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Asian Journal of Agriculture

| Asian J Agric | vol. 5 | no. 2 | December 2021 | E-ISSN: 2580-4537 |

Published semiannually **PRINTED IN INDONESIA**

E-ISSN: 2580-4537

9 772580 453101

Asian Journal of Agriculture

| Asian J Agric | vol. 5 | no. 2 | December 2021 |

ONLINE
http://smujo.id/aja

e-ISSN
2580-4537

PUBLISHER
Society for Indonesian Biodiversity

CO-PUBLISHER
Universitas Mulawarman, Samarinda, Indonesia

OFFICE ADDRESS
Department of Agroecotechnology, Faculty of Agriculture, Universitas Mulawarman. Jl. Pasir Balengkong No.1, Kampus Gunung Kelua, Samarinda 75119, East Kalimantan, Indonesia. Tel./Fax.: +62-541-749159/738341, email: editors@smujo.id

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ASIAN JOURNAL OF AGRICULTURE
Volume 5, Number 2, December 2021 E-ISSN: 2580-4537
Pages: 45-52 DOI: 10.13057/asianjagric/g050201

Review:
Use of duality theory in organic farming: Evidence from India

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Manuscript received: 23 March 2021. Revision accepted: 12 June 2021.

Abstract. *Prajapati HR. 2021. Use of duality theory in organic farming: evidence from India. Asian J Agric 5: 45-52.* The duality analysis provides an alternative way for solving the problem of cost minimization. In this method, a specified suitable cost function has been used as an objective function with certain constraints, rather than using production functions. In duality theory, both cost and profit functions are used as an objective function under a well-defined production technology along with related behavioral assumptions. This paper has applied translog cost function as an objective function under certain input constraints for the estimation of five input parameters viz. Land, Labor, Capital, Machinery, and Irrigation based on field survey data of 284 organic and non-organic wheat producers in four rain-fed districts of Gujarat. Based on these parameters, all inputs price elasticity and elasticity of input substitution have been calculated using Iterated Smilingly Unrelated Regression Equations (ISURE) method of estimation. The results of the estimation, for both organic and non-organic farms, have found both positive and negative signs as was expected theoretically but the value is not significant.

Keywords: Conventional farming, duality theory, elasticity of substitution, input price elasticity, organic farming

INTRODUCTION

In economic analysis, the aim of the producer is to maximize objective function under given constraints. The problem of producers, especially in the agriculture sector, is to optimally allocate the resources, such as land, labor, capital, technology, and irrigation in such a way that his output or profit is maximized. Thus, the optimum and efficient use of resources is a challenging task for the producer with specific objective of maximization of production or minimization of cost. In economic theory, it has been recognized that the producer is motivated by the desire to maximize his/her utility or satisfaction. Many studies have been conducted on farm household decision-making behavior based on the classical theory of firm. All these studies assumed a single objective of profit maximization as the motivation for farmers' decision-making behavior. Thus, these studies have ignored the role of other factors that influence the decision of farm households and are usually motivated by multiple, often conflicting goals, rather than only profit maximization (Romero and Rehman 1989).

The duality approach was developed by Shephard (1953), while its empirical applications became popular from the 1970s onwards. The first empirical study which exploited duality theory was conducted by Nerlove (1961). He used Cobb-Douglas type cost function as an indirect way for estimation of the parameters of the production function in electricity consumption. After that, the concept of flexible functions was invented and later they were used for the derivation of probable dual cost and profit functions in the early literature of 1970s (Diewert 1971; Christensen et al. 1973). It was an important step that led to the proliferation of empirical application of duality theory. There are several studies that are concerned about the agricultural sector. Of these, the study by Binswanger (1974) using U.S.A. data appears to be one of the earliest. Recently two studies were conducted by Roas and Lence (2017, 2019) using pseudo-data of U.S. agriculture, they found that parameters are not correctly resulting in the expected sign of elasticity as per economic theory. Thus, the results were dependents on data source and sample size.

Why is the use of duality theory contentiously increasing? The reason behind the growing popularity of duality theory in production economics is that it allows a greater degree of flexibility in factor demand specification and output supply response equations along with showing very close relationship between economic theory and practice. For example, suppose transformation or production function depends on several input factors, the specified production technology, and a vector of output levels for empirical investigation factors equation can be derived through first-order condition of cost minimization problem. If the producer assumed the profit maximization, then the output supply response equation can also be derived from first-order condition of profit function. Unfortunately, in duality analysis very simple restrictive functions are used for the function transformation such as Cobb-Douglas and Constant Elasticity Substitution (Lopez 1982). Thus, the use of duality theory permits, to side-step problems by solving first-order conditions through either directly specifying minimization of appropriate cost function or profit maximization function rather than production function.

