	4PML (X_{17})
Partial coefficient	-576.635	13.078	7.048	-4.902
t value	-29.898	23.060	5.200	-3.441
P value	0.000	0.000	0.000	0.000

In this study, the relationship between morphological traits and body weight was estimated. As a result, three independent variables including SW, 3PML and 4PML were found to have significant effects. Moreover, path coefficients are also the partial regression coefficients of standard variables in regression equation. Hence, the independent variables in optimal regression equation are equal to those selected in path analysis (Wang et al., 2008b). In the present study, the independent variables retained in above two analysis processes were the same morphological traits including SW, 3PML and 4PML.

Confirmation of morphological traits influencing body weight

In both path analysis and determination coefficient analysis, only when total sum of correlation index (R^2) is more than or equal to 0.85, can indicate that the main independent variables have been found (Liu et al., 2011). In this work, the codetermination coefficient of three independent variables (SW, 3PML and 4PML) was 0.977, suggesting 97.7% of variations of body weight in *C. feriata* are determined by these three morphological traits. While the rest 2.30% of variations are caused by undetected factors and the random errors. It also showed that these three morphological traits are the key factors influencing body weight in *C. feriata*. In previous study, two morphological traits (carapace length and fixed finger height of the claw) were determined to have significant direct effects on body weight of *Scylla paramamosain* (Ma et al., 2013). Besides, the key independent variables have been identified to influence body weight in other animals, such as *Pinctada martensii* (Deng et al., 2008) and *Portunus trituberculatus* (Liu et al., 2009).

Selective breeding indexes of quantitative traits

Body weight is one of important target traits in selective breeding, so it is a basic work to quantify the influence of morphological traits on body weight for artificial selective breeding. This research discussed the relationship between quantitative traits of *C. feriata* using length traits. The morphological traits are taken as independent variables, their regression correlation to body weight was extremely significant, therefore it is appropriate to take morphological traits as independent variables in *C. feriata*. Similar researches have been conducted in other marine organisms such as *Eriocheir sinensis* (Geng et al., 2007), *Portunus trituberculatus* (Gao et al., 2008), *Paralichthys olivaceus* (Wang et al., 2008a), *Hucho taimen* (Tong et al., 2011) and *Ctenopharyngodon idellus* (Li et al., 2012). This research suggested that three morphological traits (SW, 3PML and 4PML) are the key factors directly or indirectly influencing body weight in *C. feriata*, and these traits should be the ideal target traits in artificial breeding of *C. feriata*.

Conclusion

In the present study, 17 morphological traits and body weight in *Charybdis feriata* were first characterized, and then three phenotypic traits (SW, 3PML, and 4PML) which played a key role in influencing body weight were identified. It is suggested that these three morphological traits shall have an important potential in artificial selective breeding of *C. ferata*.

Conflict of interests

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors thank the Special Scientific Research Funds for Central Non-Profit Institutes (East China Sea Fisheries Research Institute; #2016M08) and the National Program for Support of Top-Notch Young Professionals.

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academicJournals

Vol. 12(6), pp. 435-449, 9 February, 2017
DOI: 10.5897/AJAR2015.9810
Article Number: C3960D562693
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Structure of soyabeans markets in Benue and Enugu States, Nigeria

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Received 10 April, 2015; Accepted 12 August, 2015

The importance of agricultural marketing in national development cannot be over-emphasized. The study examined the structure of soyabeans markets in Benue and Enugu States, Nigeria. Primary data were collected using questionnaire admininstered to 207 marketers. Data were analysed using descriptive statistics, regression model, HHI, Gini coefficient and lorenz curve. The result showed that the major determinants of soyabeans marketed were price of soyabeans, transfer and handling costs, education and quantity of credit. The study also found that Benue soyabeans markets were by dominated rural assemblers while they were not found in Enugu markets. Soyabeans markets were characterized by many buyers and sellers with little or no barrier to entry and exit. However, the seeds were homogenous. High values of HHI (2,017.18 and 1,081.97) and gini coefficient (0.84 and 0.81) were got for wholesalers and retailers implying high concentration of sales in the hands of few wholesalers and retailers. Soyabeans marketing did not exhibit competitive market behaviour. Education of marketers, provision of credit facilities as well as construction and rehabilitation of roads should be carried out. Increased household utilization could improve the competitiveness of soyabeans markets. Again, MIS should be established for better dissemination of information and improved decision making.

Key words: Structure, soya beans, Gini coefficient, marketing, concentration.

INTRODUCTION

A good and efficient marketing system accelerates the pace of economic development by encouraging specializations which leads to increase in output. Olayemi (1982) observed that food marketing is a very important but rather neglected aspect of agricultural development. More emphasis is usually placed by government on policies that increase food production with little or no consideration on how to distribute the food produced efficiently and in a manner that will enhance productivity. Moreso, a good and well-coordinated national food marketing system can affect food production and household's food security in two ways. One, it can stimulate increased commercial activities that could generate more funds for plough back investments in both agricultural and agro-allied industrial sectors. The resultant increased agricultural production will lead to

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increased food production and increased food output. Secondly, it can lead to employment generation for both food distributors and rural farmers. The involvement of rural people in food marketing could uplift the rural populace’s standard of living and increase their personal income thereby enhancing the prospect of food security at the household, local and national levels.

Soyabean (*Glycine max*), a herbaceous annual food legume, is an important food, feed, oil and cash crop in the world. It has been the dominant oilseed produced since the 1960s and is used as human food, livestock feed, and for various industrial purposes (Myaka et al., 2005). Its industrial uses range from the manufacture of edible oil, infant food supplements, pharmaceutical, paints, cosmetics, soap-making to animal feeds (Singh et al., 1987). Available research has shown that greater demand for soyabeans comes from livestock industry for the manufacture of livestock feeds (Omotayo et al., 2007).

Market structure can be defined as those characteristics of the organisation of a market which seem to influence strategically the nature of competition and pricing within the market (Olukosi et al., 2005). According to them, the factors considered important in determining market structure are:

1. The number and relative size of buyers and sellers
2. The degree of product differentiation
3. The ease of entry of buyers and sellers into and out of the market
4. The status of knowledge about costs, prices and market conditions among the participants in the market

The number and conduct of competitors define the market structure and the firms’relative success in the market is measured by its market share (Nwokoye, 1996). Market structure relates essentially to the degree of competition in a market. It tends to consider whether the number of firms producing a product is large or whether the firms are of equal sizes dominated by a small group. It is also concerned with whether entry for new firms is easy or difficult and whether the purchases of the product is in a competitive state or not. Structure also relates to the degree of market knowledge which is available to these firms.

The complexity of agricultural marketing system increases when a large number of small farmers, dispersed all over the country have diverse production practices. Hays (1976) found that the food grain marketing system encourages the participation of a large number of individuals at the various types of markets and exchange points, where the marketing services of assembly, storage and transportation and breaking of bulk are performed. Furthermore, Onu and Iliyasu (2008), in their study titled ‘Economic Analysis of Food Grain Market in Adamawa State, Nigeria, found that there were six categories of food grain traders in the markets, namely: the farmers, assemblers, wholesalers, retailers, speculators and the processors.

The proportions of their sampled market participants showed that wholesalers and retailers were the two most dominant groups in the markets surveyed. The smallest category, they found was the assemblers/collectors. Similarly, Babatunde and Oyatoye (2000) in their work titled “Food Security and Marketing in Nigeria: The case of maize marketing in Kwara State noted that a typical food market in the State is generally localized and consists of numerous independent small-scale farmers and itinerate retailers who buy from farm gate usually lacking the wherewithal to continue the marketing functions further, re-sell the food produce at the nearest market place. Furthermore, a study by Omotayo et al. (2007) shows that the commodity chain for soyabeans marketing shows that middlemen play a significant role in the distribution of soyabeans from farmers’ field (the primary markets) to the processors. Two categories of middlemen were identified by them. They included those who bought directly from farmers, re-bagged, stored and transported to the feeder and central markets; and those who bought from these feeder and central markets and supplied to industrial processors. These middlemen play significant roles in meeting the demand for soyabased products by different levels of processors.

Soyabeans, although consumed in few homes, is mainly produced for local and international markets. Most farmers do not produce this crop because of their inability to identify markets. While production has sustainably increased in some States, there is no information whether it is being marketed efficiently since its industrial demand far outweighs its domestic household demand. According to Omotayo et al. (2007), unlike the marketing of other food crops in Nigeria, the soyabeans marketing chain appear simple but fragmented; it would seem that the business is in the hands of various middlemen who dictate local prices of soya grains and other soya based raw materials. And the local price of soyabeans tend to follow international trend adjusted for foreign exchange rate fluctuations. With the available evidence of increased soyabeans production in Nigeria in recent times as a result of increased general awareness of its ecomomic importance and government efforts through different agencies (FMAWRD, 2006), there is therefore a need to examine how this important crop is being marketed. Thus, the objectives of the study were to:

1. Identify the determinants of the volume of soyabeans marketed;
2. Examined the structure of the soyabeans market.

MATERIALS AND METHODS

The study area

The study area is Benue and Enugu States of Nigeria. These

States belong to the North-Central and South Eastern zones of the country, respectively. Benue State, created on 3rd February, 1976, is located in the middle belt of Nigeria, approximately between latitudes 6°30'N and 8°10'N of the equator and longitudes 6°35'E and 8°10'E of the Greenwich meridian, at an elevation of 97 m, above sea level in the southern guinea savannah agroecological zone. It has a landmass of 6.595 million hectares [Benue State Agricultural and Rural Development Authority (BNARDA), 1998]. Benue State has a total population of 4,219,244 (NPC, 2006), and is made up of 413,159 farm families (BNARDA, 1998). Benue State derives its name from the River Benue; the second largest river in Nigeria. The State is made up of 23 Local Government Areas and is divided into three agricultural zones.

Enugu State was created on August 27, 1991, with the city of Enugu as its capital. Enugu State is located between latitudes 5°56'N and 7°6'N and longitudes 6°53'E and 7°55'E of Greenwich meridan [Enugu State Agricultural Development Project (ENADEP), 2009]. The State occupies a landmass of approximately 8,022.95 km^2 and a population of 3,257,298 (NPC, 2006). It has 17 Local Government Areas and according to ENADEP (2012), the State is further divided into six agricultural zones. According to BNARDA (1998) and William (2008), the predominant occupation of the people of Benue and Enugu States is farming. Marketing of all food stuffs especially farm produce are extensively carried out in several markets in the two States.

