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*Full Length Research Paper*

# Determinants of rice farmers' access to credit in Benin: A case study of the municipality of Glazoue

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**This study aims to identify the factors that limit the accessibility of rice farmers to credit in Benin. Data were collected from 120 randomly selected rice households in the municipality of Glazoue. The logit dichotomous model was used to analyze the data and various statistics were produced for this purpose using the Stata 13 software. The results of prediction model show that the model has a high predictive power and the explanatory power giving by the value of the Pseudo $\chi^2$ of McFadden (60.85%) show that more than 60% of the explanatory variables of the model make rice farmers' access to credit easier to understand. Literacy (P <0.001) and the part of income from rice in the monthly income of the rice farmer (P <0.001) had a positive effect on the rice farmer's capacity to have access to credit. Rice as the main speculation in terms of income (P <0.001) and household size (P <0.001) had a negative effect on access to credit. In order to facilitate rice farmers' access to agricultural credit, particular emphasis should be placed on the level of literacy of farmer, his monthly income from rice production, the size of his household and his main crop. This study recommends that the actors adapt to the service offering of microfinance to the socio-economic conditions of rice farmers to enable them to access credit and increase rice production. This would help to meet the demand for rice, and, in turn, contribute to the reducing food insecurity in Benin.**

**Key words:** Determinant, access to credit, rice production, Benin.

## INTRODUCTION

Agriculture is the main source of growth for developing countries and helps reduce poverty and preserve the environment (World Bank, 2008). In Benin, agriculture accounts for about 75% of the total population and contributes significantly to the creation of value added (29.89% of GDP in 2008) and nearly 80% of export currencies (PSRSA, 2011). Since the 1960s, the government of Benin has invested in the development of canal irrigation schemes in order to intensify food crop production and reduce food insecurity (Nonvidé faced with the scarcity of financial institutions (banks), decentralized financial services (DFS) are becoming an indisputable resource to serve the rural world in financial services. It is important to note that despite the progress made in the past two decades, access to financing in developing countries remains a major problem (Kacem

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and Zouaril, 2013). New Rice for Africa (NERICA) was developed by the Africa Rice Center by crossing high-yielding Asian rice (*Oryza sativa* L.) with locally adapted African rice (*Oryza glaberrima* Steud.). Community-based seed production of NERICA varieties was introduced in a village in central Benin in 2006 through seed dissemination projects. It was reported that high-adoption rates of these varieties were mainly due to high demand by development projects for seed dissemination, and to incentives (that is, selling the rice seed at a higher than local market price to a local extension service) for farmers to grow NERICA varieties (Yokouchi and Saito, 2017).

According to Nonvide (2018), irrigation offers important opportunities for enhancing crop yield and production in developing countries. Also, the future security of the supply of rice for food in Africa depends on improving the level of local production to achieve self-sufficiency. In order to cope with the existing gap between production and actual demand, combining a high level of rice blast tolerance and a high-yield potential is necessary (Yelome et al., 2018).

In Benin, rice producers face enormous funding challenges. However, according to Sossou (2014), important constraints limit the development of the rice sector in Glazoué among which we can mention the lack of microcredit. The difficulty of access to financial services for farmers is one of the main obstacles linked to agricultural development in Benin (Sossou, 2014). According to Singbo and Nouhoeflin (2012), producers are often poor, not because of the size of their farms, but because of lack of access to institutional services. According to Lesaffre (2000), the short-term global financing of the agricultural sector is 14% in developing countries (UEMOA). On the other hand, in the tertiary sector, overall financing amounts to 79.18% (Sossa, 2011). Thus, to answer this problem of financing in the rice sector is to find very adapted financing mechanisms with very convenient means of granting.

In Benin, the microfinance sector has experienced significant growth with the creation of several credit institutions, cooperatives and mutual savings companies and the establishment of agricultural financing mechanisms in rural development projects and programs (Sossou, 2014). These institutions often fail to meet the demand for credit from agricultural people. This forces them to adopt credit rationing, which is an element that directly or indirectly affects the efficient use of credit and therefore has a negative impact on its performance.

Despite the efforts of microfinance institutions to serve the farming community, they do not have access or have difficult access to financial services. This is because there is reluctance related to the supply of credits. These are repayment prospects that are not secured due to weather conditions, low yields, or the unstable socio-economic environment (Deveze, 2000). With a sub-equatorial climate, the commune knows two rainy seasons a small and two dry seasons including a small one too. The average annual rainfall is 959.56 to 1255.5 mm; the average temperature varies between 24 and 29°C. The relief is marked by the presence of plateaus (200 to 300 m), dominated by hills in places (Sokponta, Gomé, Camaté, Tankossi, Tchatchégou, Thio, Ouèdèmè, Assanté and Aklampa), which constitutes tourist assets. Hydrography is formed on one hand by a major watercourse Ouémé River which waters the commune at the villages of Aklampa, Bethel, Riffo and part of the district of Zaffé and small local watercourse (Adoué, Kotobo, Trantran, Tehoui, Antadji, Tchololoé, etc.) which encourage the development of off-season market gardening and artisanal fishing activities. There are also several types of soils, the most important of which are: white sandy soils suitable for growing cassava, groundnut and groundnuts; the black sandy soils found locally and suitable for all crops; stony soils that are generally poor.

With regard to the rice potential offered by the municipality of Glazoue, with a total area of 9456 ha and agro-ecological conditions favorable to rice production, rice farmers are limited to their financial power of production if only for sustenance. Faced with this situation, it is important to think of an external or internal financing mechanism that can reliably support rice farmers with the aim of intensifying rice production. To the best of our knowledge, prior research has not yet systematically examined such a mechanism, the issue addressed in this article. The econometric approach is used in this study to better tailor the determinants of rice farmers' access to credit in Benin. The paper first presents a brief description of the conceptual framework and methodology of the study, then analyses and discusses the determinants of rice farmers access to credit in Benin and draw some policy implications.

## METHODOLOGY

### Data collection

The data was collected in the municipality of Glazoue. This town was chosen because of its strong rice potential and many rice farmers who live there. The selection of rice farmers surveyed was conducted randomly in 9 villages in the commune (Figure 1). A total of 120 rice farmers were surveyed. This size is function from the available number of rice farmer in each village of Glazoue. In each village, the random method was used to select the rice farmer producers. The data was collected using a structured interview guide designed for this purpose. The data collected were related to the socio-economic characteristics of the respondents, the evolution of rice production, the use made of rice production, and access to credit for rice production. Table 1 shows the sample size in the study area.

### Data analysis

To analyze the data, the methodological approach, both statistical and econometrics, were adopted. This approach made it possible to use tools such as tables, graphs, and an econometric model. The


**Figure 1.** Zone study area.

**Table 1.** Sampling by the village.

| District | Village | Number | Proportion (%) |
|---|---|---|---|
| Ouèdème | Kpota | 18 | 18 |
| | Yagbo | 12 | 12 |
| Kpakpaza | Kpakpaza | 8 | 08 |
| | Sowé | 19 | 19 |
| | Yawa | 09 | 09 |
| Thio | Abèssouhoué | 06 | 06 |
| Gomé | Gomé | 15 | 15 |
| Sokponta | Sokponta | 20 | 20 |
| Magoumi | Masso | 13 | 13 |
| Total | | 120 | 100 |

tables and graphs were made with the Excel 2010 software. Also, the descriptive statistics were used. The latter made it possible to characterize rice producers and their farms through the calculation of means (measurement of central tendency) and standard deviations (measurement of dispersion) as well as relative frequencies. For econometric analysis, the logit model was used. Table 2 groups together the description of the variables used in this model.

***Model specification***

To analyze the determinants of access to credit for rice farmers in the commune of Glazoué, econometric modeling was used. In fact, econometric analysis proposes several methods that make it possible to explain the decision-making behavior of individuals through the use of direct choice models. The most used models are discriminant analysis, Probit models, Logit models and linear probability models. The linear probability models, although frequently used in econometrics because of their simplicity in the application (estimation by the MCO) nevertheless present enormous theoretical deficiencies. Indeed, they lead to the construction of probability density taking values outside the interval [0, 1], which is meaningless. Thus, several authors advise against the use of these models (Griffith et al., 1993; Njankoua, 1999; Koua, 2007).

Indeed, two linked multifactorial analysis techniques generally used in studies of choice, are the Logit and Probit models. Both models use a variety of farm and farmer characteristics (which may be continuous or discrete) to predict the likelihood of choice (Maddala, 1983). The functional difference between these two models is that Logit assumes that the dependent variable follows by a logistic distribution while the Probit assumes a normal cumulative distribution (Koua, 2007). For most analyses, the interpretation of

**Table 2.** Description of variables.

| Variable | Description |
|---|---|
| **Dependent variable** | |
| Credit | Access to credit 1=Yes, 0=No |
| **Independent variable** | |
| Sex | 1=Woman, 0=Male |
| Age | Quantitative variable (Years) |
| Alphaa | Literacy 1=Yes, 0=No |
| Spreven | Rice as the main income speculation, 1=Yes, 0=No |
| Partri | Part of rice income in monthly income (%) |
| Foriz | Training received in rice production, 1=Yes, 0=No |
| Nomef | Household size (Persons) |
| parven4 | Part of sold production (%) |

the data, although estimated by Logit or Probit, will be very similar. The differences appear only in the size of the distribution, that is to say, for individuals with a very or very low probability of access since the logistic function has a flatter curve. However, calculations are simpler in the case of Logit and more complex in the case of Probit. As part of the analysis of the determinants of access to credit, the model adopted is, therefore, the Logit dichotomous model. This choice is justified by the following:

(1) The variable explained in the context of the study is qualitative and dichotomous (having access or not having access);
(2) The Logit model facilitates the interpretation of the β parameters associated with the explanatory variables Xi according to Hurlin (2003);
(3) The Logit model does not establish a linear relationship between dependent and independent variables and does not affect homoscedasticity; moreover, its use does not require a normal distribution of variables (Jera and Ajayi, 2008);
(4) THE Logit model is frequently used because of the interpretation of the exponential coefficient of a co-variable as an Odds Ratio.

"Odds Ratio" is the quotient:

$$\frac{P}{1-P} = \frac{P\left(Yi = \frac{1}{xi}\right)}{P\left(Yi = \frac{0}{xi}\right)} = e^{xi\beta}$$

where P is the probability that a rice farmer has access to credit; Yi is the dependent variable whose value is 1 or 0; and xi the explanatory variables.

OR (xi) is the ratio of luck under xi:

(1) The Logit model shows that the log of the odds ratio follows the linear model xiβ. The interpretation of β is as follows: For a qualitative variable, there is β times more chance that the event yi = 1 is realized or not realized;
(2) In the specific case of this study, the Logit model was used by Pitipunya (1995) and Fujimoto and Jahroh (2010), respectively to analyze the determinants of crop diversification on rice fields in Thailand and on the diversification of fish and vegetables in irrigated rice fields in Sumatra, Indonesia.

## Description of the model and validity test

In order to explain the decision of the rice farmer on the choice of the access or not to the credit, one supposes that the rice grower is placed in front of two exclusive choices represented by a random utility (U1 for the choice to have access to the credit and U0 for the choice of not having access to credit). Consider the dependent qualitative variable credit. The two methods it can take are conventionally codified 1 and 0, that is, Credit = 1 if the rice farmer has access to credit and Credit = 0 if the rice farmer does not have access to credit.

The choice to access credit depends on the following explanatory variables listed. So the probability for the rice farmer to have access to credit is:

$$Pi\ (CREDIT = 1) = F(\beta_1 + \beta_2 sex + \beta_3 age + \beta_4 alpha + \beta_5 spreven + \beta_6 partri + \beta_7 foriz + \beta_8 nomef + \beta_9 parven4$$

Noting β the vector of the coefficients, X the vector of the explanatory variables and P the vector of the probabilities, we have in matrix form:

Pi = P (CREDITi) = 1/Xi) = F(Xiβ)

F being the distribution function associated with the probability distributions.

## Validity test

The tests and their rules of decision are explained according to the description of Doucouré (2005).

## Global significance test (model quality)

As in the case of linear regression models with continuous dependent variable, Fisher's test is performed to see overall significance of the model. To test the significance of one or more model coefficients in the case of models with qualitative variables, we referred to the test on the LR Likelihood Ratio. Thus, the following hypotheses have been tested:

H0: wrong model
H1: good model

### *Decision rule*

The LR statistic follows a Chi-square law with k degrees of freedom;

**Table 3.** Description of the respondents.

| Variable | Modalities | Access to credit | No. access to credit | All |
|---|---|---|---|---|
| Sex | Woman | 37.84 | 32.61 | 35.83 |
| | Man | 62.16 | 67.39 | 64.17 |
| Literacy | Yes | 21.62 | 73.91 | 41.67 |
| | No | 78.38 | 26.09 | 58.33 |
| Rice as the main income speculation | Yes | 66.22 | 58.70 | 63.33 |
| | No | 33.78 | 41.30 | 36.67 |
| Training on rice production | Yes | 68.92 | 95.65 | 79.17 |
| | No | 31.08 | 4.35 | 20.83 |

with k the number of explanatory variables. We will reject H0 if the critical probability is less than 5%.

**Hosmer-Lemeshow test**

This test makes it possible to assess the quality of the adjustment made. Thus, the following hypotheses have been tested:

H0: good adjustment
H1: bad adjustment

***Decision rule***

H0 is accepted if the value of the corresponding probability is greater than 5%. Otherwise, H0 is rejected.

**Evaluation of the predictive power of the model**

Here, the percentage of correct predictions is calculated, that is, the percentage of cases where the observed value is equal to the predicted value. Also, the percentage of the contrary cases (false predictions) is calculated.

***Decision rule***

Since the percentage of false predictions is low (close to 0), the prediction power is high.

**Evaluation of the explanatory power of the model (pseudo R squared of McFadden)**

The McFadden R-square is the analog of R squared in the case of linear regression. It is still called the pseudo R squared. It allowed appreciating the explanatory power of the model. Thus, a high value (close to 1) means that the model has good explanatory power.

**Evaluation of the discriminating power of the model (ROC curve)**

In order to construct the prediction model, it is of interest to examine its discriminating power. This examination was done by calculating the area below the Receiver Operating Characteristic (ROC) curve or efficiency characteristic curve. The area under this curve was used to assess the accuracy of the model to discriminate accessing and non-accessing to credit. Discrimination is exceptional when the OCR area ≥ 0.9.

***Significance test of the coefficients of the explanatory variables***

The following hypotheses were tested:

H0: $\beta i = 0$
H1: $\beta i \neq 0$

***Decision rule***

H1 is accepted when the critical probability is less than 5%. It is rejected in the opposite case

## RESULTS AND DISCUSSION

### Socio-economic characteristics of the respondents

The description of the respondents is shown in Table 3 that 64.17% of men are surveyed against 35.83% of women. These results show that the majority (67.39%) of men have access to credit for agricultural production. In terms of informal education, only 41.67% of respondents are literate. Of those rates with literacy training, only 21.62% do not have access to credit. Rice is the main income speculation for more than 60% of respondents, of whom more than 58% have access to credit for rice production. In terms of capacity building, descriptive statistics show that 79.17% of the respondents were trained in rice production. Training in rice production is a factor that has facilitated access to credit because more than 95% of those trained in rice production had access to credit for rice production.

Table 4 shows that the population with access to credit is relatively young. The size of households in this population is on average six inhabitants against eight for

**Table 4.** Distribution of age, household size and income according to access to credit.

| Variable | Access to credit | |
|---|---|---|
| | **No** | **Yes** |
| Age | 46.14±11.32 | 44.46±8.98 |
| Households size | 8.31±3.97 | 6.59±1.51 |
| Part of the income from rice in monthly income | 30.48±2.10 | 50.13±2.75 |
| Part out of 100 sold | 57.3±2.99 | 65.9±0.91 |

**Table 5.** Results of the logistic model regression.

Dependent variable: Credit
Estimation method: Maximum likelihood (logit binary model)
Sample size: 120

| **Variable** | **Coef** | **Std. Err** | **P-value** |
|---|---|---|---|
| Constant | 0.63 | 2.06 | 0.76 |
| Sex | -1.20 | 0.76 | 0.11 |
| Age | -0.04 | 0.03 | 0.22 |
| Literacy | 3.08*** | 0.96 | 0.00 |
| Rice as the main income speculation | -5.39*** | 1.61 | 0.00 |
| Part of rice income in monthly income | 0.81*** | 0.27 | 0.00 |
| Training received in rice production | -0.04 | 1.09 | 0.96 |
| Household size | -1.13*** | 0.28 | 0.00 |
| Part of sold production | 0.36 | 0.22 | 0.10 |
| Pseudo $\chi 2$ : | 0.61 | | |
| LR Statistics (ddl=8) : | 97.22 | LR Probability | 0.00 |
| H-L Statistics : | 6.30 | H-L Probability | 0.61 |
| % of correct prediction: | 86.67 | % of incorrect prediction | 13.33 |
| Discrimination power of the model: | | 0.95 | |

***P<0.001.

those who do not have access to credit. The part of income from rice production in the monthly income of the farmer is about 50% for those who have access to credit unlike those who do not have access to credit which is about 30%. This result shows that rice production generates subsequent income for those who have access to credit because it makes it easier for them to spend on production. Similarly, farmers who have received credit sell more than 65% of their production against an average of 57% for those who do not have access to credit.

## Results of econometric modeling

The estimation of the logit model with the Stata 13 software gives the results which are shown in Table 6. The results of the logit estimation of the model show the probability of the LR statistic of 0.00. This value, much less than 0.05 makes it possible to affirm that the model is globally significant at the 1% level. The probability statistic of Hosmer-Lemeshow (HL) test at the 5% level is 0.61; which is greater than 0.05. Thus, the model presents a quality of fit that is good.

The prediction model is as shown in Figure 3 and shows that 86.67% of the predictions are correct and only 13.33% are incorrect. This result makes it possible to accept the hypothesis according to which the model has a high predictive power.

The value of the pseudo $R^2$ of McFadden which makes it possible to appreciate the explanatory power of the model gives a value of 0.6085 or 60.85%. This means that more than 60% of the explanatory variables make rice farmers' access to credit easier to understand. The evaluation of the discriminating power of the model involves the calculation of the area delimited by the ROC curve. In the case of the logit model of this study, the area delimited by the ROC curve is 95.56%, which

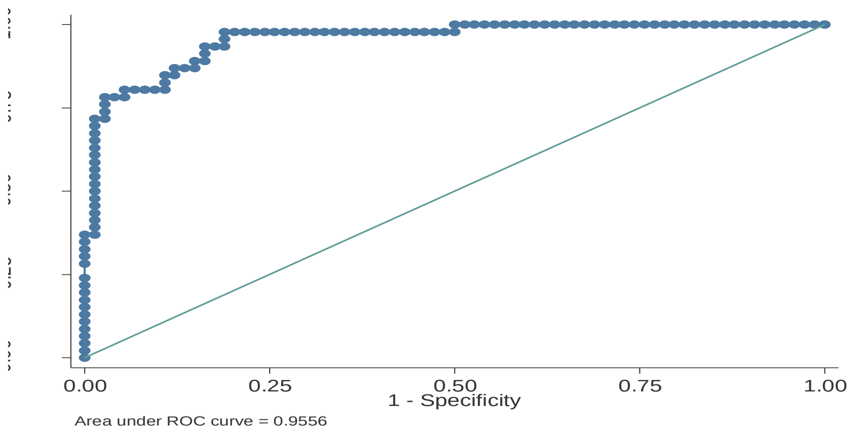


**Figure 2.** ROC curve.

**Table 6.** Odds-Ratio and Marginal Effects

| Variable | Odds-ratio | | Marginal effects | |
|---|---|---|---|---|
| | Odds-ratio | P-value | dy/dx | P-value |
| Sex | 0.302 | 0.114 | -0.131 | 0.117 |
| Age | 0.958 | 0.225 | -0.004 | 0.244 |
| Literacy | 21.726 | 0.001*** | 0.383 | 0.005 |
| Rice as the main income speculation | 0.005 | 0.001*** | -0.765 | 0.000 |
| Part of rice income in monthly income | 2.292 | 0.002*** | 0.078 | 0.014 |
| Training received in rice production | 0.953 | 0.965 | -0.005 | 0.965 |
| Household size | 0.322 | 0.000*** | -0.106 | 0.005 |
| Part of sold production | 1.428 | 0.105 | 0.034 | 0.088 |

***P<0.001.

reflects an exceptional discriminating power (Figure 2).

The test used to test the significance of the coefficients is the Likelihood Ratio Test (LRT). Thus, the analysis of the results in Table 6 shows that the coefficients of four variables are significant at the 1% level. These are the variables literacy, rice as the main speculation in terms of income, share of rice income in monthly income and household size. Gender, age, training received in rice production and share of products sold are not significant.

The marginal effects and odds-ratios of the continuous variables were calculated at the mean of the data and for the dummy variables, a value of 0 was used if the mean is less than 0.5 and a value of 1 was used if the average is greater than or equal to 0.5 (Banerjee, 2008).

## Analysis of logit model regression results

The value of the probability that tested the null hypothesis that all the coefficients of the explanatory variables are zero is significant at the 1% level. This leads to the conclusion that the model is globally significant at the 1% level. The Hosmer-Lemeshow test shows the existence of a good quality of the fit of the model. This means that the difference between observed and predicted variables is not significant. In addition, the McFadden pseudo $R^2$ value is 60.85%, which means that the variation of the dependent variable, access to credit, is explained at 60.85% by the variation of the explanatory variables. Similarly, the percentage of incorrect predictions (13.33%) is very low compared to that of correct predictions (86.67%), which makes it possible to say that the model has a very high power of prediction.

On the other hand, in a linear model (Logit in the case of this study), the parameters of the variables are not directly interpretable. But according to Doucouré (2005), the most important is the sign of the coefficients that indicate whether the associated variable influences the probability upward or downward.

Thus, the results of the coefficient estimation reveal that literacy and the share of rice income in monthly income increase the chances of having access to credit. However, there is a deficit in that having rice as the main speculation in terms of income and household size decreases the chance of having access to credit. The odds-Ratio and marginal effects results will be interpreted

| Classified | D | ~D | Total |
|---|---|---|---|
| + | 37 | 7 | 44 |
| - | 9 | 67 | 76 |
| Total | 46 | 74 | 120 |

Classified + if predicted Pr(D) >= .5
True D defined as credit != 0

| | | |
|---|---|---|
| Sensitivity | Pr( +\| D) | 80.43% |
| Specificity | Pr( -\|~D) | 90.54% |
| Positive predictive value | Pr( D\| +) | 84.09% |
| Negative predictive value | Pr(~D\| -) | 88.16% |
| False + rate for true ~D | Pr( +\|~D) | 9.46% |
| False - rate for true D | Pr( -\| D) | 19.57% |
| False + rate for classified + | Pr(~D\| +) | 15.91% |
| False - rate for classified - | Pr( D\| -) | 11.84% |
| Correctly classified | | 86.67% |

**Figure 3.** Predictive power of the model.

independently to highlight the impact of each exogenous variable on the exogenous variable.

### *Literacy*

Literacy is an important factor to have access to credit for agricultural production. The regression coefficient for this variable is 3.078 and a P-value of 0.001. This variable is significant at the 1% level. This result means that the fact that the farmer is literate increases the chances of having access to credit for rice production by 21.72 times. Thus, the econometric analysis shows that the level of literacy of the credit applicant is a significant factor for access to credit. More the applicant is alphabetized, more likely he is to obtain credit from financial services.

This result confirms those of Evans et al. (1999), which showed that low literacy levels affect the decision of the credit grantor. It can be concluded that literacy is a criterion for selecting credit applicants. However, the descriptive analyzes reveal that the highest access rate is observed in the category of literates (73.91%). The most important consideration here is to have a qualifier to have access credit. The basic qualifier for a credit applicant is to be literate. This implies a strong negotiating capacity and a spirit of discernment. For Eloundou et al. (2013), a high level of literacy is an asset for women who can play the role of leaders or leaders of groups and even act as true intermediaries between the rural world and external partners. But illiteracy creates a dependency on others who may limit the potential power of action of an individual.

### *Rice as the main speculation in terms of income*

The regression coefficient of the rice variable as the main income speculation is -5.38 with a probability of 0.001. This means that this variable negatively and significantly influences the possibility of having access to credit for rice production at 1% level. In addition, Table 3 shows that those who have rice as the main income speculation do not have access to credit (66.22%). This can be explained by the fact that the income from rice when it is taken as the main speculation is really considerable so that the farmer no longer needs to apply for credit. In other words, if the farmer produces his rice and has sufficient added value to meet the other expenses, he no longer needs to go to a financier to apply for credit. In this case, it can be self-financing. This is explained by the negative sign of this variable in the logit model.

### *Part of rice income in monthly income*

The level of the part of income in monthly income has a positive influence and is significant at the 1% level of access to credit for rice production. Thus, the part of rice income in the monthly income of the farmer increases the chances of having access to credit for rice production by 2.29 times with a probability of 0.002. The marginal effect estimated at -0.78 implies that an increase of 0.002 USD of income from rice will increase the probability of having access to credit for rice production of 0.78%. Thus, the probability of having access to credit is an increasing function of income from rice production.

When the farmer's income is growing or stable, the repayment of credit is guaranteed. Nowadays, microfinance institutions do not give credit to anyone and anyhow in Benin. The credit applicant must show a guarantee worthy of the name and validly represented.

### *Household size*

The regression coefficient for the household size variable is -1.13 with a gain of 0.000. These results imply that the household size variable influences negatively and significantly the possibility of having access to credit for rice production at a 1% level. The marginal effect estimated at -0.106 implies that an increase of one unit of the producer's household size decreases the probability of having access to credit for rice production by 0.106%. In other words, it should be noted that the effect of household size has been anticipated to be negative whereas it is positive in reality. As a result, the effect of household size on productivity depends more on the quality and skills of household members than on the size of the household (Bamba et al., 2014). If they have a certain level of education and proven experience in rice production, it will help the head of the household to perform better. In many cases, the family workforce (which is the largest) is often made up of women and children who are not often experienced or have not attained a high level of education. These results confirm those of Fall (2009) who showed that size is a datum that informs both the level of family burden and the potential of agricultural labor available within a household. Thus, size acts differently depending on these two considerations. The first aspect justifies the search for higher incomes to meet the needs of the family and thus influences attempts to intensify production.

Eloundou et al. (2013) have shown that the importance of the number of people living in a household can be explained by two phenomena: age of union and early sexual intercourse in rural areas. Indeed, this trend is not limited only to parents and children, but also extends to cousins and grandparents. In their study, women with more than 8 people in their household are much more members belonging to a microcredit institution. Thus, this high representativeness of members can be attributed to the fact that households with more "mouths to feed" are forced to find sources of safe, available and continuous money loans for family members.

## Conclusion

Rice farmers face several factors limiting their access to factors of production in general and specifically to financial services. The purpose of this study was to identify and analyze these factors. Literacy, the part of income from rice in the farmer's monthly income, rice as the main income speculation and household size can be considered as the main factors limiting rice farmer's access to services of microfinance institutions in rural areas. For easy access of rice farmers to agricultural credit, this study recommends that actors adapt the service offer of microfinance to the socio-economic conditions of rice farmers in order to enable them to access credit and increase their rice production, which would help meet the demand for rice and, by extension, contribute to reducing food insecurity in Benin.

Whatever the scientific value given to this document, we must recognize that it has certain shortcomings. Indeed, most of the data used in this study come from field surveys. Given the imperative of time related to the requirements of the available financial means, all the producers of the municipality were not met. In addition, the data were collected by single passage where the respondents' memory is used. It should also be noted that the mistrust shown by some respondents in the provision of information has been a serious handicap for access to qualitative data and other quantitative data. However, the similarities, or even the repetitiveness of some information obtained from several respondents, make it possible to grant relative reliability to all of these collected data. Also, throughout the data collection phase, our constant concern has been to minimize, as much as possible, the gaps in reality. Despite these constraints in the field and these limits, the analysis of the data recorded throughout this study provides a better understanding of the functioning of the shrimp industry in Benin, through the value chain.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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# Productivity of pigeon pea and maize rotation system in Balaka District, Southern Malawi

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**In Malawi, some parts of the country, such as Balaka District in Southern Malawi, are particularly prone to erratic rains with poor soil productivity. In the 2015/2016 rainy season some learning centres (LCs) focusing on pigeon-pea (*Cajanus cajan*) – maize (*Zea mays* L) rotations were established in four sections of Ulongwe Agriculture Extension Planning Area (EPA) in Balaka District to enhance soil fertility, nutrition and income diversification for increased resilience to production under erratic rain condition. Up to 132 plots of pigeon were established in 2005/2016 season. Of these 44 fields were sampled for yield, biomass, plant stand and 32 sites for soil data. In the second season of 2016/17, a maize fertilizer response trial with five rates of NPKS (0, 23:21:0+4S, 46:21:0+4S, 69:21:0+4S, and 92:21:0+4S) was super-imposed in the 44 fields, where farmers incorporated pigeon pea residues, a parallel study conducted in a nearby, adjacent field. In the first season, rainfall was low and erratic. Three dry spells (>10 non-rainy days) were recorded in two of four rain gauge stations, and two dry spells in one station. The soil test results showed low P, K and N status. Pigeon pea plant stand was low, with an average of 2.22 plants $m^{-2}$ compared to an expected 4.44 plants $m^{-2}$. Grain yields and stover weights were quite variable with a mean of 442 and 1698 kg/ha, respectively. In the second season maize yields grown in both old pigeon pea or continuous maize plots gave a linear response to fertilizer. The gains from pigeon rotation averaged 620, 308, 496 and -1072 for Chibwana Nsamala, Hindahinda, Mulambe and Chitseko sections respectively. The highest recorded yield was 4049 kg/ha from Hindahinda.**

**Key words:** Pigeon peas, *Cajanus cajan*, green manures, maize response to nitrogen.

## INTRODUCTION

Malawi is one of the countries that experience adverse effects of climate change. Environmental Affairs Department (EAD) (2002) noted that vulnerability of Malawi to climate change also mainly arises from socio-economic, demographic and climatic factors which include a slim economic base, limited agro-processing facilities, over-reliance on rain-fed agriculture and fuel wood for energy.

Balaka District is one of the districts in Malawi that are vulnerable to climate shock, particularly drought (Government of Malawi, GoM, 2006). In Malawi climate change has been evident through inconsistent delays in planting rains, frequent dry spells within the seasons and early termination of rains. This is one of the main contributors to low yields particularly amongst smallholder famers. Between 2010/2011 and 2014/2015 average smallholder grain yields for maize and staple food ranged between 1.48 and 2.66 t/ha, compared to the potential yields of 5-7 t/ha (Ministry of Agriculture, Irrigation and Food Security, MoAIWD, 2012). International Maize and Wheat Improvement Centre (CIMMYT) (2013) noted that 40% of the area under maize in Sub-Saharan Africa experiences drought stress, which causes yield loss of 10 to 25%. Other constraints to production include poor soil fertility (Blackie and Mann, 2005; Kumwenda et al., 1997) and agronomic practices by famers, and insect pests, parasitic weeds and diseases (Kabambe et al., 2008; Kabambe et al., 2014; Ministry of Agriculture, Irrigation and Water Development (MoAIWD, 2012). For example, phosphorus levels range from sufficient to low with widespread deficiencies in nitrogen and organic carbon ranging from 0.8 to 1.5% in Malawian smallholders fields (Snapp, 1998). To handle the poor soil fertility problem, the Government of Malawi initiated the Farm Input Subsidy Program (FISP), which has been making fertilizers and grain legume seeds available at very low prices (MoAIWD, 2015). Field application of manure is one of the approaches that increase plant water availability in the field, also referred to as *in-situ* water harvesting (Hatibu and Mahoo, 1999). In Malawi grain legume residues incorporation is widely encouraged as a green manure source. The main legume crops are groundnuts, pigeon peas, soybeans and cowpeas (MoIFS, 2012). Kumar Rao et al. (1987), Adu-Gyamfi et al. (2007) and Egbe et al. (2007) reported biological nitrogen fixation (BNF) of 20-118 kg/ha by pigeon pea. In Malawi, International Centre for Research in Semi-Arid Tropics (ICRISAT)/Ministry of Agriculture and Irrigation, MAI (2000) reported 300-500 kg/ha yield increases when maize was grown in rotation after pigeon peas residues were incorporated, while Ngwira et al. (2012) also reported increased yields in maize grown after legumes residues were incorporated compared to continuous maize.

In Malawi legume productivity by smallholder famers is much lower than potential yields. Between 2010/2011 and 2014/2015 pigeon pea area ranged between 196,552 to 238,738 ha with average yields of 1119 to 1465 ha. The production area in 2014/2015 was 20.7% of total area under legumes (MoAIWD, 2015). The important factors for high productivity include well drained fertile soils, use of improved varieties and appropriate good agricultural practices (GAP) (MoAIWD, 2012). These include early planting with first rains, effective weed control and timely harvesting. Use of clean, fungicide and insecticide treated seeds is important to achieve optimal plant densities (ICRISAT/MAI, 2000; MoAFS, 2012). Good early field crop establishment is useful for optimal extended capture of sunshine. Although legumes require phosphorus, there are no fertilizer recommendations in the production of pigeon peas in Malawi and many countries in tropical Africa (MoAFS, 2012; Singh et al., 2001).

The objective of this report was to measure the productivity of single cycle pigeon peas- maize rotation and determine the incremental benefits of incorporating legume residue of subsequent maize crop in drought-prone Balaka District. The process and results of the study were part of a broader objective to acquaint staff and farmers with broader understanding of managing and militating against climate variability.

## MATERIALS AND METHODS

A two year study was conducted in Ulongwe Extension Planning Area (EPA) in Balaka District, southern Malawi to evaluate the productivity of pigeon peas and maize rotation system.

### Site description and study design

The average 32- year rainfall for Balaka between 1979/1980 and 2010/2011 was reported as 809.8 with standard deviation of 229.3 mm (MoAIWD, 2012). In the first season (2015/2016) pigeon peas were planted in the rotation plots of 0.2 ha and 0.1 ha to establish one year cycle of legume-cereal rotations. Insecticide-treated basic seed of medium maturity 'mwai wathu alimi' was used. Up to 132 plots of pigeon pea were established. In each of the four sections there were 3 villages in which we had a lead famer and 10 follower farmers making 33 farmers per section and a total of 132. Of these 44 fields were sampled for yield, biomass, plant stand and 32 sites for soils data.

In the second season of 2016/2017, five fertilizer treatments (Table 1) were randomly super-imposed in plots of the 44 fields of 2015/2016, where farmers incorporated pigeon pea residues. These fertilizer rates and packages represented choices available and recommended to farmers based on the fertility of their area (MoAIWD, 2012). A parallel trial was also conducted in which each of the farmers hosting the response curve treatments were also asked to plant the same fertilizer in a nearby, adjacent field where they had grown their own pure maize crop in 2015/2016. Planting dates were within the period, 15 November to 15 January 2016. The maize variety used was medium maturity hybrid DKC8033. To establish the baseline for the season, data were recorded from field samples taken from 3 rows 0.75 m apart x 4 m plots. Three such plots were taken from a farmer, and means were calculated for each farmer. Only the farmer means were used in all further data analyses and reporting.