THEORETICAL ADVANCES

The theoretical advances of duality have passed through various phases, from hypothetical understanding, logical reasoning, and mathematical model formulation to empirical testing. As discussed above, the empirical application of duality was popular during 1970s, after the Nerlove work in 1961 and later continued by Diewert (1971) and Christensen et al. (1973). Both Binswanger (1974) and Rosas and Lence (2017) have applied duality theory in agriculture sector using a U.S.A. production data set with actual and pseudo-data and found contradictory results.

In duality mechanism, a set of essential properties of profit or cost functions are implied under a 'well behaved' production technology along with related behavioral assumptions. The application of duality theory has several advantages by specifying profit or cost function rather than transformation of production function. To derive the estimation factors, demand and output supply responses, there is no need to solve any complex production system of the first-order condition. The behavioral response equations can be obtained through differentiation of the dual function with respect to input or output prices. Another advantage is its application, as it needs less algebraic implications along with the flexibility to specify complex functions. It does not impose restrictions on the value of elasticity of substitution, separability, homotheticity, etc. (Lopez 1982). During the last four decades, the cost approach was more popular. It is used to estimate Hicksian input demand in addition to obtain information regarding properties of the underlying production technology. On the other hand, profit function approach allowed estimating Marshallian factors demand jointly with multi-output supply responses.

THE COST FUNCTION APPROACH

The cost function approach is the most popular and is applied for measuring the inputs/factor's demand elasticity, elasticity of substitution and technical changes in agriculture production. In early literature, Binswanger (1974) and Kako (1978) specified a translog cost function that estimates inputs/factor shares in log-linear form. Both have applied the cost function, which is further adopted by Lopez (1982):

$$ln\,C = \alpha_0 + \alpha_y \ln Y + \sum_i^n v_i lnP_i + ½ \sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j + \sum_j \gamma_{it} \ln P_i \ln t \quad (1)$$

Where, C is the cost of production or cultivation and Y is output, p_i is the price of input factors i, and t is used for a time trend variable as a proxy for technical change. Factor share specification can be obtained from equation (1) where factors/inputs share(S_i) is calculated by using logarithmic differentiation of Shephard's lemma.

$$S_i = v_i + \sum_i \gamma_{ij} \ln P_j + \gamma_{it} \ln t \quad \ldots\ldots\ldots\ldots\ldots.. (2)$$

Where $\gamma_{ij} = \gamma_{ji}$ and $i = 1, 2, 3.....N$

Both Binswanger (1974) and Kako (1978) have measured the elasticity of agriculture production inputs like; land, labor, machinery, fertilizers, and other intermediate inputs. By using the above specification of cost function (1) and share/input equations (2), we can separate the effect of biased such as technical change (γ_{it} parameters) of factor/input share from the effect of ordinary factor substitution due to change in factor/input price (γ_{ij} parameters) in equation (2). The result of both studies shows that technical change is very important and explains ample of the observed changes in factor shares in the U.S.A. and Japan. Though, both studies were based on the rigid assumption of homothetic production technology, with linear expansion paths, changes in the scale of production would not affect factor's share. In other words, factors/inputs shares in equation (2) are assumed to be independent of the level of output. It means that all changes in factor/input share are attributed to substitution or factors/inputs augmenting in technological change. If the production technology is not homothetic, a risk of overestimating the effect of factor/input substitution or, more likely, technical change, exists. It happens because the time trend variable is used as a proxy for technical change and positively correlated with output levels.