Sampling procedure

A two-stage sampling technique was adopted in selecting the respondents. First, from the two selected States, four markets each were purposively selected based on the relative predominant availability of soyabeans in the area. The markets surveyed in Benue include Wannune, Lessel, Gbajimgba and NorthBank whereas Orie Orba, Ogbete, Eke Agbani and Orie Awgu were sampled in Enugu State. Subsequently, from each of the selected soyabeans markets, a minimum of 20 middlemen (wholesalers, retailers and rural assemblers) were selected using simple random sampling technique; although rural assemblers were not found in Enugu markets. Thus, a total of 97 and 110 respondents were sampled in Enugu and Benue markets, respectively which summed up to 207.

Data collection

The study made use of primary data. Primary data were obtained mainly through the use of structured questionaire administered to soyabeans marketers.

Data analysis

Data were analyzed using both descriptive and inferential statistics. OLS regression analysis was used to realise Objective I. Objective II was achieved using Herfindahl Hirschman Index (HHI), Gini coefficient model and Lorenze curve.

Model specification

Regression analysis

Regression model was used to ascertain the factors that determined the volume of soyabeans marketed. The implicit form of the regression model was specified as:

$$Y = f(X_1,\ X_2,\ X_3,\ X_4, - - - X_n) + e$$

Where, $Y =$ Volume of soyabeans marketed (kg); $X_1 =$ Price of soyabeans (~~N~~); X_2= Years of marketing experience- years; $X_3 =$ Transfer and handling costs (~~N~~); $X_4 =$ Educational background (years); $X_5 =$ Loan over period of experience (~~N~~), and e = error term.

In this study, transfer cost included transportation costs and produce while loading, offloading, revenue, LG fees and storage costs constituted handling cost. Different functional forms (linear, semi-log, double log and exponential) were fitted and the lead equation was chosen based on the conformity of the explanatory variables with the aprior expectation with respect to signs of the parameter estimates, magnitude of adjusted R^2 and overall significance of the model as indicated by the F-value.

Herfindahl Hirschman Index (HHI) for market concentration

HHI is expressed as follows:

HHI $= \sum_1^n P_1^2$

Where: HHI= Herfindahl Hirschman Index; n= Total number of marketers in the industry, and Pi= total market shares of those m largest soyabeans traders expressed in percentage.

This was computed by dividing the total volume of soyabeans sales of the biggest traders by the total volume of soyabeans sale of all sellers in the industry. An advantage of HHI is that it can be used to measure changes in the market shares because it takes into account all firms in the market (Sayaka, 2006).

The HHI can have a theoretical value ranging from close to zero to 10,000. If there exists only a single market participant which has 100% of the market share the HHI would be 10,000. If there were a great number of market participants with each company having a market share of almost 0% then, the HHI could be close to zero. The US Federal Trade Commission and the Department of Justice Anti-Trust Division uses the following rule of thumbs: When the HHI value is less than 100, the market is highly competitive; when the HHI value is between 100 and 1000, the market is said to be not concentrated and when the HHI value is between 1000 and 1800, the market is said to be moderately concentrated. However, when the HHI value is above 1800, the market is said to be highly concentrated.

Gini coefficient

Gini coefficient was calculated using the formula below as used by Enete and Agbugba (2008) in their work titled Charcoal Marketing in Abia State:

$$G/I = \sum_{k=0}^{k=n-1} (\partial\gamma_{k-1} + \gamma_k)(\partial X_{k-1} - X_k)$$

Where, G = Gini index; X = marketing agents; Y = volume of trade; $\partial X =$ cumulated proportion of marketing agents; $\partial\gamma =$ cumulated proportion of sales (volume of trade); n = number of observations, and K= n-1

Mathemetically, it is expressed as one minus the sum of the product of the proportion of market participants and the cumulative proportion of their sales earnings arranged in class intervals from the lowest to the highest (Ike and Chukwuji, 2005). The value ranges from 0 to 1 with a value greater than 0.35 indicating inequality in distribution of sales as well as income earned according to Dillon and Hardaker (1993).

Table 1. Regression models showing the factors that determine the volume of soyabeans marketed.

Variables	Linear	Semi-Log	Quadratic	Square root	Lead equation Cobb- douglas
(Constant)	1270.81 (0.68)	-5115.74 (-0.468)	2388.76 (1.402)	-444.264 (-0.154)	10.556 (5.573)***
Price SB (X_1)	-0.161 (-1.02)	360.62 (0.147)	-0.064 (-0.354)	-17.261 (-1.261)	-1.515 (-3.573)***
Mkt Exp (X_2)	14.429 (0.24)	589.65 (0.75)	-0.310 (-0.242)	255.969 (0.536)	0.057 (0.423)
Transfer and handling costs (X_3)	0.247 (0.59)	726.63 (1.553)	-0.000009.48 (-0.175)	38.318 (1.126)	0.345 (4.257)***
Education (X_4)	135.55 (1.012)	104.37 (0.297)	7.387 (0.918)	421.793 (0.730)	0.157 (2.583)**
Loan (X_5)	0.006 (2.23*)	141.68 (1.572)	0.0000000015 (0.903)	7.791 (2.86**)	0.035 (2.230)**
F	1.444	1.110	0.430	2.258	10.754***
R^2	0.035	0.027	0.012	0.053	0.211
Adjusted R^2	0.011	0.003	-0.014	0.030	0.191

Dependent Variable: Volume marketed, Kg/Month. Figures in parentheses are t-values, ***(**) Significant at 1 and 5% respectively. Source: Computed from field data, 2014.

RESULTS AND DISCUSSION

Determinants of the volume of soyabeans marketed

The results of the regression showing the factors that determine volume of soyabeans marketed were presented in Table 1. The equation of 'best fit' was selected with conformity to a priori economic criteria of the magnitude of the coefficients, magnitude of the standard error, signs and significance of the coefficient of multiple determination, F-ratio and t-ratio. Here, Cobb Douglas was selected as the lead equation because of its very minimal standard error, high F-value and high R^2. The main objective of this section was to test for the significance of independent variables that influenced the volume of soyabeans marketed. Volume of soyabeans marketed as used here indicated the quantity of soyabeans the marketer bought at a given time.

The result showed the adjusted R^2 as 0.191 while R^2 was found as 0.211 implying that only 21% of the variations in the volume of soyabeans marketed were explained by variations in the independent variables. The low R^2 got in this model signified that outside the tested variables, some other variables which might be relevant in the regression model were inadvertently omitted for logistic reasons. The result indicated that prices of soyabeans, transfer and handling costs, number of years in education, and the amount of loan borrowed affected the volume of soyabeans marketed. This means that these factors were among the major determinants of volume of soyabeans marketed. In other words, an increase in level, quantity or quality of these variables with the exception of price increases the quantity of soyabeans marketed.

Furthermore, the result of the regression showed that price and volume of soyabeans marketed had an inverse relationship. This meant that as the price of soyabeans increased, the volume of soyabeans marketed decreased. This is in line with the law of demand that as price of a commodity increases, the quantity demanded decreases. From the result, one unit decrease in the price of soyabeans led to a 1.5 units increase in quantity marketed. When prices increase, marketers tend to withdraw from buying as they are not sure of the future price. This result agrees with the findings of Lokman and Hatemi-J (2005) who found stock price as one of the three dominant factors that had very close association with the trading volume in Indian stock market. Similar result was also obtained by Alper and Mehmet (2010) in Turkey.

Conversely, transfer and handling cost and volume of soyabeans marketed had a positive relationship which implied that as the transfer cost increases, the volume of soyabeans marketed also increases. A unit increase in transfer cost, translated to a 0.35 units increase in the volume of soyabeans marketed. This is as a result of the fact that the more quantity of soyabeans one has, the more expenditure one makes on handling and transportation. Similar result was obtained Zamasiya et al. (2014), who discovered that average distance to the market explained the intensity (amount of soyabeans sold) of smallholder farmers' participation in soyabeans market in Zimbabwe. In a similar manner, Sapna and Dani (2014), found out that transportation cost was among the three critical statistically significant factors that affect the volume of trade in Asian developing economies. Again, Onu and Iliyasu (2008), found that cost of storage facility and cost of transportation were significant factors that determined the volume of food grains marketed in Adamawa State, Nigeria. An increase in transportation

Table 2. Proportion of traders in the sampled markets.

State	S/N	Market place	Wholesalers (%)	Retailers (%)	Rural assemblers (%)
Benue	1	Lessel	3 (14.3)	4 (19.0)	14 (66.7)
	2.	Wannune	14 (53.8)	1 (3.8)	11 (42.3)
	3	Gbajimgba	7 (16.3)	6 (14.0)	30 (69.8)
	4	North Bank MKD	7 (35.0)	13 (65.0)	
Enugu					
	5	Orie Orba	18 (66.7)	9 (33.3)	
	6	Ogbete Enugu	12 (42.9)	16 (57.1)	
	7	Eke Agbani	4 (20.0)	16 (80.0)	
	8	Orie Awgu	5 (22.7)	17 (77.3)	

Figures in parentheses are percentages. Source: Computed from field data, 2014.

brings about a maximum utilization of transport available by increasing the quantity of grains transported.

Similarly, years spent in education and volume of soyabeans market had a positive relationship implying that as one's education level increases, the level of soyabeans marketed also increases. People with higher educational status tends to be knowledgable, flexible and could easily manage large volume of trade. Significant education level as a determinant of the volume of soyabeans agreed with the findings of Onu and Iliyasu (2008) that education contributed to the volume of grains marketed. Moreso, the result corroborated the findings of Opata (2012) (University of Nigeria Nsukka, unpublished Ph.D thesis) that education influenced the volume of cocoyam marketed in South Eastern Nigeria.

Furthermore, the result showed that the quantity of loan contributes to the volume of soyabeans traded. From the result, a unit increase in the amount of loan borrowed led to 2.2 unit increase in the quantity of soyabeans marketed. This result could be likened to the findings of Zamasiya et al. (2014) that livestock wealth (cattle owned) explained the intensity (amount of soyabeans sold) of smallholder farmers' participation in Zimbabwe soyabeans market. Again, similar result was obtained by Onu and Iliyasu (2008) thereby reinforcing the fact that the quantity of loan obtained by marketers contributed to the volume of trade. However, marketing experience did not have any influence on the quantity of soyabeans marketed. This result contradicted the findings of Onu and Iliyasu (2008) that marketing experience contributed to the volume of grains marketed. This disparity could be as a result of little or no special skills required for soyabeans marketing compared to other food grains.

Structure of soyabeans market

Market structure is defined in terms of the organisation of a market which seems to influence strategically the nature of competition and pricing within the market (Bain, 1968). The dimensions of market structure evaluated in this study were ease of entry and exit, standards and grades, packaging, number of buyers and sellers, price information and setting, degree of wholesalers and retailers concentration, volume of trade and market shares of different participants.