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**Table 1.** Fertilizer treatments for 2016/2017 plots.

| Treatment number | Treatment description |
|---|---|
| 1 | Maize without any fertilizer |
| 2 | Maize with 23:21:0+4S. Applied as a basal dressing only, from the compound 23:21:0+4S. |
| 3 | Maize with 46:21:0+4S. 23:21:0+4S applied as a basal the compound 23:21:0+4S and top dressing of 23 $kgha^{-1}$ N from and urea. |
| 4 | Maize and 69:21:0+4S. 23:21:0+4S applied as a basal the compound 23:21:0+4S and top dressing of 23 $kgha^{-1}$ N from and urea. |
| 5 | Maize and 92:21:0+4S. 23:21:0+4S applied as a basal the compound 23:21:0+4S and top dressing of 23 $kgha^{-1}$ N from and urea. |

#### Data recording and analysis

Data were recorded on plant stand at harvest (plants $m^{-2}$), stover weight ($kgha^{-2}$), pod number and grain yield. Stover and yield were taken after sun-drying for about two weeks, such that the moisture of the grain was considered the normal 10% storage level. For each crop and section the target was to harvest from all 3 lead farmers; there was hence a total of 15 farmers per section, and 45 farmers per EPA. Soil samples were collected from 0 to 20 cm depth from the same farmers and the pH, organic carbon %, organic matter %, nitrogen %, phosphorus %, potassium %, calcium %, magnesium %, zinc %, clay, silt and sand % of the soil were analyzed. The analyses were done using standard methods at Chitedze Research Stations Soil and Plant Analytical Laboratory. In the second season, moisture content of the maize grain was taken at harvest by a grain moisture meter and this was used to adjust yield to storage content of 12.5%. Yield data were subjected to analysis of variance. Analysis of variance was made separately for each pigeon pea – maize and continuous maize trial. Mean separations were made using the least significant difference, $LSD_{0.05}$. Other simple calculations were done to compare results, such as % change and value differences. Nitrogen use efficiency (NUE) was calculated for each of the treatments 2-5 as follows:-

NUE = Increment of nitrogen from unfertilized control/Increment of nitrogen from unfertilized control

Means of the variables for each section are presented. Regression and correlation analysis was done on pairs expected to have some relationships.

## RESULTS

### First season baseline rainfall, soils analyses and crop data

A summary of rainfall data monitored in four stations is shown in Table 2. Rainfall distribution was quite different between the stations. Dry spells of > 10 days were dominant. The rainfall recorded was lower than average rainfall of 840-900 mm for Mulambe and Chitseko sections, and 1,001 to 1,100 mm for Chibwana Nsamala and Hindahinda sections (Juwawo, EPA in charge, personal communications, 2015). Results on soils and crop parameters, shown as means of sections, are given in Tables 3 and 4. Results on pigeon pea grain yield (kg/ha) and plant stand (plants/$m^2$) are presented as summary means and standard deviation for each section in Table 4. There was wide variability in all parameters. For example, the expected plant stand at harvest was 4.44 plants $m^{-2}$; however, recorded means ranged from 1.05 to 4.04 plants/$m^2$.

### Second year maize yield results with and without pigeon pea residue incorporation

Maize yield results for maize after legume and continuous maize are shown in Tables 5 to 8. Significant treatment differences were recorded in all the sections. The pattern of response was linear for both pigeon pea to maize and maize to maize. The yield benefits of incorporating pigeon pea residue were highest in Chibwana Nsamala section (average 620 kg/ha, Table 5) followed by Mulambe (495 kg/ha, Table 8), and Hindahinda section (308 kg/ha) (Table 6). In Chitseko section (Table 7), yields without residue were higher than those with residue by an average of about 1.0 t/ha. Nitrogen use efficiency varied in magnitude for all the sections. NUEs were highest (up to over 30 kg grain/kg N) in Mulambe section.

## DISCUSSION

### Soil fertility status, rainfall and first year legume agronomic data

The results from year one (2015/2016) in which the legumes were established pointed to some clear potential production constraints in the area. The rainfall amounts

**Table 2.** Summary rainfall characteristics monitored at four stations in the EPA, 2015/2016.

| Section | Village | Total rainfall (mm) | Rain days | Dry spells | Number of rainy pentades |
|---|---|---|---|---|---|
| Chibwana Msamala | Chibwana | 407 | 13 | 3 | 6 |
| Chibwana Msamala | Chombe | 326 | 11 | 3 | 6 |
| Chitseko | Kalembo 1 | 527 | 36 | 0 | 6 |
| Mulambe | Namunde | 461 | 16 | 2 | 6 |

**Table 3.** Means and standard deviation in brackets for soil chemical properties plots by section.

| Section | pH water | % OC | % OM | % N | P (ug/g) | K (ug/g) | Ca (ug/g) | Mg (ug/g) | Zn (ug/g) |
|---|---|---|---|---|---|---|---|---|---|
| Chibwana N=10 | 6.32(0.45) | 0.77(0.34) | 1.33(0.60) | 0.066(0.030) | 0.466(0.262) | 0.244(0.128) | 5.96(3.72) | 2.42(0.73) | 8.40(2.44) |
| Hindahinda N=6 | 6.89(0.75) | 1.67(0.51) | 2.89(0.89) | 0.144(0.04) | 0.884(0.16) | 0.631(0.334) | 8.93(6.08) | 4.13(3.28) | 29.33(22.62) |
| Chitseko N=10 | 6.54(0.34) | 1.31(0.32) | 2.35(0.37) | 0.11(0.18) | 0.470(0.254) | 0.370(0.169) | 7.96(3.93) | 2.42(1.37) | 17.43(3.93) |
| Mulambe N=6 | 6.05(0.59) | 0.654(0.27) | 1.12(0.46) | 0.056(0.023) | 0.307(0.119) | 0.306(0.218) | 4.18(1.39) | 2.67(0.91) | 10.2(5.04) |
| G. Mean N=32 | 6.45(0.56) | 1.13(0.47) | 1.94(0.82) | 0.97(0.04) | 0.533(0.274) | 0.378(0.238) | 7.07(4.06) | 2.96(1.76) | 17.8(17.6) |

**Table 4.** Means and standard deviations of agronomic variables and soil texture by section.

| Section | Plants M2 | Stover kg ha$^{-1}$ | Grain yield kg ha$^{-1}$ | Pod wt ha$^{-1}$ | Harvest index | % clay | % silt n=32 | % sand n=32 |
|---|---|---|---|---|---|---|---|---|
| Chibwana-Nsamala | 2.044(0.378) | 1274(724) | 330(280) | 794(679) | 0.22(0.17) | 13.6(3.7) | 5.4(3.9) | 80.9(3.7) |
| Hindahinda | 2.452(0.67) | 1820(752) | 433(228) | 1037(586) | 0.20(0.07) | 20.8(8.8) | 10.7 | 68.5 |
| Chitseko | 1.970(0.76) | 1343(708) | 543(365) | 1262(809) | 0.32(0.13) | 18.6(3.9) | 7.0(4.8) | 74.4(6.3) |
| Mulambe | 2.299(0.52) | 2684(886) | 92(265) | 248(701) | 0.04(0.11) | 10.2(5.0) | 5.2(2.8) | 56.0(3.2) |
| Grand mean n=44 | 2.18(0.52) | 1698(886) | 373(321) | 889(760) | 0.12(0.15) | 17.4(5.3) | 7.2(4.5) | 73.4(8.2) |

were low combined with dry spells (Table 2). It is likely these dry spells resulted in the poor crop pigeon pea establishments. MoAIWD (2012) noted that suitable rainfall for pigeon peas in dry areas is 700 mm per annum. Dry spells of > 10 days are considered serious enough to cause crop yield loss. The results on soil fertility point to soil fertility status as a problem for the area. Based on threshold values of Chilimba and Nkosi (2014), on average, the soils were very in low available P, low in K, very low - medium for N, very high in Zinc and almost neutral in pH. According to Chilimba and Mkosi (2014), these soils would require 40 kg/ha phosphorus, 30-60 kg/ha potassium and 46-92 kg/ha nitrogen for optimal maize production. Snap et al. (1998) also reported similar low fertility from most soils in Malawi.

The pigeon pea yields were quite low compared to national average of 1465 kg/ha in 2014/2015. The main reason could be the dry spells which also occurred during flowering of the pigeon pea variety planted. Mhango et al. (2017) reported similar low yields in pigeon peas and attributed this to early season dry spells. The authors

**Table 5.** Maize grain yield (kg/ha) and nitrogen use efficiency (NUE, kg grain/kg N) with and without pigeon pea rotation in Chibwana Nsamala Section.

| Fertilizer rate (kg/ha) (N:P:K:S) | With residues | NUE | Without residues | NUE | Value difference over no residues | % change over no residues |
|---|---|---|---|---|---|---|
| 0 | 1717 | - | 1074 | - | +643 | 60.0 |
| 23:21:0+4S | 2052 | 14.5 | 1619 | 23.7 | +433 | 26.7 |
| 46:21:0+4S | 2433 | 15.5 | 1931 | 18.6 | +502 | 50.2 |
| 69:21:0+4s | 2830 | 16.1 | 2171 | 15.9 | +659 | 30.3 |
| 92:21:0+4S | 3224 | 16.4 | 2524 | 15.7 | +700 | 27.7 |
| Mean | 2451 | | 1831 | | +620 | 33.9 |
| F Prob | 0.031 | | <0.001 | | | |
| LSD | 991 | | 671 | | | |
| CV% | 51.1 | | 47 | | | |

**Table 6.** Maize grain yield (kg/ha) and nitrogen use efficiency (NUE, kg grain/kgN) with and without pigeon pea rotation in Hindahinda Section.

| Fertilizer rate (kg/ha) (N:P:K:S) | With residues | NUE | Without residues | NUE (kg grain/kg N) | Value difference over no residues | % change over no residues |
|---|---|---|---|---|---|---|
| 0 | 1137 | - | 1047 | - | 90 | 8.6 |
| 23:21:0+4S | 1703 | 24.6 | 1438 | 14.3 | 265 | 18.4 |
| 46:21:0+4S | 2066 | 20.2 | 1815 | 16.7 | 251 | 13.8 |
| 69:21:0+4s | 2584 | 21.0 | 2122 | 15.6 | 462 | 21.8 |
| 92:21:0+4S | 2822 | 18.3 | 2607 | 11.1 | 215 | 8.2 |
| Mean | 2062 | | 1754 | | 308 | 17.5 |
| F Prob | <0.001 | | <0.001 | | | |
| LSD | 1023 | | 497 | | | |
| CV% | 37.0 | | 41.7 | | | |

**Table 7.** Maize grain yield (kg/ha) and nitrogen use efficiency (NUE, kg grain/kg N) with and without pigeon pea rotation in Chitseko Section.

| Fertilizer rate (kg/ha) (N:P:K:S) | With residues | NUE | Without residues | NUE | Value difference over no residues | % change over no residues |
|---|---|---|---|---|---|---|
| 0 | 1023 | | 1811 | - | -788 | -43.5 |
| 23:21:0+4S | 1572 | 23.9 | 1828 | 0.7 | -256 | -14.0 |
| 46:21:0+4S | 1597 | 12.5 | 2610 | 17.3 | -1013 | -38.8 |
| 69:21:0+4s | 1778 | 10.9 | 3135 | 19.2 | -1357 | -43.3 |
| 92:21:0+4S | 2095 | 11.7 | 3613 | 19.6 | -1518 | -42.0 |
| Mean | 1613 | | 2685 | | -1072 | -39.9 |
| F Prob | 0.002 | | 0.015 | | | |
| LSD | 521 | | 1789 | | | |
| CV% | 42.4 | | 48.6 | | | |

reported that plant density and inorganic P were main drivers for biological nitrogen fixation (BNF). Kumar Rao (1987) reported that pigeon pea can fix 69-100 kg N/ha. Myaka et al. (2006) and Egbe et al. (2007) reported that pigeon pea can have a net contribution of 2-60 kgN/ha depending on the genotype and environmental factors. Most of the variation may be explained by variation between fields. Edmeadnes et al. (2000) reported that for fields varying in topography, texture and thickness of top soil, yields may vary ten-fold.

**Table 8.** Maize grain yield (kg/ha) and nitrogen use efficiency (NUE, kg grain/kg N) with and without pigeon pea rotation in Mulambe Section.

| Fertilizer rate (kg/ha) (N:P:K:S) | With residues | NUE | Without residues | NUE | Value difference over no residues | % change over no residues |
|---|---|---|---|---|---|---|
| 0 | 2129 | - | 1828 | - | +301 | +16.5 |
| 23:21:0+4S | 2796 | 29.0 | 2581 | 32.7 | +215 | +8.3 |
| 46:21:0+4S | 3416 | 28.0 | 2818 | 21.5 | +598 | +21.2 |
| 69:21:0+4s | 3695 | 22.7 | 3333 | 21.8 | +362 | +10.9 |
| 92:21:0+4S | 4049 | 20.9 | 3470 | 17.8 | +579 | +16.7 |
| Mean | 3213 | | 2718 | | +495 | +18.2 |
| F Prob | <0.001 | | <0.001 | | | |
| LSD | 538 | | 562 | | | |
| CV% | | | 21.6 | | | |

## Maize yield response to nitrogen fertilizer application rate

The significant responses to N application in all sections in both legume and non-legume rotation crops are expected as the soils were low in nitrogen. Many soils in Malawi are low in nitrogen and require its application (Chilimba and Nkosi, 2014; MoAIWD, 2012; Kumwenda and Benson, 1998). The highest yields recorded of 2.5- 4 t/ha at 92 kg/ha N reflect are similar to upper yields reported from nation-wide trials by Kumwenda and Benson (1998). Therefore it is suggested that to raise yields beyond these levels, other constraints of the soil must be addressed, such as improving water holding capacity and soil organic matter of soil, identifying and applying some key missing nutrient. Yield benefits from the legume-maize rotation system were recorded in three of the four sections at varying levels. Rotational benefits from legume rotations have been widely reported in Malawi (ICRISAT/MAI, 2000; Mhango et al., 2017; Njira et al., 2017; Ngwira et al., 2012). The magnitude of benefits is at varying degrees, and could be due to many factors such as landscape position, tillage practices, adoption of *in-situ* rainwater harvesting technologies at farm level. However, the inverse results observed at Chitseko cannot be well explained.

## Conclusion

The main lesson from these results is soil fertility in the study is low particularly for N and P. Due to the linear response observed, further studies to determine optimum rates are recommended and to determine the role of P and other nutrients in raising the upper yield ceilings of 2.5 to 3.0 t/ha recorded in the studies. Future crop management interventions should explore role of technologies such as in-situ rainwater harvesting techniques in counteracting the effects of dry spells at all stages of crop growth for both legumes and maize

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

# Productivity and profitability on groundnut (*Arachis hypogaea* L) and maize (*Zea mays* L) in a semi-arid area of southern Malawi

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**In many parts of Malawi, including Balaka district in Southern Malawi, are prone to erratic rains with poor soil productivity and famer practices. A research and outreach project was initiated in October 2015 to establish learning centres (LCs) of groundnut: maize rotations as an entry point to diversify nutrition and income base of smallholder farmers, while building up on soil fertility for increased resilience to production under climatic variation. Some 132 plots of groundnut were established in 2015/2016 in four sections of Ulongwe Extension Planning Area (EPA) in Balaka district. Of these, 44 fields were sampled for yield, biomass, plant stand and soils data. In the second season of 2016/2017, a maize fertilizer response trial (five rates of $NP_2O_5K_2O$; 0, 23:21:0+4S, 46:21:0+4S, 69:21:0+4S, and 92:21:0+4S) was super-imposed in plots where farmers incorporated groundnut residues, in comparison with continuous maize from adjacent own field. In the first season, rainfall was below average and erratic, with 10-day dry spells recorded in two of four recording stations. The soils were generally poor, with test values below threshold for many variables including organic matter, nitrogen and phosphorus. Groundnut average yields and standard deviation were 754 (±186) kg/ha, respectively. Plant stands were poor, with up to 24% of the 46 LCs attaining ≤50% of targeted plant stand of 8.88 plants $m^{-2}$. Poor plant stand is suggested as a major contributor to low yields. Results from the 2016/2017 fertilizer response trials showed linear response of maize to fertilizer application. Yields ranged from an average of 1.47 t/ha without fertilizer application to 4.0 t/ha at 92:21:0+4S. It is concluded that the poor soil fertility, low field plant densities, and dry spells are the main causes of low yields. Gross margins were positive for groundnut yield of 1,000 kg/ha and fertilizer rates on maize of 46:23:0+4S and above.**

**Key words:** Groundnut-maize rotation, nitrogen response, drought spells.

## INTRODUCTION

Malawi is a country with an agriculture-based economy. In 2015, agriculture accounted for 30% of the gross domestic product (GDP) and 80% of the export earnings (Malawi Government, 2015). In 2013, agriculture employed 64.1% of the work force. The country has 2.4 M-ha of under cultivation, mostly by smallholder farmers who cultivate an average of 0.64 ha of land. Of the agriculture GDP, 70% is from smallholder farmers (Malawi Government, 2016). Agricultural production is almost fully dependent of rain-fed cultivation. There is one rainy season of 3 to 5 months per annum. Climate variability, particularly in the form of erratic rainfall is one of the major biophysical constraints to agricultural productivity (Challinor et al., 2007). Climate projections for Southern Africa to 2050 suggest an average increase in temperature by 2.12°C, a delay in the onset of the rains and more intense and widespread of droughts and floods (Cairns et al., 2013). CIMMYT (2013) noted that 40% of the area under maize in sub-Saharan Africa experiences drought stress, which causes yield loss of 10 to 25%. The effects of drought increase the risk of crop failure which becomes a strong disincentive to farmers to invest in chemical fertilizers which are widely known to have positive influence on crop productivity. Other main constraints to crop production include poor and declining soil fertility (Zambezi et al., 1993; Kumwenda et al., 1997; ICRISAT/MAI, 2000; Blackie and Mann, 2005; MoAIFS 2005) and insects' pests, parasitic weeds and diseases (Kabambe et al., 2008; Kabambe et al., 2014; MoAIWD, 2012). For example, phosphorus levels range from sufficient to low with widespread deficiencies in nitrogen and organic carbon ranging from 0.8 to 1.5% on Malawian smallholders fields (Snapp, 1998). Thus, to overcome the widespread problems of soil fertility decline a more integrated soil fertility management (ISFM) approach is required. These include long term rehabilitation to build up soil fertility before crops respond to efficient use of applied nutrients (Tittonell et al., 2007). A major national intervention to redress the poor soil fertility problem has been the Farm Input Subsidy Program (FISP), which has been making fertilizers available at very low prices (GoM, 2012). The FISP also includes a component of legume seeds.

In Malawi, grain legumes are increasingly growing in importance. The national export strategy identified groundnuts to be among the four crops in priority area one for the export of oil seed products (GOM, 2013). As a green manure source, grain legumes are an important climate adaptation intervention as they help retain soil water (Tisdale et al., 1985). They contribute directly to household food security, and to the household cash income. Legume systems can positively contribute to the nitrogen economy of soils through biological nitrogen fixation, BNF (Snapp, 1998; Nyemba and Dakora, 2010). Recent studies in Malawi indicate that groundnut can fix between 21 and 124 kg/ha of N (Njira et al., 2012; Mhango, 2011). In Kenya, Ojiem et al. (2007) reported N fixation of 41 kg/ha under low rainfall and 124 kg/ha under high rainfall. Turner and Rao (2013) noted that while systems that apply N fertilizer have higher yields, they will be more impacted and have larger reductions in yields from climate change. However, Turner and Rao (2013) reported that even if impacted by periods of drought, these higher yields would still be higher than yields without fertilizer or with low inputs. In a study involving maize planting dates, cultivars and crop nutrient management under low and high rainfall environments in Zimbabwe, Rurinda et al. (2013) reported that nutrient management had an overriding effect on crop production, suggesting that nutrient management is the priority option for adaptation in rain-fed smallholder cropping systems.

Balaka is one of the districts in Malawi that are vulnerable to climate shock, particularly drought (GOM, 2006). The intensification of legumes in smallholder farming systems therefore has the benefits of diversifying food and income sources as well as the potential to increase soil N and increase water available. The studies in this report were therefore aimed at assessing the productivity of groundnut-maize rotations system in drought prone Balaka district, Southern Malawi.

## MATERIALS AND METHODS

### Study sites and design

A two-year legume-maize rotation study was conducted in Ulongwe Extension Planning Area (EPA) in Balaka district in Machinga Agricultural Development Division (ADD) in southern region of Malawi. Specifically, experimental sites were located in four sections of the EPA, namely Chibwana Nsamala, Hindahinda, Chitseko, and Mulambe. Being a field rotation study, field plots were established in 2015/2016 as the first season. In this season, pure stands of groundnuts were planted in fields of famers designated as lead (0.1 ha) or follower (0.05 ha) farmers and a designated density of 8.88 plants $m^{-2}$. The farmers were provided with basic seed and trained on good agricultural practices. The groundnut variety used was CG7 which has maturity period of 130 to 150 days and yield potential 2,500 kg/ha. Farmers were trained and supervised to ensure that recommended planting geometry of 75 cm between ridges, 15 cm between station, and 1 plant per station (MoAFS, 2012) were followed and that residues were incorporated. In the second season (2016/2017), five fertilizer treatments were imposed as shown in Table 1. These fertilizer rates and packages represented choices available and recommended to farmers based on the fertility of their area (MoAIFS, 2012). In addition, this was aimed at improving the teaching value of the studies. Plots had 4 rows and 6 m × 0.75 m apart (18 $m^2$), giving an expected density of 5.33 plants $m^{-2}$. Yield, plant count data were recorded from the two middle rows plot. All five treatments were randomly laid out in one field. The design was thus a randomized block with a farmer as a replicate.

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**Table 1.** Fertilizer treatments in the maize rotation plots, 2016/2017 plots.

| Treatment No. | Treatment description |
|---|---|
| 1 | Maize without any fertilizer |
| 2 | Maize with 23:21:0+4S. Applied as a basal dressing only, from the compound 23:21:0+4S. |
| 3 | Maize with 46:21:0+4S. 23:21:0+4S applied as a basal the compound 23:21:0+4S and top dressing of 23 kgha$^{-1}$ N from and urea. |
| 4 | Maize and 69:21:0+4S. 23:21:0+4S applied as a basal the compound 23:21:0+4S and top dressing of 23 kgha$^{-1}$ N from and urea. |
| 5 | Maize and 92:21:0+4S. 23:21:0+4S applied as a basal the compound 23:21:0+4S and top dressing of 23 kgha$^{-1}$ N from and urea. |

### Data collection and number of farmers involved

In the first year, 132 famers hosted groundnut plots, also designated as Learning Centres (LCs) in four sections. In each village, there was one lead famer and ten follower farmers. Of these 10 famers, all lead famers and 3 follower famers were sampled, for a targeted total of 48 farmers. From these famers, data were collected on soil, yield and stover to provide a basis for understanding the year two results. In year two, maize was grown as rotation crop on the same 48 farmers. This study design was randomized complete design with each farmer as replicate. Grain moisture content was recorded at harvest, and maize grain yields reported were adjusted to 12.5% storage moisture levels.

### Data analysis

For the baseline year, data was summarized into means and standard deviations for each section and by legume crop type. For the year two data, analysis of variance was done on yields from legume maize plots and continuous maize separately using the structure sections×fertilizer level for each section.

### Gross margin analysis computations

The computation for gross margin analysis involved determination of the difference between gross income from sales and production costs. The gross income was based on produce sales quoted at farm gate with negligible marketing cost. This is the actual situation in Malawi whereby small or big traders mount buying points in rural areas. The cost related to marketing is packaging which comprise a new sack for each 50 kg of harvest. The labour costs for groundnuts included land preparation, planting, weeding, stripping, shelling and grading while for maize these have included land preparation, ridging, planting, shelling, cleaning and packaging. These are basic components described by several authors (Dzanja, 2008; Ngulube et al., 2001; Takane, 2008). Dzanja (2008) estimated the total labour requirement to be 240 man-days for groundnut and 139 man-days for maize and these were used in the calculations. However, Ngulube et al. (2001) estimated the labour requirement for groundnut to be 637 man-days, while Takane (2008) estimated labour requirement for maize to be 176 man-days. Tables 2 and 3 show the total costs for groundnuts and maize at the five rates of fertilizer. The costs of inputs and labour use were those of the 2017/2018 cropping season in Malawi. At this time the exchange rate of the Malawi Kwacha to US $ was 1: 733 (June 2018 Newspapers). The labour was costed based on the minimum wage daily rate of MK 962,00 for the time of computation (June 2018). Calculations were made for different price and output scenarios. Breakeven yield was determined by dividing total costs of production by the price level.

## RESULTS

### First year soils, groundnut stover and grain yield baseline results

Results of rainfall from four measuring points are shown in Table 4. The total rainfall, ranging from 326 mm at Chombe village in Chibwana Msamala village in Chibwana Msaamala section of 527 mm at Kalembo 1 village in Chitseko was much less than normal rainfall. The long term annual rainfall for the EPA is 840 to 1000 mm. The rainfall was erratic, with up to 3 dry spells (periods with at least 10 days of no rain or trace rainfall) recorded in two sections, and 2 dry spells in another. Kalembo 1 village in Chitseko section had no dry spells as well as the highest rainfall.

Results of soil properties, stover and grain yield are shown in Tables 5 and 6. The results largely show poor soil fertility status, based on Chilimba and Mkosi (2014) thresholds. From the raw data (data not shown) all soil $pH_w$ values were above 6.0 (neutral category) in all sections except Mulambe where values just below 6.0 were observed. All soils were very low in phosphorus and potassium with values <8.0 ug/g and <5.0 (very low categories). In terms of organic matter, soils were mostly in low (<2.1%) to medium (2.1 to 3.9%) category. For nitrogen, soils belonged to very low (<0.08%), medium (0.08 to 0.12%), low or medium (0.12 to 2.0) categories. All soils were very high in zinc (>3.0 ug/g). According to Chilimba and Mkosi (2014), these soils would require 40

**Table 2.** Variable costs (Malawi Kwacha, MK) used in the gross margin calculations for groundnuts (cf 1 US$=MK 733, June 2018).

| Input of production | Groundnut yield level $kgha^{-1}$ and input/output value MK | | | |
|---|---|---|---|---|
| | 300 $kgha^{-1}$ | 500 $kgha^{-1}$ | 1000 $kgha^{-1}$ | 1500 $kgha^{-1}$ |
| 80 kg seed | 80,000 | 80,000 | 80,000 | 80,000 |
| Labour 240 mandays at K962 | 250,120 | 250,120 | 250,120 | 250,120 |
| Packaging bags | 1200 | 2000 | 4000 | 6000 |
| Total variable costs | 331,320 | 332,120 | 334,120 | 336,120 |

**Table 3.** Variable costs (Malawi Kwacha) for the different fertilizer rates used in the gross margin calculations for maize (cf 1 US$=MK 733).

| Input type | Fertilizer package $kgha^{-1}$ NPKS and inputs costs in MMK $ha^{-1}$ | | | | |
|---|---|---|---|---|---|
| | 0 | 23:21:0:4 | 23:21:0:4 | 23:21:0:4 | 23:21:0:4 |
| Seed 25 kg/ha | 22,000 | 22,000 | 22,000 | 22,000 | 22,000 |
| Labour at MK 962/man-day | 265,512 | 265,512 | 265,512 | 265,512 | 265,512 |
| Fertilizer | 0 | 44,000 | 66,000 | 88,000 | 110,000 |
| Total variable costs | 287,512 | 331,512 | 353,512 | 375,512 | 375,512 |

**Table 4.** Summary rainfall characteristics monitored at four stations in the EPA, 2015/2016.

| Section | Village | Total rainfall (mm) | Rain days | Dry spells | No. of rainy pentades |
|---|---|---|---|---|---|
| Chibwana Msamala | Chibwana | 407 | 13 | 3 | 6 |
| Chibwana Msamala | Chombe | 326 | 11 | 3 | 6 |
| Chitseko | Kalembo 1 | 527 | 36 | 0 | 6 |
| Mulambe | Namunde | 461 | 16 | 2 | 6 |

**Table 5.** Baseline yield, stover and soils texture from groundnut farmers fields in 2015/16. Figures in brackets are standard errors of means.

| Section | Stover (kg $ha^{-1}$) | Grain yield kg ha-1 | % Clay | % Silt | % Sand |
|---|---|---|---|---|---|
| Chibwana-Nsamala | 2887±1791 | 864±447 | 9.57±6.38 | 5.33±4.30 | 68.42±4.90 |
| Hindahinda | 2107±1011 | 1016±534 | 16.08±1.74 | 7.56±1.67 | 76.36±2.69 |
| Chitseko | 1865±1263 | 639±651 | 18.19±3.43 | 4.44±1.94 | 77.36±4.24 |
| Mulambe | 1222±1260 | 303±239 | 16.84±1.79 | 4.4±1.67 | 78.70±2.61 |

**Table 6.** Soil chemical characteristics from groundnut farmers' fields.

| Section | pH water | % OM | % N | P (ug/g) | K (ug/g) | Ca (ug/g) | Zn (ug/g) |
|---|---|---|---|---|---|---|---|
| Chibwana-Nsamala | 6.03±0.43 | 0.92± 0.36 | 0.046±0.018 | 0.45±0.24 | 0.307±0.276 | 9.57±6.38 | 5.33±4.30 |
| Hindahinda | 6.18±0.60 | 2.19±0.41 | 0.109±0.20 | 0.453±0.204 | 0.237±0.073 | 7.25±3.12 | 12.05±6.24 |
| Chitseko | 6.71±0.47 | 2.43±0.72 | 0.12±0.04 | 0.458±0.32 | 0.407±0.194 | 6.55±2.20 | 21.89±11.19 |
| Mulambe | 5.96±0.12 | 1.08±0.54 | 0.054±0.027 | 0.311±0.157 | 0.265±0.076 | 4.85±1.24 | 14.57±10.88 |

$kgha^{-1}$ of $P_2O_5$, 30 to 60 $kgha^{-1}$ of $K_2O$, and 46 to 92 $kgha^{-1}$ of N. However, sulphur, a potential important element, not determined. While all soils were low in fertility, the yields were quite variable. Average grain yield was the highest (1016 $kgha^{-1}$) in Hindahinda section and lowest (303 $kgha^{-1}$) in Mulambe. Of the individual plot grain yield (raw data not shown), the results showed that 27% of the 43 Learning Centres (LCs) studied obtained very low yields of >300 $kgha^{-1}$, while 24% obtained yields >1,000 $kgha^{-1}$ (Table 7). The target plant density in the study was

**Table 7.** Proportionate distribution of groundnuts yields from learning centres across four sections.

| Yield range (kg/ha) | N | % of famers |
|---|---|---|
| ≤300 | 12 | 27.3 |
| ≥300 - ≤500 | 7 | 16.3 |
| ≥500 - ≤1000 | 14 | 32.5 |
| ≥1000 - ≤1500 | 6 | 13.9 |
| ≥1500 | 5 | 11.6 |

**Table 8.** Association between actual plant densities and groundnut stover and grain yield across four sections.

| Density category | Proportion of full stand (%) | N | Mean | Mean stover ($kgha^{-1}$) | Mean grain yield ($kgha^{-1}$) |
|---|---|---|---|---|---|
| ≤0.44 | ≤25 | 10 | 3.67 | 1403 | 473 |
| ≥4.44 - <5.25 | 50-60 | 17 | 4.80 | 2142 | 743 |
| ≥5.25 | ≥60 | 19 | 5.92 | 2412 | 920 |

**Table 9.** Maize grain yield ($kgha^{-1}$) and nitrogen use efficiency (NUE, kg grain/kgN) with and without groundnut rotation in Chibwana Nsamala section.

| Fertilizer rate $kgha^{-1}$ NPKS | Grain yield | NUE | Without residues | NUE | Value difference over no residues | %change over no residues |
|---|---|---|---|---|---|---|
| 0 | 1356 | - | 1200 | - | 156 | 13.0 |
| 23:21:0+4S | 1743 | 14.9 | 1634 | 18.9 | 109 | 6.7 |
| 46:21:0+4S | 2048 | 15.0 | 1870 | 14.6 | 178 | 9.5 |
| 69:21:0+4s | 2376 | 14.8 | 2141 | 13.6 | 235 | 11.0 |
| 92:21:0+4S | 2636 | 13.9 | 2605 | 15.3 | 31 | 1.2 |
| Mean | 2078 | - | 1872 | - | 206 | - |
| F Prob | <0.001 | - | <0.001 | - | - | - |
| LSD | 731 | - | 54 | - | - | - |
| CV% | 27 | - | 36 | - | - | - |

8.88 plants $m^{-2}$. However, up to 22% of the 46 LCs had ≤50% of targeted plant stand of 8.88 plants $m^{-2}$, 37% achieved a plant density of between 50 and 60% of the desired plant stand suggesting poor establishment. This was most likely due to dry spells. There could be other soil factors too, particularly those linked to water holding capacity of soils. The reasons for poor stand were not studied. Table 8 shows the close association between grain and stover yield with the plant density categories.

## Maize results in year two

Results on maize yield response to fertilizer rates in rotation with groundnuts or under continuous maize are shown in Tables 9 to 12. Significant treatment differences were detected in all the sections. The pattern of response was linear in all cases (Table 13). The incremental benefits due to groundnut rotation and residues incorporation varied according to the section. The benefits were highest in Chitseko section (range 233 to 732 kg/ha), followed by Chibwana Nsamala section (range 31 to 253). In Hindahinda, the results varied with some negative differences as well. There were no records obtained from Mulambe section.

## Gross margin and break even yields

The gross margin for groundnuts were determined at four levels of production (300, 500, 100 and 1,500 kg/ha) and thrice price scenarios (MK 250, 350 and 500) to reflect the actual level obtained in the study. The results in Table 14, as expected, show that positive gross margins were only found and at yield levels of 1000 to 1,500 kg/ha and the K350 or K500 price scenarios. These yield levels were associated with plots that had high crop establishment (Table 8). Using a median total variable

**Table 10.** Maize grain yield (kgha$^{-1}$) and nitrogen use efficiency (NUE, kg grain/kgN) with and without groundnut rotation in Hinda-hinda section.

| Fertilizer rate kg/ha NPKS | With residues | NUE | Without residues | NUE | Value difference over no residues | %change over no residues |
|---|---|---|---|---|---|---|
| 0 | 1382 | - | 1468 | | -86 | -5.9 |
| 23:21:0+4S | 1954 | 24.9 | 2194 | 31.6 | -240 | -10.9 |
| 46:21:0+4S | 2441 | 23.1 | 2405 | 204 | 36 | +1.5 |
| 69:21:0+4s | 2884 | 21.7 | 3008 | 22.3 | -124 | -4.1 |
| 92:21:0+4S | 3514 | 23.2 | 3131 | 18.1 | 383 | 12.2 |
| Mean | 2526 | - | 2134 | - | 392 | - |
| F Prob | <0.001 | - | <0.001 | - | - | - |
| LSD | 702 | - | 492 | - | - | - |
| CV% | 35 | - | 24 | - | - | - |

**Table 11.** Maize grain yield (kgha$^{-1}$) and nitrogen use efficiency (NUE, kg grain/kgN) with and without groundnut rotation in Chitseko.

| Fertilizer rate kg/ha NPKS | With residues | NUE | Without residues | NUE | Value difference over no residues | %change over no residues |
|---|---|---|---|---|---|---|
| 0 | 1880 | - | 1362 | - | +518 | +27.8 |
| 23:21:0+4S | 2610 | 31.7 | 2088 | 31.6 | +522 | +25.0 |
| 46:21:0+4S | 3389 | 32.8 | 2657 | 28.1 | +732 | +27.5 |
| 69:21:0+4s | 3811 | 30.0 | 3302 | 28.1 | +509 | +15.4 |
| 92:21:0+4S | 4354 | 26.9 | 4121 | 30.0 | +233 | +5.6 |
| Mean | 3170 | - | 2706 | - | +464 | - |
| F Prob | <0.001 | - | <0.001 | - | - | - |
| LSD | 881 | - | 882 | - | - | - |
| CV% | 25 | - | 41.9 | - | - | - |

**Table 12.** Maize grain yield (kgha-1) and nitrogen use efficiency (NUE, kg grain/kgN) with groundnut rotation in Mulambe.

| Fertilizer rate kgha$^{-1}$ NPKS | Yield | NUE |
|---|---|---|
| 0 | 1654 | - |
| 23:21:0+4S | 1941 | 12.5 |
| 46:21:0+4S | 2391 | 10.7 |
| 69:21:0+4s | 2546 | 19.4 |
| 92:21:0+4S | 3044 | 15.1 |
| Mean | 2437 | - |
| F Prob | <0.001 | - |
| LSD | 644 | - |
| CV% | 28 | - |

*Results from continuous maize plots were not available.

cost value of K334,120, the break even yield was 1336, 955 and 668 kg/ha for the MK250, 350 and 500 price scenario. For maize, positive gross margins were only possible at yields equal or above 2,500 which were associated with a rate of 46:23:0:4 or higher (Table 15). The break even yields were 1467, 1698, 1817, 1938, and 2058 for nil to 92:23:0:4 rate, respectively.