Another similar study conducted by Lopez (1980), applied a more general specified cost function using Canadian agricultural data. This specification allowed for a non-homothetic production function under some degree of flexibility. In this study, he had applied a flexible cost function known as generalized Leontief cost function and written as:

$$C = Y \sum_i \sum_j b_{ij} P_i^{1/2} P_j^{1/2} + Y^2 \sum_i \alpha_i p_i + Y_t \sum_i \gamma_i p_i \,.. (3)$$

In equation (3) applying Shepard's lemma, the factor/input demand equations in input/output ratio can be obtained in following forms:

$$\frac{Xi}{Y} = \sum_j b_{ij} \left(\frac{p_i}{p_j}\right)^{1/2} \alpha_i Y_t + \gamma_{it} t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

Where, the coefficient $b_{ij} = b_{ji}$ and $i = l, 2, 3 ..., N$

In equation (4) Lopez (1980) analysis allowed separating the effect of relative factor price substitution, factors augmenting technical change and the scale of production on the input-output ratios. In equation (4) it allows, as a special case, for homothetic. This occurs if $\alpha_i = 0$ for all i, that is, when the input-output ratios are independent of the output. By estimating a function of four factors (labor, capital, land and structures and other intermediate inputs), input-output ratios showed that the hypothesis of homotheticity is rejected by a wide margin and that changes in the scale of production explain a very important proportion of changes in the input-output or share equations. The effect of non-neutral technical change was found to be insignificant, which was a rather surprising result. However, a recent more disaggregated study by Lopez and Tung (1982) using combined cross-section and time-series data for Canadian agriculture, considered the inputs of: energy, energy-based, labor, capital, land, and other intermediate inputs. They showed that the factors augmenting technical change parameters (it) were jointly significant. Though, the technical change effect was substantially less dramatic than those obtained by Binswanger (1974) and Kako (1978), while the output scale effect is very strong and significant.

Table 1 shows that the own factor price elasticity of Hicksian input factors demand are quite similar for the four studies, despite using different data and models. The results concluded that factor demands are inelastic; where land (*L*) demand elasticity ranges from -0.35 and -0.50, the demand of labor (*La*) elasticity ranges between - 0.40 and - 0.50, but the Binswanger's result presents an outlier. The demand for fertilizers and chemicals (*Fer* + *Ch*) tends to be more elastic at least in the studies using North American data (-0.9) and farm capital (*K*) demand also exhibits somewhat lower values than the former. It means the estimated demand elasticity may provide some guidance to policymakers with several notions of the various degrees of price responsiveness of the inputs used in agricultural production.

These studies have applied different cost functions and found that the inputs demand are moderately responsive to prices. There exists a significant substitution possibility among several input pairs of which energy-based inputs and land appear to exhibit the greatest potential. The aggregate agricultural technology is not homothetic and the simpler production function specifications such as the Cobb-Douglas or Leontief are not appropriate specifications as shown by the studies of Binswanger (1974a) and Lopez (1980), respectively.

EMPIRICAL MODEL SPECIFICATION AND RESULTS

The aim of the farm producer is to choose the best technology that maximizes his profit or minimizes the total cost of cultivation. The overall objective is to estimate farm input demand relationship, input elasticity, elasticity of substitution, and farm-level structural differences under cost minimization problem. The ultimate purpose of this research is to provide policy guidelines for the promotion of specific farming methods based on input-demand requirements. The empirical support provides in the form of input numerical coefficients required to derive the desirable values of the theoretical validity of farmer behavior. For obtaining the required value of inputs parameters, translog cost function approach is applied.

The translog cost function

The primary aim is to derive the parameter estimates of inputs. In the literature Binswanger (1974), Lopez (1982), Ray, (1982) and Chaudhary and Mufti (1999) have applied translog cost function in case of pool and cross-section data for deriving parameter estimates for inputs. However, the use of translog production function is also found in literature, but if it is homogeneous in output, it does not permit separation of price and output level. In such situation, translog cost function is relatively flexible and allows for a comprehensive analysis of farmers' behavior. Thus, the duality theory established correspondence to a more flexible translog cost function, which need not be homogeneous in output and not be restrictive in explanation of producer behavior. The translog cost function is applied when the output is heterogeneous. It is written as expansion of logarithmic Taylor series of second derivative of analytical cost function:

$$ln\ C = \alpha_0 + \alpha_y(ln\ Y) + \sum_j^n \alpha_i\ (ln\ p_i) + ½ \sum_i \sum_j \beta_{ij}\ (ln\ P_i)(ln\ P_j) + \sum_j \beta_{iy}\ (ln\ P_i) \quad \text{.........................} (5)$$

Where, *C*, *Y*, and P_i are in the form of natural logarithm values, respectively, total cultivation cost, value of output and price of input *i*. The input includes land (N), labor (L), capital (K), fertilizer (F), and others (O). This cost function is an estimate of an arbitrary analytical function.