Proportion of traders in the sampled markets

The result showing the proportion of traders in the sampled market was presented in Table 2. The result showed that in Lessel and Gbajimgba markets of Benue State, majority (66.7 and 69.8%) of the market participants were rural assemblers while in Wannune, majority (53.8%) were wholesalers. The presence of numerous rural assemblers in the producing State helped in facilitating the gathering/assembling of the produce for subsequent evacuation into the urban cities and factories.

However, in North Bank Makurdi, majority (65.0%) of the marketers were retailers with only about 35.0% wholesalers. This could be as a result of the location of the market in Makurdi town and being widely known as the grain market in Makurdi, many consumers went there to buy soyabeans. Conversely, in Orie Orba Udenu LGA of Enugu State, majority (66.7%) were wholesalers. The market, due to its proximity to the supply market, provides the eastern States with food grains from the north thereby acting as a link market. However, in Ogbete Enugu, Eke Agbani and Orie Awgu, 75.1, 80 and 77.3% were retailers who sold to final consumers and local processors. This could be because soyabeans had more of industrial demand with less of household demand as it is not heavily consumed like other grains. The few wholesalers (42.9, 20 and 22.7% respectively) in these markets sold to retailers, processing companies and feed mills.

Characteristics of soyabeans market

Table 3 presented the result of the characteristics of

Table 3. Characteristics of soyabeans markets.

S/N	Market characteristics	BENUE (110)	ENUGU (97)	OVERALL (207)
		Frequency/percent	Frequency/percent	Frequency/percent
1	**Market union membership**			
	NA	42 (38.2)	1 (1.0)	43 (20.8)
	Yes	65 (59.1)	42 (43.3)	107 (51.7)
	No	3 (2.7)	54 (55.7)	57 (27.5)
2	**Compelled to join union**			
	NA	44 (40.0)	50 (51.5)	94 (45.4)
	Yes	17 (15.5)	1 (1.0)	18 (8.7)
	No	49 (44.5)	46 (47.4)	95 (45.9)
3	**Freedom to sell anywhere**			
	Yes	110 (100.0)	97 (100.0)	207 (100.0)
4	**Buyng freedom**			
	Yes	102 (92.7)	97 (100.0)	199 (96.1)
	No	8 (7.3)	-	8 (3.9)
5	**Market infn source**			
	Middle men	90 (81.8)	94 (96.9)	184 (88.9)
	Friends/neighbours	1 (0.9)	2 (2.1)	3 (1.4)
	Mkt Union/association	9 (8.2)	-	9 (4.3)
	Company agents	10 (9.1)	1 (1.0)	11 (5.3)
6	**Determinants of sale**			
	NA	1 (0.9)	1 (1.0)	2 (1.0)
	Good seeds of soyabeans	24 (21.8)	32 (33.0)	56 (27.1)
	High demand	42 (38.2)	26 (26.8)	68 (32.9)
	Good seeds of SB and high Dd	43 (39.1)	38 (39.2)	81 (39.1)
7	**Price settlement**			
	Bargaining each time	85 (77.3)	97 (100.0)	182 (87.9)
	Fixed market price	16 (14.5)	-	16 (7.7)
	Company buying agents	5 (4.5)	-	5 (2.4)
	Ind. determine price	1 (0.9)	-	1 (0.5)
	Price arrangement without buyers	3 (2.7)	-	3 (1.4)
8	**Restrictions**			
	Yes	11 (10.0)	1 (1.0)	12 (5.8)
	No	99 (90)	96 (99.0)	195 (94.2)
9	**Many buyer and sellers**			
	Yes	110 (100.0)	97 (100.0)	207 (100.0)

Figures in parentheses are percentages, NA- not applicable; Source: Computed from field data, 2014.

soyabeans markets in the study area. The survey indicated that whereas market union existed in some markets, they were absent in some especially in Benue markets (38.2%). The result showed that more than half of the sampled marketers (51.7%) belonged to market unions while 27.5% did not. However, only 15.5% from Benue markets were compelled to join the union, although majority (45.9%) were not under any compulsion to join.

Furthermore, all the marketers (100%) agreed of their freedom to sell soyabeans anywhere; whereas only 96.1% had buying freedom; although in Enugu markets, buying freedom was generally reported (100%). Moreso, information among marketers were mostly obtained from middlemen (81.8 and 96.9%) in Benue and Enugu markets, respectively; although information were equally obtained from friends (1.4%), market union (4.3%) and company agents (5.3%). Moreso, prices of soyabeans were mainly determined by the forces of demand and supply through bargaining (100% in Enugu State and 77.3% in Benue State); although in Benue State markets, there were cases of prices being fixed by company agents (4.5%) and prices arranged with buyers (2.7%) and sometimes prices determined by individuals (0.9%).

The result also indicated that there were little or no restictions (94.2%) to entry and exit from the business; even though there were restrictions (5.8%) in some markets. These restrictions could be in form of booking before purchases were made and the existence of market unions in some markets. Another major characteristics of soyabeans market was the participation of many buyers and sellers with none dominating the market. Thus, soyabeans market did not exhibit the characteristics of monopoly but had features of near competitive market although in Benue State, there were traits of inefficiencies and uncompetitive market behaviour.

Different sizes of sacs were used to pack soyabeans. In major markets sampled in Benue State, the buyers used weighing machines while at other places, farmers were being exploited by the rural assemblers who used no standard measure (Figure 2). However, in Enugu State markets, soyabeans were sold in bags or measured in tins, paint buckets and cups. The sizes of the sacs in both markets could be 100 kg, 120 kg and even 130 kg or more.

Soyabean seeds had different grades. In Benue State, BNARDA seeds were of high quality, having big and fine seeds. However, there were other local varieties with smaller and wrinkled seeds. Generally, Benue State soyabean was the least preferred among soyabeans marketers and company agents interviewed because of its poor seed quality and the presence of stones and sand which were normally added by the rural assemblers to increase the weight. Among traders in Enugu State, the quality ranges from 01 (big seed) to 04 (smallest seed). Although these grades and colour exist, there was no significant difference in the quality of seeds hence soyabean seeds were homogenous.

Conditions of entry and exit from soyabeans markets

Barriers to entry into and exit from a given marketing system influence the structure of the marketing system. Booking before purchases at the northern soyabeans markets, the associated high initial capital and market skills could be the possible entry and exit barriers to soyabeans marketing in the study area.

Booking before purchases

Before a trader is allowed into the grain markets in the northern States (Benue State inclusive), such a trader is expected to make an annual booking of between ₦800 and 1,500 to the market committee. Thereafter, the trader is issued with a number which appears on his bags as his identity in the market. Moreso, most wholesalers, retailers and rural assemblers join informal groups as a condition for starting the business.

Skills

Almost all the interviewed rural assemblers, wholesalers and retailers from all levels strictly underlined the importance of experience. The experience to buy at different times and months of the year, the skill of bargaining with the sellers, managing customers, preservation of soyabeans were needed to effectively function well in the business. Thus, the absence of these attributes could prevent people from entering the business.

Degree of concentration

The degree of wholesalers and retailers concentration was assessed using Herfindahl- Hirschman index (HHI). HHI is a more comprehensive measure of market concentration than four firm concentration ratio. The lower the HHI, the more spread out the market share with many firms whereas the higher the value, the more concentrated the market becomes.

Herfindahl Hirschman Index of wholesalers

The Herfindahl Hirschman Index (HHI) of wholesalers is presented in Appendix Table 1. It showed that the HHI value for 70 sampled wholesalers as 2,017.18. Thus, using the stated criteria for concentrated or spread out of the market share, the computed index was greater than 1,800 indicating that soyabeans market was concentrated, hence not competitive. The index accounted for the wholesaler with the largest market share (43.01^2 = 1,849.93) as well as wholesaler with the lowest market share (0.0043^2 = 0.0000185). This implied that few wholesalers can actually controlled the soyabeans market. This could be explained by the fact that soyabeans has more of industrial demand than household demand and the price was normally determined by soyabeans companies. Those that supplied to companies had larger volume of sales than those that did not. Contrary result was got by Opata (2012) who found HHI value of 193.98 for cocoyam wholesalers in South Eastern States of Nigeria even though the crops belonged to different classes of food. However, similar high HHI value (6,000) was obtained for agricultural sector (farming, fishing, and forestry) by U.S Bereau of

Labour Statistics (2014).

Herfindahl Hirschman index of retailers

The Herfindahl Hirschman Index (HHI) of 82 sampled retailers was presented in Appendix Table 2. It showed HHI of 1,081.97. This index being between 1000 and 1800 indicated moderate concentration. The market share of the largest retailer had a HHI of 683.4978 $(26.14379)^2$ while that of the lowest retailer was 0.000684 $(0.0261)^2$, with the sum of squares of the market share of all the retailers being 1,081.97. This calculated index being less than that of the wholesalers (Appendix Table 1) showed that retailers exercised less control over the market than wholesalers. Another major explanation for the moderate concentration found among retailers in the study area could be the difference in the demand for soyabeans in the two States. This result agrees with Domina and Taylor (2009) who found that the U.S. agricultural economy was highly concentrated in the hands of too few processors of major agricultural products. According to them, beef, chicken, pork, seed, and some grains markets; four or fewer firms dominated the market in such a way that competition was insufficient. However, high HHI value got for retailers disagreed with the findings of Opata (2012) who calculated HHI for cocoyam retailers in south eastern Nigeria as 196.69.

Herfindahl Hirschman Index of rural assemblers

Appendix Table 3 showed the Herfindahl Hirschman Index of the sampled rural assemblers. These category of middlemen (BRENDA) were only found in Benue State. From the result of the calculated HHI of 433.84 being between 100 and 1000, the market is said not to be concentrated. Therefore, the local assemblers exhibited competitive behaviour. The HHI of the highest market share rural assembler in the soyabeans market was $(8.27586)^2 = 68.49$ while that of the lowest market share was $(0.03448)^2 = 0.001189$. Since some of the rural assemblers were soyabean farmers and wholesalers as well, they could easily gather soyabeans from nearby farms and sell to company agents and other wholesalers who could buy off whatever quantity they had. Again, their numerous number and the ease of entry explained the fierce competitive behaviour observed among rural assemblers.

Generally, from the HHI of 2,017.18, 1,081.97 and 433.84, respectively, for wholesalers, retailers and rural assemblers; soyabeans marketing in the study area could be said to be neither monopolistic nor competitive but exhibited moderate concentration of market shares among wholesalers and retailers. This implied that few marketers could actually exert significant influence in the market price by controlling the volume of soyabeans traded. This difference in their volume of trade could be as a result of their differences in business capital. Moreso, few of them who were company agents were assisted with capital from processing companies that enabled them to buy in large quantity whereas others could only buy small quantity. This result suggested an uncompetitive and imperfect market which led to market inefficiency.