## DISCUSSION

### Baseline season results

The soil nutrient status of the soils, determined in 2015/2016 was low and below thresholds and yet groundnut grain and stover yields were quite variable.

**Table 13.** Linear regressions for nitrogen rate (kgha$^{-1}$) against maize yields (tha$^{-1}$) for groundnut-maize and maize-maize plots.

| Section | Linear equation | R-Square |
|---|---|---|
| **Groundnut after maize** | | |
| Chitseko | Y=0.039**x + 1.99 | 0.98 |
| Hindahinda | Y=0.026**x +1.396 | 0.99 |
| Mulambe | Y=0.0.014**x + 1.683 | 0.97 |
| Chibwana | Y= 0.039**x 1.1396 | 0.99 |
| | | |
| **Maize after maize** | | |
| Mulambe | Y=0.0293**x + 1.35 | 0.99 |
| Hindahinda | Y=0.018**x + 1.63 | 0.93 |
| Chibwana | Y=0.0144**x + 1.22 | 0.98 |

**Significant at P<0.01.

**Table 14.** Production costs, gross income and gross margins for groundnuts.

| Input of production | Productivity level, kg/ha and input/output value MK | | | |
|---|---|---|---|---|
| | 300 kg/ha | 500 kg/ha | 1000 kg/ha | 1500 kg/ha |
| Total variable costs | 331,320 | 332,120 | 334,120 | 336,120 |
| Gross income at MK250 kg$^{-1}$ | 75,000 | 125,000 | 250,000 | 375,000 |
| Gross income at K350 kg$^{-1}$ | 105,000 | 175,000 | 350,000 | 525,000 |
| Gross income at K500 kg$^{-1}$ | 150,000 | 250,000 | 500,000 | 750,000 |
| Gross margin at K250 kg$^{-1}$ | -256,320 | -207,120 | -84,120 | 38,880 |
| Gross margin at 350 kg$^{-1}$ | -226,320 | -157,120 | 15,880 | 188,880 |
| Gross margin at K500 kg$^{-1}$ | -181,320 | -82,120 | 165,880 | 414,000 |

**Table 15.** Production costs, gross income and gross margins for maize four fertilizer rates (rounded up average yields).

| Input type | Fertilizer package kg/ha NPKS and inputs costs in MMK/ha. | | | | |
|---|---|---|---|---|---|
| | 0 | 23:21:0:4 | 23:21:0:4 | 23:21:0:4 | 23:21:0:4 |
| Yield average kg/ha | 1500 | 2000 | 2500 | 3000 | 3500 |
| Total variable costs including packaging MK | 293,512 | 339,512 | 363,512 | 387,512 | 411,512 |
| Gross income at MK100 kg$^{-1}$ | 150,000 | 200,000 | 250,000 | 300,000 | 350,000 |
| Gross income at MK150 kg$^{-1}$ | 225,000 | 300,000 | 375,000 | 450,000 | 525,000 |
| Gross income at MK200 kg$^{-1}$ | 300,000 | 400,000 | 500,000 | 600,000 | 700,000 |
| Gross margin at MK100 kg$^{-1}$ | -143,512 | -139,512 | -133,512 | -87,512 | -61,512 |
| Gross margin at MK150 kg$^{-1}$ | -271,012 | -309,512 | -326,512 | -342,512 | -359,012 |
| Gross margin at MK200 kg$^{-1}$ | 6,488 | 60,488 | 136,488 | 212,488 | 288,488 |

This suggests that nutrient and non-nutrient factors were important, such as slope of land (not monitored), planting dates. There was significant regression relation between groundnut density and grain yield. Most of the fields recorded plant stand much lower than the expected stand of 8.88 plants m$^{-2}$. Thus, low establishment could be the main reason for low yields of groundnuts. The poor establishment is most likely due to dry spells experienced in the area. Being a large seeded crop, groundnut requires good soil moisture for establishment (MoAIWD, 2012). The result on relationship between plant stand and yield is in agreement with Mhango et al. (2017) who reported that plant density was one of the drivers of biological nitrogen fixation in groundnuts. Most of the variation may be explained by variation between fields. Edmeades et al. (2000) reported that for fields varying in topography, texture and thickness of top soil, yields may vary ten-fold.

For groundnuts, poor plant establishment was a key driver for yield. In this study, treated basic seed of groundnuts was provided and used. Hence, the reasons for poor establishment are likely to be the dry spells. Timing of planting relative to planting rains is important and this may be improved through provision of rainfall forecasting services and skills to determine moisture adequacy in soil. Possible ways to improve establishment include adoption of *in-situ* rain water harvesting practices such mulching, box ridges, and manure. It is recommended that all possible options to increase establishment should be tested and rolled out.

While there are no recommendations for nutrient application in groundnuts in Malawi, several studies have shown responses of P fertilizer application in groundnuts (Tarawali and Quee, 2014; Dakora, 1984). Mhango et al. (2017) reported that P was a key driver to BNF. It is recommended that further studies should be conducted to determine the role of P and other elements to increase yields of groundnuts in the area conducted. In a review, Chianu et al. (2011) highlighted several factors, including high soil temperatures, soil moisture stress, and P deficiency as important for groundnut yield.

### Year two maize results

While responses to fertilizer were significantly different with or with residue incorporation, the yield levels of ≤4 $tha^{-2}$ are still low as compared to potential of 5 to 10 t/ha for expected farmers' fields (MoAIWD, 2012). The low yields are expected as the soil analysis results showed that the soils were low in P and K. Higher rates would be required for higher yields (Chilimba and Mkosi, 2012). These soils would require 40 kg/ha phosphorus, 30 to 60 kg/ha of potassium and 46 to 92 kg/ha of nitrogen (Chilimba and Mkosi, 2012). The incremental benefits due to legume residue incorporation varied with section, with the highest benefits noted of 200 to 730 kg/ha recorded from Chitseko section. While the contribution legume residues to subsequent is well documented (Ngwira et al., 2012; Mwato et al., 1999; Mhango, 2011). Inconsistencies in maize response to legume rotations have previously been reported (Ngwira et al., 2012).

### Gross margin analysis and breakeven yields

The gross margins determinations showed that profitability is higher at higher yield levels, which were associated with higher plant establishment in groundnuts and higher fertilizer rates in maize. Famers may reduce cost of groundnut seed by recycling their original certified seed. However, the value of insecticide or fungicide seed treatment with purchased seed may be lost. The best ways to increase yield remain good agricultural practices, such as timely planting and weeding, and proper plant density as discussed earlier.

## RECOMMENDATIONS

The results have shown that general low yields in both groundnuts and maize are common and a constraint to profitability. For groundnuts, poor plant establishment was a key driver for yield. It is recommended that all possible options to increase establishment should be tested and rolled out. Further options to increase yields in groundnuts should be investigated, including application of P fertilizers. As the results have shown a linear response to fertilizer application in maize, an agronomic optimum could not be determined. While current fertilizer recommendation can be maintained, further studies on N response and their interaction with P should be added.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# The influence of essential amino acid in the chick's diet interferes in the weight gain

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**One of the attributes of amino acid lysine is to manufacture muscle protein, as it is a physiologically essential amino acid for immunity, development and production in birds. This study evaluates the influence of several levels of the essential amino acid lysine for chicks, with age of about 504 hours, maintained at a temperature of approximately 29 degrees Celsius. The basal diet contained 21.0% crude protein and 3,000 kcal of energy of biological transformations/kg. This formula was supplemented with levorotatory-lysine acid monohydrochloride, resulting in diets with 1.040 to 1.280% of total lysine for five experimental treatments. The treatments were found to have a mathematical expression squared influence on animals' weight gain, conversion of diet, total liver mass and protein synthesis index. The effect of the five experimental treatments was not observed in diet consumption, fat synthesis index, absolute weights of intestines and heart, and percentage of liver mass. It was concluded that the total lysine requirements for chicks aged up to 504 h were 1.240%.**

**Key words:** Thermal environment, dietary lysine, growth performance, rearing setting.

## INTRODUCTION

According to Zaboli et al. (2016), temperature control in sheds for slaughter chickens may induce thermo tolerance, possibly by modifying physiological parameters during the first days of chronic heat stress. This is due to the importance of cardiovascular and respiratory systems in the thermoregulation of these birds. In the respiratory system of the bird, blood circulation can weaken control of body temperature in a housing environment that is not stable. There is also the potential challenge, given that due to the challenges posed by environmental degradation, the global temperature will increase approximately from 0.7 to 2.6°C of at least more than 52 years or more.

In the tropical regions of Brazil State, temperature variation in the range of 34 to 45°C can occur between the months of August and May. This promotes a significant reduction in the performance of chicks. The growth of these modern birds over the years, owing to continued genetic progress and the economic growth of the poultry industry in hot climates, requires ways to mitigate thermal stress. Therefore, unequal approaches, such as sheds controlled by the artificial climate, the low population density, nutritional screening of chicks, and the decrease in weight gain have been experienced. However, many of these practices are overestimated and inefficient (Zaboli et al., 2016; Borges, 2017).

High amounts of heat of tropical origin still reduce the weight of digestive and respiratory organs in chicks, to decrease the percentage metabolic rates in birds.

This promotes the reduction of metabolic heat

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production (Lara and Rostagno, 2013; Mehaisen et al., 2017). High temperatures can be reduced with Levorotatory-Lysine Acid Monohydrochloride supplementation, without modifying the performance of chicks. Consequently, by ratifying the different responses related to the effect of high temperatures, it is evident that the requirements of chicks are modified not only according to genetics, but also as a consequence of the thermal environment to which these animals are placed, in the different stages of development (Belloir et al., 2017).

This author adds that the dietary level of rations for chicks raised at elevated temperatures may be reduced by the addition of lysine-levorotatory acid monohydrochloride without any changes in body development. Therefore, the reason for the various responses to the phenomenon of high temperatures means that the diets of chicks can be modified not only in relation to genetics but also in the thermal adaptation in which these animals are reared.

The amino acid lysine-levorotatory acid mono-hydrochloride in the diet has an essential function in protein turnover in musculature of chicks, as it promotes protein synthesis. The deficiency of this amino acid promotes compact protein synthesis, especially in the pectoralis major muscle, which is more sensitive to this amino acid than to the wings and thigh muscles. Lysine has been described as influencing the muscular development of the carcass, since it improves the performance of the musculature and decreases the fat of the carcass (Cruz et al., 2016).

Glutamate indexes found in the muscle of birds are influenced by the natural process of lysine decomposition. The results of the decomposition of lysine, piperidine carboxylic acid, DL-α-Aminoadipic Acid and saccharopine dehydrogenase were increased in broiler diets by about 150%. These results suggest that the short-term diet rich in lysine-levorotatory acid monohydrochloride can improve the meat flavor of broilers in various environmental situations (Watanabe et al., 2015). Nutritional protein for chicks is the high-priced dietary nutrient in the market, yet the use of amino acids consisting of crystals offers several advantages. Its use provides reductions in crude protein concentrations in the diet and the ejection of this nitrogen into the environment, which favors the reduction of environmental pollution. Most broiler diets are formulated with all essential amino acids, where they are fed in optimal proportions to the lysine concentration in the diet (Franco et al., 2017).

The Lysine-levorotatory acid monohydrochloride from vegetable fermentation, such as sugarcane, was as efficient as the lysine offered in the consumer market, potentially being offered in commercial dimensions (Tabassum et al., 2015). Lysine is the amino acid used as an example in chicks because it is used in the production of proteins. It means that it is the first most limiting amino acid in diets for these birds (Belloir et al., 2017).

When chicks are kept in warm environment, there is reduction in the size of the heart, liver and small intestine, to compensate for the heat load to be dissipated in the environment (Borges, 2017). Chicks up to 504 h old, raised in a heat stress environment, represented by a temperature of approximately 29 °C, have lower weights of metabolically active tissues (heart, liver and intestine). The author adds that abdominal fat deposition, noble cut yield and slaughter carcass weight are influenced by the ambient temperature. The objective of this article is to evaluate the effects of several levels of lysine for chicks up to 504 h of age, when maintained in representative heat stress at approximately 29°C; thus simulating the natural conditions in Brazil State. The research problem arises from the question: what are the effects of different level of lysine in the diets of chicks up to 504 hours of age, when kept in heat stress representative of natural conditions in Brazil State? The overall conclusion of the study is that the levels of amino acid lysine on the diet on absolute (dg) and relative weight of the heart, liver, gizzard, intestine and carcass of chicks subjected to a temperature of approximately 29°C, which were slaughtered within 504 hours of age.

## MATERIALS AND METHODS

### Chicks

Experimentation with chicks was carried out in a climatic chambers at a Laboratory of Climatic Effects and Environmental Factors on cutting chicks in Brazil State. In all, 400 male chicks were used, with a mean initial weight of 350 ± 1.5 dg, and received the vaccines against neurolymphomatosis and Newcastle diseases. The choice of male chicks was justified by the greater absolute weight of breast and legs meat compared to females, in order to verify the tendency of rations to influence increases in the deposition of breast meat and thighs. The chicks remained at 24 to 504 h of life in the experiment under conditions of heat stress at the temperature of approximately 29°C. The statistical model of the experiment it was totally random, consisting of five treatments and eight replicates per treatment. Ten chicks were housed in each replicate.

### Feeding regime in the experiment

The experimental recommendations used the spreadsheet with the set of digestibility values developed by Ajinomoto Heartland Llc (2014). In experimental diets, the animals ingested the same amount of protein and energy several times a day; that is, with diets of the same number of calories and proteins, formulated with corn, roasted soybean meal and corn gluten. They were formulated to meet the nutritional requirements, phosphorus, protein, amino acids, energy and calcium, with the exception of lysine. The basal diet was supplemented with 78.40% of Levorotatory-Lysine Acid Monohydrochloride, resulting in diets with 1.040 to 1.280% total lysine. The total amino acid values of the nutritional components of the basal diet were corrected for digestible amino acids.

### Planned experimentation

The 15 metal troughs, each with an area of 72.0 $dm^2$, received the chicks. Each compartment is a representative of an experimental unit. The objective of this study was to estimate the range indicating representative thermal stress at a temperature of approximately

**Table 1.** The heat and the water vapor in the experimental unit.

| Stage (h) | Atmosphere (°C) | Qualified atmosphere wetness | BGMC |
|---|---|---|---|
| 24 | 33.21±0.211 | 53.41±1.791 | 82.11±0.271 |
| 48 | 32.41±0.721 | 56.31±2.440 | 81.51±0.831 |
| 72 | 31.50±0.781 | 57.31±1.741 | 80.31±1.090 |
| 96 | 30.51±0.501 | 54.90±2.210 | 78.71±0.441 |
| 120 | 30.21±0.210 | 55.81±1.960 | 78.51±0.181 |
| 144 | 29.50±0.241 | 55.51±4.020 | 77.51±0.761 |
| 168-504 | 29.10±0.391 | 59.71±3.160 | 77.40±0.591 |

29°C for the initial phase of 504 h-old chicks during the artificial warm-up period. The heat and the water vapor in the experimental unit were monitored by a minimum and maximum dry rounded temperature evaluator and humid and black rounded globe. The thermometers were seated at an intermediate height relative to the central battery compartment. Temperatures were recorded daily on two occasions, at 8:30 and 6:30 p.m., performed throughout the experimental period.

The thermal environment was demonstrated in terms of the black globe moisture code (BGMC) and calculated by the following equation: BGMC = Bgt + 0.36 Dpt - 330.08, where Bgt is the black globe temperature in degrees Kelvin and Dpt is the dew point temperature in Kelvin degrees (Table 1). The diet and water were freely offered; the water was changed once a day to avoid temperature rise. An uninterrupted flow chart of 24 h of artificial light was used throughout the experimental occasion. The variables that were evaluated were: total lysine intake, diet conversion, carcass performance, protein placement, full weight and percentage of primary thigh and thigh cuts, breast weight gain and amount of feed consumed. The weight yield of the chicks that were cushioned was obtained by distinguishing between the weight at the end and the beginning of the experiment. The feed conversion was evaluated for the period of 24 to 504 h, based on information on dietary intake and weight gain. The calculation of the food intake during the experimental period was acquired using the difference between the counting of foods provided and despised by the animals and the remnants of the diets supplied. The diets were weighed at the beginning and at the end of the experiment (Alhotan and Pesti, 2016).

#### Evaluation of the physical formation and constitution of crude protein in carcass of the chicks

Four chicks of each replicate were chosen to be slaughtered, considering the mean weight of the experimental unit, and the weight deviation to + 5% and to - 5%. Then the chicks were slaughtered and plucked, the mass of gutted skeletons was determined. Following, the fatty acids of the chest were excluded and the mass determined. Two whole skeletons, including head and foot, of each repetition were sprayed in 16 minutes, one at a time, on a commercial horsepower with 1,78 rotations per minute (RPM); and after homogenization a sample was collected. The chicks were weighed after 12.5 h of fasting and then at the end of the experiment.

Considering the high fat content of the carcasses, the carcass fragments were oven dried at ± 60°C for 73 h and the fat removed in the extractor for 4 h. After this, the samples were ground and placed in chalices for further evaluation. Crude protein evaluations were performed in an animal nutrition laboratory. An additional set of chicks of 24 to 504 h of age were slaughtered to determine the body composition of the animals at the beginning of the experiment. Protein deposition in the animal skeleton was measured by the difference between estimates of carcass composition between 24 and 504 h of age of the chicks.

#### Evaluations using experimental statistics

The numerical data capture for analysis was developed with the scientific support of the computer program, Statistical and Genetic Analysis (SGA). The approximate calculations of total determination of lysine were determined with the aid of the linear or quadratic regression models and the Linear Response Plateau (LRP), observing the adaptation with smaller error.

## RESULTS AND DISCUSSION

The animals received diverse stages of lysine in the diet and were kept in a high temperature environment (29.10°C). The results of performance, specified by feedstuff eating and feed transformation, mass increase, entire lysine ingesting, protein and fat statement rates in the slaughter chick's carcass of 24 to 504 h grow old were obtained (Table 2). The Levorotatory-Lysine Acid Monohydrochloride indexes of the diet influenced the gain in animals' weight of the chicks, increasing in quadratic equation form until it gets to 1.20% indexes (Table 3); corresponding to an estimated consumption of 99.01 dg of the total lysine.

Due to the increased use of Levorotatory-Lysine Acid Monohydrochloride, no effect of lysine levels on feedstuff eating (FE) was observed. These results were similar to those obtained by those who, grow old working in high temperature conditions, did not find the effect of the stages of Levorotatory-Lysine Acid Monohydrochloride in relation to the initial consumption of chicks. However, it is different from the one pointed out by those who observed a significant modification in the consumption of chick's ration of 24 to 504 h and subjected to warmth pressure. Dietary lysine result ($p < 0.01$) in the feed conversion (FC) was verified for the chicks, which varied in the quadratic form and improved to 1.24% level, corresponding to an estimated consumption of lysine of 100.7 dg (Table 4).

Considering report that male chicks at 37°C up to 504 h of age does not require a higher level of lysine in the feed than those kept at 24°C, it is inferred that the variation of the results of this work can possibly be associated with differences in experimental environmental

**Table 2.** Entire consumption of lysine and aliquots of fat and protein account in the skeleton of male chicks of 24 to 504 h.

| Parameter | Total lysine level (%) | | | | | RSD |
|---|---|---|---|---|---|---|
| | 1.04 | 1.10 | 1.16 | 1.22 | 1.28 | |
| Weight gain (dg) | 5,390 | 5,700 | 5,890 | 5,720 | 5,790 | 0.0479 |
| Feed intake (dg) | 8,070 | 8,250 | 8,460 | 8,180 | 8,220 | 0.0452 |
| Feed: gain ratio | 1.50 | 1.45 | 1.43 | 1.43 | 1.42 | 0.0148 |
| Total lysine intake (dg) | 85 | 91 | 98 | 99 | 106 | 0.0461 |
| **Carcass deposition rate** | | | | | | |
| Fat (dg) | 440 | 460 | 470 | 430 | 460 | 0.0555 |
| Protein (dg) | 950 | 1,000 | 1,070 | 1,020 | 1,070 | 0.0449 |

RSD = Relative Standard Deviation.

**Table 3.** Gain in animals' weight (dg) of chicks from 24 to 504 h old, underneath 29.1°C.

| Weight gain | Lysine complete in diets (%) | Lysine complete doss (%) | Mathematical expression squared |
|---|---|---|---|
| 5,390 | 1.04 | | |
| 5,700 | 1.10 | 1.20 | $\hat{Y}$= -1853.67 + 4067 X - 1695.88 $X^2$ $r^2$ = 0.77 |
| 5,890 | 1.16 | | |
| 5,720 | 1.22 | | |

**Table 4.** Lysine starting point in the ration for chicks of 24 to 504 hours of age, at a 29.10°C.

| Feed: gain ratio | Lysine complete in diets (%) | Lysine complete doss (%) | Mathematical expression squared |
|---|---|---|---|
| 1.50 | 1.04 | | |
| 1.45 | 1.10 | | |
| 1.43 | 1.16 | 1.24 | $\hat{Y}$= 4.10087– 4.31539 X + 1.73764 $X^2$ $r^2$ = 0.96 |
| 1.43 | 1.22 | | |
| 1.42 | 1.28 | | |

**Table 5.** Lysine factor and coefficient of protein constitution of chicks from 24 to 504 h of phase, below 29.10°C.

| Deposition rate (dg/day) | Total lysine of ration (%) | Ideal total lysine (%) | Quadratic equation |
|---|---|---|---|
| 950 | 1.04 | | |
| 1,000 | 1.10 | | |
| 1,070 | 1.16 | 1.26 | $\hat{Y}$= - 256.843+577.436 X –229.628 $X^2$ $r^2$ = 0.71 |
| 1,020 | 1.22 | | |
| 1,070 | 1.28 | | |

conditions. Cemin et. al. (2017) explains that the requirements of the fundamental amino acids add up with the addition of protein. This suggests that, deamination and excretion of excess protein nitrogen may contribute to the excretion of the first limiting amino acid of lysine. This fact would increase your requirement. The performance results evidenced that early-stage chicks require a higher lysine level to achieve a better FC ratio than a higher gain. The action of the lysine amino acid coefficients in the diet ($p<0.01$) on the protein deposition rate (dg/daytime) of chicks from 24 to 540 h of age was verified. The coefficients of the amino acid lysine of the diet prompted the protein clarification aliquot (PCA) ($p <0.08$), which was quadratically added until the coefficient corresponds to 1.26% (Table 5). These results are similar to those obtained by those who verified the efficiency of the coefficients of the amino acid lysine in the PCA in a thermo-neutral environment. It can be inferred that, the requirement of total lysine for protein deposition (1.26%) was higher than that required for weight gain (1.20%).

**Table 6.** Complete (dg) and relation masses of heart, liver, gizzard and intestine of 504 hours old of chicks subjected to 29.10°C.

| Parameter | Total lysine level (%) | | | | | RSD (%) |
|---|---|---|---|---|---|---|
| | 1.04 | 1.10 | 1.16 | 1.22 | 1.28 | |
| | Absolute weight(dg) | | | | | |
| Heart | 40 | 40 | 50 | 40 | 40 | 13.96 |
| Liver | 140 | 150 | 160 | 150 | 150 | 11.42 |
| Intestine | 240 | 260 | 250 | 250 | 250 | 13.04 |
| | Relative weight (%) | | | | | |
| Heart | 0.95 | 0.95 | 0.97 | 0.95 | 0.97 | 15.34 |
| Liver | 3.33 | 3.23 | 3.30 | 3.38 | 3.24 | 11.45 |
| Intestine | 5.53 | 5.61 | 5.38 | 5.42 | 5.47 | 11.96 |

**Table 7.** Since liver weight until mathematical expression squared to chicks subjected to high temperature in 29.10°C.

| Liver weight (dg) | Lysine complete in diets (%) | Lysine complete doss (%) | Mathematical expression squared |
|---|---|---|---|
| 33.3 | 1.04 | | |
| 32.3 | 1.10 | | $\hat{Y} = -88.6843 + 178.405X - 76.3782X^2$ |
| 33.0 | 1.16 | 1.17 | $r^2 = 1.00$ |
| 33.8 | 1.22 | | |
| 32.4 | 1.28 | | |

$r^2$ = is portion statistical model adjustment to the detected values. The $r^2$ varies between 0 and 1, indicating how much the model explains the observed values. The higher the $r^2$, the better it fits the sample.

It was verified that, in absolute values (dg), the 1.16% lysine factor harmonized the ascending fat building (FB) effects. Considering the constitution of the carcass, the consequence ($p>0.10$) of the coefficients of the lysine amino acid of the ration on the FB was not emphasized. These results defers from those achieved by those who found a mathematical expression squared result of the lysine coefficients in the FB of chicks between 24 to 504 h of age, when they worked in a thermo-neutral atmosphere. The absolute (dg) and relative (expressed as percentage of carcass) weights of heart, liver, gizzard and intestine of 24 h old of chicks subjected to high temperature in 29.10°C. The total lysine coefficients of the diets did not influence the integral and rational weights of the organs constituted by the small and large intestines and the heart (Table 6). Absolute liver weight of the chicks varied in a quadratic form, being the highest weight found in the level of 1.17% lysine (Table 7). The increase in absolute liver weight occurred due to the increase in the body weight of the birds, since the relative weight of the liver did not vary between treatments.

## Conclusion

In this study, it was found that the coefficients of the essential amino acid lysine present in the diet influenced the yield of chicks weight gain. This yield by weight increased in a quadratic fashion up to 1.20% coefficient. This corresponds to the estimated consumption of 99.1 dg of the total amino acid lysine of the feed. The effect of the lysine coefficients of the diet is confirmed for the feed conversion, which occurs in the form of a quadratic mathematical equation. There is feed efficiency for feed conversion up to the coefficient 1.24%, which corresponds to the estimated lysine consumption of 100.7 dg. It is verified that the effect in the form of a quadratic equation of the lysine coefficients in the diet ($p<0.01$) on the rate of protein deposition in dg/day, occurs with feed efficiency of about 1.26% coefficient. The conclusion is that there was absolute (g) and relative (expressed as percentage of carcass) weights gain in gizzard, liver, heart and intestine of 504 h old chicks subjected to high temperature (29.10°C). At least in the subject of the lysine coefficients here tested, the consequence of the total lysine coefficients of the diets on the integral and unrestricted weight of the intestine and the heart was not highlighted in this paper. The absolute liver weight of the birds varied in a quadratic manner, with the highest weight found at 1.17% lysine level. The increase of the absolute weight of the liver occurs due to the increase of the body weight of the birds, since the percentage mass related to the liver does not vary in experiments.

## CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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*Full Length Research Paper*

# Caffeic acid as a preservative that extends shelf-life and maintains fruit quality of mulberries during cold storage

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**Fruits can be easily infected and damaged by microbes. Cold storage is a popular approach used to extend the shelf-life of fruits. In this paper, the effect of caffeic acid on physiological parameters and shelf-life of mulberries (*Morus alba* L.) stored for 21 days at 4°C was evaluated. The results showed that the shelf-life was significantly improved in the mulberries treated with the different concentrations of caffeic acid solution for 5 min ($P$ < 0.05). Certain physiological parameters, like phenolics, anthocyanins, flavonoids and Vitamin C were also significantly increased ($P$ < 0.05) in the treated mulberries. The results showed that the rotting rate and the weight loss ratio were 47.0 and 6.6% in the 0.20 g/L caffeic acid-treated fruits after storing for 21 days at 4°C, respectively. While these two parameters were 79.0 and 9.7% in the control. The malondialdehyde (MDA) content was significantly lower ($P$ < 0.05) in the 0.20 g/L caffeic acid-treated mulberries than that in the samples treated with 0.00, 0.10, 0.25 and 0.30 g/L caffeic acid. Moreover, the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activities in the caffeic acid treated mulberries were significantly higher than those in the control ($P$ < 0.05). Therefore, caffeic acid, as a preservative, is favorable for elongation of the shelf-life, maintenance of the quality and inhibition of fruit decay in mulberries. This study is greatly informative to mulberry growers and commercial sellers.**

**Key words:** Caffeic acid, mulberry fruits, cold storage, postharvest quality.

## INTRODUCTION

Mulberries (*Morus alba* L.) are sweet and juicy fruits. The berries contain rich nutrients of sugars, proteins, vitamins and minerals, and abundant antioxidants of anthocyanins, flavonoids, and phenolic acids (Heinonen et al., 1998).

Cold storage can slow down the respiration of fruit and inhibit the reproduction of microorganism on fruits and vegetables (Saltveit and Morris, 1990). A successful cooling storage needs to ensure that the quality of the commodities is maintained desirable until they reach consumers (Formerhead, 2005). Low temperature effectively reduces enzyme activity and inhibits growth of microorganisms (Leccese et al., 2010). During the postharvest periods of mulberries, prompt cooling and favorable temperature (e.g., -1 to 4°C) are very important

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factors to restrain the undesirable quality changes (Saltveit and Morris, 1990). However, the flavor of the fruits stored by cold has greatly been changed thus quality in the stored fruits is not comparable with that in the fresh fruits (Galli et al., 2008). Nonetheless, cold is widely recognized as a healthy, safe and effective technology for fruit storage (Yang et al., 2016).

Various methods have been developed for preservation of mulberry fruits. Chen et al. (2015) demonstrated that the shelf-life in the 60 mg/L chlorine dioxide treated samples was extended to 14 days while it was 8 days in the control. However chlorine dioxide produces irritating odors and has unfavorable impact on the flavor of fruits so that it is not suitable for practical application (Huber et al., 2005). Oz and Ulukanli (2013) found that 1-MCP alone or plus $CaCl_2$ treatment reduced the browning rate and maintained the fruit color. Hu et al. (2014) observed that $H_2S$ fumigation was able to slightly decrease soluble protein, acidity and ascorbate content. They also demonstrated that the activities of representative antioxidant enzymes in $H_2S$-treated samples were higher than those in the control samples during storage. However, hydrogen sulphide produces a strong odor of rotten egg that may negatively affect the flavor of mulberry fruits, limiting use of this reagent for storage in practice. Because these limitations existed in the previous studies, we screened some natural compounds that can be desirably used for storage of mulberries.

Caffeic acid (CA) is widely distributed in nature and possesses strong antioxidant activity (Wang et al., 2014). This natural compound shows a variety of potential pharmacological effects *in vitro* and in the model animals *in vivo* (Wang et al., 2009). Caffeic acid also shows immunomodulatory and anti-inflammatory activity. Ojeda-Contreras et al. (2008) found that caffeic acid phenethyl ester (CAPE) can prevent fungi from tomato fruits. Treated with CAPE, tomato fruits can be stored for 20 days at 25°C. Carreno et al. (2017) evaluated the cellular antioxidant activity (CAA) of CAPE, and found that CAPE has a cellular protective effect against reactive oxygen species (ROS). This study is aimed at evaluating the effects of different concentrations of caffeic acid on maintenance of postharvest fruit quality and to extend the shelf life of mulberry fruit through comprehensive analysis of several physiological parameters in the treated fruits with those in the control. This study is the first time to comprehensively analyze caffeic acid potentially used for preservation of mulberries during storage.

## MATERIALS AND METHODS

Mulberry fruits of Dashi (*M. alba* Lin.) were collected at 90% commercial maturity in Zhenjiang, Jiangsu Province (Yang et al., 2016). The fruits with uniform size, color and absence of visual damages were chosen for the experiments. Mulberries were randomized into six groups with 150 fruits each. Six treatments with graded concentrations of caffeic acid were arranged in this study, including 0.00 (as the control), 0.10, 0.15, 0.20, 0.25, and 0.30 g/L of caffeic acid, respectively. The fruits were dipped into the solutions for 5 min. The treated samples were drained by a plastic sieve for 1 h and a low rotation speed fan was used for a fast drying. Then the treated samples were wrapped with a 105×105×40 mm plastic box and stored at 4°C. The fruits were stored for eight time points at 0, 3, 6, 9, 12, 15, 18 and 21 days, respectively, and were collected at each time point for an immediate analysis of rotting rate and weight loss. Then the samples were frozen in liquid nitrogen and stored at -80 °C for further analysis of other physiological parameters.

### Weight loss and rotting rate

The weight loss rate was measured by weighting the pre- and post-storage fruits, and expressed as a percentage of the initial weight.

The rotting rate was categorized into five groupings, where 1 = unaffected, 2 = trace (up to 5% surface affected), 3 = slight (5-20% surface affected), 4 = moderate (20-50% surface affected), and 5 = severe (> 50% surface affected) (Ayala-Zavala et al., 2004). Rotting rate (%) was calculated with an equation:

$$\text{Rotting rate (\%)} = \sum \frac{\text{rot scale} \times \text{number of fruit at the rot scale}}{\text{the highest rot scale} \times \text{total number of fruit in the treatment}} \times 100;$$

These measurements were performed in triplicates.

### Evaluation of $LD_{90}$

Previous studies used the rotting rate as the only index for evaluation of storage ability. However, only this index alone cannot well reflect the actual value of the storage ability in fruits. In the study of insect toxicology and pathology, the $LC_{50}$ or $LD_{50}$ values for pesticides or pathogenic microorganisms are often needed to be calculated for evaluation of pesticide efficacy or microbe susceptibility (Walker et al., 2000). Similarly, we borrowed this strategy in this study for analysis of evaluation of caffeic acid to improve the mulberry storage ability. $LD_{90}$ represents the storage days when percentage of the intact fruits reaches 90%. Probit software rooted in the SPSS19.0 for Windows module (probability unit regression) was used for estimation of $LD_{90}$.

### Physiological parameters

The total anthocyanin content of the fruit extracts was determined by using a previously described method (Proctor, 1974), with a slight modification. To isolate the anthocyanin, 1.5 g of mulberry fruit was added to 36 ml of 77% (v/v) ethanol containing HCl (1%, v/v), and then ultrasonically homogenized for 2 h at 50°C and 400 W. The extracting solution was diluted with KCl-HCl buffer (pH 1.0) and HAC-NaAC buffer (pH 4.5) and mixed well. Then, the extracts were maintained at room temperature for 30 min. Absorption was measured at 512 and 700 nm in buffers at pH 1.0 and 4.5. Anthocyanin content of the mulberry fruits was calculated with an equation:

$$\text{Anthocyanin content (mg/g FW)} = \frac{[(A_{512} - A_{700})_{pH1.0} - (A_{512} - A_{700})_{pH4.5}] \times V \times n \times M}{\varepsilon \times m}$$

where V (mL) is the total volume of extracting solution, n is the dilution ratio of the extracting solution, M (g/mol) is the molecular mass of cyanidin-3-*O*-glucoside, ε is the extinction coefficient of cyanidin-3-*O*-glucoside, and m (g) is the mass of the sample. These measurements were performed in triplicates.

Vitamin C content was determined using the protocol of Malik and Zora (2005), with slight modifications. The content of Vitamin C content was calculated on a 100% (W) ascorbic acid standard curve and expressed as mg of ascorbic acid (AA) per 100 g of the fresh weight (FW).

The total flavonoid content of mulberry fruits was determined by the spectrophotometric method described by Lu et al. (2012), with a slight modification. Total flavone was extracted from 1.5 g mulberry fruits using 20 mL of 95% (v/v) ethanol, and the mixture was sonicated for 2.5 h. The liquid extract (1 mL) or a standard solution of rutin was transferred to a 10 mL volumetric flask with 0.3 mL of 5% (w/v) $NaNO_2$. After standing at room temperature for 6 min, 0.3 mL of 10% (w/v) $Al(NO_3)_3$ was added to the solution, and the mixture was homogeneously mixed and allowed to stand for 6 min. Finally, 4 mL of 4% (w/v) NaOH was added. The 60% (v/v) ethanol was added into the solution till a final volume of 10 mL then stood for 12 min. The absorbance of the samples was measured at 510 nm. The total flavonoid content was calculated as mg/g FW. All samples were analyzed in triplicates.