Table 1. Hicksian Input Demand Elasticity.

Study	Data	Production function	Finding (input DE)
Binswanger (1974)	U.S. Ag; cross sec + time series	Translog	-0.34 (L), -0.91 (La), -0.95 (Fer +Ch), -1.09 (K)
Kako (1978)	Japan rice farm, cross-section + time series (1953-1970)	Translog	-0.49 (L), -0.46 (La), -0.32 (Fer +Ch), -0.59 (K)
Lopez (1980)	Canada Ag; time series (1946-1977)	Gen Leontief	-0.42 (L), -0.52 (La), -0.41 (Fer +Ch), -0.35(K)
Lopez and Tung (1982)	Canada Ag; cross sec + time series (1961-1979)	Gen Leontief	-0.42 (L), -0.39 (La), -0.89 (Fer +Ch), -0.63(K)

Note: L: Land; La: Labour; Fer+Ch: Fertiliser and chemical, K: Farm capital. Source: Lopez (1982).

Here we assume that farmer is a rational producer, who acts as the sole decision-maker to choose farming methods and factors of production with given factors/inputs price and other constraints. The farmer's aim is to grow a certain level of output at the minimum cost at a given expenditure outlay, factors/inputs prices, and perfect competition in both product and input/factor market. It assumes symmetry across the price effect, which implies that $\beta_{ij} = \beta_{ji}$. Further, it follows homogeneity in prices, which is defined as $\lambda g\ (Y, P_i, \ldots, P_n) = \lambda g\ (\lambda Y, \lambda P_i, \ldots, \lambda P_n)$, it requires following restrictions on the parameters:

$\Sigma_i \alpha_i = 1$;
$\Sigma_i \beta_{iy} = 0$;
$\Sigma_i \Sigma_j \beta_{ij} = 0$;
$\Sigma_i \beta_{ij} = \Sigma_i \beta_{ji}$

The estimation of this cost function can go two ways: either it may be estimated directly or through cost-share equations or simultaneously both through cost function and inputs/factors share equations jointly. The estimation through cost-share equation needs to derive first share equation by using Shepherd's Lumma, which ensures that the cost minimization level of any input, X_i is equal to the derivatives of the cost function with respect to its price. Using first derivatives and applying Shepherd's Lumma as:

$\partial(ln\ C)/\partial(ln\ P_i) = (P_i/C)\ (\partial C/\partial P_i)$
Where: $\partial C/\partial P_i = X_i$
Putting the value $\partial C/\partial P_i = X_i$ above we obtain

$$\partial(ln\ C)/\partial(ln\ P_i) = P_i X_i/C = S_i \quad \ldots\ldots\ldots\ldots (6)$$

Where S_i is the cost share of input *i*. taking the derivative $\partial(\ln C)/\partial \ln P_i)$ value on equation (5) and substituting in equation (6), the following set of cost-share equations are obtained as;

$$S_i = \alpha_i + \sum_j \beta_{ij}\,(ln\ P_i) + \beta_{yi}(ln\ Y) \quad \ldots\ldots\ldots\ldots (7)$$

Where, $i = 1, \ldots n$

Econometric estimation procedure

The econometric estimation of parameters using a five-factor cost function considering the dual production problem provides an estimate of the minimum cost (TC) of producing the level of output (y) given the factor prices (P) of land (N), labor (L), capital (K), Fertilizer (F), and Irrigation (I). A translog cost function is used (Berndt and Christensen 1973; Berndt and David 1975; Chaudhary and Mufti 1999), yielding the specification as:

$$\begin{aligned} lnTC = {} & \alpha_0 + \alpha_N lnP_N + \alpha_L lnP_L + \alpha_K lnP_K + \alpha_F lnP_F + \alpha_I lnP_I + \alpha_y lny + ½\,\gamma_{NN} lnP_N^2 + +½\,\gamma_{LL} lnP_L^2 + +½\,\gamma_{KK} lnP_K^2 \\ & + ½\,\gamma_{FF} lnP_F^2 + ½\,\gamma_{II} lnP_I^2 + ½\,\gamma_y lny^2 + \gamma_{NL} lnP_N lnP_L + \gamma_{NK} lnP_N lnP_k + \gamma_{NF} lnP_N lnP_F + \gamma_{NI} lnP_N lnP_I \\ & + \gamma_{LK} lnP_L lnP_K + \gamma_{LF} lnP_L lnP_F + \gamma_{LI} lnP_L I + \gamma_{KF} lnP_K lnP_F + \gamma_{KI} lnP_K lnP_I + \gamma_{FI} lnP_F lnP_I \\ & + \gamma_{Ny} lnP_N lny + \gamma_{Ly} lnP_L lny + \gamma_{Ky} lnP_K lny + \gamma_{Fy} lnP_F lny + \gamma_{Iy} lnP_I lny, \ldots, (8) \end{aligned}$$