Gini coefficient for market participants

Gini coefficient was also used to measure variations in sales distribution among wholesalers, retailers and rural assemblers. The interpretation of Gini coefficient was based on Lorenz curve. The value ranges from 0 to 1 with a value greater than 0.35 indicating inequality in distribution of sales as well as income earned according to Dillon and Hardaker (1993). Higher Gini coefficient (GC) means higher level of concentration, inequitable distribution of sales and income and consequently, high inefficiency in the market structure. The result of Gini coefficient was presented in Table 4. Gini coefficient of wholesalers was calculated as 0.84. This value being higher than 0.35 implied high inequality in sales and income distribution among the wholesalers in the study area. This very high value of Gini coefficient implied that few wholesalers controlled large shares of soyabeans supply in the study area. This result corroborated the earlier result of very high HHI value in this study (Table 4). During the course of the study, it was found that few wholesalers especially company agents bought as much as one or more trailer loads of soyabeans at a given time while others bought few bags. These wholesalers who were company agents could influence supplies by increasing or decreasing the quantity marketed. In other words, few wholesalers' share were significant part of volume of trade in the market such that it could affect the market price which would invariably lead to market imperfection.

Similarly, among retailers in the study area, the value of Gini coefficient calculated from Table 4 was 0.81 (1-0.19). This equally showed great inequality in sales distribution among retailers surveyed. Among rural assemblers found only in Benue State, the value of Gini coefficient was 0.61. This implied high inequality in market shares and income distribution among this category of marketers. This meant that each of these traders could exert pressure on the market by influencing quantity and price. These high inequalities, 84, 81 and 61%, respectively, found for wholesalers, retailers and rural assemblers of soyabeans, however differed from the low values 36 and 24% for wholesalers and retailers, respectively found by Enete and Agbugba (2008) in charcoal marketing in Abia State. However, it corroborated the findings of Ike and Chukwuji (2005)

Table 4. Sales distribution and Gini coefficient for soyabeans marketers in Benue and Enugu States.

S/N	Sales class Qty sold/month (kg)	Frequency	Proportion (X)	Cumulation	Total sales (kg)	Proportion of total sales	Cumulation proportion (Y)	∑XY
1	**Wholesalers**							
	40-500	7	0.1	0.1	1600.0	0.000860	0.000860	0.00086
	501-5000	32	0.4571	0.557	92300	0.0496	0.05046	0.0231
	5001-10000	7	0.1	0.657	51400	0.0276	0.07806	0.00781
	10001-50000	17	0.2429	0.9	432000	0.23226	0.31032	0.07538
	50001-100000	5	0.0714	0.97	343000	0.18440	0.49472	0.03532
	100001-500000	1	0.01429	0.984	143000	0.07688	0.5716	0.0082
	500001-800000	1	0.01429	1.00	800000	0.43011	1.00	0.0143
	Total	70	1.0		1,860,000	1.0		**0.16**
	G.C.	**1- 0.16 = 0.84**						
2	**Retailers**							
	40-500	57	0.695	0.695	11000	0.0719	0.0719	0.04997
	501-5000	18	0.22	0.915	35300	0.23072	0.30262	0.06658
	5001-10000	2	0.024	0.939	13400	0.08758	0.3902	0.0094
	10001-50000	5	0.06	1.00	93800	0.61307	1.00	0.06
	Total	82	1.0		153,000	1.0		**0.19**
	G.C.	**1- 0.19 = 0.81**						
3	**Rural assemblers**							
	40-500	3	0.055	0.055	920.00	0.00264	0.00264	0.000145
	501-5000	31	0.564	0.619	76100	0.218678	0.221318	0.1248
	5001-10000	13	0.236	0.855	94600	0.271839	0.493157	0.1164
	10001-50000	8	0.145	1.00	177000	0.508621	1.00	0.145
	Total	55	1.0		348,000	1.0		**0.39**
	G.C.	**1- 0.39 = 0.61**						

Source: Computed from field data, 2014.

who got a value of 68% for cashew marketers in Enugu State.

Overall, the structure of soyabeans market indicated both small and large-scale dealers such that the market could be controlled by few marketers. This was caused probably by the nature of the commodity as its industrial demand outweighed its household demand. Hence, this type of market could be said to be uncompetitive because individual marketers especially company agents had great influence on the market price. This did not agree with the work of Enete (2003) in cassava marketing in Nigeria, Enete and Agbugba (2008) in Charcoal marketing in Abia State and Hayami et al. (1999) in rice marketing in Philippines. A high Gini coefficient of 0.68 was obtained by Ike and Chukwuji (2005) which implied that there was significant inequality in the distribution of income among the cashew nut sellers and hence, a high level of concentration. This agreed with the result of this study.

Furthermore, the proportions of sampled market participants showed that wholesalers and retailers were the two most dominant groups in the market surveyed. The smallest category was the rural assemblers although a small portion of them were wholesalers and farmers. This implied that there was vertical integration across the marketing chain in the study area thus agreeing with Fafchamps and Minten (2001). Similar result was obtained by Onu and Iliyasu (2008).

Lorenz curve

Lorenz curves were obtained from Table 4 and presented in Figure 1. The curves relate the cumulative proportion of total sales by wholesalers, retailers and rural assemblers to the cumulative proportion of the wholesalers, retailers and rural assemblers after ordering the population according to increasing levels of sales (Dillon and Hardaker, 1993). The 45° line [Egalitarian Line (EL)] represents the perfect equality of sales by households. If the distribution is totally equitable, the curve will fall on a 45-degree line (EL). The greater the

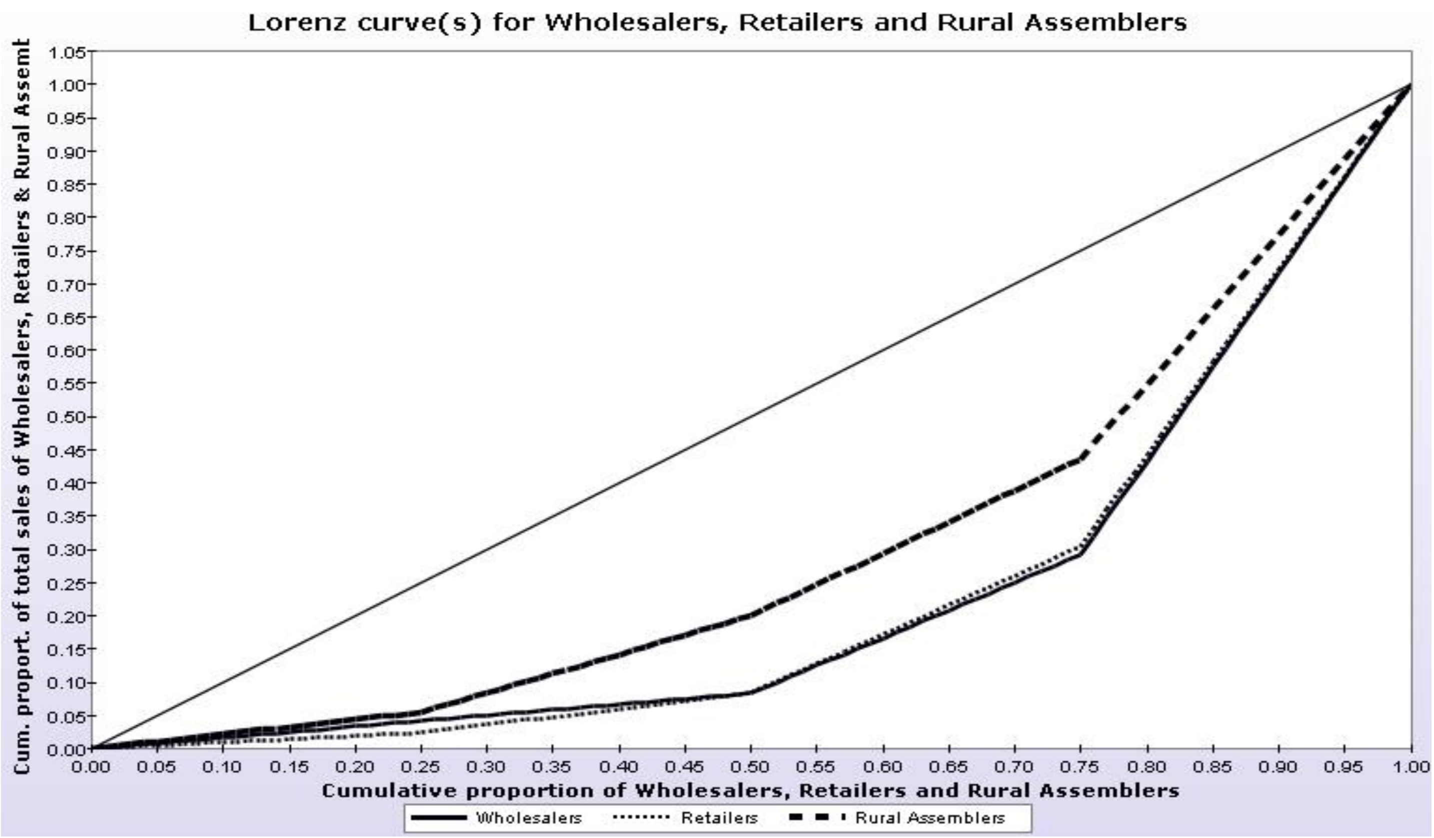

Figure 1. Lorenz curves for wholesalers, retailers and rural assemblers.

Figure 2. Soyabeans being measured in mudu and basin without scale in Gbajimgba and Daudu markets.

inequality, the greater the departure from the 45-degree line. The most common measure of income inequality that is based on the lorenz curve is the gini coefficient. Higher gini coefficient means higher level of concentration, inequitable distribution of sales and income consequently high inefficiency in the market structure. The lorenz curve of soyabeans wholesalers and retailers showed the greatest departure from the 45 degree line and this is consistent with the value of gini coefficient of 0.84 and 0.81 respectively. This implies high variations in the income and sales distribution of market participants. However, the lorenz curve for rural assemblers was found closer (0.61) to the 45° line of equality than wholesalers and retailers. Lorenz curve similar to that of rural assembler was obtained for retailers by Opata (2012) in marketing of cocoyam in South Eastern States of Nigeria.