The polyphenol content of the mulberry fruits was measured using Folin-Ciocalteu reagent (Slinkard and Singleton, 1977). Polyphenols were extracted from 1 g mulberry fruit using 70 mL of 60% (v/v) ethanol then an additional ultrasonic extraction for 3 min. The filtered residue was extracted again, and the two extracts were mixed to detect the polyphenol content of mulberry fruits. The polyphenol content was expressed as milligrams of gallic acid equivalent (GAE) per kilogram. Two millilitres of Folin-Ciocalteu's phenol reagent was added into 5 mL of the extracting solution, mixed well and then 15% (w/v) $Na_2CO_3$ was added into the mixture till the final volume of 25 mL. The mixture solution was allowed to react at 45°C for 40 min and then cooled to room temperature. Subsequently, the absorbance of the samples was detected at 765 nm. Three replicates were used to determine the results of each assay.

The standard curves of vitamin C, polyphenols and total flavone were Y = 59044300 X - 19356.5, $R^2$ = 0.9987; A = 71.92 C - 0.053, $R^2$ = 0.9987; A = 5.449 C + 0.00562, $R^2$ = 0.9918, respectively, where Y is the peak area, X and C are concentrations (mg/mL), and A is the absorbance (Malik and Zora, 2005).

### MDA content

Malondialdehyde (MDA) content in the fruits was determined using the method of Dhindsa et al. (1981) with slight modification. Fresh tissue (0.2 g) from mulberry was homogenised with 1 mL of 10% (m/V) trichloroacetic (TCA). The reaction mixture was spun at 12,000 ×g for 10 min. The supernatant (0.5 mL) was mixed with 0.5 mL of 0.6% (W/V) thiobarbituric acid (TBA), incubated at 100°C for 20 min and quickly cooled down. After centrifugation at 3000 ×g for 10 min, the absorbance of the supernatant was detected at 532, 450 and 600 nm using I3 Spectramax (USA). The MDA content of the mulberry fruits was calculated with equation:

$$\text{MDA content } (\mu\text{ mol/g FW}) = \frac{[6.45 \times (A_{532} - A_{600}) - 0.56 \times A_{450}] \times V}{m}$$

where V (L) is the total volume of the extracts, the total volume of the reaction mixture solution and the volume of the extracted solution in the reaction mixture solution, and m (g) is the mass of the sample.

### DPPH activities

The antioxidant activity of the mulberry fruits was evaluated using the method of Cheung et al. (2003), with a slight modification. To determine free radical scavenging activity, samples were extracted with methanol. One hundred and ninety microlitres of 0.6 mM DPPH radical were dissolved in methanol. Ten microlitres of mulberry fruit extract or (±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid standard solution were added to 0.6 mM DPPH radical in methanol, mixed well and kept at room temperature for 1 h in the dark. The absorbance was measured spectrophotometrically at 517 nm. The percent in reduction in DPPH was expressed as mg Ve per g fresh weight of mulberry fruits.

### Statistical analysis

The experimental values of three replicates were expressed as the means ± standard deviation. To estimate statistically any significant differences among the mean values, the data were analysed with a one-way analysis of variance (ANOVA test). Statistical comparisons of the data were based on the Pearson correlation coefficient, and levels lower than 0.05 were considered significant. *R* programming language was used to determine the significance of the differences between the samples.

## RESULTS

### Effects of caffeic acid (CA) treatments on physiological parameters of mulberry fruits during storage at 4 °C for 21 days

As shown in Table 1, the levels of anthocyanin in mulberries showed an increased trend during storage within 21 days. On the 21st days of the storage, the mulberries treated with 0.20 g/L caffeic acid had the highest level of anthocyanin compared with the remaining treatments. In most cases, the treatments with 0.20 and 0.30 g/L caffeic acid showed the best abilities to maintain anthocyanin in the stored mulberries compared with the remaining treatments (Table 1).

The polyphenol and flavonoid contents of mulberry fruits varied with storage days and different concentrations of caffeic acid (Table 1). On the 21st day of the storage, the fruits treated with 0.15 and 0.20 g/L caffeic acid had the highest level of polyphenol and flavonoid contents as compared with the remaining

**Table 1.** Effects of caffeic acid (CA) treatments on physiological parameters of mulberry fruits during storage at 4°C for 21 days.

| Storage days (day) | CA concentration (%) | Anthocyanin (mg/g FW**) | Vitamin C content (mg/100 g FW) | Polyphenols (mg/g FW) | Total flavone (mg/g FW) |
|---|---|---|---|---|---|
| 0 | - | 1.08±0.03 | 168.19±0.83 | 10.09±0.42 | 2.127±0.678 |
| 21 | Control | 1.29±0.03$^{b}$ | 166.44±1.27$^{c}$ | 11.85±0.64$^{d}$ | 2.13±0.15$^{d}$ |
| 21 | 0.10 g/L | 1.21±0.03$^{b}$ | 179.95±1.05$^{c}$ | 10.28±1.27$^{e}$ | 1.92±0.26$^{e}$ |
| 21 | 0.15 g/L | 1.13±0.03$^{c}$ | 248.17±2.98$^{a}$ | 14.09±2.16$^{a}$ | 4.17±0.49$^{a}$ |
| 21 | 0.20 g/L | 1.82±0.03$^{a}$ | 258.61±1.78$^{a}$ | 13.48±0.49$^{b}$ | 3.02±0.16$^{b}$ |
| 21 | 0.25 g/L | 0.99±0.03$^{c}$ | 175.80±1.65$^{c}$ | 11.55±0.41$^{d}$ | 2.14±0.24$^{d}$ |
| 21 | 0.30 g/L | 1.34±0.03$^{b}$ | 197.29±0.60$^{b}$ | 12.96±0.37$^{c}$ | 2.58±0.25$^{c}$ |

[1)]The data are represented as the mean ± SD of three replicate samples. Means in same column with different letters are significantly different ($P$ < 0.05) determined with Duncan's multiple range test. [2)] FW indicates fresh weight.

**Table 2.** Effects of caffeic acid on $LD_{90}$ of the mulberry fruits stored at 4 °C for 21 days.

| Treatment | $LD_{90}$ (days)* |
|---|---|
| Control | 6.4 |
| 0.10 g/L CA | 9.4 |
| 0.15 g/L CA | 10.9 |
| 0.20 g/L CA | 11.8 |
| 0.25 g/L CA | 8.9 |
| 0.30 g/L CA | 11.8 |

[1)]$LD_{90}$ represents the storage time until the rate of the good fruits reaching at 90%.

treatments. Table 1 also showed changes of the total vitamin C content in the mulberries within 21 days of the storage of all treatments. The initial vitamin C content of mulberries was 168.19 mg/100 g. On the 21st day of the storage, vitamin C content in the mulberries treated with 0.20 g/L caffeic acid was the highest (258.61 mg/100 g) among the treatments, and extensively higher than that in the control (166.44 mg/100 g). Therefore, the 0.20 g/L caffeic acid showed the best ability to inhibit vitamin C from degradation in the stored mulberries (Table 1).

## Effects of caffeic acid on $LD_{90}$ of the mulberry fruits stored at 4°C for 21 days

Mulberry is a soft fruit and easily to decay by mechanics and microbe factors (Yang et al., 2016). The mulberry fruits treated with 0.20 g/L caffeic acid had a significantly ($P$ < 0.05) lower weight loss compared with the control (Figure 1). After storage for 15 days, the mulberry fruits treated with 0.20 g/L caffeic acid had a significantly ($P$ < 0.05) lower rotting rate compared with the control (Figure 2). On the 21st day, 0.30 g/L caffeic acid showed the lowest rotting rate, followed by 0.20, 0.25, 0.15, 0.10 and 0.00 g/L treatments. The $LD_{90}$ values of the 0.20 g/L and 0.30 g/L caffeic acid treatments were 11.8 and 11.7 days, respectively. However, $LD_{90}$ in the control was 6.8 days (Table 2). Therefore, the 0.20 and 0.30 g/L caffeic acid showed the best potential to impede the weight loss and fruit decay compared with the control after the storage of 15 days.

## Effects of caffeic acid on MDA content of the mulberry fruits stored at 4°C for 21 days

MDA is the product of membrane lipid peroxidation, which can reflect the degree of cell ageing (Liu et al., 2011). All treatments showed an increasing trend of MDA content in the mulberries with extension of the storage days (Figure 3). On the 21st day, the MDA content of control rapidly increased to $13.88\times10^{-5}$ μ mol/g, and MDA in the 0.20 g/L caffeic acid-treated mulberry fruits was the lowest ($10.53\times10^{-5}$ μ mol/g, $P$ < 0.05) compared with other treatments (Figure 3).

## Effects of caffeic acid on DPPH content of the mulberry fruits stored at 4°C for 21 days

As shown in Figure 4, the DPPH radical scavenging activities of mulberry fruits had an increase-decline-increase-decline trend during storage within 21 days. On the 21st days of the storage, the mulberries treated with 0.20 g/L caffeic acid had the highest level of DPPH

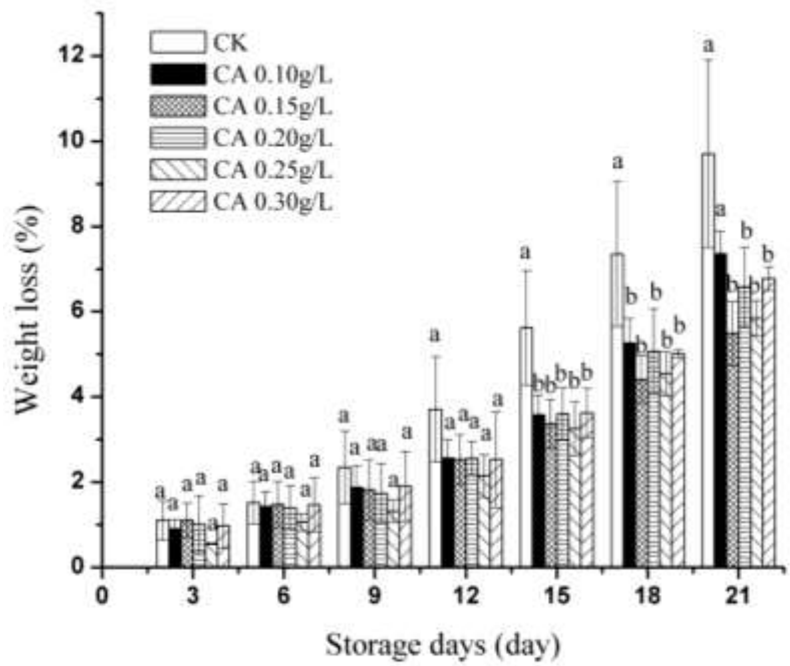


**Figure 1.** Changes in weight loss of mulberry fruits treated with 0.00, 0.10, 0.15, 0.20, 0.25 and 0.30 g/L caffeic acid when stored at 4°C for 21 days. Data is presented as 'mean ± SD' of three replicates. Difference small letters (a or b) above the bars show significant differences at $P < 0.05$.

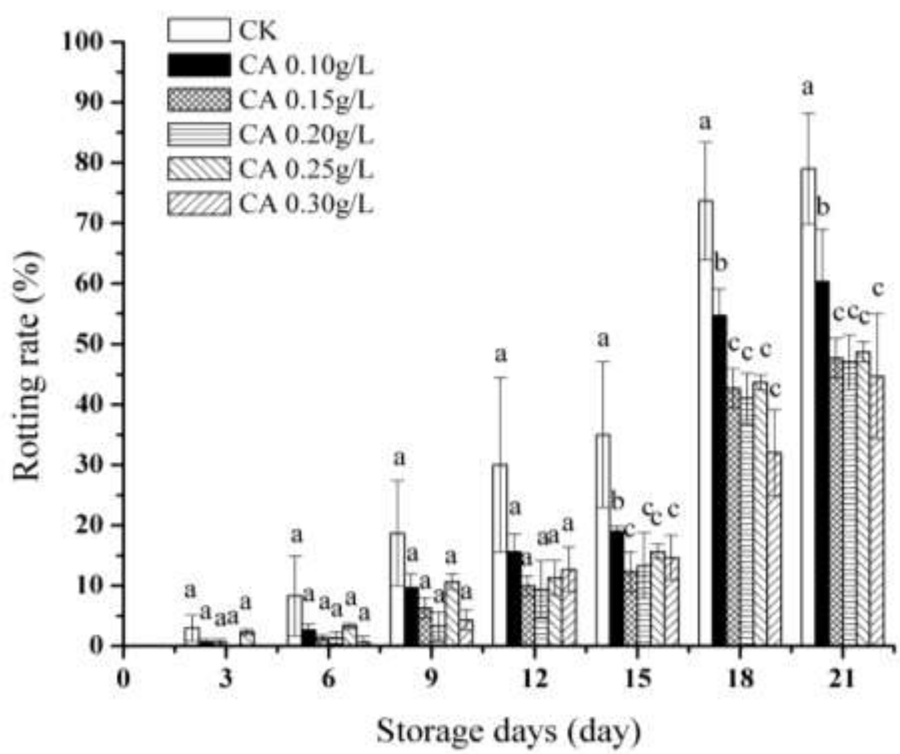


**Figure 2.** Rotting rate of mulberry fruits treated with 0.00, 0.10, 0.15, 0.20, 0.25 and 0.30 g/L caffeic acid when stored at 4°C for 21 d. Data is presented as 'mean ± SD' of three replicates. Difference small letters (a or b) above the bars show significant differences at $P < 0.05$.

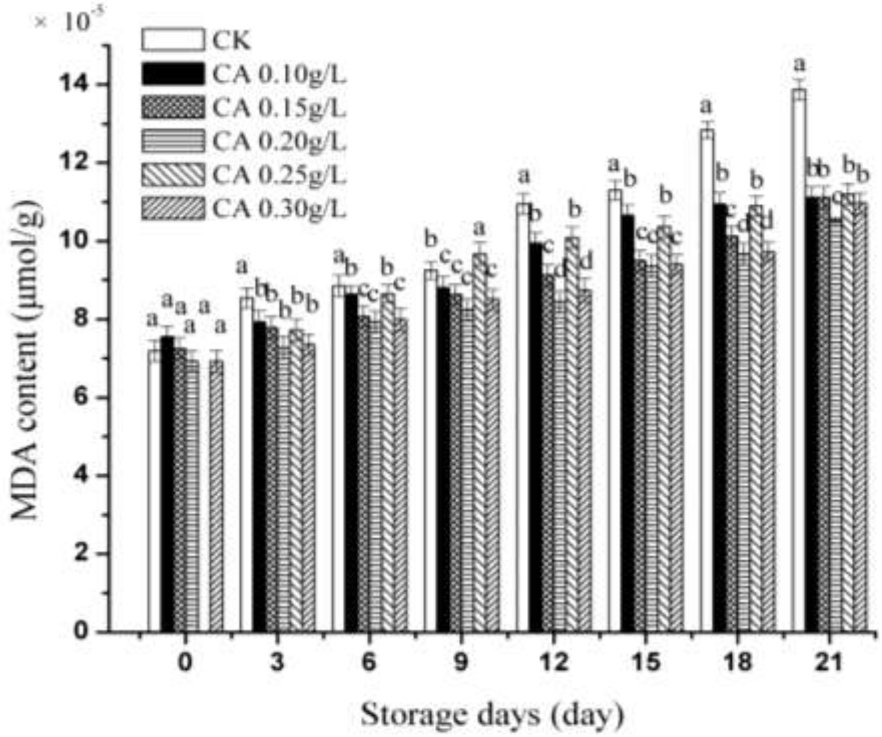


**Figure 3.** Changes of MDA content in the mulberry fruits treated with 0.00, 0.10, 0.25 and 0.30 g/L caffeic acid when stored at 4°C for 21 days. Data is presented as 'mean ± SD' of three replicates. Difference small letters (a or b) above the bars show significant differences at $P < 0.05$.

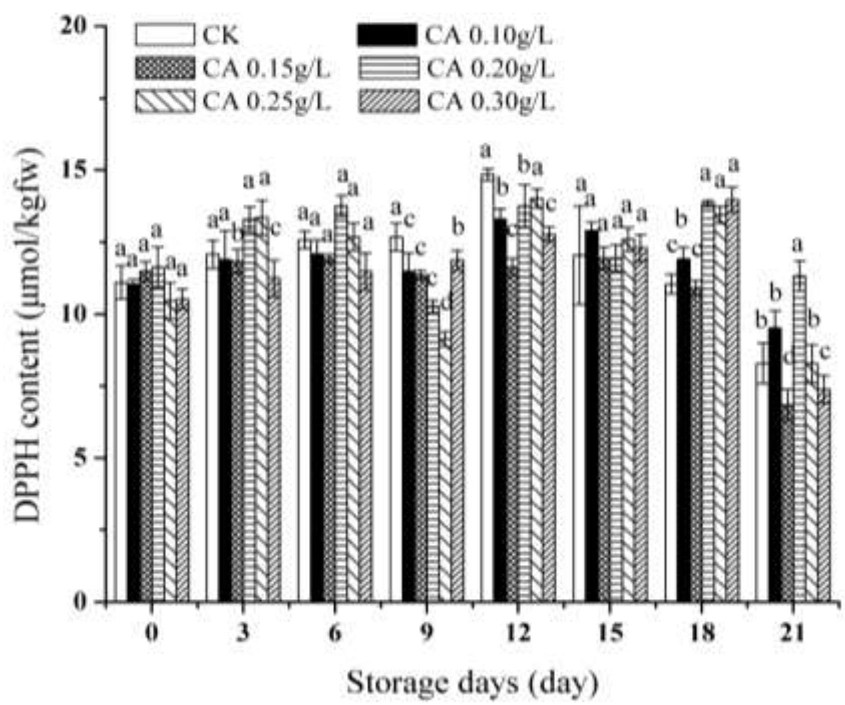


**Figure 4.** DPPH scavenging activities of mulberry fruits treated with 0.00, 0.10, 0.15, 0.20, 0.25 and 0.30 g/L caffeic acid when stored at 4°C for 21 days. Data is presented as 'mean ± SD' of three replicates. Difference small letters (a or b) above the bars show significant differences at $P<0.05$


**Figure 5.** Appearance quality of the mulberry fruits treated with 0.00, 0.10, 0.15, 0.20, 0.25 and 0.30 g/L caffeic acid when stored at 4°C on day 9 (a) and day 21 (b).

content as compared with the remaining treatments. The control and caffeic acid-treated mulberry fruits exhibited similar changes in the DPPH radical scavenging activity during storage (Figure 4).

### Effects of caffeic acid on overall appearance quality of the mulberry fruits stored at 4°C for 21 days

The overall appearance quality in Figure 5b shows that the control fruits were almost entirely decayed and infected by pathogens. But half of the mulberry fruits treated by 0.15g/L caffeic acid were decayed. However, the 0.20, 0.25 and 0.30 g/L caffeic acid treatments had the best preservation efficacy without obvious pathogens on the surfaces of the mulberry fruits. These observations were in accordance with the previously measured parameters in Figures 1 and 2.

## DISCUSSION

Many fruits and vegetable containing natural anthocyanins demonstrate positive efficacy on human healthcare. Our study indicates that total anthocyanin in the stored mulberries was extensively affected by caffeic acid treatment and the cold storage period. The accumulation of pigment and anthocyanin content in mulberries were increased with extension of the storage time (Chen et al., 2015). An enhanced anthocyanin content during storage was previously reported for raspberries, strawberries, low bush blueberries and high bush blueberries (Kalt et al., 1999). This phenomenon may be due to the continued biosynthesis of phenolic compounds after harvest, and it is related to the ripening processes (Wang and Gao, 2013).

Polyphenol and flavonoid contents in fruits are affected by numerous factors and varied among species, cultivars, temperature, climactic and environmental conditions during the growth period (Kalt, 2005). The polyphenol and flavonoid contents of the stored mulberries had an increasing trend along with storage time (Table 1). This observation is in agreement with the report by Chen et al. (2015). This phenomenon was also found in the stored raspberries, strawberries, low bush blueberries and high bush blueberries without coatings (Kalt et al., 1999).

Vitamin C in the fruits is an unstable compound and easily oxidized during postharvest (Hassanpour, 2014). Therefore, it is reasonable that Vitamin C in both the treated and untreated samples was decreased during the storage (Table 1). However, our study also shows that caffeic acid effectively inhibited decomposition of Vitamin C in the stored mulberries (Table 1).

CAPE is a propolis constituent that has gained attention due to its broad pharmacological activities (Zhang et al., 2014), including antibacterial, antiproliferative, antiparasitic and antioxidant effect, among others (Wang et al., 2014; Alday-Provencio et al., 2015). CAPE is more biologically effective than other natural hydroxycinnamic acid derivatives because of its structural properties, possessing better bioavailability in lipophilic systems due to its partition coefficient (Zhang et al., 2014). In this paper, we fund that caffeic acid can decrease the rotting rate; it may be that caffeic acid is able to protect the mulberries from pathogen infection. Data of three parameters, weight loss, rotting rate and LD90 (Figures 1 and 2 and Table 2) suggest that caffeic acid may impede the aging process and maintain quality of the stored mulberries, which further indicates that caffeic acid may decrease transpiration and respiration processes in fruits (Zhu et al., 2008). The results indicated that caffeic acid had an obvious effect on decrease of the weight loss in mulberry fruits. This is probably due to the fact that caffeic acid has the capacity against water evaporation in the mulberry fruits (Wang et al., 2014). A lower rotting rate in the caffeic acid treated mulberry fruits may be attributed to the antibacterial ability of caffeic acid (Wang et al., 2009). The rotting rate was often used for evaluation of the preservation consequence in horticultural crops (Yang et al., 2016). However, only having this index alone may not reflect the overall economic values of mulberries. For this reason, LD90 was used in this study for evaluation of caffeic acid capacity on maintenance of the storage fruit quality in mulberries. Although several parameters, e.g., anthocyanins, polyphenol content and flavonoid content were increased with the storage time within 20 days (Table 1), LD90 suggested the optimum time for storage of the mulberry fruits treated with caffeic acid was for 11 days or shorter (Table 2).

MDA is often used as an index representing cell oxidative damage suffering from lipid peroxidation (Xu et al., 2009). MDA was suppressed by salicylic acid in 'Qingnai' plum fruits (Luo et al., 2011) and cucumbers (Hu et al., 2009). However, few previous studies have been conducted concerning evaluation of caffeic acid on suppression of MDA during the cold storage. The DPPH radical scavenging activities are associated with the contents of phenols and anthocyanins (Chen et al., 2014). The DPPH radical scavenging activities fluctuated during storage. Our study showed that DPPH radical-scavenging was improved by caffeic acid treatments, in agreement with the previous report by Concellónab et al. (2012).

From all these evidences, caffeic acid is suggested to use as a preservative for the cold storage of the mulberry fruits.

## Conclusions

The cold stored mulberry fruits pre-treated with caffeic acid had higher anthocyanin, phenolic compounds, flavonoid and Vitamin C contents and lower rotting rate, weight loss and MDA than the control fruits. The results reveal that the caffeic acid treatments have a positive effect on preservation of the mulberry fruits. This natural compound is suggested for use as a preservative to extend the shelf-life and maintain the fruit quality for the cold storage of the mulberry fruits. Further investigation is also needed to elucidate the underlying molecular basis of the caffeic acid with the capacity to improve the preservation quality of the stored mulberry fruits.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENT

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*Full Length Research Paper*

# Impacts of food production, consumption fluctuations and marketing on food prices volatility in the Sudan: Evidences from Gadarif State

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**This study aimed to investigate the impacts of fluctuations in agricultural production, consumption and marketing bottlenecks on main food prices in Gadarif State, east of Sudan in the period of 1996 to 2011. On the supply side, an adjusted Nerlovian model of supply response was used to calculate elasticities of prices of selected agricultural products. On the consumption side, the distribution of the agricultural supply among local consumption and external export was analyzed. The price margin of these products was calculated to explain how this margin is shared by the different market players. With reference to results of this study, supply response analysis of sorghum and sesame showed that production did not respond to finance or price factors, indicated by the low elasticities. Analysis of marketing channels of the above crops showed that the various fees and taxes imposed on different crops have weakened the competitiveness of export of these crops and hindered farmers from gaining reasonable revenues. Thus, prices of these crops in some seasons exceeded the world prices. Results of the price margin showed that the real producers receive the minimum price margin as compared to the other market players.**

**Key words:** Supply response, price margin, market channels, agricultural surplus, competitiveness.

## INTRODUCTION

Production, marketing and finance are essential ingredients that promote effective business management. On one hand, the objective of the supply side analysis in agriculture aims to investigate the effect of different factors responsible for fluctuations in agricultural production. On the other hand, analysis of agricultural commodities consumption provides the patterns and trends of cereals consumption and the shift in demand, completes the picture of food security in the country, and helps in developing food policy strategies.

From the marketing aspect, an efficient and effective marketing system is necessary to enable agricultural business corporations and speculators. Therefore, it is necessary to direct emphasis on this aspect to improve the situation of farmers and protect them through enhancing basic infrastructure, improving handling methods and implementing better working practices.

With regards to agricultural supply response, multiple

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regressions and simultaneous equations are used to estimate elasticities of production functions' arguments of selected crops. The basic model used in this study is based on Nerlove (1985) which is considered as one of the successful methods in supply response literature. This model enables one to calculate short- and long run elasticities and gives the flexibility to introduce non-price shift variables in the model. These non-price variables are rainfall, acreage, temperature, risk and related variables. In this context, the surveys of Askari and Cummings (1976, 1977) provide clear evidences. Empirically, many studies have been conducted to test the supply response of agricultural products. For example, a wide study of food price in Sub-Saharan Africa conducted by Minot (2014) concludes that there is little or no evidence to show statistically significant increase in food price volatility in Africa.

With reference to market channels, in practice, the flow of agricultural commodities starts at the farm and goes directly to rural markets where products are stored or passed to secondary markets where intermediaries or middlemen and wholesalers start to purchase sizable amounts of stock and convey it to primary or main markets and/or for storage. From these final market places, the products are usually sold to retailers, wholesalers and big companies for export.

The importance of market chain analysis is that it facilitates an understanding of the allocation of many costs incurred along the value chain to the corresponding transaction levels. Therefore, adequacy in information and knowledge obtained on market costs and margins by different players help not only in understanding the market situation, but also in enhancing competition along the food chain and reducing price volatility and costs (FAO, 2011).

Thus, the aim of marketing margins analysis is usually to help in market integration by showing the efficiency of the market and the spread of the margins among different players of the market. Therefore, the emphasis will be on the farmers' share that would push production and marketing mechanisms for the achievement of food security and social welfare objectives.

In the context of agricultural marketing, many studies reveal that farmers lose more on the prices of their products. For example, in Uganda, Davis (2015) reported that mango farmers experience up to 30% post-harvest losses and 58% are sold to brokers. Furthermore, Leonuda et al. (2015) argued that majority (58%) of geographically separate from the markets, poor local road networks and poor access to market information.

In very recent analysis of market chain in Ethiopia, Getahun et al. (2017) stated that entrance and exit in the smallholder farmers of Kiolo district in Tanzania sold their products to intermediaries due to the fact that they are fruits markets of Maji Zone are blocked by licenses and access to channel that links producers to local wholesalers through brokers with concentration ratio ranging from 42 to 91.1%.

Along the same line, a study of food supply chains in Tanzania carried out by Isakson (2014) concludes that small-scale farmers are strongly hit as they have become more uncertain and weaker *vis-a-vis* as other actors in the agro-food supply chain.

In the Sudan, Yousif (2010) argued that the market margin shares of Sudanese sesame exporters exceeded those of assemblers, that is, the share of the farmers' price is 75% of the export price and the share of the exporters exceeded that of intermediaries. Abdalla et al.'s (2015) study on banana marketing in the Sudan reveals that the price gained by wholesalers is higher than that of retailers.

Gadarif State, according to the Strategic Planning Council of the State (2012), provides a considerable amount of the whole country's and region's food need (about 30 to 40% of total country production of sorghum; 40 to 50% of total country production of sesame; 20 to 30% of total country production of millet and 15 to 20% of total country production of Gum Arabic). However, the state suffers from high food price instability over the past years which jeopardize the food security of the country as a whole.

In spite of government and non-government bodies efforts to improve production and productivity in Gadarif State's agricultural sector, the situation of smallholder farmers remain worst. Nonetheless, efforts to promote market channels, identify and reduce agricultural production bottlenecks and provide efficient marketing co-ordination for small farmers are necessary for price stability and food security.

From the marketing aspect, the inefficiency of basic cereal markets caused by the intervention of many players has resulted in poor situations of smallholders and increased smuggling through the boards to neighboring countries. Thus, investigation of different chains in these markets is needed.

For many years, it has been widely observed that farmers in the state fail to sell their produce at reasonable prices. Consequently, they fail to fulfill their financial obligations towards the banks thus, a number of farmers, especially smallholders, have been imprisoned.

This study aims to provide a comprehensive analytical framework on production and consumption trends and marketing efficiency of basic cereals in Gadarif State during the period 1996 to 2012 with the aim of developing policy options that can help the real producers of agricultural commodities to promote production and get a fair proportion of benefits through more efficient marketing.

## DATA AND METHODOLOGY

For the purpose of this study, the supply response analysis, the

Nerlovian model was adjusted to include the following explanatory variables: price, acreage, rainfall and agricultural finance as shown in the following function:

$$Y_t = f(P_{t-1}, A_t, F, R_t)$$

Where $Y_t$, $Pt$, At, Ft and Rt are production of the particular crop, price, acreage, finance devoted to the agricultural sector and average rainfall, respectively, in time (t). Based on this function, the following equation in its logarithmic form was estimated for each crop:

$$Y_t = a_0 + a_1 A_t + a_2 P_{t-1} + a_3 F_t + a_4 R_t + U_t$$

where $a_0$ is the vector, $a_1$ to $a_4$ are the elasticities of production to particular factors and Ut is the random variable.

With reference to the rain variable, as in the literature, a deviation of less than 20% from the optimal rainfall for the particular crop is normal for the total in a given region Mythili, (2006). Regarding the area variable, it is important to distinguish between small and large farmers. Small farmers face more constraints in responding to area than the large farmers who can respond more flexibly.

Considering the price variable, as the lagged price is expected to affect the current production thus, it should be noted that an increase in prices might also encourage more marginal inferior lands, which were previously not cultivated. This of course may reduce average yield. In addition, the relative price of substitutes may be used instead of the price of a measured crop.

To adapt the literature of supply response to the situation of Gadarif State, agricultural finance variable was introduced to the model, as it constitutes about 60% of the total finance in the state (MoA&F 2012). Hence, it is expected to impact positively on the production of basic crops in the state.

To analyze trends in the State's basic cereals production during the study period, ratio and growth analysis was used, while ordinary least squares (OLS) technique was utilized to capture the production response and area cultivated to several explanatory factors.

## Marketing channels for selected commodities in Gadarif State

In Gadarif State, there are many players from the farm gate to the final consumers for the main cereals. These include intermediaries, brokers and wholesalers in large markets. Thus, the price of the consumer reflects the share of all these actors. However, the basic production chain of cereals in Gadarif State can be explained as follows successively:

1. Farm gate producer: located near large agricultural schemes or small holders in rural areas where the commodity is firstly exchanged. Thus, the price is in its lower level.
2. Assembly: where small sellers or the producers themselves collect small farmers' quantities. This channel helps in enabling sellers of small quantities from remote areas to meet distant buyers and dealers.
3. Wholesale: where traders of assembly markets sell to relatively large-scale traders with larger amounts of the particular product. Usually, wholesalers move their quantities in terms of sacks, (Guntar or Ardab) to the central markets for local consumption, in-country or for export.
4. Retail or Consumer: where agricultural commodities reach their final users. Thus, quantities are in small volumes such as sacks, (Keila and Malwa). This distribution or exchange takes place in markets of cities or villages.

## Share of different market participants

The percentage shares of different market players are calculated as follows:

$$Farmer's\,Share\% = \frac{FarmGate\,Price(FGP)}{Retail\,Price(RP)} \text{ X 100}$$

$$Wholesaler's\,Share(HS)\% = \frac{(HS\,Price) - FGP}{RP} \text{ X 100}$$

$$\text{Retailer's share \%} = \frac{RP - HSP}{RP} \text{ X 100}$$

$$Intermidiaries'\,Share = \frac{(HSP - FGP) + (RP - HSP)}{RP}$$

Or it is the sum of wholesaler and retailer.

Alternatively, the difference between the retail price and the farm gate price can be calculated as percentage of the farm gate price to give the percentage of total mark-up as follows:

$$TotalMarkup = \frac{RP - FGP}{FGP} \text{ X 100}$$

Finally, marketing efficiency (MEFF) is known as the maximization of the input-output ratio. Calculation of this indicator enables identification and then promotion of the marketing services of the particular commodity. It is calculated as follows:

$$Marketing\,EFF. = \frac{Marketing\,Cost}{Marketing\,Cost + Production\,Cost}$$

If this ratio is above 50%, it means that marketing cost is less than production cost and vice versa.

Two sets of data were used in this study. MoA&F of Gadarif State provided secondary data of cereals production, area cultivated and productivity. Gadarif Crops Market provided prices of cereals and the fees structure.

Primary data used in the study was provided from surveys carried out on markets of different parts of the state considering the homogeneity of the farmers in these areas to measure the spread of market surplus. These areas include villages of Miskeen, Ardeib Eltijani and Umkoraa.

## GADARIF STATE: A SOCIOECONOMIC REVIEW

Gadarif State, together with Kassala and Red Sea States, comprise the region of the Eastern Sudan as defined by the Eastern Sudanese Peace Agreement (ESPA). The state is located between longitudes 33° 30‘ and 36° 30‘ to the East, and latitudes 12° 40‘ and 15° 46‘ to the North. Gadarif state shares an international border with Ethiopia from its east direction.

The state's total population is estimated to stand at some 1.35 million people with an annual growth rate of 3.87%. Over two-thirds of the populations live in rural areas and population density on a statewide basis stands at about 19 persons per kilometer. The total area of Gadarif state is calculated to be about 71,000 km (Central Bureau of Statistics, Gadarif State 2011).

### Geography and natural resources

Many seasonal rivers pass across the state from south to north. These include Rahad, Saiteet, Basalam and Atbarawi. Furthermore, North and Northwestern parts of the state are semi-dry in character with an annual average of 100 to 500 mm rainfall from July to October, the majority of the state, especially in the south receives somewhere between 500 and 900 mm of rainfall in the rainy season.

With reference to the animal resources, the state has a herd of about 6.6 million heads of different types of livestock (MoA&F, 2012). Semi-mechanized farming in Gadarif state constitutes the backbone of the state's economy and is considered the most important source of employment for the state's residents.

However, the absence of land rotation and the over-cultivation of existing tracts of land have led to the deterioration of soil quality; the decline of biodiversity and the spread of deforestation in recent years. These threats range from flooding along the major rivers to crop diseases and pestilence as well as severe deforestation.

### Agricultural systems

Agriculture is the main activity in Gadarif State. Hence, about 70% of the populations are working in the agricultural sector. The cultivable area is about 11.3 million (feddans) of improved and fertile lands (Abdelrahman, 1996).

There are two major types of agricultural systems in the state: Rain fed and irrigated agriculture. The irrigated agriculture exists in the Rahad scheme. The scheme is shared between Gadarif and Gezira State by 45 and 55%, respectively.

The rain fed agriculture is divided into two types: traditional and semi-mechanized farming. The semi-mechanized agriculture covers most of the rain fed areas. Therefore, the state is considered as the pioneer for this type of agriculture in the Sudan. It started in the area of Gadambelya– 45 km west of Gadarif city in the 1940s and then expanded to most rain fed areas and became the main producer of sorghum and sesame in the country. Nevertheless, this type of agriculture is commercially oriented and most farmers depend on bank credits to finance their activities.

Traditional rain fed agriculture on the other hand exists around the villages in small farms known as Bildat. The main crops cultivated here are sorghum, millet and sesame for subsistence purposes. Farmers practicing this type of agriculture use traditional forms of finance to run their activities. These forms are locally known as Sheil (traditional form of crediting: the case of selling crops (always with low price) by money paid in advance); Katafally (the case of transferring an asset possession or property at lower value; and Kasir (the case of selling commodities in advance payment at low price). Small farmers used to engage in these types of costly forms of finance due to the difficulties in accessing the bank credits.