The log of TC equation contains the log of all input factors, level of output, their squares, and their cross-products of one to another input. Partial differentiation of the total cost function with respect to log input price, get the shares equations for all inputs. These share equations are expressed as elasticity of the cost function with respect to the factor prices. The input share equations are derived by logarithmic differentiation of the cost function and applying Shephard's lemma (McFadden 1978). Assuming that there is competition among input/factor providers in upstream markets and input prices are determined by the input market. The input demand functions are derived applying cost-minimizing procedure at a certain level of output by logarithmically differentiation of equation (8);

$$\frac{\partial lnTC}{\partial lnP_i} = \frac{\partial TC}{\partial P_i}\frac{P_i}{TC} = \alpha_i + \textstyle\sum_j lnP_j\,, i, \text{ Where j = N, L, K, F, I}$$

Then by applying Shephard's Lemma it has found that,

$$S_i = \frac{\partial TC}{\partial P_i}, i = N, L, K, F, I$$

Here, using above procedure, the share equations of inputs are obtained as;

$$S_N = \frac{P_N N}{TC} = \alpha_N + \gamma_{NN} lnP_N + \gamma_{NL} lnP_L + \gamma_{NK} lnP_K + \gamma_{NF} lnP_F + \gamma_{NI} lnP_I + \gamma_{Ny} lny$$

$$S_L = \frac{P_L L}{TC} = \alpha_L + \gamma_{LN} lnP_N + \gamma_{LL} lnP_L + \gamma_{LK} lnP_K + \gamma_{LF} lnP_F + \gamma_{LI} lnP_I + \gamma_{Ly} lny$$

$$S_K = \frac{P_K K}{TC} = \alpha_K + \gamma_{KN} lnP_N + \gamma_{KL} lnP_L + \gamma_{KK} lnP_K + \gamma_{KF} lnP_F + \gamma_{KI} lnP_I + \gamma_{Ky} lny$$

$$S_F = \frac{P_N F}{TC} = \alpha_F + \gamma_{FN} lnP_N + \gamma_{FL} lnP_L + \gamma_{FK} lnP_K + \gamma_{FF} lnP_F + \gamma_{FI} lnP_I + \gamma_{Fy} lny$$

$$S_I = \frac{P_I I}{TC} = \alpha_I + \gamma_{IN} lnP_N + \gamma_{IL} lnP_L + \gamma_{IK} lnP_K + \gamma_{IF} lnP_F + \gamma_{II} lnP_I + \gamma_{Iy} lny \quad \ldots\ldots\ldots\ldots (9)$$

The estimation procedure described above, and its analysis may proceed by estimating cost function directly (8) or by estimating the cost-share equations (9), or by estimating both together. While the direct estimation facilitates the determination of returns to scale embodied with underlying technology and the characteristics of farm input demands, this estimation has risk of reduction in the degree of freedom which adversely affects the statistical significance of the estimates. The alternative, the cost-share estimation does not lend itself to the determination of three parameters α_0, α_y, and α_{yy}. The estimation of cost-share equations allows for the estimation of input demand characteristics, elasticity, elasticity of substitution, but does not permit examining the nature of returns to scale of using underlying technology for crop production.

The joint estimation of translog cost function and associated cost share equations in literature were used by Zellner (1962, 1963), Kementa and Gilbert (1968), Binswanger (1974), Lopez (1982) and Chaudhary and Mufti (1999). It has a dual advantage, as it increases the degree of freedom on the one hand and on the other hand, it provides more information. Here the general form of the translog non-homothetic cost function along with share equations is estimated by applying Iterated Smilingly Unrelated Regression Equations (ISURE) approach. This estimation approach has some restrictions such as the values of the factor shares must be equal to one. In this estimation process, only$(n - 1)$ of the share equations are estimated and the parameters of *n*th omitted equation are recovered by adding up restrictions. It can be written as:

$$\sum_{i=1}^{n} \frac{P_i X_i}{C} = 1 \quad \text{Or} \sum_i S_i = 1 \qquad \text{(10)}$$