CONCLUSION AND RECOMMENDATIONS

This study assessed the market structure of soyabeans in Benue and Enugu States, Nigeria with a view to assisting the industry in contributing to social and economic developments in the area and in the country at large. Results also showed that although soyabeans provided cheap high protein, it had more aggregate industrial demand than household demand. The socio-economic characteristics of marketers were clear evident of their poor resource situations which constrained their competitiveness in the industry leading to economic losses. Prominent among the factors that contributed to the volume of soyabeans trade were prices of soyabeans, transfer costs, high educational status and the amount of loan received. In other words, their differences in the volume of trades could be accounted for by their differences in educational level and amount of loan borrowed. Therefore, an increase in the marketers' educational level, transfer costs and the amount of loan borrowed or capital base could increase their volume of trade and vice versa. The result also showed that soyabeans marketing did not exhibit competitive market behaviour but characterized by high concentration of sales by few wholesalers and retailers, unethical practices of cheating although the produce were homogenous and there was no barriers to entry and exit into the business.

Farmers and traders should be educated on the importance of soyabeans Increased awareness on the nutritional importance of soyabeans should be carried out by government agencies, private organisations, NGOs and foreign bodies. As a result of soyabeans high quality protein content, home scientists and Food Technologists should come up with different simple ways of utilizing soyabeans at the household level. Intense research should be carried out by different levels of governments especially in its household utilization. Government should deliberately establish specifically soyabeans food research and processing companies. These efforts will increase household demand thereby making soyabeans sub-sector to become competitive.

Credits should be given to marketers to increase their volume of participation in the business. Transportation problems could be addressed through provision of good roads and checkmating the activities of officers at road blocks to shield traders from multiple taxation. Moreso, Government should set up a market information system (MIS) in order to improve the availability and accessibility of market information. Better market information services would enable market agents to read price signals more accurately and promptly, and therefore to make more reliable price forecasts that would aid them in making correct marketing decisions. This will diminish the uncompetitive nature of the business.

Conflict of Interest

The authors have not declared any conflict of interest.

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APPENDIX

Table 1. The Herfindahl Hirschman Index for wholesalers.

S/N	List of wholesalers	Volume of sales	% market share	Sq of % market share	Summary	Cumulative HHI
1	W1-W3	80.0 (3)	0.0043	0.0000185 (3)	0.0000555	0.0000555
2	W4	260.0	0.014	0.0001954	0.0001954	0.0002509
3	W5	340.0	0.0183	0.000334	0.000334	0.0005849
4	W6-W7	380.0 (2)	0.0204	0.0004174 (2)	0.0008348	0.0014197
5	W8-W10	1000.0 (3)	0.0536	0.0029 (3)	0.0087	0.01012
6	W11-W13	1200.0 (3)	0.0645	0.0042 (3)	0.0126	0.02272
7	W14-W17	1520.0 (4)	0.0817	0.0067 (4)	0.0268	0.04952
8	W18-W20	2000.0 (3)	0.1075	0.0116 (3)	0.0348	0.08432
9	W21	2800.0	0.1505	0.0227	0.0227	0.10702
10	W22-W24	3000.0 (3)	0.1613	0.0260 (3)	0.078	0.18502
11	W25	3200.0	0.172	0.0296	0.0296	0.21462
12	W26	3600.0	0.194	0.0375	0.0375	0.25212
13	W27-W36	4000.0 (10)	0.215	0.046 (10)	0.460	0.71212
14	W37-W39	5000.0 (3)	0.269	0.072 (3)	0.216	0.92812
15	W40-W41	6000.0 (2)	0.3226	0.1041 (2)	0.2082	1.13632
16	W42	7000.0	0.376	0.1416	0.1416	1.27792
17	W43-W45	8000.0 (3)	0.430	0.185 (3)	0.555	1.83292
18	W46	8400.0	0.452	0.204	0.204	2.03692
19	W47	10400.0	0.559	0.3126	0.3126	2.34952
20	W48	11600.0	0.624	0.389	0.389	2.73852
21	W49	12000.0	0.645	0.4162	0.4162	3.15472
22	W50	13360.0	0.718	0.5159	0.5159	3.67062
23	W51-W53	20000.0 (3)	1.075	1.156 (3)	3.468	7.13862
24	W54-W55	24000.0 (2)	1.290	1.665 (2)	3.33	10.46862
25	W56	28000.0	1.505	2.266	2.266	12.73462
26	W57-W58	28400.0 (2)	1.527	2.331 (2)	4.662	17.39662
27	W59	32000.0	1.720	2.9599	2.9599	20.35652
28	W60-W63	40000.0 (4)	2.151	4.6248 (4)	18.4992	38.85572
29	W64	57200.0	3.075	9.4573	9.4573	48.31302
30	W65	60000.0	3.2263	10.4058	10.4058	58.71882
31	W66	66000.0	3.5484	12.591	12.591	71.30982
32	W67-W68	80000.0 (2)	4.301	18.499 (2)	36.998	108.30782
33	W69	142800.0	7.677	58.94	58.94	167.24782
34	W70	800000.0	43.01	1849.93	1849.93	2,017.1778
	Total	1,860000		1,977.35		**2,017.1778**

W1-70 = Wholesaler 1 to 70. Source: Computed from field data, 2014.

Table 2. The Herfindahl Hirschman index for retailers.

S/N	List of retailers	Volume of sales	% market share	Sq of % market share	Summary	Cumulative HHI
1	R1-R5	40 (5)	0.0261	0.000684 (5)	0.00342	0.00342
2	R6	50	0.03268	0.001068	0.001068	0.004488
3	R7	60	0.03922	0.001538	0.001538	0.006026
4	R8-R14	100 (7)	0.0654	0.004272 (7)	0.029904	0.03593
5	R15-R17	120 (3)	0.0784	0.006152 (3)	0.018456	0.054386
6	R18-R20	130 (3)	0.08497	0.00722 (3)	0.02166	0.076046

Table 2. Contd.

7	R21-R27	140 (7)	0.0915	0.008373 (7)	0.058611	0.134657
8	R28-R29	160 (2)	0.10458	0.01094 (2)	0.02188	0.156537
9	R30-R34	180 (5)	0.11765	0.01384 (5)	0.0692	0.225737
10	R35-R36	200 (2)	0.13072	0.0171 (2)	0.0342	0.259937
11	R37-R38	240 (2)	0.15686	0.02461 (2)	0.04922	0.309157
12	R39-R49	260 (11)	0.16993	0.02888 (11)	0.31768	0.626837
13	R50	280	0.1830	0.03349	0.03349	0.660327
14	R51	340	0.2222	0.04938	0.04938	0.709707
15	R52-R54	400 (3)	0.2614	0.0684 (3)	0.2052	0.914907
16	R55-R57	500 (3)	0.3268	0.1068 (3)	0.3204	1.235307
17	R58	560	0.3660	0.134	0.134	1.369307
18	R59	600	0.3922	0.15379	0.15379	1.523097
19	R60	800	0.5229	0.2734	0.2734	1.796497
20	R61-R63	1040 (3)	0.6797	0.46205 (3)	1.38615	3.182647
21	R64	1520	0.9935	0.98697	0.98697	4.169617
22	R65	1600	1.04575	1.0936	1.0936	5.26322
23	R66	1720	1.12418	1.2638	1.2638	6.527017
24	R67	1920	1.25490	1.57478	1.57478	8.101797
25	R68-R69	2000 (2)	1.30719	1.70874 (2)	3.41748	11.519277
26	R70	2280	1.4902	2.22068	2.22068	13.739957
27	R71	2400	1.5686	2.46059	2.46059	16.200547
28	R72-R73	2680 (2)	1.75163	3.06822 (2)	6.13644	22.336987
29	R74	4400	2.87582	8.27032	8.27032	30.60731
30	R75	5000	3.26797	10.6797	10.6797	41.28701
31	R76	5360	3.50327	12.2729	12.2729	53.558907
32	R77	8000	5.2288	27.3399	27.3399	80.89881
33	R78	11600	7.581699	57.48217	57.48217	138.38098
34	R79	12000	7.843137	61.51480	61.51480	199.89578
35	R80	13000	8.49673	72.1945	72.1945	272.0903
36	R81	17200	11.24183	126.3787	126.3787	398.46898
37	R82	40000	26.14379	683.4978	683.4978	1081.9668
	Total	**153,000**		1075.41		**1,081.9668**

R1-R82= Retailer 1 to 80. Source: Computed from field data, 2014.

Table 3. The Herfindahl Hirschman index for rural assemblers.

S/N	List of assemblers	Volume of sales	% Market share	Sq of % market share	Summary	Cumulative HHI
1	A1	120	0.03448	0.001189	0.001189	0.001189
2	A2-A3	400 (2)	0.1149	0.013212 (2)	0.026424	0.027613
3	A4-A5	1000 (2)	0.287356	0.08257 (2)	0.16514	0.192753
4	A6-A8	1600 (3)	0.45977	0.211389 (3)	0.634167	0.82692
5	A9-A12	1720 (4)	0.49425	0.244286 (4)	0.977144	1.804064
6	A13	1800	0.517241	0.267539	0.267539	2.071603
7	A14-A18	2000 (5)	0.57471	0.330295 (5)	1.651475	3.723078
8	A19	2280	0.65517	0.429251	0.429251	4.152329
9	A20	2320	0.66667	0.44444	0.44444	4.596769
10	A21-A22	2400 (2)	0.68966	0.47562 (2)	0.95124	5.548009
11	A23	2800	0.8046	0.64738	0.64738	6.195389
12	A24-A28	2880 (5)	0.82759	0.6849 (5)	3.4245	9.619889

Table 3. Contd.