The total agricultural land (11.3 million Feddans), according to the Strategic Planning Council of Gadarif State (2012) is distributed among the different types of farming and forestry as follows:

1. Total arable land: 8.602.600 Feddans
2. Forestry: 2,732,700 Feddans
3. Grazing: 4,200,000 Feddans

Gadarif State, according to the same source contributes to the agricultural production of the whole country as follows:

1. 30 to 40% of total country production of sorghum.
2. 40 to 50% of total country production of sesame.
3. 20 to 30% of total country production of millet.
4. 15 to 20% of total country production of gum Arabic.

With regard to the users of the agricultural land, according to the Agricultural Mechanized Corporation (2011), they are classified as follows:

1. Very large lease holders: constitutes only 0.9% of total land users, reflecting inequitable share of land.
2. Large scale lease holders: 36%. This group includes farmers who own land larger than 1,500 Feddans
3. Lease holders with 1,000-1,500 Feddans: 35%.
4. Leaseholders with 500-999 Feddans: 20%
5. Small holders: Bildat around villages: 5-40 Feddans.
6. Corporations: renting land from large scale holders

Table 1 shows the classification of farmers and their cultivated areas in thousands Feddans. Table 1 shows that 40.4% of the total cultivated area is unregistered. This may be the reason why farmers do not declare their real land area to avoid paying registration fees imposed by MAC. The same reason is valid in the case of Bildat; that is the total area of Bildat seems to be too inflated (26.9% of total arable land).

## RESULTS

### Supply response analysis

#### *Sorghum*

This is the main cereal in the state, and in some years, the production of the crop reaches millions-tons. The state serves local consumption and most of the needs of other parts of the Sudan.

### Production trends

Considering the price and the production of sorghum, as shown in Figure 1, one can observe the positive relation between the production and the price, that is, the increase in price encourages the farmers to increase the area cultivated and consequently the production. Figure 1 also shows that the rapid fluctuations in price of sorghum cause uncertainty in farmers' forecasting and planning for production.

### Supply response analysis of sorghum

In some studies on agricultural supply response, acreage equation is used to capture the supply response of some crops instead of the production by adding its lagged

**Table 1.** Distribution of total arable land (in '000 Feddans) among different holders in Gadarif State.

| Area* | Large holders | % | Corp. | % | Bildat | % | Small holders | % | Not stated | % | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| North | 1065 | 56 | 4 | 2 | 398.5 | 20 | 202 | 57 | 1236 | 40 | 2896 |
| Centre | 388 | 20 | 62.5 | 31 | 945 | 46 | 150.5 | 42 | 693.6 | 23 | 2239 |
| South | 465 | 24 | 134.5 | 67 | 700 | 34 | 3.8 | 1 | 1141 | 37 | 2444 |
| Total | 1918 | 25.3 | 201 | 2.6 | 2043 | 26.9 | 356.3 | 4.7 | 3070.6 | 40.4 | 7589 |

*The Northern area includes Kasamour, Abu Siena, Gadambalya and Kilo (6). The Central Area includes Am-Trimbi, Fashaga, Al-Nahal, Algabob, Altamargo, and Alhoury. The Southern Area includes Basonda, Wad-Alshair, Alkaffay, Abu-Orwa, Samsam, Um-Sinat and Abu-Sabeeka.
Source: Mechanized Agriculture Corporation, Gadarif State– 2012

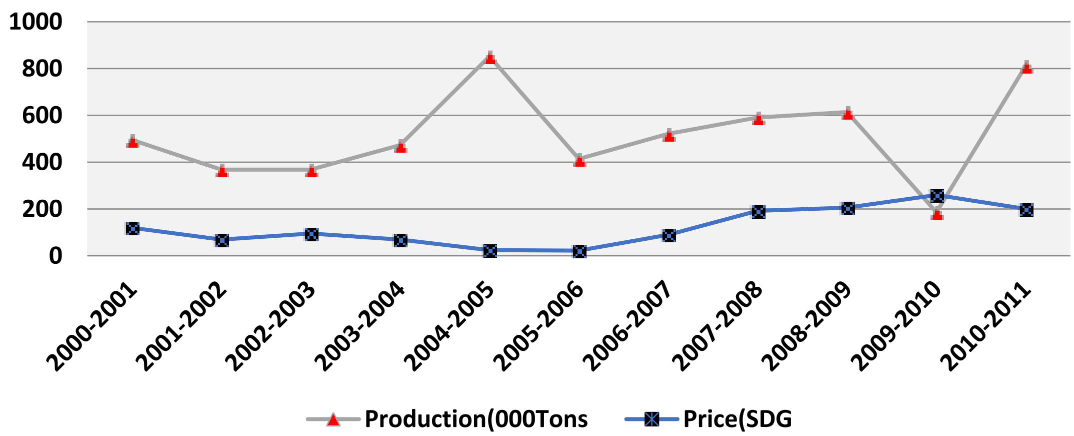


**Figure 1.** Production and prices of sorghum in Gadarif State during the period 2000-2010.

**Table 2.** Results of acreage regression of sorghum of the period, 1996-2010.

| Dependent variable | Independent variable | Elasticity | T-value | Sig. | $R^2$ | F change |
|---|---|---|---|---|---|---|
| | (Constant) | -33287.26 | -33.89 | 0.000 | | |
| | LogR | 0.03 | 0.32 | 0.749 | | |
| LogA | LogPt-1 | 0.49 | 1.65 | 0.123 | 0.99 | 0.99 |
| | LogF | 17.88 | 0.68 | 0.509 | | |
| | LogAt-1 | 10329.08 | 38.76 | 0.000 | | |

Source: Own calculation.

values to the arguments of the acreage function. In this context, the regression of the acreage of sorghum runs in the following predictor variables: rain (R), price (P), finance (F) and acreage (A) in the logarithmic form using data of the period, (96/1997-2010/2011) to estimate the elasticities of acreage to the above factors. Using OLS technique, the results of the regression are shown (Table 2).

Results of Table 2 revealed that of the four independent variables used, only the lag of acreage was found to be significant to the acreage of sorghum. This is because the crop has no substitute. Therefore, farmers continue to cultivate the same area under all circumstances. Moreover, it is found that about 99% of the variations in acreage are explained by variations in rain, price, finance and lag of acreage.

## Millet production trends

Figure 2 explains the paths of total area and production of mille t during the period (2000-2010). The positive

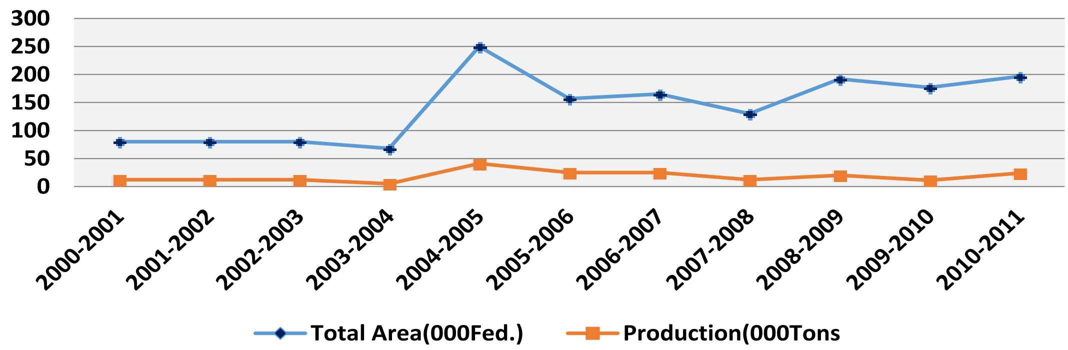


**Figure 2.** Total area (000 Fed.) and production of millet in Gadarif State during the period, 2000-2010).

**Table 3.** Results of regression of millet from data of the period, 1996-2010.

| Dependent variable | Independent variable | Elasticity | t-value | Sig. | $R^2$ | F change |
|---|---|---|---|---|---|---|
| | (Constant) | 0.82 | 0.48 | 0.64 | | |
| | LogPt-1 | -0.32 | -2.28 | 0.05 | | |
| LogMlt | LogF | 0.04 | 0.08 | 0.94 | 0.79 | 8.58** |
| | LogIR | -0.35 | -0.64 | 0.54 | | |
| | LogA | 0.95 | 3.65 | 0.01 | | |

**Denotes significant at 5%. Source: Own calculation.

relation of the two variables is clearly observed as confirmed by the results of the regression.

## Supply response analysis of millet

Table 3 shows the results of production of millet regression to the explanatory of lag of its price, finance, rain and acreage in the logarithmic form during the period (1996-2010).

According to Table 3, results of the millet production regression shown that of the four explanatory variables used in the model, the area cultivated by millet and the price were found as significant for the millet production with elasticities of 0.95 and 0.3, respectively. The low elasticity of price indicates the weak effect of price on the production of millet. With regard to the finance factor, the production of millet was found to be insignificant, indicating the neutrality of finance. This result is attributed to the fact that, according to the experience of the farmer, there is highly misalignment between the flow of the finance and agricultural activities. In addition, it is observed that many farmers direct the agricultural finance to other purposes rather than agriculture.

## Acreage equation

Table 4 below shows the results of the acreage of millet response to variables of price, agricultural finance, lagged values of acreage and rain falling during the period (1996-2010). The results above revealed that among all explanatory variables of the acreage equation of millet which include lagged values of prices, finance, acreage and the rain falling, only the cultivated area of the past year was found to be significant. These results are attributed to the fact that the crop receives no attention of most farmers since it is not used for local consumption or export.

## Sesame

### *Production trends*

Regarding the paths of production and prices of sesame as shown in Figure 3, no significant correlation was observed between the two paths of production and price.

## Supply response of sesame

In this context, two equations were attempted: production and acreage. The explanatory variables of the production function are acreage, agricultural finance, price of sorghum and the rain.

## Production equation

Results of regression of the period (96/1997-2010) for

**Table 4.** Regression results of acreage equation of millet (1996-2010).

| Dependent Variable | Independent Variable | Elasticity | t-Value | Sig. | $R^2$ | F Change |
|---|---|---|---|---|---|---|
| | (Constant) | 0.85 | 4.49 | 0.002 | | |
| | LogPt-1 | -0.001 | -.08 | 0.94 | | |
| LogA | LogF | 0.000 | 0.005 | 0.99 | 0.99 | 798.8* |
| | LogR | -0.07 | -1.16- | 0.28 | | |
| | LogAt-1 | 4.56 | 32.896 | 0.000 | | |

Source: Own calculation.

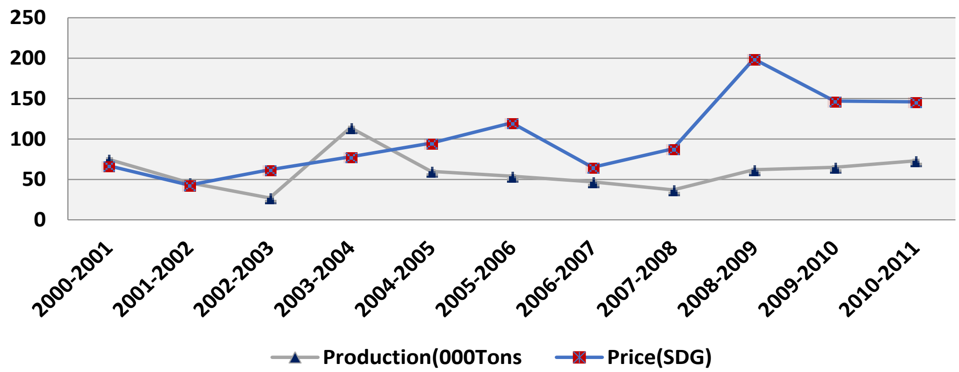


**Figure 3.** Production and prices of sesame in Gadarif State during 2000-2010.

**Table 5.** Regression results of sesame production (1996-2010).

| Dependent variable | Independent variable | Elasticity | t-value | Sig. | $R^2$ | F change |
|---|---|---|---|---|---|---|
| | (Constant) | -2.299- | -1.59 | 0.15 | | |
| | LogA | 0.91 | 3.26 | 0.01 | | |
| LogSsm | LogF | 0.18 | 0.53 | 0.61 | 0.67 | 4.60** |
| | LogPt-1 | 0.29 | 1.69 | 0.13 | | |
| | LogR | 0.34 | 0.73 | 0.49 | | |

Source: Own calculation.

sesame production are shown in Table 5.

Table 5 shows that 67% of variations in sesame production are explained by variations in acreage, price, agricultural finance and rain falling, and the remaining 33% is caused by qualitative variables not included in the model; for example, the higher production cost and timing of the finance. Of all the explanatory variables tested in the model, only the acreage cultivated was found to be significant for production of the crop during the period (1996-2010).

## Acreage equation

Table 6 shows the response of the area cultivated by sesame to the same explanatory variables of the above production equation. Of all the explanatory variables shown in Table 6, rainfall and lag of area cultivated were found to be significant for the area cultivated with the crop. The inappropriate timing of finance and the influence of share of different market players were thought to be responsible for this result.

## Marketing analysis

Gadarif Crops Market is considered as the largest crops market in Sudan. It contains one of the two largest crop stores of the country. The capacity of the store is 100,000 tons or (1,000,000 sacks).

**Table 6.** Regression results of area cultivated to sesame (1996-2010).

| Dependent variable | Independent variables | Elasticity | t-value | Sig. | $R^2$ | F change |
|---|---|---|---|---|---|---|
| | (Constant) | -0.23 | -6.74 | 0.00 | | |
| | LogF | 0.01 | 0.88 | 0.40 | | |
| LogA | LogPt-1 | 0.00 | 0.08 | 0.94 | 1.00 | 8366.1* |
| | LogR | 0.04 | 3.68 | 0.01 | | |
| | LogAt-1 | 6.54 | 154.33 | 0.00 | | |

*Significant at 1% degree of confidence.
Source: Own calculation.

**Table 7.** Marketing fees for selected crops in Gadarif State (November 21/2011).

| Type | Fee (SDG) per sack |
|---|---|
| Sorghum | 2 |
| Sesame | 3 |
| Millet | 2 |
| Sunflower | 3 |
| Groundnuts | 3 |

Source: Gadarif Crops Market (2012).

**Table 8.** In-country transported crops fees for selected crops in Gadarif State in 2011.

| Type | Fee per sack (SDG) |
|---|---|
| Sorghum | 2 |
| Sesame | 3 |
| Millet | 2 |
| Sunflower | 3 |
| Groundnuts | 2 |
| Purified Groundnuts | 4 |

Source: Gadarif Crops Market (2012).

## Fees and taxes

The government of the state imposes various fees on marketing services. Table 7 shows the marketing services fees scheme for selected crops in Gadarif Crops Market (issued in November 21/2011).

## In-country transport fee

This fee is imposed on the quantity of crops transported from Gadarif state to other states of the country. Table 8 shows this fee for different crops.

## Total cost of exporting selected oil seeds at Port Sudan in 2011

Tables 9 and 10 show the cost of exporting one guntar of sesame and sun flower from Gadarif Crops Market to Port Sudan in 2011. The higher cost of production due to services and other various fees on sesame made the crop un-competitive as compared to other producer countries of the crop. Thus, farmers and traders of the crop prefer to sell it to the local users, namely the oil producers.

According to Table 10, various taxes and services fees imposed on the crop have increased the total cost of the ton of sun flower to about 15% of its price in Gadarif Crops Market. Thus, the weak competitiveness of the crop discourages the production of the crop for export.

## Price margin spread analysis

Table 11 explains the distribution of the market surplus spread of sorghum among different participants of the market during the period of 2000 to 2011. Table 11 shows that the sorghum farmers' share in the consumer price decreased from 78% in 2009-2010 to 7 and 60% in 2010/2011 and 2011/2012 seasons, respectively, indicating continuous deterioration in their marketing facilities. With regard to the retailers, their price share in the same seasons is improved. It increased from 11 to 12 and 29% for the same seasons, respectively. This situation is attributed to the weak market facilities of transport, handling and information. The wholesalers of sorghum gained an average of 13% in the same seasons.

## Price margin spread of sesame

Table 12 shows the summary of price spreads and margins of sesame in the period, 2009-2011, in Gadarif state. Table 12 shows that sesame farmers' price share has decreased during the three seasons of the analysis. It decreased from 62% of total price in season 2009/2010 to 59 and 52% in seasons 2010/2011 and 11/2012,

**Table 9.** Cost of one Guntar (45 kg) of sesame at Port Sudan in 2011.

| Particular | Cost (SDG) |
|---|---|
| Daily average price | 237 |
| Auction fees | 1 |
| Following up and control | 1 |
| Packaging and checking | 0.5 |
| Handling | 3 |
| Empty sack for export | 4 |
| Marketing services fee | 1.5 |
| Transporting cost (from Gadarif) | 3 |
| Quality and health check fee | 0.5 |
| Quality & control | 0.3 |
| Transport to Port Sudan per 45 kg | 3 |
| VAT (15%) | 0.45 |
| Loss of purification (5% ) | 13.4 |
| Documentation & typing | 0.25 |
| Export stamp | 0.5 |
| Business profit tax | 1 |
| Selling operation fee (of each) | 2 |
| Purification of Guntar (45 kg) | 1.8 |
| Total cost of Guntar | 273.9 |
| Total cost of ton(1 ton = 22.26 Guntar) in Port Sudan | 6097.9 |
| Export parity price | $1500 |
| Export parity price in SDG (1$=2.76SDG) in 2011 | 4140 SDG |

Source: Adapted from Gadarif Crops Market fees scheme – 2011.

**Table 10.** Cost of one Guntar (45 kg) of sun flower at Port Sudan in 2010.

| Particular | Cost (SDG) |
|---|---|
| Daily Average Price | 2200 |
| Empty sack (especial) | 28 |
| Handling | 26 |
| Mediating services | 18 |
| Quality check fee | 3 |
| Health fee | 2 |
| Transport to Port Sudan | 55 |
| VAT | 9 |
| Business Profit Tax | 17 |
| Loss of purification (7%) | 154 |
| Empty sack | 3 |
| others | 5 |
| Total cost of Ton | 2520 |

Source: Adapted from Gadarif crops market fees scheme of 2012.

respectively. This situation can be attributed to the higher costs of harvesting in the end of the season because of the lack of finance. Thus, farmers are forced to engage in costly traditional forms of finance, namely the Sheil. Therefore, they sell their products at lower prices to perform their financial obligations. Unlike farmers, wholesalers and retailers gain a relatively higher share in the consumer price. They reported an average of 19 and 24%, respectively, in the last two seasons.

## Price margin spread of millet

Table 13 shows the summary of price spreads and margin of millet in Gadarif state in the period, 2009-2011. Table 13 explains that the farmers of millet gained 75, 60 and 66% of the price margin in the later three seasons, respectively. The low price share of farmers is due to the fact that millet is not considered as the main food source in Gadarif state.

In conclusion, the higher shares of different market players instead of the real producers discourages the production and causes problem of accessibility in the food and consequently jeopardizes the food security of the whole country. These results are consistent with most relevant studies. For example, that of Davis (2015) in Uganda and Yousif (2010) in Sudan.

## Consumption of main crops

Consumption of cereals produced in the state can be

**Table 11.** Distribution of price of sorghum among different market actors in Gadarif state (SDG per sack).

| Participant | Season | | | |
|---|---|---|---|---|
| | 2009/2010 | 2010/2011 | 2011/2012 | Average |
| Farm Gate Price | 70 | 80 | 105 | 85 |
| Wholesaler price | 80 | 97 | 125 | 101 |
| Retailer price | 90 | 110 | 175 | 125 |
| Farmer share (%) | 78 | 73 | 60 | 68 |
| Wholesaler share (%) | 11 | 15 | 1 | 13 |
| Retailer share (%) | 11 | 12 | 29 | 19 |

Source: Field survey results (2012).

**Table 12.** Summary of Sesame price spreads and margins in Gadarif State (SDG per sack) in the period (2009-2011).

| Participant | Season | | | |
|---|---|---|---|---|
| | 2009/2010 | 2010/2011 | 2011/2012 | Average |
| Farm Gate Price | 125 | 180 | 250 | 185 |
| Wholesaler price | 155 | 240 | 350 | 248 |
| Retailer price | 200 | 305 | 480 | 328 |
| Farmer share (%) | 62 | 59 | 52 | 57 |
| Wholesaler share (%) | 15 | 20 | 21 | 19 |
| Retailer share (%) | 23 | 21 | 27 | 24 |

Source: Field survey results (2012).

**Table 13.** Summary of millet price spreads in Gadarif State (SDG per sack) in the period, 2009-2011.

| Participant | Season | | |
|---|---|---|---|
| | 2009/2010 | 2010/2011 | 2011/2012 |
| Farm Gate Price | 96 | 104 | 145 |
| Wholesaler price | 107 | 120 | 188 |
| Retailer price | 128 | 172 | 220 |
| Farmer share (%) | 75 | 60 | 66 |
| Wholesaler share (%) | 9 | 9 | 19 |
| Retailer share (%) | 16 | 30 | 15 |

Source: Field survey results.

categorized into three types: local consumption, in-country consumption and export. Analysis of consumption of these cereals is explained as follows:

## Sorghum

Figure 4 shows that an average of 55% of the produced sorghum in the period of 2009-2011 is consumed locally in the state; 28% for export and 17% transported to other states of the country. However, the higher share of local consumption of sorghum is explained by smuggling across borders and states as avoidance of fees and regulations. Regarding the quantity exported, the main importer of sorghum to the state is Ethiopia.

## In-country consumption of sorghum

As sorghum is considered the main source of food in the Eastern and Central parts of the country, many states depend on the one produced in Gadarif State. Figure 5 shows the percentage of transported quantities of sorghum to the different states. Figure 5 shows that among the different states receiving the transported sorghum from Gadarif State, Kassala, Red Sea and

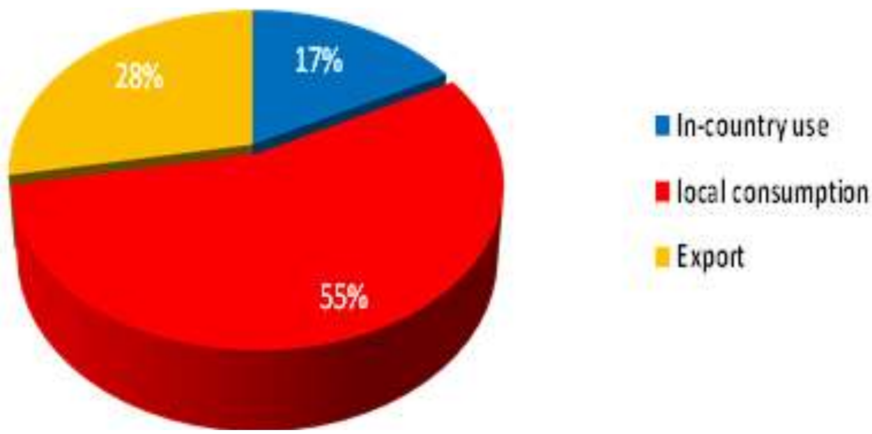


**Figure 4.** Average (%) distribution of total production of sorghum during (2009-2011).

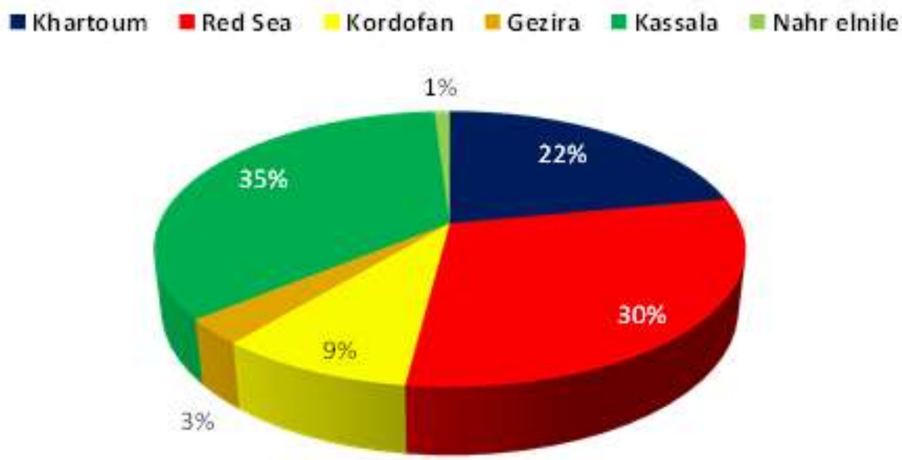


**Figure 5.** Percentage distribution of in-country consumption of sorghum among different states in the period (2009-2011).

Khartoum states shared higher rates. They received averages of 35, 30 and 22%, respectively during the period of 2009-2011. It is noteworthy that part of the quantity of sorghum transported to Kassala and Red Sea states is used for export to Eritrea and Ethiopia.

### In-country use of sesame

Figure 6 shows that of 90% of the produced sesame in the state is transported to the Red Sea state for export, and the remaining quantity is used by local oil industries.

## DISCUSSION

Regressions results of the agricultural supply response analysis revealed that of different explanatory variables tested for different crops, finance and price variables were found to be insignificant. The reasons for these results are as follows:

1. The inefficiency of the market channels caused by the poor roads and various fees imposed on these commodities;
2. The problem of banking finance flow; where farmers receive their loans in the end of the seasons after they are forced to be involved in costly traditional forms of finance;
3. Most of the agricultural finance are directed to other sectors especially the commerce.

Consumption analysis of the main crops revealed that about half of the locally produced sorghum in Gadarif State is consumed in the state; 30% is transported to Red Sea state; 35% to Kasala state and 22% to Khartoum.

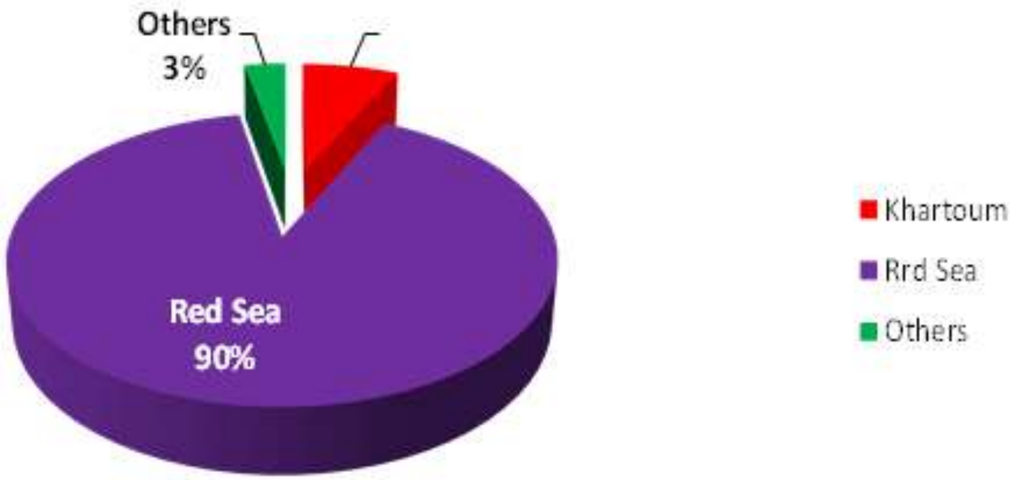


**Figure 6.** Distribution of in-country use of Sesame of Gadarif State during (2009-2011).

The results also revealed that of the 90% of the sesame transported to the Red Sea State is for the purpose of export. However, smuggling across borders and states may be comprehensible as traders face heavy fees and taxes and complicated administrative regulations.

The analysis of basic food consumption shows that, the higher smuggling reduces the supply and consequently makes the prices of these commodities to increase. Moreover, the various fees and cost involved in transportation, handling and other operations force producers to demand higher prices.

The households' food expenditure has higher share in their income. Thus, in the period, 2007 to 2010, the average is 68.5% of the total income, indicating the importance of food in the consumer bundle in the state. This higher share of food in consumer expenditure makes the prices of food to increase.

According to the price margin spread analysis, the higher share of various market players and the different administrative and services fees cause increase in prices of agricultural commodities. The export prices of some commodities were higher than the export parity prices causing higher markets in-efficiency and lower competitiveness of most of the agricultural commodities in the state and the country.

## Conclusion

Considering the results of this study, the following policy measures are recommended to promote the situation of price stability and food security in both the state and the country:

1. Small-scale business like oil pressing, vegetable processing and flour industries should be encouraged to utilize the opportunity of the world high food prices increasing to optimize Gadarif state's huge agricultural potential.
2. Smallholder's farmers need to be organized in practical and effective ways that protect their interests in production and marketing. The existing unions and farmers' associations are almost nonfunctional and only serve the wellbeing of large and wealthy farmers, traders and politicians.
3. Promotion of improved agricultural and market infrastructure of roads, stores and communications are highly needed to reduce transportation and handling costs.
4. The development of an effective information base and the wide publication of marketing information help farmers in marketing and exporting their products which would be a major contribution to better production and marketing.
5. Improving the access of farmers to financial resources through an effective microfinance strategy that protect farmers against the exploitation of traditional forms of loans. The current microfinance systems are too complicated and inefficient to be of value for potential clients.
6. Reduction of in-country and cross border smuggling by setting reasonable fees and taxes to stabilize the food prices.
7. Strengthening the role of the Strategic Reserve Corporation to perform its role of intervening in the high production seasons to protect farmers from price fall and maintain food security.

**Abbreviations: ERDP,** Eastern Sudan Recovery and Development Program; **ESPA,** East Sudan Peace Agreement; **MoA&F,** Ministry of Agriculture and Forestry; **MAC,** Mechanized Agriculture Corporation; **MoAR&F,** Ministry of Animal Resources and Fishery; **MoFE&L,**

Ministry of Finance, Economy and Labor Force; **GDP,** gross domestic product; **OLS,** ordinary least squares; **FAO,** Food and Agriculture Organization; **FGP,** farm gate price; **WSP,** wholesale price; **RP,** retail price; **NGOs,** non-government organizations; **SRC,** Strategic Reserve Corporation; **US$,** United States of America dollar.

**Conversion factors:** One Hectare = 2.381 feddans = 2.476 acres; Keila = 4 Malwas approximates 3.15-2.96 kg for millet and most of sorghum types; Malwa = 0.25 of Keila; SDG = Sudanese Pound; Feddan = 4200 $m^2$ or 0.42 ha; Bildat = small farm around villages less than 500 Feddans; One US $: = Five Sudanese Pounds in June 2012; Guntar = 44.628 kg; Ardab = two sacks of a particular crop (sorghum, millet, e.tc.); one sack of sorghum = 91.5 kg; one sack of sesame = 73.7 kg; one sack of millet = 94.35 kg; one sack of groundnuts = 45 kg.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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# Economics of aflatoxin control in maize production among smallholder farmers in Oyo State, Nigeria

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**In Africa, the prevalence of aflatoxin contamination in agricultural production places the stability of food security at risk. This study investigated the socio-economic characteristics of farmers; assessed the prevalence of aflatoxin in maize production; identified the aflatoxin control practices used; and estimated the net returns to users and non-users of the control practices. A multistage sampling procedure was employed to select 240 farmers, comprising users and non-users of aflatoxin control practices. Data were collected on farmers' socioeconomic characteristics, maize farmland cultivated, the proportion affected by aflatoxin as well as quantity and prices of inputs and output from the maize farms with the aid of pretested structured questionnaire and interview guide in a focus group discussion. Data were analyzed using descriptive statistics and budgeting technique. Results showed that most of the farmers are married (86.7%), with over 20 years of farming experience and active ages of between 41 and 60 years. 42% of their average maize farm of 2.7 ha were affected by aflatoxin contamination. About 28% of the farmers used different types of aflatoxin control practices. A larger proportion (72%) of the farmers did not use any of the control measures. There was a significant difference (p<0.05) in the net returns earned between users and non-users of aflatoxin control practices. It was concluded that use of aflatoxin control practices in maize production should be promoted among farmers in Oyo state as it enhances maize yield and the net returns earned from maize production.**

**Key words:** Aflatoxin control, maize, smallholders, food security, gross margin.

## INTRODUCTION

Maize (*Zea mays,* L.) is one of the major food crops grown across a range of agro ecological zones in Nigeria and is currently the third most traded cereal after wheat and rice, with a total production of about 822 million tonnes on over 160 million hectares of land (Onuk et al., 2010; FAO, 2012). It is produced annually more than any other grain and about 50 species exist, consisting of different colours, textures; grain shapes and sizes (IITA, 2007, 2008). Maize is a source of food for humans and animals with about 80% consumed by man and animals,

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while 20% is utilized as basic raw material for the production of starch, alcoholic beverages, ethanol, food sweeteners and fuel (Adegboye, 2004; FAO, 2007; FAOSTAT, 2015). It is an important source of carbohydrate, protein, iron, vitamin B and minerals. Maize is predicted to become the crop with the greatest production globally, and in the developing world by 2025 (Rosegrant et al., 2008).

Despite its importance, maize production in Africa is bedevilled with low productivity with average yield of about 1.5 tons/ha (CIMMYT, 1999; De Groote et al., 2003). Low maize yield is often ascribed to various factors such as climate change, price fluctuations, poor storage facilities, and in particular, pests and diseases (Ojo, 2000; Tirado et al., 2010). Among the pest and diseases that currently threatens maize productivity growth is aflatoxin, known to be one of the most potent and dangerous groups of mycotoxins worldwide (IITA, 2012). Aflatoxins are toxic to crops and animals, pose serious risk to human health resulting into food insecurity, hunger, famine and huge economic losses (Cardwell et al., 2001; Stronider et al., 2006; Legreve and Duveiller, 2010; Waliyar and Sudini, 2012; IITA, 2012).

Several maize growing states in Nigeria, including Oyo state, have been identified with the incidence of aflatoxin occurring beyond the acceptable threshold of 247 and 276.1 ppb (Meridian Institute, 2013), and the level and frequency of occurrence are particularly high in 30% of maize in stores (IITA, 2013). According to Udoh et al. (2000), 33% of maize samples from different ecological zones of Nigeria are contaminated with aflatoxins. Thus, tackling aflatoxin contamination has become a priority in maize enhancement programmes among farmers in Nigeria with different measures employed for aflatoxin control. These control measures include timely planting, maintaining optimal plant densities, proper plant nutrition, avoiding drought stress, proper harvesting, and control of other plant pathogens, weeds and insect pests (Bruns, 2003). However, these measures have been used with varying degrees of effectiveness across agro ecological zones in Nigeria (Ogunsunmi, 2005; Adeoye et al., 2011). It therefore becomes imperative to evaluate the economic implications of using Aflatoxin control measures among maize farmers. Thus, the important questions to ask are: What are the socio-economic characteristics of smallholder farmers in maize producing areas? What proportion of maize land is affected by aflatoxin contamination? Which are the control practices employed by maize farmers to control aflatoxin? Are there differences in the costs and returns to maize production between users and non-users of aflatoxin control practices? This paper therefore evaluates the economic implications of aflatoxin control on maize production in Oyo State, Nigeria. Specifically, the paper describes the socioeconomic characteristics of the maize farmers; examines the prevalence of aflatoxin in maize farms; identifies the types of aflatoxin control measures used; and determines the net returns to use of aflatoxin control measures in the study area.

## MATERIALS AND METHODS

### Study area

The study was conducted in Oyo State in Southwestern Nigeria. The state is located between latitudes 7 °3′ and 9 °12′ north of the equator and longitudes 2° 47′ and 4° 23′ east of the Meridian, and covers a total land area of about 27,249 sq km, with a ratio of almost 1:1 distribution of male to female population (NPC, 2006). Based on the prevailing climatic conditions and vegetation types, the state has three agro-ecological zones, viz: rainforest, savannah and derived savannah. The rainforest is characterized by high relative humidity and supports the cultivation of tree crops like citrus, oil palm and cocoa as well as arable crops like cassava, yam and maize. The vegetation of the savannah and derived savannah zones mainly supports the cultivation of crops such as cassava, cowpea yam and maize. By virtue of its location between 40°N and 40°S latitude, Nigeria's environment offers suitable growing conditions for the fungi, aflatoxin (Agboola, 1987; Udoh et al., 2000).