Elasticity of substitution estimation and price elasticity

In theory, the elasticity of substitution measures the degree of substitution between the inputs. The elasticity of substitution can be estimated by using both cost and production function and researchers have applied both methods as per available data. For the estimation of elasticity of substitution through cost function, different methods can be used either to estimate directly or through using Allen partial elasticity as well as Allen-Uzawa elasticity. The elasticity of substitution estimation is made by using a well-behaved second differentiation of production function. The direct estimates of elasticity of substitution can be obtained by the following partial derivatives:

$$C_{LK} = \partial ln\,(L/K)\,/\partial ln\,(P_L/P_K) \qquad \text{(11)}$$

However, the Allen partial elasticity substitution of inputs is obtained by following estimates;

$$C_{ij} = C\,C_{ij}/\,C_i C_j \qquad \text{(12)}$$

Where, the subscripts *i* and *j* of *C* indicate partial differentiation of cost function with respect to the factor/input price of *i* and *j*.

Here the expression (12) provides information of the cross-demand elasticity for inputs but does not directly show the behavior of relative share (McFedden 1978). The Allen partial elasticity is characterized by symmetry across the two inputs *i* and *j*, that is, $\sigma_{ij} = \sigma_{ji}$,it can be calculated from translog cost function at the mean value of the share of the inputs. It can be obtained from following share equations:

$$\sigma_{ij} = \frac{(\beta ij + Si\,Sj)}{Si\,Sj} \qquad i \neq j \qquad \text{(13)}$$

$$\sigma_{ii} = \frac{\beta_{ii} + S_i^2 - Si}{S_i^2} \qquad \text{(14)}$$

The price elasticity of input demand (E_{ij}) is obtained by using following method;

$$E_{ij} = \frac{\partial ln x_i}{\partial ln p_i} \qquad \text{(15)}$$

Where, quantity of output and all other inputs prices are constant, Allen (1938) has illustrated that Allen Elasticity of Substitution (AES) is analytically related to the price of elasticity of demand for factors of production, therefore;

$$E_{ij} = S_i \sigma_{ij} \qquad \text{(16)}$$

Thus, even though $\sigma_{ij} = \sigma_{ji}$in general but $E_{ij} \neq E_{ji}$

Data and variables description

This study is based on sample of organic and conventional farm survey of rain-fed four districts of Gujarat. The total sample was 284 farmers who had been personally interviewed, from more than 20 villages and 11 talukas of four districts. The entire sample consisted of equal number of organic and conventional farms for the purpose of making comparison. The structured schedule had been used for accessing the information. The variables used for the analysis were; land (N), labor (L), capital (K), fertilizer (F), and irrigation (I). The price of land (P_N) Rs/acre, was calculated on the rent paid on lease land and rented value of own land existed in the village.

Here the price of labor (P_L) force included bullock cost also, which equals three-men power, calculated as Rs per day paid to both types of labor force. Capital price (P_K) is calculated as cost incurred on the use of hired or own machine and cost of interest paid to work and fixed capital Rs per hour paid to machinery. The price of fertilizer (P_F) was the sum of price of pesticides per packet and price of per bag 50 kg of chemical fertilizer or price of manure Rs per quintal, while the price of irrigation (P_I) included the cost of irrigation charges per hour.

PARAMETER ESTIMATES AND DISCUSSION

The parameter coefficients were estimated from the restricted translog cost function and share equations for organic and conventional farms and the results are presented in Tables 2 and 3. Most of the estimated coefficients showed desired statistical properties. Specifically, the expected regression coefficients are commenced with theoretically consistent algebraic signs and statistically significant with at least 5 % level of significance. The Breusch-Pagan test was applied to test the contemporaneous correlation across the equations. During the process of estimation, absence of autocorrelation was found among observations in the data. Therefore, the validity of the derived estimates is as per regression axioms. While the estimates of the cost function and share equations have desirable statistical characteristics, such as expected sign, appropriate p-value, etc. The values of R^2 are not much important in ISUR application, they were, 0.719 for (TC) equation and 0.865 for (N), 0.395 (L), 0.632 (K), and 0.847 (F) share equations for conventional farm. Similarly, the value of R^2 were 0.565 (TC) for and 0.811 for (N), 0.633 (L), 0.600 (K), and 0.367 (F) in organic farm.