13	A29	3440	0.98850	0.9771	0.9771	10.596989
14	A30-A33	4000 (4)	1.14943	1.3212 (4)	5.2848	15.881789
15	A34	4600	1.32184	1.7473	1.7473	17.629089
16	A35-A36	5720 (2)	1.64368	2.70168 (2)	5.40336	23.032449
17	A37-A39	6000 (3)	1.72414	2.97265 (3)	8.91795	31.950399
18	A40-A44	8000 (5)	2.2989	5.28471 (5)	26.42355	58.37395
19	A45-A47	8400 (3)	2.4138	5.8264 (3)	17.4792	75.85315
20	A48-A49	11600 (2)	3.3333	11.111 (2)	22.222	98.07515
21	A50	16000	4.59770	21.1389	21.1389	119.21405
22	A51	23200	6.6667	44.4444	44.4444	163.65845
23	A5-A53	28400 (2)	8.16092	66.6006 (2)	133.2012	296.85965
24	A54-A55	28800 (2)	8.27586	68.49 (2)	136.98	433.83965
	67830.0	**348,000**				**433.83965**

A1-A55 = Rural Assemblers 1 to 55, Source: Computed from field data, 2014.

academicJournals

Vol. 12(6), pp. 450-458, 9 February, 2017
DOI: 10.5897/AJAR2016.11660
Article Number: 5D9975E62695
ISSN 1991-637X
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http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Relations among phenotypic traits of soybean pods and growth habit

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Received 3 September, 2016; Accepted 20 October, 2016

This study aims to identify the phenotypic effects of traits associated with soybean pods and their growth habit. The experiments were carried out during the 2012 - 2013 agricultural year. It was done in randomized blocks arranged in a 2×20 factorial design (environments × soybean cultivars) with three replications. Data were subjected to individual analysis of variance for each environment and growth habit to verify the homogeneity of variances. Phenotypic path analysis among agronomic traits was performed for each environment within the soybean growth habits. The results showed considerable influences of growth habit via traits associated with soybean pods. The traits number of pods with two, three, and four grains directly influenced the grain yield of genotypes with indeterminate growth habit regardless of the environment. The soybean genotypes with determinate growth habit contributed greatly to grain yield through the traits number of pods with one, two, and three grains and thousand grain weight via pods with two or four grains. Indirect selection of superior genotypes for pods per plant and grain weight could provide satisfactory results for soybean yield in relation to the growth habit. The interrelationships obtained between growth habits and environments, can be applied to superior genotypes selection strategies in breeding soybean programs.

Key words: Agriculture science, biometric models, *Glycine max* L., indirect selection, grain yield, soybean breeding.

INTRODUCTION

Soybean (*Glycine max* L.) is one of the main commodities grown in Brazil due to its great range of genotypes and differential traits that enable the development and production in diverse environments (Carvalho et al., 2010). Differentiated phenotypic responses are intrinsic to the effects of genotype × environment interaction, where a particular genotype may present different associations between the traits involved

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in grain yield because of the environmental effects (Cavalcante et al., 2014).

Comprehending the interrelations between the traits associated with soybean yield potential is essential, because the degree of contribution is intrinsic to the number of pods, grains per pod, and grain weight of the genotype. Correlations among these parameters become important for the indirect selection of superior genotypes (Nogueira et al., 2012). Moreover, correlations may occur by genetic causes which are associated with the gene pleiotropism and linkage (Falconer, 1987) and phenotypical and environmental causes (Carvalho et al., 2002). Furthermore, study of Rodrigues et al. (2010), revealed that the simple correlation coefficients do not allow the exact understanding of the actions linked to the traits. Partitioning of direct and indirect effects of the traits through the path analysis is necessary for reliable interpretation of cause and effect of the correlation coefficients (Wright, 1921). The breakdown of simple correlations allows one to quantify the contribution of the explanatory traits of soybean yield and elucidate the effects attributed to environmental modifications.

This study aimed to identify the phenotypic effects of traits associated with soybean pods and its relations with growth habit.

MATERIALS AND METHODS

The experiments were carried out during the 2012 - 2013 agricultural year, in two locations in Southern Brazil: in Tenente Portela - RS, where the coordinates correspond to latitude of 27º22'10.20''S and longitude of 53º45'23.00''W, with an altitude of 420 m. The soil is classified as typical ferric red Oxisol. In Santa Rosa - RS, the coordinates correspond to latitude of 27º52'16.00''S and longitude of 54º28'55.00"W, with an altitude of 268 m. The soil is classified as dystrophic Red Oxisol. According to Köppen climate classification, the climate is classified as *Cfa* subtropical humid with balanced rain system and no dry season defined for both locations.

The experimental design was randomized blocks arranged in a 2×20 factorial design (environments × soybean cultivars) with three replications. The cultivars utilized for indeterminate growth habit (IGH) were: FPS Paranapanema RR, FPS Solimões RR, FPS Netuno RR, FPS Iguaçu RR, FPS Júpiter RR, AMS Tibagi RR, BMX Magna RR, BMX Apolo RR, BMX Potência RR, BMX Alvo RR, ROOS Camino RR, NA 5909 RR, BMX Turbo RR, and TMG 7161 RR. The cultivars with determinate growth habit (DGH) were: BRS Tordilha RR, Fepagro 37 RR, Fepagro 36 RR, FPS Urano RR, A 6411 RR, and BMX Ativa RR.

Each experimental unit consisted of four rows with spacing of 0.45 m between rows and 10 m long. Plant population density for all genotypes was 300,000 plants ha^{-1}. Moreover, direct seeding system with established fertilization according to crop necessities was used in both locations. The control of insect and diseases was carried out with caution. Evaluations were performed in the central rows of each experimental unit, discarding the first few meters from each end in order to reduce the effects of borders. Later, ten random plants were sampled in order to obtain the agronomical important traits composing the average of each trait of the experimental unit. The following traits were evaluated:

i) Thousand grain weight via pods with one grain (TGW I): Traits were measured after selection of pods with only one viable grain, followed by counting of eight repetitions with one hundred grains, adjusting a thousand grain weight in grams.

ii) Thousand grain weight via pods with two grains (TGW II): Traits were measured after selection of pods with two viable grains, followed by counting of eight repetitions with one hundred grains, adjusting one thousand grain weight in grams.

iii) Thousand grain weight via pods with three grains (TGW III): Traits were measured after selection of pods with three viable grains, followed by counting of eight repetitions with one hundred grains, adjusting one thousand grain weight in grams.

iv) Thousand grain weight via pods with four grains (TGW IV): Trait was measured after selection of pods with four viable grains, followed by counting of eight repetitions with one hundred grains, adjusting a thousand grain weight in grams.

v) Number of pods with one grain (NP I G): obtained by counting of all pods per plant containing only one grain.

vi) Number of pods with two grains (NP II G): obtained by counting all pods per plant containing two grains.

vii) Number of pods with three grains (NP III G): obtained by counting all pods per plant containing three grains.

viii) Number of pods with four grains (NP IV G): obtained by counting all pods per plant containing four grains.

ix) Grain yield (YIELD): obtained by the total grain weight per experimental unit with subsequent correction of grain moisture to 13%. Ratio of the grain weight per plot by the number of plants was done. The grain weight per plant was adjusted to the plant density utilized and the results were expressed in kg ha^{-1}.

Obtained data were submitted to individual analysis of variance for each environment and growth habit to verify the homogeneity of variances. Phenotypic path analysis among agronomic traits was performed for each environment within the soybean growth habits.
For path analysis, estimates of direct and indirect effects were carried out considering the following statistical model:

$$y = p_1x_1 + p_2x_2 + ... + p_nx_n + p_eu$$

where y = grain yield or dependent variable; x_1, x_2,....,x_n = explanatory variables; p_a, p_2,...p_n = path analysis coefficients.
Estimates of the path analysis coefficients are estimated based on the following equations

X´Xβ = X´Y (Li, 1975):

$$X'Y=\begin{pmatrix} r_{1y} \\ r_{2y} \\ \vdots \\ r_{ny} \end{pmatrix}, X'Y=\begin{pmatrix} 1 & r_{12} & \dots & r_{1n} \\ r_{12} & 1 & \dots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{1n} & r_{2n} & \dots & 1 \end{pmatrix} e\ \beta=\begin{pmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{pmatrix}$$

In this way, the decomposition of the correlation between the dependent variable and the explanatory variables is performed as follows (Cruz et al., 2004):

$$r_{1y} = p_1+p_2r_{12} + \dots + p_nr_{1n}$$

$$r_{2y} = p_1r_{12}+ p_2+ \dots + p_nr_{2n}$$
... ...
$$r_{ny}= p_1r_{1n}+ p_{n2}+ \dots + p_n$$

$$r_{iy}= p_i+ \sum_{j\neq i}^{n} p_j\, r_{ij}$$

Where:
r_{iy}: correlation among the principal variable selected by the researcher (y) and the i-th explanatory variable;
p_i: measure of the direct effect of the i variable on the principal variable;
$p_i r_{ij}$: measure of the indirect effect of the i variable via j variable on the principal variable.

According to Cruz et al. (2004), when the deletion of variables is not desired by the researcher, procedures similar to ridge regression analysis are adopted. In this methodology, it is assumed that with the presence of multicollinearity, the least squares estimator obtained from X´Y may be linked to very high variances. This adverse effect can be slightly modified in the normal equations system with introduction of K constant in the diagonal of the matrix X´Y. Thus, path analysis coefficients are obtained: (X´X + KI) = X´Y;

$$\sigma = \begin{bmatrix} p_1^* \\ p_2^* \\ \dots \\ p_n^* \end{bmatrix}$$

With the inclusion of the K constant, the decomposition of correlation between the explanatory variables and the basic variable is given by:

$$r_{1y} = (1+K)p_1^*+p_2^* r_{12} + \dots + p_n^* r_{1n}$$

$$r_{2y}= p_1^* r_{12} +(1+K)p_2^*+ \dots + p_n^* r_{2n}$$

$$\dots \quad \dots \quad \dots$$

$$r_{ny} = p_1^* r_{1n} +p_2^* r_{n2}+ \dots + (1+K)\, p_n^*$$

Thus, we have:

$$r_{iy} = (1+K)p_{1i}^*+ \sum_{j\neq i}^{n} p_j^*\, r_{ij}$$

Values from 0 to 1 are considered for K constant, where Cruz et al. (1997) point out that among the values it should choose for the lower value of the constant, for which most of the path analysis coefficients linked to various traits are stabilized. The determination of the path diagram is given by:

$$R^2 = p_1 r_{1y} + p_2 r_{2y}+ \dots + p_n r_{ny}$$

The residual effect is estimated by:

$$\rho_{\varepsilon} = \sqrt{1- R^2}$$

The statistical software Genes (Cruz, 2006) was utilized in order to perform the analyses.

RESULTS AND DISCUSSION

Analysis of variance for traits

Analysis of variance revealed a significant interaction p>0.05 to IGH among environments x soybean cultivars for the variables TGW I, TGW II, TGW III, TGW IV, NP III G. The DGH revealed significant interaction p>0.05 for the traits TGW II, TGW IV, and NP III G. The obtained results demonstrated considerable influences of the growth habit via traits associated with soybean pods.

The number of grains per pod and grain weight directly influenced the soybean yield potential. These traits are responsive to the plant arrangement in the canopy, efficiency in the photosynthetically active radiation use, and considerable reduction of grain weight through water deficit (Rambo et al., 2002). Unsatisfactory water offerings provide decreases in the pod size, with negative effects on grain filling (Thomas and Costa, 2010). Moreover, research of Santos et al. (2013) reported beneficial effects of crop rotation, with the increase in the number of pods and grain yield per plant.