### Sampling procedure and data collection methods

A multistage sampling technique was employed to select respondents for the study. The first stage involved the purposive selection of three local government areas (LGAs), namely Afijio, Saki East and Ibarapa East where maize is predominantly produced. In the second stage, two villages with relatively higher incidence of maize area affected by aflatoxin were purposively selected from each of the LGAs to give 6 villages. Stratified sampling was used in the third stage to categorize farmers in each village into two: those that control for aflatoxin, and those who did not control for aflatoxin. Finally, between 15 and 25 farmers were randomly selected from each category, based on the proportion of maize farmers in each village, to give a total of two hundred and forty respondents for the study. Primary data were collected using pretested structured questionnaire. Interview guide was also used to complement the questionnaire in focus group discussion sessions. Data collected included farmers' socio-economic characteristics such as gender, age, level of education, farm size, household size and proportion of maize land affected by aflatoxin as well as input-output quantities and prices to use and non-use of aflatoxin control practices.

### Data analysis

Data was analysed using descriptive statistics and budgeting technique. The descriptive statistics was used to describe the study variables and it involved the use of means, standard deviation, frequency counts and percentages. The difference between mean tests was used to compare estimates for farmers who controlled for aflatoxin and those who did not. The partial budgeting approach to budgeting technique was used to estimate the costs, returns and gross margin (net profit) to use of aflatoxin control measures as described below.

#### *Budgeting technique*

To determine the gross margin or net returns per hectare to aflatoxin control maize farms, the partial budgeting approachused in budgeting technique was employed (Upton, 1979; Bamire et al., 2007; Segun-Olasanmi and Bamire, 2010; Adeoye et al., 2011). The gross margin is assumed to be due only to the effects of use of at least one of the aflatoxin control measures and was computed using cost-return analysis. The cost consists of fixed cost (FC) and variable cost (VC). Fixed costs are indirect production costs which are incurred independent of the level of production regardless of the volume of sales or level of output; while variable costs are direct production costs which are consumed directly in the production process and which are used roughly in direct proportion to the level of production. Note that in this study, only the variable cost was used with the assumption that users and non-users of aflatoxin control measures have the same background living within the same geographical area and with similar sociocultural and demographic characteristics, and only differ in their use or non-use of aflatoxin control measures (Upton, 1979; Bamire, 1999; Adeoye et al., 2011). Data were collected on the quantities and prices of variable cost items such as seed, fertilizer, herbicides, pesticides, aflatoxin and labour, while returns to maize production was computed by collecting information on quantities and prices of outputs.

Costs were computed by multiplying the quantity of inputs ( $Xj$ ) used in kg per hectare on each farm by their average prices ( $P_j$ ) in Naira (₦), that is, $P_jXj$ , and the summation of variable costs (TVC) for all respondents is given as $\sum P_jXj$ , while returns were computed by multiplying the quantity of maize output ( $Q_i$ ) in kg per hectare by their market prices ( $P_i$ ) in Naira (₦), that is, $P_i\ Q_i$ , and the summation of returns (TR) for all respondents is given as $\sum P_i\ Q_i$ . The partial budgeting technique employed to compute the gross margin is specified as:

$$GM = TR_i - TVC_j \quad (1)$$

Where i and j represent the number of observations (i, j = 1, 2, 3, 4, …,240); GM is gross margin in (₦/ha); TR is total revenue = average quantity of output *i* in kg/ha ( $Q_i$ ) x average price of output *i* ₦/kg ( $P_i$ ), and for all observations, $\sum P_i\ Q_i$ ; TVC is total variable cost = average quantity of input*j* used in kg/ha (X*j*) x average price of input *j* in ₦/kg (P*j*), and for all observations,

$$\sum P_jXj \quad (2)$$

Equation 2 was computed for users and non-users of aflatoxin control measures as well as for the entire sample.

## RESULTS AND DISCUSSION

This section presents the results of data analysis based on the objectives of the study. It compares the socioeconomic characteristics of users and non-users of aflatoxin control measures among the smallholder maize farmers in Oyo State, Nigeria; describes the extent of aflatoxin contamination based on the proportion of maize area affected by aflatoxin; reports the different types of aflatoxin control practices used; and estimates the gross margin or net returns to use of the aflatoxin control measures.

### Socioeconomic characteristics of maize farmers

The socio-economic characteristics of farmers in the study area, comprising users and non-users of Aflatoxin control measures are shown in Table 1. From Table 1, a relatively larger percentage of the farmers in the entire sample were married, while only few 4.6% were single. All users of aflatoxin control measures were married, while 93.2% of non-users were married with only few (6.8%) single. The mean age of users of aflatoxin control methods was 50.64±8.83 years with a minimum of 26 and maximum of 72 years, while that of non-users of aflatoxin control methods, it was 48.64±14.11 years with a minimum of 16 and maximum of 80 years. There was no significant difference between the ages of the farmers in the two groups, suggesting that the farmers are generally within the same age group. About 83% of the entire respondents and about 89 and 80% of users and non-users of aflatoxin control measures respectively were 60 years and below. This may suggest that on the average, farmers in the study area are expected to be productive. A larger percentage of the respondents who are users (88.5%) and non-users (77.2%) of aflatoxin control practices were between the ages of 41 and 60 years. This further suggests that most of the respondents are in the active and productive age bracket and supports the findings of Bamire et al. (2007) and Ohajianya et al. (2010) that farmers within this age range are resourceful and active.

The human capital endowment of the farmers is often represented by household size as it reflects potential labour supply for farming services (Afolayan, 2012). The difference between the household size for users (7.55±3.02) and non-users (7.63±3.39) of aflatoxin control practices was not significant at the conventional levels of probability. Majority of the respondents (60%) had a household size of between 6 and 10 members and about 16% had more than 10 members. This suggests that maize farmers in the study area have the opportunity of possibly engaging household members in their farming activities.

The highest percentage of users (45.8%) and non-users (48.6%) of aflatoxin control practices had secondary education, 43.8 and 41.7% users and non-users had primary education, respectively. Also, about 4 and 7% of users and non-users of the control practices had tertiary education, while only 6.3 and 2.8% did not have any formal education. The high level of basic education attained by the farmers could be attributed to the free and compulsory primary education policy of the Federal Government of Nigeria for all Nigerians.

The number of years of experience in any setting, including farming, is expected to improve proficiency as a result of knowledge and better skills acquired over time (Bamire et al., 2007; Oyekale and Idjesa, 2009). More than 80% of the respondents had over 10 years of experience in farming. The difference between the mean

**Table 1.** Socioeconomic characteristics of maize farmers in Oyo State, Nigeria

| Item | All respondents | | Users of aflatoxin control measures | | Non-users of aflatoxin control measures | | t-value |
|---|---|---|---|---|---|---|---|
| | Frequency (n=240) | % | Frequency (n=78) | % | Frequency (n=162) | % | |
| **Marital status (%)** | | | | | | | |
| Single | 16 | 13.3 | 5 | 10.4 | 11 | 15.3 | |
| Married | 104 | 86.7 | 43 | 89.6 | 61 | 84.7 | |
| **Age (years)** | | | | | | | |
| <21 | 12 | 10.0 | 4 | 8.3 | 8 | 11.1 | |
| 21 - 40 | 30 | 25.0 | 18 | 37.5 | 12 | 16.7 | |
| 41 - 60 | 53 | 44.2 | 15 | 31.3 | 38 | 52.8 | |
| >50 | 25 | 20.8 | 11 | 22.9 | 14 | 19.4 | |
| Mean (Std. Dev.) | | | 48.6 (14.11) | | 50.6 (8.83) | | 1.451 |
| **Household size (#)** | | | | | | | |
| 1 - 5 | 11 | 9.2 | 5 | 10.4 | 6 | 8.3 | |
| 6 - 9 | 80 | 66.7 | 33 | 68.8 | 47 | 65.3 | |
| 10 - 15 | 29 | 24.1 | 10 | 20.8 | 19 | 26.4 | |
| Mean (Std. Dev.) | | | 7.6 (3.39) | | 7.6 (3.02) | | 1.341 |
| **Level of education (%)** | | | | | | | |
| No formal education | 5 | 4.2 | 3 | 6.3 | 2 | 2.8 | |
| Primary education | 51 | 43.3 | 21 | 43.8 | 30 | 41.7 | |
| Secondary education | 57 | 46.7 | 22 | 45.8 | 35 | 48.6 | |
| Tertiary education | 7 | 5.8 | 2 | 4.1 | 5 | 6.9 | |
| **Years of farming experience (years)** | | | | | | | |
| 1 - 5 | 22 | 18.3 | 12 | 25.0 | 10 | 8.3 | |
| 6 - 10 | 34 | 28.3 | 20 | 50.0 | 14 | 11.7 | |
| 11 - 15 | 36 | 30.0 | 7 | 14.6 | 29 | 24.2 | |
| 16 - 20 | 15 | 12.5 | 4 | 8.3 | 11 | 9.2 | |
| >20 | 13 | 10.9 | 5 | 2.1 | 8 | 6.6 | |
| Mean (Std. Dev.) | | | 24.5 (14.12) | | 23.9 (11.35) | | 1.701* |

*Significant at $p<0.05$.

years of farming experience of users (23.9±11.35) and non-users (24.5±14.12) of aflatoxin control measures was significant ($p<0.10$). This shows that users of aflatoxin control measures are more experienced in maize farming than non-users. In other words, farmers with more years of farming experience use aflatoxin control practices.

## Prevalence of aflatoxin in maize production

The prevalence of aflatoxin infestation, indicated by the proportion of maize land affected by Aflatoxin in the study area, is shown in Table 2.

There was no significant difference between the mean farmland area cultivated by users (4.91±3.22 ha) and non-users (4.44±2.84 ha) of aflatoxin control measures in the study area. About 86% of the farmers cultivated below five hectares of land, which suggests that most of the respondents are small scale farmers; those that cultivated above 5 hectares constituted 8.3% for the sample, 6.3% for users of aflatoxin control methods and 9.3% for non-users. The size of maize farmland is in agreement with Ojo (2000) that established that the crop production is mainly small scale in size. A larger proportion of the farmers (73%) reported that less than 0.5 hectares of their maize farms was affected by aflatoxin. Also, about 76% of those that controlled aflatoxin and 71% of those that did not use control measure had less than 0.5 hectares of their farms affected by aflatoxin. The difference between the proportion of farmers who used control measures (42%) and those that did not (41%) was not statistically

**Table 2.** Prevalence of aflatoxin in the maize farms (% respondents).

| Item | All respondents | | Users of aflatoxin control measures | | Non-users of aflatoxin control measures | | t-value |
|---|---|---|---|---|---|---|---|
| | Frequency (n=240) | % | Frequency (n=78) | % | Frequency (n=162) | % | |
| **Maize land area (ha)** | | | | | | | |
| ≤1 | 16 | 13.3 | 10 | 20.8 | 6 | 8.3 | |
| 1-2 | 50 | 41.7 | 27 | 56.3 | 23 | 31.9 | |
| 2-3 | 45 | 37.5 | 9 | 18.7 | 36 | 50.1 | |
| >3 | 9 | 7.5 | 2 | 4.2 | 7 | 9.7 | |
| Mean (Std. Dev.) | 2.67 (2.01) | | 2.44(1.94) | | 2.91 (2.12) | | 2.10 |
| **Proportion of farmland affected by aflatoxin** | | | | | | | |
| ≤ 0.5 | 87 | 72.5 | 51 | 75.6 | 36 | 71.0 | |
| 0.51-1.00 | 21 | 17.5 | 14 | 11.5 | 6 | 20.4 | |
| 1.01-1.50 | 7 | 5.8 | 3 | 5.1 | 5 | 6.2 | |
| 1.51-2.00 | 4 | 3.4 | 3 | 6.4 | 1 | 1.9 | |
| >2.0 | 1 | 0.8 | 1 | 1.4 | - | 0.6 | |
| Average | 41.5 | | | 42.0 | | 41.0 | 1.05 |

*Significant at ($p<0.05$); Source: Field survey, 2015.

**Table 3.** Aflatoxin control practices used in the maize farms (% respondents).

| Aflatoxin control practice | % |
|---|---|
| Traditional | 15 |
| Biological | 2 |
| Chemical | 11 |
| Traditional/biological | 1 |
| Traditional/chemical | 9 |
| Biological/chemical | 1 |
| Biological/chemical/traditional | 1 |
| No control | 59 |

n=240.

significant ($p>0.5$). This implies that the proportion of maize farms affected by aflatoxin is as large as those not affected by aflatoxin in the study area as reported by IITA (2013).

### Aflatoxin control practices used in Oyo State, Nigeria

The different aflatoxin control practices used by maize farmers in Oyo State are shown in Table 3. There are various control practices employed by maize farmers in Oyo State; traditional, chemical, biological, and a combination of the practices of which the traditional/ biological method had the highest percentage (9%). This classification is in consonance with the study of IITA (2013) classifying methods of controlling aflatoxin in food crop. About 67.5% of the farmers did not use any control practice which suggests that most farmers do not control aflatoxin on their maize farms. Out of the remaining 32.5% that controlled for aflatoxin, about 15% used traditional method as the dominant control measure, 11% used chemical methods and only 2% used biological methods. This implies that farmers that controlled for aflatoxin mostly used traditional or local methods that involve drying/use of traditional storage systems to store maize. Use of chemical control measures involved the use of fungicides and herbicides in controlling aflatoxin. Only few farmers employed the use of biological control measures that involved bio-control of fungal growth in the field in combating aflatoxin infestation. This view was supported by focus group discussion reports and further enunciated by seminal works of Onuk (2010) and Waliyar and Sundini (2012).

### Net returns to use of aflatoxin control measures

A comparison of the average costs incurred and net returns (profit) to users and non-users of Aflatoxin control measures in the study area is shown in Table 4. From the table, there was a significant difference between the total revenue earned per hectare by users of aflatoxin control measures (₦299,959.01) and that of non-users (₦247,690.67), implying that use of aflatoxin control measures earned higher revenue than its non-use. However, the difference between the total variable costs of production of users of control measures (₦170,763.69) and that of non-users (₦165,616.99) was not significant

**Table 4.** Average net returns (₦) of use and non-use of aflatoxin control measures.

| Item | All respondents (n=240) | No control (n-162) | Control | | |
|---|---|---|---|---|---|
| | | | Biological (n=6) | Traditional (n=42) | Chemical (n=30) |
| **Revenue (₦)** | | | | | |
| Quantity of maize | 2362.44 | 1955.71 | 2593.57 | 2150.00 | 2589.80 |
| Price/kg (₦) | 126.97 | 126.65 | 126.93 | 127.72 | 127.60 |
| Total revenue | 299,959.01 (1.88)* | 247,690.67 | 329,210.84 (3.95)*** | 274,598.00 (3.14)*** | 330,458.48 (8.42)*** |
| **Variable costs (₦)** | | | | | |
| Seeds | 11,498.08 | 11,998.08 | 11,735.71 | 11,300.26 | 12,105.00 |
| Labour | 103,138.89 (1.67)* | 100,397.37 | 104,558.10 (1.84)* | 105,700.00 (2.38)** | 101,960.22 (1.88)* |
| Transportation | 10,728.21 (0.89) | 10,567.90 | 11,314.29 (0.67) | 10,400.52 (0.82) | 9,866.45 (0.51) |
| Herbicides | 5,864.32 | 5,294.24 | 6,660.52 | 6,073.57 | 6,280.00 |
| Insecticides | 1,048.72 | 683.95 | 1,119.05 | 945.23 | 1,440.40 |
| Pesticides | 812.61 | 418.40 | 1,257.14 | 1,067.35 | 1,125.43 |
| Fungicides (aflatoxin) | 1,302.21 | 0.00 | 1,521.23 | 0.00 | 1,241.24 |
| Fertilizer | 36,370.05 | 36,257.05 | 36,307.14 | 35,854.37 | 36,126.98 |
| **Total variable cost (₦)** | 170,763.09 (1.57) | 165,616.99 | 174,473.18 (0.36) | 171,341.30 (0.57) | 170,145.72 (0.39) |
| Gross margin (4-14) | 129,195.92 (2.44)** | 82,073.68 | 154,728.66 (10.72)*** | 103,256.70 (3.31)*** | 160,312.76 (10.32)*** |

*Significant at10%; **significant at 5%; ***significant at 1%. Figures in parentheses ( ) are t-values. Source: Field Survey, 2015.

(p>0.5), suggesting that the two groups incurred almost similar costs in their maize production operations. An analysis of cost items showed that labour accounted for the highest percentage for both users (48%) and non-users (49%) of aflatoxin control measures; and fertilizer cost accounted for 17% for users and 18% for non-users of control methods. There was a significant difference (p< 0.01) between the mean net returns earned by users of aflatoxin control methods (₦88,719.28) which more than doubled that of non-users (₦43,597.68). The same trend was obtained for the difference between the mean gross margin of users of aflatoxin control measures (₦129,195.92) and that of non-users (₦82,073.68) which was significant at the 5% level of probability. This suggests that users of aflatoxin control measures in maize production earned higher net returns than non-users as supported by Bruns (2003) and Legreye and Duveiller (2010).

## CONCLUSION AND RECOMMENDATIONS

Aflatoxin contamination ruins maize harvests, and consequently leads to low productivity, food insecurity, reduces farmers' income generating potentials and destroys the lives and livelihoods of millions of people (Udoh et al., 2001; IITA, 2013). There is a relatively high prevalence of aflatoxin contamination in the study area, as indicated by the proportion of maize farmland affected by the fungi. Though, maize production generally earns positive net returns to production in the study area, use of aflatoxin control measures provide significant increases in the net returns to farmers' production efforts than its non-use. However, the non-use of aflatoxin control measures by a large percentage of farmers in Oyo State suggests the need for enlightenment programmes aimed at sensitizing farmers on the dangers of aflatoxin on their farms, and in promoting the use of aflatoxin control measures through effective extension services in the study area for increased maize production. Also, a significant proportion of the farmers used the traditional control measures among the different types of control measures, suggesting the need to guide farmers in appreciating the advantages and effectiveness of the other aflatoxin control practices (biological, chemical and a combination of the measures) in maize production.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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# Sensitivity stability and fitness of *Botrytis cinerea* isolates to captan

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**The present study investigated the sensitivity and stability of *Botrytis cinerea* isolates collected from vineyards to captan. To determine the stability of sensitivity to captan, *B. cinerea* isolates on fungicide-free potato dextrose agar (PDA) was evaluated after 15 culture cycles. In some isolates with reduced sensitivity to captan, $EC_{50}$ value of the isolates did not change compared to that of isolates that were initially sensitive to captan; suggesting that the decrease/increase in the sensitivity to fungicide may be stable. Isolates sensitive to captan adapted to increasing doses of captan by decreasing their sensitivity, and this adaptation remained stable in the fungicide-free medium. The fitness components included mycelial growth rate, sporulation, and virulence of the isolates. There were significant differences between isolates sensitive to captan and those with decreased sensitivity to captan, in terms of mycelial growth rate, sporulation, and virulence. The growth rate of isolates with decreasing sensitivity to captan was as high as the growth rate of those sensitive to captan. However, isolates with decreased sensitivity to captan showed higher virulence than those sensitive to captan, and the difference between these isolates was significant. Sporulation was dependent on the performance of the individual isolates.**

**Key words:** Gray mould, sensitivity, captan, fungicide, virulence.

## INTRODUCTION

*Botrytis cinerea* Pers.: Fr. (Teleomorph: *Botryotinia fuckeliana*) is known to cause important economic losses in vineyards found in Turkey (Delen et al., 2000; Özer et al., 2004; Köycü et al., 2005; Köycü 2007; Köycü et al., 2012). This is similar to that observed in many countries (Leroux, 2004). The use of fungicides and cultural control measures is important in the fight against this pathogen (Courderchet, 2003). However, rapid development of resistance to single-site fungicides used in chemicalcontrol of *B. cinerea* has increased the importance of implementing effective chemical control measures in vineyards (Courderchet, 2003; Leroux, 2004). Therefore, every country has implemented an effective chemical control program by determining the resistance profile of these pathogens against available fungicides (Leroux et al., 1999; Koplay et al., 2004;

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Köycü, 2012). The use of single-site fungicides, such as benzimidazoles and dicarboxamides, in combination with multi-site fungicides, such as chlorothalonil and dichlofluanid, and captan on vegetables has been suggested to be an effective control measure for preventing rapid development of resistance to single-site fungicides (Elad et al., 1995). Although no instances of decreased sensitivity to captan in fungal pathogens have been encountered, there have been reports of decreased sensitivity to captan among *B. cinerea* isolates recovered from ornamental plants and strawberries (Lorenzini 1983; Dianezet al., 2002; Walter et al., 2007). Studies in Turkey have reported decreased sensitivity of *B. cinerea* isolates to captan in greenhouses and vineyards (Delen et al., 1999; Koplay et al., 2004; Köycü, 2007). In particular, the activity of captan against *B. cinerea*in vineyards varies from 39 to 57% (Delen et al., 2000; Köycü, 2007). In other countries, captan is licensed for use against *B. cinerea* on vegetables and fruits. In Turkey, captan has been used under license since 1970 against *B. cinerea* on vegetables as well as against downy mildew (*Plasmopara viticola*) and dead-arm (*Phomopsis viticola*) in vineyards (Tosun and Onan, 2014). Captan, which is a multi-site fungicide belonging to trichloromethyl thiocarboxides, influences cell metabolism by preventing inorganic phosphates from being assimilated in the fungal cell; resulting in a fungitoxic effect by interacting with thiols in the cell membrane structure of the fungus. These reactions also involve thiol-containing enzymes, leading to the deterioration of the cell membrane structure and inhibition of oxidative phosphorylation in the cell (Delen, 2016).

The emergence of isolates resistant to fungicides within the fungal population largely depends on the fitness of isolates with resistance (Wang and Coley-Smith, 1986; Raposo et al., 2000; Leroux, 2004). The decrease in the ability to fitness in subpopulations resistant to fungicides is important for preventing development of fungicide resistance in the field. Although captan has not been licensed for use as a multi-site fungicide against *B. cinerea* in vineyards, determining the stability of *B. cinerea* sensitivity to captan is important for the continuity of reactivity of single-site fungicides against this pathogen as well as for the success of chemical control measures and cross-sensitivity of this pathogen to fungicides. Therefore, the purposes of the present study are (a) to determine the stability in sensitivity of *B. cinerea* isolates subcultures to fungicide captan and (b) to determine fitness of isolates in terms of sporulation, mycelial growth, and virulence in subcultures.

## MATERIALS AND METHODS

### Selection of Isolates

*B. cinerea* isolates were recovered from table and wine grape vineyards in Trakya Region and cultivated in a potato dextrose agar (PDA, Merck/Turkey). A discriminatory dose of 30 µg/ml captan was used (Köycü, 2007) to identify isolates with sensitivity and those with decreased sensitivity to captan (Best Captan 50 WP, Agrobest, Turkey). The spores of each isolate were inoculated on PDA plus fungicide prepared at a dose of captan 30 µg/ml. After inoculation of spores, isolates showing colony development and those showing no colony development were classified as decreased sensitivity to captan and sensitive to captan, respectively. The fungicide stock solution was prepared in ethanol. A total of 29 single-spores isolates were evaluated in terms of mycelial growth after amendment with captan at concentrations of 10, 15, 30, 100, 150, and 300 µg/ml to determine their $EC_{50}$ (dose inhibited 50% mycelial growth) and Minimal Inhibition Concentration (MIC, µg/ml) on PDA plates. Mycelial plugs (4 mm in diameter) were cut from actively growing margins of 72-h-old colonies on PDA plates; three replications for each isolate were tested on PDA for fungicide amendment. Based on the evaluation, seven isolates with the highest $EC_{50}$ value were selected as isolates with decreased sensitivity (R: main isolates), and three isolates with the lowest $EC_{50}$ value were selected as isolates with sensitivity (S: main isolates). Isolates were stored at +4°C in PDA slants until they were used in the experiment.

### Sensitivity levels

To determine whether decreased captan sensitivity among *B. cinerea* isolates was stable, seven *B. cinerea* isolates with resistance were transferred on the fungicide-free medium after completion of colony development for 2 weeks in captan-free PDA (Bardas et al., 2007). The isolates were re-cultured 15 times. The subcultures were named as Re isolates. Colony development of three S isolates that were selected as captan-sensitive isolates was performed on a PDA plate at 10-µg/ml. These isolates were developed with continuous dose escalation up to a captan dose value of 440 µg/ml in PDA plate and were named as Sy subcultures. These isolates obtained with high captan doses were inoculated again on a fungicide-free PDA as many times as the number of dose escalations. The resulting pathogen subcultures were named Ss isolates. The R, Re, S, Sy, and Ss isolates obtained from the test results were evaluated with respect to mycelial growth at doses of 3, 10, 15, 30, 100, 150, and 300 µg/ml, and their $EC_{50}$value were obtained by Log-probit analysis. FC was calculated by comparing the $EC_{50}$ value of the R and S isolates to those of the Re, Sy and Ss isolates. The experiment was conducted with five replications using a randomized complete block design. Both experiments were repeated twice.

### Fitness of Isolates

The fitness components, including sporulation, mycelial growth rates, and virulence, were evaluated to determine fitness and competitive ability of *B. cinerea* R, Re, S, Sy, Ss isolates (Dekker, 1982). Sporulation and mycelial growth rates of the isolates were evaluated *in vitro* in a PDA, and the virulence was assessed on leaves of Emir (white type) wine grapes, which were previously determined to be sensitive to *B. cinerea* (Köycü et al., 2005).

For evaluating mycelial growth rates, each isolate was placed on a 4 mm mycelial plug after 72 h of incubation at 23°C. For evaluating sporulation, the isolates were then cultivated on PDA at 23°C for 10 days with a 12-h photoperiod, and spore concentration measured in a hemocytometer.

For virulence assessments, medium-sized leaves of Emir were washed with tap water and were then kept in 1% sodium hypochlorite (NaOCl) for 5 min; a repeated rinsing with sterile distilled water followed this. A fourfold of sterile and dry paper was placed in plastic containers. Two-centimeter-wide wood chips pre-sterilized in an autoclave were placed in the plastic containers to prevent direct contact of the leaves with the drying papers. The leaves were laid on top of the drying paper, with only the stems touching the moistened drying paper. Two leaves were used at every repetition. The leaves were battered using a fine-tip sterile injector, so that only epidermal tissues were punctured. After the *B. cinerea* isolates were cultivated on PDA at 23°C in darkness, they were inoculated with 1-cm-diameter agar plugs taken from the sides of 4-day-old colonies. Three discs were placed on each leaf (Vallejo, 2003). Then, the plastic containers were placed in transparent polyethylene plastic bags at 23°C and were allowed to incubate for 4 days with a 12-h photoperiod. The data were obtained by measuring lesion diameters. The experiment was performed with three replications, using a randomized complete block design.

#### Statistical analysis

Analysis of variance was conducted using SPSS (version 22; IBM Corp., Armonk, NY) for sensitivity levels of the isolates and all data from fitness tests. Means were separated using the Duncan Multiple Comparison Test ($P \leq 0.05$).

## RESULTS AND DISCUSSION

### Sensitivity levels

Numeric distribution of $EC_{50}$ and MIC values for 29 isolates tested for their *in vitro* sensitivity to captan is provided. Two of the isolates had $EC_{50}$ values of 10 to 20 μg $ml^{-1}$; one isolate had values of 21 to 25 μg $ml^{-1}$; eight isolates had values of 26 to 30 μg $ml^{-1}$; 11 isolates had values of 31 to 40 μg $ml^{-1}$; and six isolates had values of 41 to 50 μg $ml^{-1}$. However, only one isolate was found to have an $EC_{50}$ value of >50 μg $ml^{-1}$. The MIC values of the isolates varied between 30 and 300 μg $ml^{-1}$. One isolate had an MIC value of 30 μg $ml^{-1}$, 10 isolates had an MIC value of 100 μg $ml^{-1}$, four isolates had a MIC value of 150 μg $ml^{-1}$, and 14 isolates had a MIC value of 300 μg $ml^{-1}$.

Captan-sensitive and those with decreased sensitivity were selected based on their $EC_{50}$ values. Three *B. cinerea* isolates (4d, 15a, and 17b) with an $EC_{50}$ value of <25 μg $ml^{-1}$ were regarded to be sensitive (S) and seven *B. cinerea* isolates (12a, 12b, 12c, 22b, 49a, 49b, and 57b) with an $EC_{50}$ value of >40 were regarded to have decreased sensitivity (R), and Re, Sy, and Ss subcultures of these isolates were obtained. These isolates were included in the experiment to evaluate the stability of sensitivity to fungicide. FC varied between 1.09 and 4.73 within the group of R and Re isolates (Table 1).

FC1 and FC2 changed 0.67 and 1.60 within the group S, Sy and Ss subcultures. FC1 of three S main isolates and those of Sy and Ss subcultures of the same isolates were less than, but there was an increase in $EC_{50}$ values of their Ss subcultures, except for one isolate. Although the $EC_{50}$ value of the S isolate 15a was 10 μg $ml^{-1}$l, the $EC_{50}$ value of its subcultures, Sy and Ss, was 15 μg/ml (Table 2).

*B. cinerea* can lead to the development of resistance to single-site fungicides because of its heterokaryotic structure (Leroux, 2004), and isolates resistant to fungicide may also have a high level of fitness and become competitive with isolates with sensitivity and therefore, lead to an increased number of isolates that is resistance in nature (Dekker, 1982). In contrast, it is more difficult for pathogens to acquire resistance to multi-site inhibiting fungicides. Therefore, chemical control programs have been based on the use of a mixture of single-site and multi-site inhibiting fungicides to avoid development of resistance in *B. cinerea* strains. Regarding studies on *B. cinerea* isolates recovered from ornamental plants, like strawberry, eggplant, pepper and tomato, researchers have found that captan may become ineffective against the pathogen when it is intensely used in areas severely affected by the disease as the isolates develop resistance to captan (Lorenzini, 1983; Delenet al., 1999; Sarıbıyık and Benlioğlu, 2004; Walter et al., 2007). Glutathione levels were higher in isolates with decreased sensitivity than in wild-type isolates (Barak and Edgington, 1984). Studies have reported variable sensitivity profiles against captan for *B. cinerea* isolates obtained from vineyards in Turkey. The $EC_{50}$ values of *B. cinerea* isolates in the Aegean region were reported to vary between 4 and 24 μg/ml (Koplay, 2003), whereas $EC_{50}$ values of isolates in the Trakya region were found to be between 5 and 100 μg $ml^{-1}$ (Köycü, 2007). The decrease in fungicide sensitivity occurs by sporulation and transfer of resistance to subsequent generations; therefore, the problem of fungicide resistance emerges in the vineyards. The current research concludes that resistance to captan might be stable based on the findings that there is a slight decrease in $EC_{50}$ values of the isolate 12b (R) and Re subculture. Similarly there was an increase in $EC_{50}$ values of Sy isolate subcultured from the isolate 15a (S) due to exposure to high doses of captan, and increased $EC_{50}$ values remained stable after transfer of this isolate to a fungicide-free PDA. In fact, researchers suggest that there is an accelerated decrease in the sensitivity of isolates to captan because of continuous application of captan on vegetables, and this sensitivity reduction is stable in most isolates (Delen et al., 2000). Captan can prevent spore germination in isolates obtained from vineyards at a dose of 100 μg $ml^{-1}$ (Köycü, 2007), and may become ineffective against the pathogen when it is applied >12 times a year, particularly in strawberry fields (Walter et al., 2007); thus results revealed that sensitivity to captanin field conditions has increased over time.

Researchers have found a significant decrease in cross-reactivity of *B. cinerea* isolates recovered from greenhouses to captan in comparison to thiram, and to

**Table 1.** Changes in $EC_{50}$ values of *B. cinerea* isolates with decreased sensitivity to captan.

| Isolate No. | $EC_{50}$ ($\mu g\ ml^{-1}$)[A] | | $FC^B$ |
|---|---|---|---|
| | R | Re | |
| 12[a] | 46 | 29 | 1.59 |
| 12[b] | 46 | 42 | 1.09 |
| 12[c] | 52 | 11 | 4.73 |
| 22[b] | 40 | 31 | 1.29 |
| 49[a] | 42 | 30 | 1.40 |
| 49[b] | 46 | 14 | 3.28 |
| 57[b] | 42 | 13 | 3.23 |

A: Effective concentration at 50% ($EC_{50}$) values in µg $ml^{-1}$. B: FC: Factor of change R/Re. R: Main isolate with decreased sensitivity to captan.
Re: Subculture isolates with decreased sensitivity to captan and then cultivated in a fungicide-free medium 15 times.

**Table 2.** Changes in $EC_{50}$ values of *B. cinerea* isolates sensitive to captan.

| Isolate No. | $EC_{50}$ ($\mu g\ ml^{-1}$)[A] | | | $FC1^B$ | $FC2^C$ |
|---|---|---|---|---|---|
| | S | Sy | Ss | | |
| 4[d] | 16 | 18 | 10 | 0.89 | 1.60 |
| 15[a] | 10 | 15 | 15 | 0.67 | 0.67 |
| 17[b] | 16 | 18 | 10 | 0.89 | 1.60 |

A: Effective concentration at 50%($EC_{50}$) values in µg $ml^{-1}$. B: FC1: Factor of change 1: S/Sy. C: FC2: Factor of change 2: S/Ss.
S: Isolates sensitive to captan. Sy: Subculture isolates cultivated in a medium with a high dose of fungicide. Ss: Subculture isolates cultivated in a medium with a high dose of fungicide and then cultivated in a fungicide-free medium.

captan in comparison to Mancozeb (Delen et al., 1999, 2000; Leroux, 2004). The results of this study suggest that low FC for a few isolates [12b (R) and three S] might increase the number of isolates with resistance in the field conditions; leading to decreased sensitivity to captan currently licensed for use against *B. cinerea* in the vineyards, which may cause development of cross-resistance. Moreover, determining the presence of *B. cinerea* isolates with high $EC_{50}$values among those obtained from vineyards (Koplay et al., 2004; Köycü, 2007) reveals that isolates with resistance can compete with sensitive isolates in the field. Indeed, the fact that Köycü (2007), detected $EC_{50}$ values as high as 100 µg $ml^{-1}$ for some *B. cinerea* isolates obtained from vineyards in this region indicates that isolates resistant to fungicides may have a high level of fitness and therefore, can compete with isolates sensitive to captan. Similarly, this study suggested that the R and Re isolates could compete with the S, Sy, and Ss isolates with respect to growth rate and virulence as in the case of isolates 12a, 12c, 49b, and 57b R. If the reduction in sensitivity to captan occurs because of adaptation of the pathogen to captan, then the reduction in the fungicidal sensitivity may not be a problem in field conditions. Indeed, Sarıbıyık and Benlioğlu (2004) reported no significant difference in decreased sensitivity to captan among *B. cinerea* isolates recovered from strawberry parcels after application of captan 10 times, and they, therefore, supported the notion that a reduction in fungicidal sensitivity may not emerge as a problem in field conditions. However, decreased sensitivity to fungicide may be regarded to be stable because in the present study, decreased sensitivity in isolates 12b (R) and 15a (S) persisted in the subcultures of these isolates. With some exceptions, it is known that an increase in fungicide doses also increases the resistance in pathogens (Dekker, 1982). In addition, isolate 15a (S) sensitive to captan showed adaption to escalating doses of captan by increasing $EC_{50}$ values and a subculture of this isolate sensitive to captan on a fungicide-free medium resulted in no change in $EC_{50}$ values; a finding that might be indicative of a shift toward fungicide-resistance over time.