The statistical significance is estimated by p-value or t statistic of respective variables with appropriate sign but the power of prediction of the function is equally important for correct decisions. The prediction power of the function and the validity of the restrictions imposed on the estimating procedure depends on the significance of its F-value. The F-value is computed using usual formula as; the weighted residuals sum of square divided by number of restrictions and then divided by the ratio of the weighted sum of the square residuals with number of independent variables. Without imposing restriction, the number of the residual degrees of freedom is less than its tabulated value at 5% level of significance for both types of, Farms.

Tables 2 and 3 revealed that the coefficients of the equation on the share of land (N)for conventional farms, log of prices of all inputs are statistically highly significant and the same for organic farms at 5% level of significance. Similarly, share of labor (L) equation coefficients were again highly significant for both these categories of farms. For the share of capital (K) in conventional farms prices log labor (L), fertilizer (F) and irrigation (I) were not statistically significant. The share equation of Fertilizer (F), log prices of all input were significant in both farms. The coefficient of irrigation (I) share equation is derived from the cross-equation restriction and symmetry constraints.

Table 2. Estimates of parameter for conventional farms using ISUR estimation procedure with cross equations and symmetry restrictions.

Input	_cons (α_i)	N (β_{i1})	L (β_{i2})	K (β_{i3})	F(β_{i4})	I (β_{i5})	Y
S_N	-0.334	0.174*	-0.056*	-0.034*	-0.067*	-0.017*	-0.021
	(-11.65)	(223.79)	(-77.14)	(-43.40)	(-111.68)	(-25.19)	(-2.53)
S_L	0.625	-0.056*	0.157*	-0.029*	-0.056*	-0.017*	0.006
	(7.75)	(-77.14)	(16.16)	(-4.38)	(-11.49)	(-2.97)	(0.26)
S_K	-0.023	-0.034*	-0.029*	0.123*	-0.048*	-0.012*	0.012
	(-0.49)	(-43.40)	(-4.38)	(15.83)	(-10.19)	(-2.38)	(0.91)
S_F	0.769	-0.067*	-0.056*	-0.048*	0.199*	-0.028*	-0.007
	(16.98)	(-111.68)	(-11.49)	(-10.19)	(38.70)	-(6.89)	(-0.56)
S_I	4.353	-103.267	65.343	31.938	133.332	30.614	1.371

Source: Derived from Field Sample data, * at 5% level of significance, t statistics in brackets

Table 3. Estimates of Parameter for organic farms using ISUR estimation procedure with cross equations and symmetry restrictions.

Input	_cons (α_i)	N (β_{i1})	L (β_{i2})	K (β_{i3})	F (β_{i4})	I (β_{i5})	Y
S_N	-0.42	0.164*	-0.068*	-0.029*	-0.049	-0.019*	0.018
	(-5.86)	(156.13)	(-74.45)	(-21.36)	(-45.02)	(-16.39)	(0.81)
S_L	0.92	-0.068*	0.199*	-0.049*	-0.054*	-0.028*	-0.018
	(5.47)	(-74.45)	(16.97)	(-8.73)	(-5.13)	(-5.61)	(-0.36)
S_K	0.05	-0.029*	-0.049*	0.125*	-0.043*	-0.005	-0.021
	(0.57)	(-21.36)	(-8.73)	(15.68)	(-6.18)	(-0.84)	(-0.85)
S_F	0.31	-0.049*	-0.054*	-0.043*	0.160*	-0.015*	0.057
	(1.71)	(-45.02)	(-5.13)	(-6.18)	(11.49)	(-2.43)	(1.04)
S_I	-0.05	-60.339	66.182	14.405	56.315	22.907	0.365

Source: Derived from Field Sample data, * at 5% level of significance, t statistics in brackets

Input elasticity of substitution

The Allen elasticity of substitution (AES) is calculated using pairs of inputs and the estimates of parameters of share equations with the mean values of shares. The coefficients of β_{ij}'s are used for calculation of AES, in the manner shown by equations (14) and (15) presented in Tables 4 and 5.Theoretically, a negative (positive) value of AES shows that input of pair is complement (substitute) to each other. According to this criterion, N and L are substitutes to each other in conventional farms and complimentary in organic farms. Here, labor (L) (both manual and animal) and land (N) are essential for the production activity.