Direct and indirect effects between traits

Regarding the IGH for the variable TGW I, this trait does not contribute to crop yield (Table 1), observing the null correlation coefficients for direct effects in Tenente Portela -RS. According to Kurek et al. (2001), the coefficients can assume positive, negative or null magnitudes. The total Pearson correlation (r=0.441) evidenced intermediate and positive correlation coefficient, where the traits when grouped contribute to the principal variable.

The trait TGW I for IGH evidenced the direct effects, low and positive correlation coefficients to grain yield in Santa Rosa -RS. Indirect effects are obtained via TGW II with low and positive correlation coefficients. The contrasting results show the grain weight contribution to soybean yield potential, closely related to favorable environment and genotype. The Pearson correlation shows (r=0.548) intermediate and positive coefficient in relation to the principal trait. Simple correlations with high magnitudes can cause misinterpretations (Table 1), where they obtained responses are from direct or indirect effects of a particular trait or group of traits (Carvalho et al., 2002).

The TGW I for DGH demonstrated null correlation coefficients in the direct effects, with lack of response of this parameter to soybean yield in Tenente Portela -RS. The indirect effects via NP II G revealed a low and negative correlation coefficient, being low and positive via NP III G. Therefore, genotypes with DGH in this environment give preference for the formation of pods with three grains and facilitate support to soybean yield. Coimbra et al. (2005) reported that two variables are interconnected when one variable responds positively and other responds negatively for a given trait. Under these conditions the correlation of Pearson (r=-0.031) is practically null.

TGW I for DGH in Santa Rosa -RS expressed by the

Table 1. Estimate of the phenotypic direct and indirect effects for thousand grain weight via pods with one grain (TGW I), pods with two grains (TGW II), and pods with three grains (TGW III) in soybean for growth habits and environments.

Effects	Indeterminate growth habit		Determinate growth habit	
	Tenente Portela-RS	Santa Rosa-RS	Tenente Portela-RS	Santa Rosa-RS
Thousand Grain Weight via Pods with one Grain (TGW I)				
Direct Effect on YIELD	0.096	0.189	-0.084	0.177
Indirect Effect via TGW II	0.026	0.117	0.009	-0.019
Indirect Effect via TGW III	0.058	0.027	-0.032	-0.060
Indirect Effect via TGW IV	0.038	0.096	0.005	0.185
Indirect Effect via NP I G	0.016	0.050	-0.021	0.040
Indirect Effect via NP II G	0.084	0.029	-0.258	-0.079
Indirect Effect via NP III G	0.016	-0.011	0.308	-0.097
Indirect Effect via NP IV G	0.076	0.011	0.049	-0.217
Total	0.441	0.548	-0.031	0.061
Thousand grain weight via pods with two grains (TGW II)				
Direct Effect on YIELD	0.034	0.128	0.122	-0.045
Indirect Effect via TGW II	0.073	0.172	-0.006	0.075
Indirect Effect via TGW III	0.067	0.031	-0.017	-0.306
Indirect Effect via TGW IV	0.042	0.114	0.020	0.219
Indirect Effect via NP I G	-0.007	0.031	0.000	0.026
Indirect Effect via NP II G	-0.009	-0.020	0.045	-0.043
Indirect Effect via NP III G	-0.004	-0.034	-0.069	-0.282
Indirect Effect via NP IV G	0.099	0.032	-0.004	-0.318
Total	0.306	0.481	0.096	0.677
Thousand grain weight via pods with three grains (TGW III)				
Direct Effect on YIELD	0.070	0.032	-0.042	-0.335
Indirect Effect via TGW II	0.079	0.158	-0.065	0.031
Indirect Effect via TGW III	0.032	0.123	0.051	-0.040
Indirect Effect via TGW IV	0.044	0.114	-0.063	0.117
Indirect Effect via NP I G	-0.013	0.014	-0.082	-0.021
Indirect Effect via NP II G	-0.023	-0.078	-0.263	-0.050
Indirect Effect via NP III G	0.018	-0.052	0.156	-0.286
Indirect Effect via NP IV G	0.107	0.039	0.047	-0.288
Total	0.337	0.357	-0.264	0.831
Coefficient of determination	0.844	0.890	0.962	0.958
K-value	0.300	0.201	5.066	5.256
Effect of the residual variable	0.394	0.322	0.193	0.203
Determining variable	0.343	6.527	6.942	2.101

direct effect with low and positive correlation coefficient, indirectly the TGW IV parameter reveals a low and positive coefficient, low and negative coefficient via NP IV G. Genotypes with DGH tend to reduce the number of pods with four grains. On the other hand, they express superiority for grain weight, contributing positively to crop yield. The Pearson correlation coefficient was (r=0.061) similar among environments (Table 1), justified by the absence of linearity in the response of traits.

The increases in the weight and number of grains per legume have high and positive correlation coefficients regarding the grain yield (Ribeiro et al., 2001). Phenotypic correlations provide different trait associations, being influenced genetically and environmentally (Falconer, 1987). The thousand grain weight via pods with two grains TGW II expressedthe directly affects null correlation coefficient for IGH in Tenente Portela -RS (Table 1). The Pearson correlation coefficient (r=0.306) evidenced positive and intermediate correlation.

Regarding the IGH in Santa Rosa -RS, direct effects are observed with low and positive coefficient of correlation via TGW II, where the contribution to the principal trait is expressed through the indirect effects of TGW I and TGW IV. For IGH, the soybean yield potential is largely dependent on the grain weight of pods with one, two, and four grains, being phenotypically more important than the number of pods per plant. Proven performance by direct and indirect effects and via Pearson correlation coefficient (r=0.481) shows a positive intermediate correlation directly contributing to grain yield. Studies of Almeida et al. (2010), found significant contribution of thousand grain weight on soybean grain yield.

TGW II in Tenente Portela-RS for DGH demonstrated direct effects of low and positive coefficient of correlation, where Pearson correlation (r=0.096) was null, with low effects of the explanatory variable on the dependent trait. According to Cruz et al. (2004), correlation coefficients reduced or equal to zero do not express absence of relation among parameters, but nonlinearity among traits. In Santa Rosa-RS for DGH, the direct effects revealed null correlation coefficient via TGW II. For the indirect effects, intermediate and negative correlation coefficients via TGW III, NP III G, and NP IV G were observed, being low and positive via TGW IV. Genotypes with DGH in this environment promoted the reduction of the number of pods with three and four grains, but potentiate the increase of grain weight in pods with four grains. This confirmed the result by Carvalho et al. (2002), where modifications in grain weight and number of grains per pod occurred because of the soybean plasticity, which can increase or reduce these traits according to environmental requirements. The contribution of TGW II to soybean yield is justified by the Pearson correlation coefficient (r = 0.677) with an intermediate and positive correlation.

Negative effects on soybean yield occur through abiotic causes via water stress, with the reduction of pods with three grains (Tavares et al., 2013), and through biotic stresses decreasing the number and weight of grains per pod (Mesquini et al., 2011). In both environments for IGH, the variable TGW III evidenced null coefficient of correlation to the direct effects (Table 1). Pronounceable effects are evidenced indirectly via NP IV for Tenente Portela-RS, where the independent variable contribution exhibited greater significance for pods with four grains than the grain weight per pod.

In Santa Rosa-RS, low and positive indirect effects were expressed via TGW I, TGW II, and TGW IV. Environmental effects on soybean pods are justified by the performance of explanatory traits linked to grain weight, which contributes with greater relevance to the principal parameter. The Pearson correlation coefficients (r=0.337 and 0.357) exhibited intermediate and positive correlations with the contribution of TGW III to soybean yield for both environments (Table 1). The comprehension of associations among traits allows indirect selection of parameters that affect the soybean yield (Carvalho et al., 2002).

The performance of TGW III to the DGH for Tenente Portela-RS demonstrated absence of response to the direct effects. Pronounceable results are expressed indirectly via NP II G with low and negative correlation coefficients. Moreover, the Pearson correlation (r=-0.264) was also similar. Therefore, genotypes with DGH in this environment have opposite behavior, where increases in pods with two grains reduce crop yield. The simple correlation shows different directions between the principal variable and the independent TGW III trait. Research carried out by Carvalho et al. (2002), found that the thousand grain weight presents greater phenotypic correlation coefficients than the genotypic ones, proving environmental influence on the secondary trait, and this trait influences grain yield.

In Santa Rosa-RS, the DGH for TGW III reveals direct effects with intermediate and negative correlation coefficient. The indirect effects were observed by low and positive correlation coefficients for TGW IV and low and negative for NP III G and NP IV G. In this environment, genotypes reduced the formation of pods with three grains and consequently their grain weight. Contribution to soybean yield is elucidated by pods with four grains that are in smaller proportions but with heavier grains. Moreover, it is justifiable by Pearson correlation (r=0.831) characterized as strong and positive. This magnitude and direction are attributable to the responses of independent traits to the principal parameter.

The variable TGW IV for IGH in Tenente Portela-RS demonstrated null direct effects on the dependent trait (Table 2). Pearson correlation coefficient (r=0.198) demonstrated low and positive correlation. Moreover, a study performed by Kurek et al. (2001), revealed coefficients with magnitude and direction similar between the number of grains per pod and grain yield. In Santa Rosa-RS, the direct effects of the variable TGW IV were observed with low and positive correlation coefficient. Indirectly, the TGW I and TGW II traits expressed low and positive coefficients, contributing to the principal trait performance.

In this environment, the genotypes with IGH promote the formation of pods with four viable grains with greater weight, contributing to the yield of genotypes. Obtained results for the Pearson correlation (r=0.337) revealed intermediate and positive correlations, where the thousand grain weight provides contribution to the soybean yield potential, regardless of the origin pod dimensions. Meotti et al. (2012), found high and positive correlation coefficient between the grain weight and soybean yield.

The performance of TGW IV variable to the DGH demonstrated low and positive coefficients to the direct effects for both environments. In Tenente Portela-RS, indirect contribution to the principal trait is revealed via NP II G and NP IV G with low and positive correlation

Table 2. Estimate of the phenotypic direct and indirect effects for thousand grain weight via pods with four grains (TGW IV), number of pods with one grain (NP I G), and number of pods with two grains (NP II G) in soybean for growth habits and environments.