## Fitness of Isolates

In the fitness tests of R and S *B. cinerea* isolates, isolates 12a and 4d were not selected. For all isolates tested, the fitness parameters were significantly ($P \leq 0.01$) different between the main isolates and subcultures of those

**Table 3.** Fitness components of *B. cinerea* isolates.

| Isolate No. | Fitness components | | |
|---|---|---|---|
| | Growth rate$^{A}$ | Sporulation$^{B}$ | Virulence$^{C}$ |
| $12^{b}$ R | 8.50*$^{a}$ | $4.33^{e}$ | $3.32^{ab}$ |
| $12^{b}$ Re | $6.90^{d}$ | $0.67^{e}$ | $2.73^{bc}$ |
| $12^{c}$ R | $8.50^{a}$ | $12.67^{de}$ | $3.24^{ab}$ |
| $12^{c}$ Re | $7.67^{abcd}$ | $0.67^{e}$ | $2.68^{bc}$ |
| $22^{b}$ R | $7.53^{bcd}$ | $5.67^{e}$ | $3.29^{ab}$ |
| $22^{b}$ Re | $4.23^{e}$ | $1.33^{e}$ | $3.97^{a}$ |
| $57^{b}$ R | $7.40^{bcd}$ | $12.33^{de}$ | $3.11^{ab}$ |
| $57^{b}$ Re | $7.50^{bcd}$ | $0.67^{e}$ | $3.54^{ab}$ |
| $49^{a}$ R | $8.50^{a}$ | $32.00^{bc}$ | $3.27^{ab}$ |
| $49^{a}$ Re | $8.50^{a}$ | $11.33^{de}$ | $2.83^{bc}$ |
| $15^{a}$ S | $8.13^{abc}$ | $31.67^{bc}$ | $2.72^{bc}$ |
| $15^{a}$ Sy | $2.90^{f}$ | $1.00^{e}$ | $2.75^{bc}$ |
| 15a Ss | $4.17^{e}$ | $0.33^{e}$ | $2.18^{c}$ |
| $17^{b}$ S | $8.23^{ab}$ | $22.33^{cd}$ | $2.92^{bc}$ |
| 17b Sy | $8.00^{abc}$ | $55.00^{a}$ | $3.07^{b}$ |
| $17^{b}$ Ss | $7.33^{cd}$ | $42.33^{b}$ | $2.98^{bc}$ |

R: Main isolate with decreased sensitivity to captan. Re: Subculture isolate with decreased sensitivity to captan. S: Isolates sensitive to captan

Sy: Subculture isolates cultivated in a medium with a high dose of fungicide. Ss: Subculture isolates cultivated in a medium with a high dose of fungicide and then cultivated in a fungicide-free medium. A: Growth rate: Average growth rate measured after 3 days in PDA. B: Spore yield $\times 10^{6}$ $ml^{-1}$

C: Diameter of lesions on vine leaves (cm). *Each value is the average of three repetitions. The values indicated by different letters in the same column are significantly different from each other according to the Duncan multiple comparison test (P≤0.05).

isolates (Table 3).

Comparison of mycelial growth rates of S isolates showed that there were differences in growth rates between the main cultures and subcultures of some isolates, whereas no differences were observed in other isolates. The mycelial growth rates of S isolates were as high as those of R isolates. There was a significant (P ≤ 0.05) difference between the growth rates of R and Re subcultures of the isolate 22b and the growth rate in the Re subculture was decreased. However, no significant differences were found between the mycelial growth rates of R and Re subcultures of isolates 57b and 49a. In S isolates, mycelial growth rates of Sy and Ss subcultures of the S isolate 15a were lower than those of the main isolate. In contrast, the growth rate of the S isolate 17b was found to be close to those of the Sy and Ss subcultures.

The evaluation of sporulation showed significant differences between R and S isolates and their subcultures in terms of sporulation. Within R and S isolates, spore production was found to be high, except for 17b S, Sy, and Ss, and spore production of Re subcultures of the same isolates were found to be lower. No significant differences were found in the spore production of Re subcultures of the R isolates 12b and 22b, whereas there was a significant difference between the R and Re isolates of 49a (P ≤ 0.05). Sporulation of the S isolate of 15a was found to be quite high; whereas that of the Sy and Ss subcultures of the same isolate was found to be very low, with no significant difference between them. However, sporulation was found to be higher in the Sy subculture of isolate 17b and showed a slight decrease in the Ss subculture.

About virulence, there was a significant (P ≤ 0.05) difference between the virulence of the R and S isolates and their subcultures. There was a decrease in the virulence of subcultures of other R isolates. In S isolates, the virulence did not change in the Sy isolate of 15a subjected to high doses; whereas the virulence was greater in the Sy isolate of 17b in comparison with that of the main isolate. However, it was determined that the virulence of Ss isolates of both S isolates decreased again. Therefore, we can suggest that isolates with sensitivity also show a tendency toward developing resistance over time, and isolates sensitive to fungicides can be the basis of emerging resistance to captan used against *B. cinerea* in field conditions as much as their counterparts that are resistant to captan with high fitness parameters. These results are important as they show whether a successful chemical control program against the pathogen could prove to be sustainable, and it is likely that isolates resistant to multi-site fungicides may develop over time. Therefore, captan should be revalued and recommended to be used as a mixture with other single-site fungicides to prevent the development of resistance against it in *B. cinerea* in vineyards.

## Conclusion

*B. cinerea* is high-risk pathogen for fungicide resistance due to its high genetic variability. However, it is very difficult for *B. cinerea* to resist multi-site fungicides. For this reason, it is recommended to use single-site fungicides in a mixture in the control programs. Stability of resistance development for multi-site fungicides in *B. cinerea* isolates and fitness of resistant isolates is important both for reorganization and the recommendations of the single-site fungicides and the multi-site fungicides mixtures in the fungicide application programs and to prediction regarding the risk for resistance evolution.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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# Technical and water use efficiency estimation of adopters and non-adopters of pressurized irrigation systems among hazelnut farmers

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**Water demand is continuously increasing worldwide parallel with the growing population. Because agriculture is considered as a significant water consumption sector, water demand in this sector may be reduced by improving water use efficiency to make farming more irrigated and sustainable. This study was planned to estimate the technical and water use efficiency of hazelnut growers in Carsamba district of Samsun, Turkey. For this purpose, a sample of 350 farmers representing this district was drawn in advance. Hazelnut growers were identified from this sample, and they were contacted in Spring 2016 season to administer a questionnaire regarding their farming practices, particularly irrigation. Results of the study showed that only 27.70% hazelnut growers were irrigating their hazelnut orchards by a specific source of water (canal, reservoir, or groundwater). Among these farmers who used irrigation for hazelnuts only 13.40% adopted the pressurized irrigation systems, namely sprinkler or drip irrigation, and the remaining farmers were using the floating irrigation method. The adopters used lower quantity of water and received higher yields as compared to non-adopters. Similarly, they were 98% technically efficient, and their water use efficiency level was 78%. The same figures for non-adopters were 94 and 54%, respectively. It was concluded that both of the two groups were technically efficient, but hazelnut growers may focus on water saving by adopting the pressurized irrigation systems which reduce water wastage and enable the growers to use water sources efficiently.**

**Key words:** Water use efficiency, technical efficiency, pressurized irrigation, sprinkler irrigation, drip irrigation, floating irrigation, hazelnut farming, data envelopment analysis (DEA).

## INTRODUCTION

Feeding world population of more than 9 billion in 2050 is a consistent and colossal challenge, which puts extra pressure on limited and scarce natural resources of the world. The increase in world population, the desire of having high living standards, more luxurious life, and increased per capita income along with climate changes has intensified the use of fresh water resources (Wallace, 2000; Zhang et al., 2017; Falkenmark, 2000). Water resources are limited and scarce on the earth. Moreover, the ability of humans to add to existing water resources is also finite (Gleick, 2003; Guvercin and Boz, 2003).

Water scarcity is not only local but also a global issue

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and its use for agriculture are divided into livestock and irrigation categories. But globally, the water use for irrigation is much higher as compared to livestock (Alcamo et al., 2000). More than 80% of total freshwater is used for agriculture irrigation in the world (Condon et al., 2004). This level of consumption by agriculture irrigation in total freshwater use is unsustainable (Hamdy et al., 2003) due to increasing competition for the use of fresh water for other purposes (industrial and domestic needs) and general thinking is that the agriculture water use is wasteful (Postel, 2000). As the returns are much lower from agriculture, the use of fresh water should be reduced, in spite of increasing demand for food all over the world (Jury and Vaux, 2005). This could be possible by developing agri-environmental programs focusing on sustainable use of agricultural resources. One of the essential objectives of these programs is to extend the use of pressurized irrigation systems which enables farmers to economic use of irrigation water (Boz, 2016; Tatlidil et al., 2009). The efficient use of water is necessary all over the world especially in developing countries mainly due to two reasons. (1) The increase in world population will mostly continue in the next 25-30 years, which is a period to prepare against huge implications. (2) Most of this population increase will be in poor (third world) countries. Thus, the focus should be on the efficient use of existing scarce water resources.

Water use efficiency is a complex concept which is mostly misinterpreted and misunderstood not only by ordinary people but sometimes also by the scientific community (Lilienfeld and Amild, 2007). Water use efficiency is a vital as well as an informative measure for the evaluation of water-saving in irrigated crops (Kang et al., 2017; Kiziloglu et al., 2009). It is an economic term rather than an engineering concept based on input specific technical efficiency (Kaneko et al., 2004; Wang and Li, 2005). Technical efficiency of water is defined as total agriculture production per unit of water used and economic efficiency as the total value of production per unit of water volume used. On the other side, water application efficiency is a property of irrigation. The efficiency of each irrigation system is different. Water use efficiency varies from 75 to 95% in the drip irrigation system and from 70 to 90% in the sprinkler irrigation system. The floating method is seen as the least efficient system having an efficiency of 50 to 70% (Rogers et al., 1997).

Water demand is increasing with the rapid economic development in Turkey, but the inefficiency of water use is a significant obstacle in the development of agriculture as irrigation plays an important and vital role both in increasing and diversifying productivity to fulfill the food demand of the large population. Water use efficiency in Turkey is low mainly due to lack of coordination among employees as well as institutions, political interventions, lack of training of both farmers and employees, excessive use of improper irrigation and agriculture practices, salinity, alkalinity problems, use of polluted groundwater, illegal use of wells for irrigation, low water prices, higher evaporation from open water transfer channels, and seepage problems (Cakmak and Kendirli, 2002; Kanber, 2006; Cakmak, 2010). The use of water in agriculture in Turkey was 22.01 $km^3$ in 1990, and it is expected to increase more than three times to reach 71.5 $km^3$ in 2030 (Cakmak et al., 2007). This means Turkey can face severe water scarcity problems in the near future.

Currently, inefficient use of water is not only a common problem in Turkey but also all over the world. Although many studies have been conducted in developing countries (Haji, 2006; Chavas et al., 2005; Abay et al., 2004; Dhungana et al., 2004; Binam et al., 2003; Wadud and White, 2000; Ul-Haq et al., 2016b), they mostly focused on crops such as maize, wheat, sugarcane, coffee, and tobacco. Similarly, most of the studies that have been conducted in Turkey (Yazar et al., 2002; Onder et al., 2009; Bozkurt et al., 2006; Istanbulluoglu et al., 2002) also focused on field crops. Moreover, these studies have not focused clearly on water use efficiency of the pressurized irrigation system, particularly on hazelnut growers in Turkey. Turkey is the largest hazelnut producer in the world. A total of 740.141 ha of agricultural land is allocated to hazelnut cultivation which makes about 77% global hazelnut cultivation area. The average annual production in Turkey was 525 thousand tons in 2009-2014 period which was approximately 68% of total global hazelnut production.

In the same period Turkey's total export of hazelnuts was 505 thousand tons, which was 72.2% of total global exports of hazelnuts. The average production is 92 Kg/decare (Chamber of Agricultural Engineers, 2016; Tuncer and Boz, 2017). Black Sea Region of Turkey has favorable climatic conditions for hazelnut production. Hazelnut is best grown in the regions where the annual average temperature is 13-16°C. Also, the lowest temperature in these regions does not fall below -8, -10°C and the highest temperature does not exceed 36-37°C. The total annual rainfall must be over 700 mm and the distribution of rain should be balanced over the year. Besides, the relative humidity in June and July should not fall below 60%. Hazelnut is not very selective regarding soil requirements, but it shows a good improvement in nutrient-rich, temperate-humus and deep soils (Tabıder, 2018).

Although Turkey has an enormous potential for hazelnut production and exports the government has difficulties in managing this sector. Due to periodicity in hazelnut farming, the level of output exceeds the normal amount in some years, accompanied by limited exports opportunities, causes low prices for consumers whose income largely depends on hazelnut production. The government tried to respond to these inconsistencies in 2000 by implementing an alternative crop production policy but this policy produced no positive results because of the alternative crops could not compete

**Figure 1.** Sprinkler irrigation.

**Figure 2.** Drip irrigation.

with hazelnut due to climatic conditions.

Hazelnut areas are also under the pressure of urbanization, industrialization, housing, and mainly rural tourism facilities in the Eastern Black Sea Region of Turkey. Therefore, the primary policy must focus on keeping hazelnut farms environmentally, economically and socially sustainable. For these reasons besides creating alternative consumption and exports opportunities, a sustainable hazelnut farming system is also required. One of the critical elements of reaching this system is to increase the productivity of hazelnuts applying advancing cultivation technologies one of which is assumed to be pressurized irrigation methods. Although irrigation among hazelnut farmers is not common in the research area, some farmers have started to irrigate hazelnuts using three different ways which are showed in Figures 1, 2, and 3.

The present study is planned to estimate the technical and water use efficiency levels of hazelnut growers irrigating their orchards by pressurized or floating irrigation systems. The specific objectives of this study were to determine socioeconomic characteristics of hazelnut growing farmers in Carsamba district of Samsun province, to determine technical and water use efficiency scores for the farmers who used pressured or floating irrigation methods and to develop recommendations for a higher water use efficiency in the region.

## MATERIALS AND METHODS

### Study area and sample size

The study area was limited to Carsamba district of Samsun province. To draw an accurate sample to represent the average

**Figure 3.** Floating irrigation.

farmer in the district, 13 villages were selected with the help of the agricultural extension service personnel of the district directorate of the Ministry of Food Agriculture and Livestock (MFAL). Selection criteria of the villages were their proximity to city center, agricultural potential, number of farmers, and socioeconomic characteristics of the village. The lists of farmers including their names and farm sizes were obtained in advance, and these made the accessible population of the study. Considering the frequency distribution of the farm size in the entire accessible population, three strata were created as farmers owning less than 15 decares, between 15 and 30 decares, and more than 30 decares of agricultural land. For an accurate sample size determination, the proposed stratified sampling formula by Yamane (2001) was used which is described below.

$$n = \frac{N \sum N_h S_h^2}{N^2 D^2 + \sum N_h S_h^2}, \quad D^2 = \frac{e^2}{t^2}$$

n = Sample size.
N = Number of farmers in the accessible population
$N_h$ = Number of farmers in each single stratum
$S_h$= Standard deviation within each stratum
$D^2$= Expected variance
e = Accepted error from mean
t = Value of t corresponding the accepted confidence interval

Accepting an alpha level of 0.05 and working at 95% confidence interval (t = 1.645) a sample size of 350 farmers was drawn, and this was proportionally divided into three strata. Respondents from each stratum were randomly selected (Figure 4).

### Technical and water use efficiency

Rodríguez-Díaz et al. (2004) described the global relationship between output and inputs as efficiency. A farm can be evaluated based on many types of efficiency emphasizing various conceptions such as technical, allocative and economic (Speelman et al., 2008). This study is limited to technical efficiency; additionally, it emphasized the water use efficiency (WUE) of the farmer. The basic concept elaborated by Farrel (1957) has been adopted for estimation of efficiency scores of farmers. According to this concept, the efficiency refers to the "ability of a farm to produce maximum possible output from a given bundle of inputs (Output oriented) or ability to use minimum possible amounts of inputs to produce given level of output (input oriented) (Coelli et al., 2002). The input-oriented efficiency estimation model was applied because of this study aim to use the resource more efficiently rather than increasing the output level. The technical efficiency further decomposed into pure technical efficiency (PTE) and scale efficiency (SE). PTE elaborates the ability of a manager or farmer to produce the maximum output at an optimal scale while SE explains the ability of manager or farmer to choose the optimal inputs amounts that will attain the expected output level (Kumar and Gulati, 2008; Ul-Haq et al., 2016b).

Kaneko et al. (2004) elucidated that the water use efficiency is "the irrigation water use efficiency is a crop specific physical measurement in relatively small agricultural fields of given irrigation technology, presuming level of management." Though, such measurement of water use efficiency considers the water as a resource in a secluded manner which states slightly about the causes of any observed differences among the farmers regarding water use (Xue-yuan, 2010). For example, the output per cubic meter does not allow considering the difference of non-water inputs among farmers (Coelli et al., 2002). Therefore, based on the input-oriented TE concept; the water use efficiency is economic rather than engineering meaning (Kaneko et al., 2004). Thus, water use efficiency is defined as "the ratio of the minimum feasible water use to the observed water use, conditional on production technology and observed levels of output and other inputs" (Xue-yuan, 2010). So that the water use efficiency explains the radial reduction of water use may be known as a nonracial measure of input specific to


**Figure 4.** Map of study area, The smaller map shows Turkey while the larger map shows all districts of Samsun province including the research area of Carsamba district.
Source: Turkiye Rehberi www. turkiye rehberi net.

TE. Such that water use efficiency describes the possible quantity of water could be saved without compromising the amounts of other inputs and output quantity produced.

**Theoretical model of data envelopment analysis (DEA)**

Parametric and non-parametric approaches of efficiency measurement are the two most frequently used approaches globally (Omezzine and Zaibet, 1998; Karagiannis et al., 2003; Dhehibi et al., 2007; Haq et al., 2017). In this study, a non-parametric approach such as DEA was applied due to some functional and theoretical benefits over parametric approach like the stochastic frontier approach (SFA). Lansink et al. (2002) described that sub vector input efficiency measurement via stochastic frontier approaches would be highly challenging. However, the DEA has some advantages over SFA in the econometric measurement of efficiency. Firstly, it is non-parametric that's why there is no need of presumptions regarding the functional form and inefficiency terms such as required in SFA. Further DEA allows construction of the best piecewise frontier based on the real input and output observation of a farm. This construction of surface or frontier over data permits the straightforward way to measure the efficiency gap that makes comparison easy of a farmer's behavior regarding the performance index relative to the best productive practices (Wadud and White, 2000; Malano et al., 2004;).

**Technical efficiency model**

As DEA provides the best-practice frontier based on the concept that a farmer using fewer inputs than other farmers to produce the same level of output can be considered as a more efficient farmer. The best practice frontier is assembled piecewise by solving ordered liner programming problems for each farm relatively to each other farm to this frontier.

$$\text{Minimize}_{\theta,\lambda}\,\theta$$
$$\text{Subject to;}$$
$$-y_i + Y\lambda \geq 0$$
$$\theta x_i - X\lambda \geq 0$$
$$\lambda \geq 0 \qquad (1)$$

If a farm (i) using K inputs and producing M outputs, the input and output matrix for the total N sampled farm will be K × N shows input matrix (X) and M × N represents output matrix (Y) in Equation 1. For the $i^{th}$ farmer, the input vector and output vector represented as $x_i$ and $y_i$ respectively. The "θ" gives the TE score, and λ presents the N × 1 vector of weights that explains the linear combination of the peers of the $i^{th}$ farmer. N1 is the vector of ones. We followed the suggestion of Charnes et al. (1978) and Banker et al. (1984) in developing the above DEA model. Equation 1 describes the constant return to scale (CRS) condition which assumes that the farm is operating at its optimal scale (Fraser and Cordina, 1999) and an increase in input level will increase the output level in the same proportion. In agriculture, the increase in amounts of inputs used by the farm manager does not result in a linear proportional increase in the amount of output obtained. Thus, the variable return to scale (VRS) looks more suitable for this study. The VRS situation was explained by adding the convexity constraint in Equation 2.

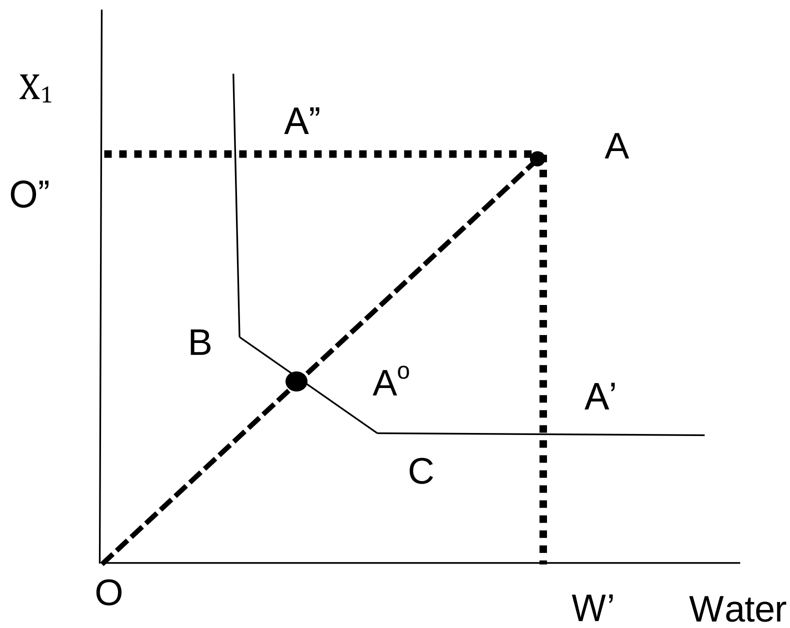


**Figure 5.** Technical and water use efficiency by DEA (Lansink et al., 2002; Frija et al., 2009).

Minimize $_{\theta,\lambda}$ $\theta$

Subject to;

$$-y_i + Y\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$N1'\lambda = 1$$

$$\lambda \geq 0 \quad (2)$$

Hence both specifications VRS and CRS will be modeled, and comparison of both situations is interesting because scale efficiency (SE) can be obtained under VRS condition. Also, a comparison of both scores is interesting because it provides information on SE. Coelli et al. (2002) present the relation between CRS and VRS conditions as follows.

$$SE = TE_{CRS}/TE_{VRS} \quad (3)$$

Equation 3 presents the SE is the ratio between the CRS TE score to VRS TE score.

**Water use efficiency model**

The water use efficiency (WUE) was estimated by adopting the proposed concept of sub-vector efficiency by Färe et al. (1994). Therefore, the WUE for the i$^{th}$ farm was measured by solving the following linear programming equation.

Minimize $_{\theta,\lambda}$ $\theta^k$

Subject to;

$$-yi + Y\lambda \geq 0$$

$$\theta^k x_i^k - X^k\lambda$$

$$\theta^{n-k} x_i^{n-k} - X^{n-k}\lambda$$

$$N1'\lambda = 1$$

$$\lambda \geq 0 \quad (4)$$

Equation 4 explains the WUE (Sub-vector input efficiency) score as $\theta^k$ for the i$^{th}$ farm. In this equation, the constraint 2 and 3 is different from the earlier described TE model. Notations $x_i^k$ and $X^k$ includes the inputs except the k$^{th}$ input such as water amount. The third constraint explains that $x_i^{n-k}$ and $X^{n-k}$ have k$^{th}$ quantity used (Table 1).

**Graphical explanation**

Figure 5 shows the graphical presentation of technical efficiency (TE) and sub-vector input (water) efficiency using the DEA. It explains the interpretation of the model presented above. The inefficient farm named as “A” and then radially contraction performed over the input vector $x_i$ as much as possible while remaining within the feasible input set. The inner boundary is piecewise linear frontier (isoquant) which is determined by

**Table 1.** Output and input variables used in the DEA analysis.

| Variables | Units/Measures | Definition |
|---|---|---|
| **Output** | | |
| Yield of Hazelnut | Kg/Decare | Hazelnut production per decare |
| **Inputs** | | |
| Costs | Turkish Liras (TL) / Decare | Cost of producing one decare hazelnut |
| Water Quantity | Liter/Decare | Water quantity used to produce hazelnut per decare |

combining frontier data points showing efficient farms in the sampled data. There are two inputs assumed being used by the farms named as $X_1$ and water. There are three farms A, B, and C. B and C lies on the best practice frontier while farm A is not on the frontier which explains that farm A is not efficiently using its inputs. The radial contraction in input vector $x_i$ (water and $X_1$) projected the point $A^o$ at the isoquant (frontier surface). This projected point explains the linear combination of observed points and constraint explained in Equation 2. It means the projected point is not outside the feasible set. The overall TE level of farm "A" can be measured by the ratio given below.

$$\theta = OA^o/OA \quad (5)$$

The θ is TE score of farm “A” which lies between 0 and 1. The value 1 means the efficient level of the farm and farm lies on the frontier while moving from 1 explains the inefficiency exists. The WUE of farm “A” could be emphasized using the scenario in which the water quantity can be reduced while the output and input $X_1$ remains constant. In this case, the A will be projected at A" such that the WUE is given as below.

$$\theta^k = O^{"}A^{"}/\,O^{"}A \quad (6)$$

The value of $\theta^k$ lies between 0 and 1. 1 shows the farm manager is the best performer and has no potential to reduce water use without reducing his farm output level. The value less than 1 indicates the existence of water use inefficiency and the farm manager has potential to reduce the water use while output and amount of other inputs remain unchanged. For example, the $\theta^k$ is 0.7 explains that the farm “A” could produce the same output level by using the 70% of the currently used level of water with a comparison of its benchmark which is constructed from the best practice frontier (isoquant) with similar characteristics. Such the farm “A” could save the water quantity by 30%.

## RESULTS AND DISCUSSION

### Use of irrigation and socioeconomic characteristics of hazelnut growers

Table 1 describes the farmers regarding their irrigation status and methods of irrigation used in their hazelnut orchards. From the table, it can be seen that the majority of farmers in the region (72%) used no irrigation for hazelnuts. The number of farmers who used irrigation with a specific source of water was 97 (27% of the sampled farmers). The reasons for farmers not using irrigation were also asked qualitatively, and most of them responded to this question focusing on the rainy climate of the region, lack of family members to deal with farming, and lack of financial support to apply irrigation.

The numbers of adopters and non-adopters of the pressurized irrigation system were also shown in Table 1. The main pressurized irrigation methods used for hazelnuts in the locality were drip and sprinkler irrigation methods, and these were adopted by only 13 (13.4%) farmers. The remaining 84 farmers (86.6%) used floating irrigation method. Considering the entire sample of 350 farmers, the adopters were only 3.7%, indicating that the adoption level of pressurized irrigation among hazelnut growers is very low. Those who applied floating irrigation were 24% of the entire sample. Farmers stressed that although the region is quite rainy, the temperature and sunny days period may extend particularly between June and August, and this makes irrigation very useful for hazelnut production.

Comparisons of socioeconomic characteristics of hazelnut farmers based on their irrigation methods are shown in Table 2. Since there were three categories of the dependent variable (pressurized irrigation, floating irrigation, and no irrigation), and all of the explanatory variables collected on a continuous basis, one-way analysis of variance was selected to achieve objective 1. The explanatory variables were the age of farmer, schooling years, farming experience, number of family labor, farm size, hazelnut area, yield per decare, and production costs per ton of yield. Results of the one-way analysis of variance showed that out of the nine selected socioeconomic characteristics two were statistically significant at 0.05 Alpha level. These were schooling years and number of parcels (Table 2). The LSD multiple comparison tests were also conducted to find out the specific differences among the three groups and the results revealed that those who adopted pressurized irrigation system had a significantly higher number of schooling years than those who used floating irrigation and no irrigation groups. On the other hand, those who adopted pressurized irrigation systems had less number of parcels in comparison with floating irrigation and no irrigation groups.

Highly educated people are more likely to observe,

**Table 2.** Frequency distribution of sampled farmers according to irrigation use.

| Variable | Frequency | Percent |
|---|---|---|
| **Irrigation status** | | |
| No irrigation | 253.00 | 72.30 |
| Irrigation | 97.00 | 27.70 |
| TOTAL | 350.00 | 100.00 |
| **Adoption status of pressurized irrigation systems** | | |
| Adopters | 13.00 | 13.40 |
| Nonadopters | 84.00 | 86.60 |
| TOTAL | 97.00 | 100.00 |

**Table 3.** Comparison of socioeconomic characteristics of hazelnut farmers on their irrigation methods.

| Name of variable | Pressurized ırrigation (PI) | Floating ırrigation (FI) | No ırrigation (NI) | F | P |
|---|---|---|---|---|---|
| Age of farmer | 52.92(14.81)* | 51.70(10.17) | 53.75(11.47) | 1.034 | 0.357 |
| Schooling years* | 8.77(5.64) | 6.33(3.12) | 6.57(3.17) | 3.115 | 0.046 |
| Farming experience (years) | 32.54(15.28) | 30.65(11.18) | 32.32(11.43) | 0.674 | 0.511 |
| Family labor (number) | 3.08(1.75) | 3.60(1.92) | 3.60(1.65) | 0.565 | 0.569 |
| Farm size (decare) | 28.37(26.19) | 35.13(34.19) | 32.94(38.53) | 0.229 | 0.796 |
| Hazelnut area (decare) | 18.83(9.27) | 24.14(15.09) | 23.53(20.36) | 0.442 | 0.643 |
| Yield per decare (Kg/ decare) | 164.6(42.12) | 156.3(56.4) | 148.8(66.34) | 0.204 | 0.816 |
| Total costs per 1 ton of yield (TL) | 815.36(166.47) | 822.08(179.16) | 816.95(203.59) | 0.674 | 0.978 |
| Number of parcels* | 1.77(0.59) | 5.33(4.73) | 5.49(5.55) | 3.245 | 0.040 |

*Standard Deviations in () bracelets.
*Mean differences among schooling years: PI - FI = 2.20, PI - NI = 2.46
*Mean differences among parcel numbers: PI – FI = -3.56, PI – NI = -3.97.

interpret, and adopt new technologies and information (Abdulai and Eberlin, 2001). Concerning agricultural innovations, Rogers (2010) investigated many studies around the world and stated the generalization that early adopters of innovations have a higher level of education in comparison with late adopters. Schooling years of the adopters in the present study were significantly higher than non-adopters while the average schooling years of farmers were almost six years which describes the hazelnut growers as primary school graduates. In many earlier studies, education level was found as a significant variable affecting farmer' decision to adopt different innovations in agriculture. Among these studies are the adoption of maize cultivation among the farmers operating in Kahramanmaras province (Boz and Akbay, 2005), adoption of newly improving cotton seeds by the farmers of Eastern Mediterranean Region (Boz and Kaynak, 2015), and adoption of innovations by dairy farm operation in Eregli district of Konya province (Yener, 2013) of Turkey.

Land division and fragmentation makes it difficult to apply many technologies at a farm level. Pressurized irrigation systems are among these technologies which can be more economically applied in regularly shaped and larger land parcels. If drip or sprinkler irrigation has to be used in smaller land parcels which are not suitable to unify by land consolidation, both of the first investment costs and later on production costs will probably be higher. Thus farmers having larger and regularly shaped parcels have a higher tendency of adopting these systems. Research finding regarding this variable showed that farmers who adopted pressurized irrigation had less number of parcels in comparison with the farmers who applied floating irrigation and no irrigation. While enabling farmers to reduce first investment and production costs, these systems will also reduce water consumption and make contributions to the sustainable use of water sources.

### Farm structure and efficiency scores of the sampled farmers

The TE, PTE, SC, and WUE scores of the adopters and non-adopters of pressurized irrigation system for hazelnut production in the research area were calculated and

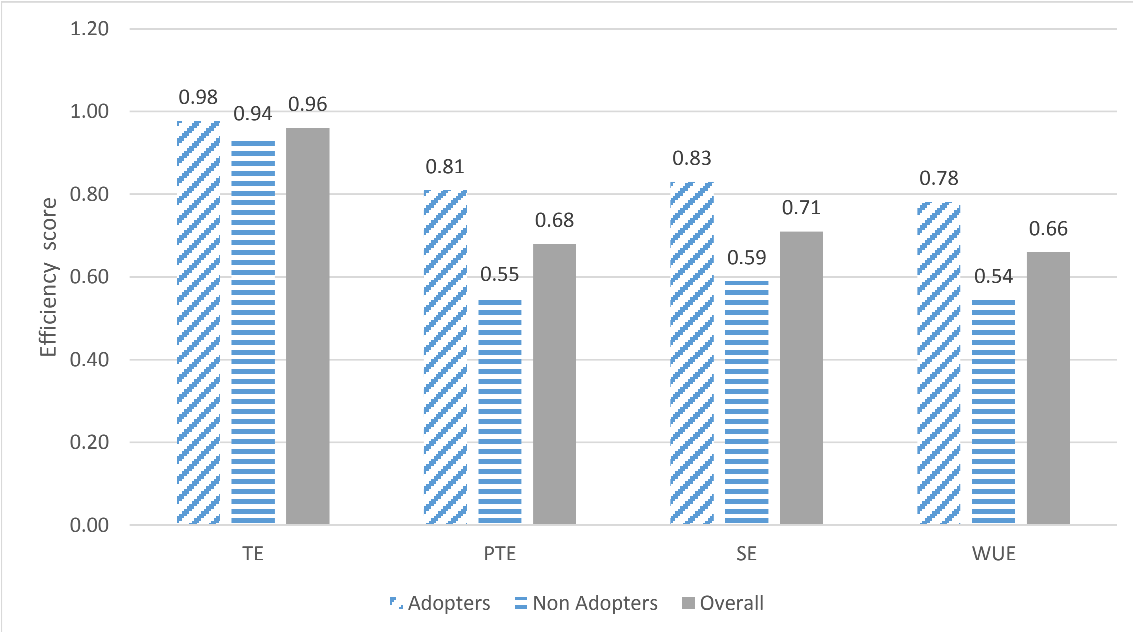


**Figure 6.** Efficiency scores of the adopters and non adopters.

presented in Figure 6. The overall TE score was calculated as 0.98 for the adopters, 0.94 for nonadopters, and 0.96 for both groups. These figures indicate that hazelnut farmers who used any method of irrigation in the locality are assumed to be technically efficient regardless of their adoption status of pressurized irrigation systems. To be entirely technically efficient the adopters and nonadopters still can reduce their inputs by 2 and 6%, respectively, without compromising their hazelnut yield.

The WUE of the adopters was significantly higher than the nonadopters. The average WUE score of adopters was 0.78 which is interpreted as the possibility of saving the water by 22% without compromising their crop yield. Similarly, the non-adopters' WUE score was 0.54 which implied that these farmers were wasting almost 46% water quantity by using floating irrigation. This finding indicates that pressurized irrigation system among hazelnut farmers increase the WUE. Previous work (Lamm, 2002; Yohannes and Tadesse, 1998) also reported the pressurized irrigation systems, particularly the drip irrigation as a more efficient method in comparison with floating irrigation. The average WUE score of all farmers was 0.66 which shows that hazelnut growers irrigating their orchards with a specific source of water could save water by 34% while getting the same level of hazelnut yield and with the same level of other inputs.

## Conclusions

Research findings indicate that hazelnut farmers in the locality have a low tendency of adopting irrigation. Only 27.70% hazelnut farmers were irrigating their orchards with a specific source of water (groundwater, canal, and reservoir). Moreover, adoption of pressurized irrigation systems enable farmers to obtain high yield and provide economically use of water resources. Among the 27.70% of hazelnut growers who used irrigation, only 13.40% adopted pressured irrigation systems like drip or sprinkler irrigation, and the remaining were using floating irrigation. Although there was a general belief that due to profoundly rainy climate in the region no irrigation is required for hazelnuts, many farmers stressed the benefits of irrigation, particularly in July and August. However, adoption of irrigation, particularly pressurized irrigation systems requires investments which are not affordable by many farmers unless governmental subsidies or long-term low-interest loans. On the other hand, a general reluctance among farmers towards farming activities was observed during the data collection process.

Results of the study showed that the adopters of the pressurizedirrigation systems were highly efficient not only in the technical use of inputs but also in water use. Regarding TE the adopters and non-adopters were efficient by 98 and 94%, respectively. A more substantial difference between these two groups was calculated regarding their WUE which was 0.78 for adopters, and 0.54 for nonadopters. This meant the adopters used lower water quantity and obtained higher yield in comparison with non-adopters. The adopters could save their water by 22% without experiencing any change in yield of crop and other inputs level. Similarly, non-adopters could save 46% water. Farmers received water from different sources such as irrigation canals constructed by the State Hydraulic Works, underground water, and water reservoirs. Irrigation associations are functional in the region trying to deliver water to farmers and helping to solve their problems with irrigation. To increase the number of hazelnut farmers who adopt pressurized irrigation systems, these associations should be more functional and definitely should employ agricultural engineers, and irrigation experts.

The lower PTE scores mean that the managerial performance to organize inputs in the hazelnut production process is also lower. Since pure technical efficiency is closely related to the managerial performance of farm operations, training programs and extension services may increase the hazelnut growers' knowledge to manage input use properly. District Directorate of the Ministry of Food Agriculture and Livestock, irrigation associations, and farmers organizations may conduct joint work to achieve this objective.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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# Intra- and inter-specific interference between slender amaranth and red pepper

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**Competition interferes with the growth and development of plants, whether of the same species or not. The aim of this work is to evaluate the intra-specific interference of slender amaranth plants (*Amaranthus viridis*) at different densities and distances, and in an inter-specific interaction with red pepper (*Capsicum baccatum* var. *pendulum*). The experiment was conducted in four replications and in a randomized complete block design using a factorial scheme of 2x4 + 2 controls, which represent two distances (5 and 10 cm) between the weeds and pepper (transplanted in the center of the box) and 4 densities of slender amaranth (3, 6, 9, and 12 plants m$^{-2}$). Cement-asbestos boxes with a capacity of 90 L were filled with clayey soils (Red Dark Latosol). The pepper seedlings were transferred to the boxes after having three fully expanded leaves, whereas the slender amaranth seedlings were transplanted when they were 5 cm in height. Growth and yield characteristics of the crop and weeds were evaluated. As a result, it was observed that as the density increased, both species suffered more damage; the red pepper showed etiolation and reduced production, and the weeds showed a reduction in growth parameters. The distance between the plants did not interfere with their intra- and inter-specific coexistence.**

**Key words:** *Capsicum baccatum, Amaranthus viridis,* density, competition, weed.

## INTRODUCTION

Red pepper (*Capsicum baccatum* L.), belonging to the family Solanaceae, is a shrubby plant, and cultivated as an annual plant (Filgueira, 2008); it has indeterminate growth, continuous flowering and fruiting, and bears fruits at different stages of maturation (Pereira et al., 2014). It is produced mainly in family farms, where value can be added to the product, and in integration systems between the farmer and the industry (Rufino and Penteado, 2006). The presence of weeds is one of the main factors that reduce the yield and quality of pepper fruits (Eure and Culpepperhtps, 2017). Among the plants found in the areas cultivated with vegetables, species of the genus

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*Amaranthus*, popularly known in Brazil as “caruru” (amaranth), stand out. Belonging to the family *Amaranthaceae*, this genus has about 60 plant species, some being cultivated and others growing as weeds: *A. viridis* (slender amaranth), *A. spinosus* (spiny amaranth), *A. retroflexus* (giant amaranth), and *A. hybridus* (purple amaranth) (Lorenzi, 2000). These plants can produce up to 235000 seeds (Lorenzi, 2000). This shows the importance of the management of these plants in agricultural areas to avoid competition with crops and to minimize the effects on the seed bank, especially considering the difficulty of their control (Robinson et al., 2008).

*Amaranthus* is one of the major genera of weeds infesting peppers in Mexico and Canada (Amador-Ramirez, 2002; Robinson et al., 2008). It is also one of the most important weeds for various bean cropping areas (Barroso et al., 2012) and vegetable cultivation sites (Marcolini et al., 2010). Barroso et al. (2012), in studies of inter-specific competition between beans and *A. viridis*, reported that the presence of weed decreased yield by 26%, negatively affecting the crop.

Knowledge of weed interference on crops is important in management decision making. The degree of weed interference on crops can be influenced by factors related to the weed community and the crop itself, such as the species present, the distribution, and the density (Barroso et al., 2012; Marcolini et al., 2010).

Competition is the main interference of one plant over another (Pitelli, 2014), and occurs when one or more of the essential resources for the growth and development of a plant becomes limited to meet the number of individuals present at the site (Rigoli et al., 2008). In this context, the density (number of individuals) and the spatial arrangement (plant spacing) of plants are factors that directly interfere with the relationship between plants (Bezerra et al., 2014). According to Carvalho and Christoffoleti (2008), high density is a more important factor for competition than the intrinsic competitive ability of the species. Thus, it is important that plants can remain under adequate conditions and in environments with available resources, so that competition is not established.

Most studies on the competition between plants are focused on comparisons between weeds and cultivated plants (inter-specific competition), seeking to quantify the effect on yield (Christoffoleti and Victoria Filho, 1996). Notwithstanding, intra-specific competition, that is, between plants of the same species, is also of great importance, since the plants have the same vegetative habit and the same needs of resources. Crops such as sunflower (Bezerra et al., 2014) and beans (Carvalho and Christoffoleti, 2008; Barroso et al., 2012) showed a decrease in yield when under intra-specific competition. However, it should be borne in mind that species agronomically considered as weeds may also suffer from intra-specific competition under conditions where resources are limited.

The hypothesis of this work is that amaranth can interfere with pepper and this interference is dependent on the density and distance of the weed crop, which may also undergo density-dependent intra-specific interference. Thus, the aim of this study is to evaluate the intra-specific interference of slender amaranth (*Amaranthus viridis*) plants at different densities and distances, and in an inter-specific interaction with red pepper (*C. baccatum*).

## MATERIALS AND METHODS

Two experiments were carried out. The first consisted of the coexistence of *A. viridis* (slender amaranth) and *C. baccatum*; in the second, *A. viridis* plants remained in intra-specific competition.

The seedlings of *A. viridis* and *C. baccatum* were produced in 128-cell trays filled with commercial substrate. The plants for both experiments were transplanted to the experimental unit on the same day, on August 3, 2015, according to each treatment. The pepper showed three fully expanded leaves, and the weeds were approximately 5 cm high. The transplantation was done in cement boxes with a capacity of 90.0 L, and dimensions of 60x60x25 cm, filled with clayey soil (Dark Red Latosol). Fertilizations were performed according to the results of the soil analysis (Table 1), based on Bulletin 100 (Van Raij et al., 1997);h the first fertilization was done 10 days before the transplant of the plants, and the cover fertilization 30 days after transplantation (DAT). Irrigation was done daily, and the insecticide Deltamethrin (concentration of 25 g $L^{-1}$), with commercial product Decis (BAYER) was applied as recommended by the manufacturer and when necessary for crop protection.

The inter-specific experiment was performed in a randomized complete block design, with a factorial scheme of 2x4 + 2 controls, representing the two distances (5 and 10 cm) between the weeds and the pepper (transplanted in the center of the box), and the four densities of slender amaranth (1, 2, 3, and 4 plants $box^{-1}$, representing 3, 6, 9, and 12 plants $m^{-2}$, respectively). A pepper control was maintained without the presence of weeds, and a slender amaranth control without any crop.

For the intra-specific experiment, only the factorial scheme was modified to 2x3 + control, representing the two distances from the center of the box (5 and 10 cm) and the three densities (2, 3, and 4 plants $box^{-1}$, corresponding to 6, 9 and 12 plants $m^{-2}$, respectively). For the control treatment, there was only one plant per box (3 plants $m^{-2}$).

The measurements of height (from the base to the beginning of the branch) and diameter at the stem base of the plants were made at 15, 30, 45, 60, and 75 DAT for *A. viridis* plants (leaves and inflorescence at the beginning of senescence), and at 15, 30, 45, 60, 75, 90, and 105 DAT for pepper (final ripening period). At the end of each experimental period, the following were evaluated: leaf area (LICOR LI3000), dry mass of leaves, and dry mass of stems (after drying in a greenhouse with forced air circulation at 65°C for three days). For the crop, the number of fruits was also counted, and, after harvest, the fresh and dry mass of fruits and the dry mass of seeds were evaluated.

The data were submitted to analysis of variance (ANOVA) and the means were analyzed by the Tukey test ($p > 0.05$).

**Table 1.** Result of the chemical analysis of a soil sample used as substrate.

| Crop | pH ($CaCl_2$) | O.M. (g $dm^{-3}$) | P resin (mg $dm^{-3}$) | K | Ca | Mg | H+Al | SB | CEC | V (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mmolc $dm^{-3}$ | | | | | | |
| Pepper | 5.8 | 26 | 140 | 2.0 | 48 | 11 | 19 | 60.5 | 79.0 | 77 |
| Amaranth | 6.2 | 31 | 111 | 1.8 | 58 | 13 | 12 | 72.6 | 84.5 | 86 |

Source: Laboratory Athenas Consultoria Agrícola - Jaboticabal/SP.

## RESULTS AND DISCUSSION

### Inter-specific interference between pepper and *A. viridis*

Regarding the coexistence of pepper with *A. viridis*, a significant difference was observed in plant height from 60 days after transplantation (DAT) in relation to weed distance (Table 2). This effect was more accentuated by the distance the plants occupy, as it can be observed that the pepper showed a higher height at 5 cm from the weeds, mainly at the highest density, of 12 plants $m^{-2}$. Notwithstanding, this result does not imply that the plant had an effective growth; the crop may have undergone light competition with weeds, which has caused etiolation.

Etiolation is a response of plants to low ambient light (Franco and Dillenburgl, 2007), in which the plant starts to invest more energy to increase stem growth (increase in length) in search of light (Dousseaun et al., 2007). However, this growth does not provide an increase in the dry mass of the plant, that is, this energy expenditure is not being well used and this may cause changes in plant metabolism (Constantin et al., 2008; Pitelli, 2014) and losses in yield. Moreover, the plant is more fragile and susceptible to breakage and to the attack of pests and diseases, which further hinders its development and cultivation (Silva et al., 2016).

This non-effective growth of the pepper plants is also observed in the other characteristics evaluated. There is a significant relation between the factors and the control for the stem diameter of pepper, and the presence of *A. viridis* negatively interfered with this characteristic from 45 DAT, decreasing it by 40% at 105 DAT with the density of 12 plants $m^{-2}$ (Table 3). According to Lima et al. (2008), etiolated plants do not accumulate mass and, therefore, their stem is much thinner when compared to a healthy plant without interference.

For the dry mass of stems and leaves and leaf area (Table 4), a significant difference was observed for the control in relation to the factors, and the presence of weeds, regardless of density and distance, caused a reduction in these characteristics. The reductions reached 74, 71, and 25% for the dry mass of stems and leaves and leaf area at the density of 12 plants $m^{-2}$, respectively. The plants with higher height did not present higher values of diameter and dry mass of stems and leaves, increasing the chances that the growth occurred as a function of the shading caused by weeds, that is, the pepper plants had etiolation. However, the leaf area was higher with 12 $m^{-2}$ plants than in the other densities. Under low luminosity, plants tend to expand leaf size to compensate for or better use low light (Lima et al., 2008). However, this change in morphology implies other changes in the leaf, such as a decrease in leaf thickness (Benincasa, 2003), which explains the reduction of dry mass of leaves in the pepper plants, a phenomenon that Lima et al. (2008) found in *Caesalpinia ferrea* seedlings.

The interception of solar radiation by weeds, preventing the passage of light into the crop, depends on the composition, density, and distribution of these plants (Pitelli, 2014). Marcolini et al. (2010) verified that the beet crop was very sensitive to the interference imposed by *A. viridis* plants, showing a significant reduction in leaf area, number of leaves, dry mass of leaves, mean root diameter, and fresh mass of roots even at low densities of weed populations.

Based on the analysis of dry mass of leaves (Table 5), there was interaction between the factors distance and density of plants $m^{-2}$. Comparing the densities of slender amaranth plants for each distance, it was observed that at the distance of 5 cm, there was no significant difference between the treatments. For the distance of 10 cm, it was observed a difference between the treatments with 3 and 12 plants $m^{-2}$, where the first treatment resulted in a higher dry matter production, probably due to the competition for resources being lower.

For the number of fruits (Table 6), there was a significant difference for the control in relation to the factors. The presence of *A. viridis* caused a mean reduction of 68% at the densities of 3 and 6 plants $m^{-2}$ (Table 6), and 81.5% at the other densities. It was observed that the distance of 5 cm provided higher losses for the number of fruits (Table 7) as density increased, reaching a reduction of 56%.

Regarding the fresh mass of fruits (Table 7), the control significantly differed from the factors; at the distance of 5 cm, the density interfered with fruit production. The treatment with 3 plants $m^{-2}$ was similar only to that with 6 plants $m^{-2}$.

Regarding the dry mass of fruits, the factors also differed from the control (Table 6). It is observed that the

**Table 2.** Mean values of height (cm) of red pepper subjected to increasing periods of coexistence with *Amaranthus viridis* at two distances and at increasing densities.

| Treatments | 15 days | 30 days | 45 days | 60 days | 75 days | 90 days | 105 days |
|---|---|---|---|---|---|---|---|
| **Distance (cm)** | | | | | | | |
| 5 | 6.82 | 15.16 | 25.28 | 26.53 a | 27.44 a | 27.72 a | 27.90 a |
| 10 | 7.51 | 15.00 | 23.09 | 23.97 b | 24.56 b | 24.88 b | 25.03 b |
| **Densities of *A. viridis* (plants m$^{-2}$)** | | | | | | | |
| 3 | 7.23 | 15.50 | 23.00 | 23.56 | 24.38 | 24.56 | 24.69 |
| 6 | 6.68 | 16.06 | 25.38 | 25.94 | 26.88 | 27.19 | 27.19 |
| 9 | 7.20 | 14.44 | 23.56 | 25.25 | 25.88 | 26.50 | 26.63 |
| 12 | 7.56 | 14.31 | 24.81 | 26.25 | 26.88 | 26.94 | 27.38 |
| Control | 7.83 | 16.00 | 22.25 | 22.38 | 23.25 | 23.25 | 24.25 |
| F Dist | 3.16 ns | 0.06 ns | 3.70 ns | 4.43 * | 5.83 * | 5.74 * | 6.08* |
| F Dens | 0.90 ns | 1.85 ns | 0.93 ns | 0.97 ns | 0.98 ns | 1.01 ns | 1.11 ns |
| F DistxDens | 0.18 ns | 2.84 ns | 2.43 ns | 2.04 ns | 1.89 ns | 2.04 ns | 1.78 ns |
| F Test x Fac | 1.31 ns | 0.98 ns | 1.29 ns | 2.48 ns | 2.37 ns | 2.93 ns | 1.61 ns |
| CV% | 15.02 | 11.57 | 13.41 | 13.82 | 13.11 | 12.93 | 12.58 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, ns: non-significant.

**Table 3.** Mean values of stem diameter (cm) of red pepper subjected to competition with *A. viridis* at two distances and at increasing densities.

| Treatments | 15 days | 30 days | 45 days | 60 days | 75 days | 90 days | 105 days |
|---|---|---|---|---|---|---|---|
| **Distance (cm)** | | | | | | | |
| 5 | 2.03 b | 3.46 | 5.45 | 7.43 | 8.43 | 9.42 | 11.49 |
| 10 | 2.32 a | 3.26 | 5.49 | 7.33 | 8.91 | 10.12 | 11.60 |
| **Densities of *A. viridis* (plants m$^{-2}$)** | | | | | | | |
| 3 | 2.04 | 3.54 | 6.35 a | 8.52 ab | 10.43 a | 11.91 a | 13.68 a |
| 6 | 2.22 | 3.67 | 6.08 ab | 8.83 a | 9.41 a | 10.04 ab | 11.98 ab |
| 9 | 2.23 | 3.12 | 4.91 bc | 6.31 bc | 7.65 b | 8.78 b | 10.19 b |
| 12 | 2.21 | 3.12 | 4.54 c | 5.86 c | 7.18 b | 8.37 b | 10.35 b |
| Control | 2.27 | 4.31 | 7.39 | 9.32 | 12.53 | 14.98 | 16.98 |
| F Dist | 8.33** | 0.47 ns | 0.01 ns | 0.03 ns | 1.14 ns | 1.32 ns | 0.03 ns |
| F Dens | 0.80 ns | 0.89 ns | 5.79** | 7.04** | 11.53** | 6.94** | 6.73** |
| F DistxDens | 1.66 ns | 1.53 ns | 0.42 ns | 2.67 ns | 0.52 ns | 0.94 ns | 0.95 ns |
| F test x factorial | 2.34 ns | 4.34* | 12.15** | 5.13* | 33.40** | 33.00** | 33.19** |
| CV% | 12.90 | 24.69 | 18.26 | 21.23 | 13.86 | 16.50 | 14.64 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

density had greater influence, since the greater the number of *A. viridis* plants, the smaller the dry mass of fruits. This effect is clearly observed in the unfolding of the treatments, where the reductions reach 60% at the distance of 5 cm in the second crop (Table 7).

For the dry mass of seeds (Table 6), the treatments differed from the control, and it was verified that the density had a greater influence than the distance.

When plants are competing both for space and for resources in the environment, those with faster growth and greater uptake of solar radiation occupy the space faster, hindering the growth and development of the others (Pitelli, 2014). In agricultural areas, weeds are considered more competitive, since they occur at a

**Table 4.** Mean values for dry mass of stems and leaves and leaf area of red pepper subjected to coexistence with *Amaranthus viridis* at two distances and at increasing densities.

| Treatments | DM Stem | DM Leaves | Leaf Area |
|---|---|---|---|
| | (g plant$^{-1}$) | | (cm$^2$ plant$^{-1}$) |
| **Distance (cm)** | | | |
| 5 | 41.14 | 12.46 | 699.06 |
| 10 | 40.00 | 12.33 | 668.64 |
| **Density (plants m$^{-2}$)** | | | |
| 3 | 54.49 a | 15.52 a | 676.76 |
| 6 | 46.58 ab | 14.23 ab | 694.31 |
| 9 | 28.66 c | 9.70 b | 644.75 |
| 12 | 32.54 bc | 10.13 ab | 719.57 |
| Control | 124.63 | 35.55 | 955.18 |
| F Dist | 0.10 ns | 0.01 ns | 0.29 ns |
| F Dens | 11.17** | 4.05* | 0.31 ns |
| F DistxDens | 0.65 ns | 0.37 ns | 0.26 ns |
| F Test x Fac | 241.35** | 113.35** | 10.16** |
| CV% | 20.44 | 27.40 | 22.48 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

**Table 5.** Unfolding of the interaction between the effects of density and distance of *Amaranthus viridis* on the dry mass of leaves of red pepper.

| Density (plants m$^{-2}$) | Dry mass of leaves (g) | | |
|---|---|---|---|
| | Distance (cm) | | |
| | 5 | 10 | F |
| 3 | 6.58 Ab | 11.83 Aa | 10.04** |
| 6 | 9.35 Aa | 9.31 ABa | 0.00 ns |
| 9 | 6.36 Aa | 8.83 ABa | 2.23 ns |
| 12 | 10.07 Aa | 6.08 Bb | 5.80* |
| F | 2.62 ns | 4.04 | |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

higher density, distribution, and with greater adaptive and reproductive capacity, causing greater damage to the cultivated plant (Pitelli, 2014; Bianchi et al., 2006).

Studying the periods of interference of weeds in pepper (*C. annuum*, cv. 'Mirasol') during three years in Mexico, with *A. palmeri* as one of the main weeds, Amador-Ramirez (2002) obtained that the period previous to interference (PPI) was 2.1 weeks after transplantation, tolerating a 5% loss in total production, or 0.9 weeks considering marketable production, with total period of weed interference (TPWI) of 12.2 and 12.3 weeks, respectively. Consequently, critical periods of weed interference (CPWI) were 2.1 to 12.2 and 0.9 to 12.3 weeks, that is these would be the periods in which the crop would have to be kept free of the presence of weeds to obtain at least 95% of the estimated total and marketable fruit production, respectively. In the present study, red pepper coexisted with slender amaranth plants for 105 days after transplantation, that is, 15 weeks, and this period exceeds the critical period obtained by Amador-Ramirez (2002), thus confirming the sensitivity of the crop to weed interference. In the case of this work, it

**Table 6.** Mean values for fresh and dry mass of fruits, number of fruits, and dry mass of seeds of red pepper subjected to coexistence with *Amaranthus viridis* at two distances and at increasing densities.

| Treatments | Number of fruits | FM fruits | DM fruits | DM seeds |
|---|---|---|---|---|
| | (N°. plant$^{-1}$) | | (g plant$^{-1}$) | |
| **Distance (cm)** | | | | |
| 5 | 33.06 | 394.31 | 44.92 | 7.90 |
| 10 | 32.38 | 380.60 | 40.92 | 6.84 |
| **Density (plants m$^{-2}$)** | | | | |
| 3 | 42.38 a | 526.59 a | 57.53 a | 9.89 |
| 6 | 39.75 a | 469.93 ab | 48.98 ab | 7.25 |
| 9 | 26.25 ab | 299.21 bc | 36.42 b | 6.72 |
| 12 | 22.50 b | 254.08 c | 28.75 b | 5.62 |
| Control | 129.00 | 1613.01 | 190.36 | 32.77 |
| F Dist | 0.03 ns | 0.09 ns | 0.57 ns | 0.61 ns |
| F Dens | 5.59** | 8.49** | 5.85** | 1.80 ns |
| F DistxDens | 4.01* | 5.14** | 6.56** | 2.14 ns |
| F Test x Fac | 239.12** | 328.77** | 343.43** | 157.37** |
| CV% | 27.04 | 24.34 | 25.30 | 37.46 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

**Table 7.** Unfolding of the interaction between the effects of density and distance of *Amaranthus viridis* on the dry mass of fruits and seeds of red pepper.

| Density (plants m$^{-2}$) | Number of fruits | | | Fresh mass of fruits | | | Dry mass of fruits | | |
|---|---|---|---|---|---|---|---|---|---|
| | Distance (cm) | | | Distance (cm) | | | Distance (cm) | | |
| | 5 | 10 | F | 5 | 10 | F | 5 | 10 | F |
| 3 | 53.75 Aa | 31.00 Ab | 7.51* | 671.81 Aa | 381.37ABb | 10.39** | 77.19 Aa | 37.88 Ab | 13.73** |
| 6 | 36.25ABa | 43.25 Aa | 0.71 ns | 438.14ABa | 501.73 Aa | 0.50 ns | 48.23ABa | 49.73 Aa | 0.02 ns |
| 9 | 18.25 Ba | 34.25 Aa | 3.71 ns | 264.35 Bb | 395.48ABa | 4.56* | 23.10 Bb | 49.73 Aa | 6.30* |
| 12 | 24.00 Ba | 21.00 Aa | 0.13 ns | 202.94 Ba | 243.81 Ba | 0.05 ns | 31.14 Ba | 26.36 Aa | 0.20 ns |
| F | 7.15** | 2.45 ns | | 10.87** | 2.76 ns | | 10.18** | 2.23 ns | |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

was observed that red pepper suffered with the presence of *A. viridis*, since fruit production was impaired. The higher energy expenditure that pepper plants had to correct cell growth processes and recover the loss of resources (Paulus et al., 2015), especially light, may have led to a decrease in the photosynthetic rate and a lower translocation of energy and sugars for fruit formation.

Another important factor that may have caused the low fruit production is the fact that *A. viridis* has a $C_4$ carbon fixation pathway (Carvalho and Christofoleti, 2008), and this photosynthetic mechanism confers several advantageous characteristics in relation to C3 plants, mainly in hot and humid environments (Paul and Elmore, 1984), which contributes to the presence of *Amaranthus* species in areas of production of oil plants such as pepper.

Omazine and Silva (2016) verified that with increasing density of *A. lividus* plants, there was a significant reduction in the cumulative dry mass of *C. annuum*. There was a reduction of 80.8% in the dry mass of pepper when cultivated with only one *A. lividus* plant, and a reduction of 97.7% when the treatment consisted of four *A. lividus* plants, showing that the crop growth was hampered due to the conviviality among the species, even at a low density. In addition, the authors point out that although the greatest damage occurs at high weed densities, the species *A. lividus* is more aggressive on

**Table 8.** Mean values of stem height (cm) of *Amaranthus viridis* coexisting at two distances and at increasing densities with red pepper.

| Treatments | 15 days | 30 days | 45 days | 60 days | 75 days |
|---|---|---|---|---|---|
| **Distance (cm)** | | | | | |
| 5 | 3.44 | 12.86 | 40.61 | 66.95 | 76.33 |
| 10 | 3.61 | 13.31 | 40.14 | 66.05 | 77.14 |
| **Density (plants $m^{-2}$)** | | | | | |
| 3 | 3.31 | 12.31 | 43.25 | 76.63 a | 91.25 a |
| 6 | 3.59 | 12.34 | 40.19 | 67.75 a | 75.75 b |
| 9 | 3.26 | 13.83 | 39.06 | 65.79 ab | 73.88 b |
| 12 | 3.95 | 13.85 | 39.00 | 55.83 b | 66.06 b |
| Control | 4.50 | 12.83 | 48.63 | 85.13 | 91.75 |
| F Dist | 0.21 ns | 0.13 ns | 0.03 ns | 0.10 ns | 0.07 ns |
| F Dens | 0.71 ns | 0.48 ns | 0.57 ns | 8.68** | 11.12** |
| F DistxDens | 0.46 ns | 1.20 ns | 1.09 ns | 1.36 ns | 0.44 ns |
| F test x Fac | 2.96 ns | 0.02 ns | 4.34* | 18.38** | 10.01** |
| CV% | 29.27 | 27.33 | 18.08 | 11.95 | 11.41 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

**Table 9.** Mean values of stem diameter (mm) of *Amaranthus viridis* coexisting at two distances and at increasing densities with red pepper.

| Treatments | 15 days | 30 days | 45 days | 60 days | 75 days |
|---|---|---|---|---|---|
| **Distance (cm)** | | | | | |
| 5 | 2.26 | 5.82 | 9.32 | 10.49 | 14.22 |
| 10 | 2.37 | 5.88 | 9.17 | 10.47 | 14.22 |
| **Density (plants $m^{-2}$)** | | | | | |
| 3 | 2.34 | 5.97 | 10.69 a | 11.60 a | 18.07 a |
| 6 | 2.29 | 5.95 | 9.13 ab | 10.54 ab | 14.49 ab |
| 9 | 2.31 | 5.84 | 8.95 ab | 10.11 ab | 12.58 b |
| 12 | 2.32 | 5.60 | 8.22 b | 9.65 b | 12.05 b |
| Control | 2.36 | 6.53 | 11.61 | 12.56 | 17.96 |
| F Dist | 1.96 ns | 0.01 ns | 0.09 ns | 0.00 ns | 0.00 ns |
| F Dens | 0.06 ns | 0.20 ns | 4.14* | 2.92 ns | 5.94** |
| F DistxDens | 0.72 ns | 1.19 ns | 1.21 ns | 1.55 ns | 0.40 ns |
| F test x Fac | 0.13 ns | 1.43 ns | 9.58** | 8.06** | 5.00* |
| CV% | 10.06 | 18.48 | 15.17 | 12.91 | 21.57 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

pepper when it is in a smaller number of individuals than at a high population rate, since the competition among plants harms their own development.

## Intra- and inter-specific interference of *A. viridis*

When analyzing the height of *A viridis* plants coexisting with pepper (Table 8), it is observed that the control (a single slender amaranth plant in the experimental unit, without pepper) differed from the other treatments from 45 DAT. It was also verified that from 60 DAT, the density caused a decrease in weed height, which reached up to 28% at 12 plants $m^{-2}$.

The same behavior was observed in relation to the stem diameter (Table 9), in which significant differences were observed from 45 DAT between the treatments and

**Table 10.** Mean values for dry mass of stem and leaves and leaf area of *Amaranthus viridis* coexisting at two distances and at increasing densities with red pepper.

| Treatments | DM stem (g plant$^{-1}$) | DM leaves (cm$^2$ plant$^{-1}$) | Leaf area (cm$^2$ plant$^{-1}$) |
|---|---|---|---|
| **Distance (cm)** | | | |
| 5 | 81.99 | 27.71 | 343.99 |
| 10 | 85.48 | 27.81 | 320.65 |
| **Density (plants m$^{-2}$)** | | | |
| 3 | 149.87 a | 49.40 a | 401.61 a |
| 6 | 77.78 b | 27.98 b | 353.58 ab |
| 9 | 59.83 b | 18.90 c | 311.11 ab |
| 12 | 47.47 b | 14.76 c | 262.97 b |
| Control | 159.18 | 59.81 | 406.82 |
| F Dist | 0.17 ns | 0.00 ns | 0.79 ns |
| F Dens | 29.10** | 62.77** | 5.08** |
| F DistxDens | 0.87 ns | 0.51 ns | 0.28 ns |
| F Test x Fac | 35.08** | 120.04** | 3.57 ns |
| CV% | 26.07 | 17.61 | 21.82 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

the control. It can be verified that with the increase of the density of plants in coexistence with the pepper crop, there was a decrease in the diameter, but the distance between the plants did not show differences.

Regarding the dry mass of stems and leaves (Table 10), it was observed that the distance did not cause interference in plant growth, while the density gradually reduced the dry matter production. With 12 plants m$^{-2}$, the reduction in dry mass was 70 and 75% for stem and leaves, respectively, for the distances of 5 and 10 cm. The same behavior was obtained for the leaf area of the plants, with a 35% decrease in the treatment and highest density in relation to the control.

When analyzing the interaction between *C. annuum* and *A. lividus* plants, Omezine and Silva (2016) verified that the dry matter accumulation of *A. lividus* was modified according to the density and the coexisting species. The authors observed that the highest dry matter accumulation of *A. lividus* occurred in the treatment with four *A. lividus* plants associated with a single *C. annuum* plant (52.33 g/pot), while the lowest accumulation occurred in the treatment with one *A. lividus* plant growing in the presence of one *C. annuum* plant (35.77 g/pot).

When *A. viridis* was cultivated alone, that is, only under intra-specific interference, the plants showed a significant difference in plant height as a function of distance only at 30 DAT (Table 11), but density was the factor that mostly interfered with this parameter of plant growth. Notwithstanding, at 75 DAT, only the treatment with the highest number of plants differed from the control, with a 21% reduction in height. In the unfolding at 30 DAT (Table 12), it is observed that when the density is 12 plants m$^{-2}$, the distance does not interfere with the plant response; instead, the number of competing individuals plays a key role. An important factor in the competition between plants is the availability of resources in the environment, in which the absence of a resource can cause reduction in biomass accumulation and yield (Pitelli, 2014).

As for the diameter under these conditions (Table 13), plant density interferes with plants at 45 DAT; at 75 DAT, the reductions reached up to 27.5% in the treatments with 6 and 9 plants m$^{-2}$, and 45% in the treatment with 12 m$^{-2}$ plants.

Regarding the dry mass of stems and leaves and leaf area (Table 14), it was verified that the factors differed significantly from the control, and that the greatest influence in the coexistence of plants is due to density: the higher the plant density, the smaller the results obtained for the three parameters. When analyzing the lowest and the highest density (6 and 12 plants m$^{-2}$, respectively), the reductions were 53 and 78% for dry mass of stems; 47 and 71% for dry mass of leaves; and 21 and 45% for leaf area, respectively.

According to Omezine and Silva (2016), for the species *A. lividus*, intra-specific competition may be more important than inter-specific competition, since they

**Table 11.** Mean values of height (cm) of *Amaranthus viridis* coexisting at two distances and at increasing densities.

| Treatments | 15 days | 30 days | 45 days | 60 days | 75 days |
|---|---|---|---|---|---|
| **Distance (cm)** | | | | | |
| 5 | 3.52 | 17.51 a | 43.24 | 64.74 | 71.68 |
| 10 | 3.48 | 14.06 b | 39.58 | 59.19 | 66.95 |
| **Density (plants m$^{-2}$)** | | | | | |
| 6 | 3.13 b | 15.15 | 44.70 a | 69.97 a | 78.41 a |
| 9 | 3.51 ab | 16.91 | 42.49 ab | 62.25 ab | 72.29 a |
| 12 | 3.87 a | 15.29 | 37.05 b | 53.67 b | 57.25 b |
| Control | 3.93 | 15.75 | 44.38 | 69.13 | 72.75 |
| F Dist | 0.04 ns | 5.19* | 4.25 ns | 1.35 ns | 1.02 ns |
| F Dens | 3.65* | 0.55 ns | 6.54** | 3.88* | 7.24** |
| F DistxDens | 0.46 ns | 0.20 ns | 9.09** | 0.51 ns | 0.33 ns |
| F test x Fac | 2.07 ns | 0.00 ns | 1.59 ns | 1.28 ns | 0.31 ns |
| CV% | 15.25 | 23.55 | 10.41 | 18.60 | 16.40 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

**Table 12.** Unfolding of the interaction between the effects of density and distance on the height of *Amaranthus viridis* evaluated at 45 days after transplantation.

| Density (plants m$^{-2}$) | Distance (cm) | | |
|---|---|---|---|
| | 5 | 10 | F |
| 6 | 41.38 ABb | 48.03 Aa | 4.67* |
| 9 | 48.17 Aa | 36.81 Bb | 13.60** |
| 12 | 40.19 Ba | 33.91 Ba | 4.16 ns |
| F | 3.91* | 11.73** | |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

**Table 13.** Mean values of stem diameter (mm) of *Amaranthus viridis* coexisting at two distances and at increasing densities.

| Treatments | 15 days | 30 days | 45 days | 60 days | 75 days |
|---|---|---|---|---|---|
| **Distance (cm)** | | | | | |
| 5 | 2.09 | 7.48 | 11.20 | 11.93 | 13.88 |
| 10 | 1.91 | 6.62 | 10.65 | 11.39 | 13.17 |
| **Density (plants m$^{-2}$)** | | | | | |
| 6 | 1.97 | 7.66 | 12.37 a | 13.15 a | 14.88 a |
| 9 | 2.04 | 7.04 | 11.10 ab | 12.14 ab | 14.48 a |
| 12 | 1.99 | 6.45 | 9.30 b | 9.69 b | 11.22 b |
| Control | 1.99 | 7.59 | 14.08 | 14.65 | 20.24 |
| F Dist | 1.05 ns | 3.73 ns | 0.69 ns | 0.37 ns | 0.92 ns |
| F Dens | 0.05 ns | 2.42 ns | 7.15** | 5.37* | 9.82** |
| F DistxDens | 1.17 ns | 0.41 ns | 0.41 ns | 0.30 ns | 0.39 ns |
| F test x Fac | 0.00 ns | 0.84 ns | 12.86** | 6.46* | 47.16** |
| CV% | 21.68 | 15.37 | 14.34 | 17.99 | 12.51 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

**Table 14.** Mean values for dry mass of stem and leaves and leaf area of *Amaranthus viridis* coexisting at two distances and at increasing densities.

| Treatments | (g plant$^{-1}$) | DM leaves (cm$^2$ plant$^{-1}$) | Leaf area (cm$^2$ plant$^{-1}$) |
|---|---|---|---|
| Distance (cm) | | | |
| 5 | 54.82 | 15.08 | 465.08 |
| 10 | 46.81 | 14.76 | 464.37 |
| Density (plants m$^{-2}$) | | | |
| 6 | 67.03 a | 19.40 a | 521.39 a |
| 9 | 53.87 a | 14.90 ab | 512.70 a |
| 12 | 31.55 b | 10.46 b | 360.08 b |
| Control | 143.25 | 36.84 | 659.60 |
| F Dist | 2.16 ns | 0.03 ns | 0.00 ns |
| F Dens | 14.46** | 7.25** | 6.17** |
| F DistxDens | 0.41 ns | 0.03 ns | 1.72 ns |
| F Test x Fac | 164.55** | 74.83** | 12.19** |
| CV% | 20.84 | 25.99 | 20.98 |

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

verified that the accumulated dry matter of this species decreased when there was an increase in its density, in the same way as the total plot dry matter (*C. annuum* + *A. lividus*) decreased with increasing density of *A. lividus*. Magro et al. (2011), in turn, found that *Cyperus difformis* biotypes are more sensitive to coexistence with rice plants (*Oryza sativa*) than with plants of the same species, that is, inter-specific competition is more important. In contrast, for the rice crop, intra-specific competition was more important.

The results indicate that the factor density caused greater damage to the growth and development of both pepper and *A. viridis* plants, due to morphological changes in the plants of both species and a decrease in the production of pepper. The distance between plants did not prove to be a significant factor in the coexistence of plants. The increase in the density of *A. viridis*, mainly with 12 plants m$^{-2}$, caused a reduction in stem diameter, leaf area, and in the number and mass of pepper fruits, besides causing plant etiolation; it also led to a reduction in height, stem diameter, leaf area, and dry mass of leaves of *A. viridis*.

## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

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