Effects	Indeterminate Growth Habit		Determinate Growth Habit	
	Tenente Portela-RS	Santa Rosa-RS	Tenente Portela-RS	Santa Rosa-RS
Thousand Grain Weight via Pods with four grains (TGW IV)				
Direct Effect on YIELD	0.062	0.128	0.221	0.250
Indirect Effect via TGW II	0.059	0.142	-0.002	0.131
Indirect Effect via TGW III	0.023	0.114	0.011	-0.039
Indirect Effect via TGW IV	0.050	0.028	0.012	-0.237
Indirect Effect via NP I G	0.003	0.002	0.098	0.013
Indirect Effect via NP II G	-0.043	-0.065	0.237	0.004
Indirect Effect via NP III G	-0.031	-0.065	0.033	0.228
Indirect Effect via NP IV G	0.054	0.025	0.103	-0.283
Total	0.198	0.337	0.726	0.377
Number of Pods with One Grain (NP I G)				
Direct Effect on YIELD	0.089	0.197	0.131	0.155
Indirect Effect via TGW II	0.017	0.048	0.013	0.046
Indirect Effect via TGW III	-0.002	0.020	0.000	-0.007
Indirect Effect via TGW IV	-0.010	0.002	0.026	0.046
Indirect Effect via NP I G	0.002	0.001	0.165	0.021
Indirect Effect via NP II G	0.214	0.210	0.233	-0.137
Indirect Effect via NP III G	0.040	0.163	0.057	-0.008
Indirect Effect via NP IV G	-0.031	-0.018	-0.008	-0.101
Total	0.345	0.665	0.626	0.021
Number of Pods with Two Grains (NP II G)				
Direct Effect on YIELD	0.282	0.306	0.363	0.519
Indirect Effect via TGW II	0.028	0.017	0.060	-0.027
Indirect Effect via TGW III	-0.001	-0.008	0.015	0.003
Indirect Effect via TGW IV	-0.006	-0.008	0.030	0.032
Indirect Effect via NP I G	-0.009	0.027	0.144	0.002
Indirect Effect via NP II G	0.067	0.135	0.084	-0.040
Indirect Effect via NP III G	0.215	0.259	-0.108	-0.018
Indirect Effect via NP IV G	0.012	-0.036	0.026	0.035
Total	0.675	0.701	0.635	0.533
Coefficient of determination	0.844	0.890	0.962	0.958
K-value	0.300	0.201	5.066	5.256
Effect of the residual variable	0.394	0.322	0.193	0.203
Determining variable	0.343	6.527	6.942	2.101

coefficients. Pearson correlation (r=0.726) was high and positive. In this environment, genotypes promote pod formation with two and four viable grains with greater weight. For Santa Rosa-RS, indirect effects are expressed via TGW I and NP III G with low and positive correlation coefficient, and low and negative coefficient via TGW III and NP IV G.

Genotypes with DGH prefer increasing grain weight derived from pods with one to four viable grains. This behavior evidenced the reduction in the number of pods with four grains and indirect effects of these traits are observed in the intermediate and positive Pearson correlation (r=0.377). The obtained results revealed that soybean sets the number of grains per pod and grain weight due to the phenotype plasticity, derived from the genotype-environment interaction. Different responses among environments influence correlation among traits and soybean phenotype expression (Carvalho et al., 2002).

Among the traits that contribute to soybean yield, number of pods per plant is an emphasized attribute, which is influenced by plant arrangement and water and nutrient management (Ventimiglia et al., 1999). Research performed by Coimbra et al. (2000) found high and positive correlation coefficient between the number of pods per plant and grain yield. The NP I G for IGH in Tenente Portela-RS revealed direct effects with null coefficients. Indirectly, low and positive correlation coefficients were observed via NP II G (Table 2). Pearson correlation (r=0.345) was intermediate and positive. The magnitude of the correlation is justified by the indirect effects, where the genotype potential is linked to the emission of pods with two grains. Direct and indirect effects allow understanding of the interrelationships between traits that affect soybean yield (Perini et al., 2012).

In Santa Rosa-RS, the variable NP I G demonstrated direct and indirect effects via NP II G and NP III G, respectively, low and positive correlation coefficients. Barbaro et al. (2006) found that the number of pods per plant was the most related parameter to the genotype yield potential. The Pearson correlation (r=0.665) was intermediate and positive. In this environment, the productive performance of IGH genotypes is justified by the greater number of pods per plant, independently of the grains per pod magnitude.

The variable NP I G performance for GHD revealed direct effects with low and positive correlation coefficients for both environments (Table 2). In Tenente Portela-RS, pronounceable indirect effects were obtained via TGW IV and NP II G with low and positive correlation coefficients. Pearson correlation (r=0.626) was intermediate and positive. Genotypes with DGH contributed to the number of pods per plant conjugated to grain weight increase derived from pods with four viable grains. In Santa Rosa-RS, indirect effects were expressed via NP II G and NP G IV and low and negative correlation coefficients were observed. Pearson correlation (r=0.021) was null. The variations in pods per plant are more related to environmental effects than soybean growth habit (Perini et al., 2012).

The NP II G in both growth habits and environments revealed direct effects with intermediate and positive correlation coefficients. For Tenente Portela-RS, IGH evidenced indirect effects via NP III G and via NP I G and NP III G in Santa Rosa-RS, with low and positive correlation coefficients in relation to dependent trait. For IGH, Pearson correlations were (r=0.675) intermediate and (r=0.701) positive. Studies reported the importance of quantifying the direct and indirect effects of independent traits with the principal parameter and determine the effects linked to the environment (Gomes et al., 2007).

In Tenente Portela-RS, the DGH demonstrated indirect effects with low and positive correlation coefficient via TGW IV and low and negative coefficient via NP III G. Results justified the contribution of increased grain weight originated from pods with four grains with the reduction of number of pods with three grains. The Pearson correlations were (r=0.635) intermediate and (r=0.533) positive. Correlations with high magnitude are linked to direct and indirect effects of the independent variables in relation to the principal trait (Vencovsky and Barriga, 1992).

For both growth habits and environments, NP III G revealed direct effects with intermediate and positive correlation coefficients (Table 3). It demonstrated that the differences between the genotype traits and their interactions with the environments revealed the NP III G trait significant contribution to the principal parameter. The phenotypic correlation partitioning in direct and indirect effects allows one to quantify the influence of independent variables on soybean yield (Bizeti et al., 2004). For IGH in Tenente Portela-RS, indirect effects via NP II G and NP IV G with low and positive correlation coefficients were observed. Pearson correlation (r=0.868) was high and positive. For Santa Rosa-RS, indirect influences were expressed via NP II G with low and positive correlation coefficient. The Pearson correlation (r=0.750) was intermediate and positive for both environments with clear contribution of the independent variable NP III G to grain yield.

The trait NP III G for the DGH revealed significant indirect effects only for Santa Rosa-RS, where the TGW III and NP IV G evidenced intermediate and positive correlation coefficient, low and negative coefficient via TGW IV. Genotypes with DGH promote the formation of pods with three and four grains, where the effects on grain yield were pronounceable by the increase of grain yield via pods with three grains. This behavior is similar to the grain weight via pods with four grains. Pearson correlations were (r=0.605) intermediate and (r=0.733) positive for both environments. Positive correlations evidence increases in the principal variable through the explanatory variables effects (Nogueira et al., 2012).

The NP IV G for IGH revealed direct and indirect effects via NP III G with low and positive correlation coefficients for both environments (Table 3). The DGH in Tenente Portela-RS revealed direct and indirect effects via TGW IV with low and positive correlation coefficients. Pearson correlation (r=0.035) was null. For Santa Rosa, intermediate and positive coefficient was observed in the direct effects. Indirectly, low and positive coefficients via TGW III and NP III G and low and negative coefficients via TGW I and TGW IV were observed. The results expressed in these conditions and growth habit evidenced the soybean plasticity and its ability to change depending on environmental conditions. The Pearson correlation (r=0.679) was intermediate and positive regarding the principal trait.

Phenotypic estimates of traits linked to soybean pods evidenced high coefficients of determination and lower residual effects. Moreover, the results justify the associations with grain yield regardless of the growth

Table 3. Estimate of the phenotypic direct and indirect effects for number of pods with three grains (NP III G) and number of pods with four grains (NP IV G) in soybean for growth habits and environments.

Efeitos	Indeterminate Growth Habit		Determinate Growth Habit	
	Tenente Portela-RS	Santa Rosa-RS	Tenente Portela-RS	Santa Rosa-RS
Number of Pods with Three Grains (NP III G)				
Direct Effect on YIELD	0.464	0.395	0.663	0.303
Indirect Effect via TGW II	0.003	-0.005	-0.039	-0.057
Indirect Effect via TGW III	0.000	-0.011	-0.012	0.042
Indirect Effect via TGW IV	0.002	-0.004	-0.010	0.315
Indirect Effect via NP I G	-0.004	-0.021	0.011	-0.188
Indirect Effect via NP II G	0.007	0.081	0.011	-0.004
Indirect Effect via NP III G	0.131	0.201	-0.059	-0.031
Indirect Effect via NP IV G	0.122	0.034	0.007	0.338
Total	0.868	0.750	0.605	0.733
Number of Pods with Four Grains (NP IV G)				
Direct Effect on YIELD	0.195	0.134	0.169	0.369
Indirect Effect via TGW II	0.037	0.015	-0.024	-0.104
Indirect Effect via TGW III	0.017	0.030	-0.003	0.039
Indirect Effect via TGW IV	0.039	0.009	-0.011	0.261
Indirect Effect via NP I G	0.017	0.023	0.135	-0.191
Indirect Effect via NP II G	-0.014	-0.027	-0.006	-0.042
Indirect Effect via NP III G	0.017	-0.084	0.057	0.050
Indirect Effect via NP IV G	0.292	0.102	0.028	0.277
Total	0.661	0.232	0.035	0.679
Coefficient of determination	0.844	0.890	0.962	0.958
K-value	0.300	0.201	5.066	5.256
Effect of the residual variable	0.394	0.322	0.193	0.203
Determining variable	0.343	6.527	6.942	2.101

Abbreviations: TGW I, thousand grain weight via pods with one grain; **TGW** II, thousand grain weight via pods with two grains; **TGW** III, thousand grain weight via pods with three grains; **TGW** IV, thousand grain weight via pods with four grains; **NP** I G, number of pods with one grain; **NP** II G, number of pods with two grains; **NP** III G, number of pods with three grains; **NP** IV G, number of pods with four grains; **YIELD**, grain yield; **IGH**, indeterminate growth habit; **DGH**, determinate growth habit.

habit.

Conclusions

The traits number of pods with two, three, and four grains directly influenced the grain yield of genotypes with indeterminate growth habit regardless of the environment. The soybean genotypes with determinate growth habit express greater contributions to grain yield through the traits number of pods with one, two, and three grains and thousand grain weight via pods with two or four grains. Indirect selection of superior genotypes for pods per plant and grain weight could provide satisfactory results for soybean yield in relation to the growth habit. The interrelationships obtained between growth habits and environments, can be applied to superior genotypes selection strategies in breeding soybean programs.

Conflict of Interests

The authors have not declared any conflict of interests.

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