One probable reason for such a complementary between land (N) and labor (L) in organic farming, that this method is labor-intensive and depends more on labor rather than machinery or capital (K). But the value of input elasticity of substitution σ_{LK} is negative in case of organic farm and positive for conventional, having different meanings in economic explanation. However, the inputs substitution have negative sign e.g. N to K (-0.001), K to F (-0.12), K to I (-.01) and F to I (-0.17) in conventional farm and N to L (-0.03), N to I (-0.05), L to K (-0.02), L to I (-0.03) and K to F (-0.18) in organic farms means there is some degree of complementary, but not so much strength because the value of elasticity substitution is less than 0.5. The substitutions between K to L (0.22) and K to F (0.22) and K to I (0.17) inputs in conventional farm and L to F (0.27) are also not strong in both types of farms, except K to I (.064) in organic farms because these five inputs are combination of a bundle of inputs and with single input/factor production is not possible.

The usage of fertilizer and pesticides may reduce labor use in nurturing the crops in conventional farming, thereby enabling farmers to save time (hours) reducing the cost but increasing the cost on the other hand with use of chemicals and fertilizers. While the use of organic compost or manure and traditional methods of weed control increases the use of labor that leads to increase in time (hours) and cost, it also reduces the cost of use of chemicals and pesticides at the same time. That's why the differences in cost of production do not differ in both types of farming.

Price elasticity of inputs demand

The price elasticity of input demand serves much useful theoretical and practical information as elasticity of substitution. Theoretically, own-price elasticity are negative (-), whereas the cross-price elasticity of inputs are positive (+) when inputs are substitutes and negative (-) when inputs are complementary in production. Theoretically, similar sign holds for the elasticity of substitution also. The price elasticity demands for five inputs are presented in Tables 6 and 7 respectively. The own-price elasticity of all inputs in both types of farms is negative (-). While the cross-price elasticity of all five inputs has positive (+) sign as was expected theoretically in case of conventional farm. But in case of organic farms only land (N) and labor (L) cross-price elasticity has negative sign. This means that the prices of land and labor have some degree of complementary to each other.

The positive own price elasticity for irrigation is contrary to the theoretical expectations. These may be some of the possible reasons for the noted contradictions. As irrigation or water charges had a fixed lump-sum amount per acre per crop. Once in each season or charges are fixed per hour basis, water charges vary among crops depending on their consumptive water requirements e.g., lower for crops like cereals and fodder crops and higher for those like rice with higher water requirements. Irrigation water charges are statutorily fixed in water-rich regions and vary in response to the irrigation water demand in scare regions like Patan, Surendranagar and Banskantha in Gujarat. A rise in the water rate may induce a shift from high water consumptive to low water consumptive crops. This will reduce the overall demand for water, indicating a negative response as per the theoretical expectation.

Table 4. Allen elasticity of substitution of inputs for conventional farms.

	σ_N	σ_L	σ_K	σ_F	σ_I
σ_N	-0.066				
σ_L	0.025	-0.469		symmetric	
σ_K	-0.001	0.219	-0.148		
σ_F	0.002	0.219	-0.107	-0.086	
σ_I	0.108	0.171	-0.008	-0.165	-0.221

Source: Derived from Field Survey Data (2015)

Table 5. Allen elasticity of substitution of inputs for organic farms.

Inputs	σ_N	σ_L	σ_K	σ_F	σ_I
σ_N	-0.034				
σ_L	-0.029	-0.169		symmetric	
σ_K	0.098	-0.018	-0.180		
σ_F	0.025	0.272	-0.180	-0.366	
σ_I	-0.052	-0.031	0.641	0.270	-1.625

Source: Derived from Field Survey Data (2015)

Table 6. Inputs price elasticity for conventional farms.

Elasticity	E_N	E_L	E_K	E_F	E_I
E_N	-0.015	0.006	0.001	0.001	0.009
E_L	0.006	-0.116	0.033	0.064	0.014
E_K	0.001	0.054	-0.022	-0.031	-0.001
E_F	0.001	0.054	-0.016	-0.025	-0.014
E_I	0.025	0.042	-0.001	-0.048	-0.018

Source: Derived from Field Survey Data (2015)

Table 7. Inputs price elasticity for organic farms.

Elasticity	E_N	E_L	E_K	E_F	E_I
E_N	-0.007	-0.009	0.015	0.006	-0.005
E_L	-0.006	-0.053	-0.003	0.065	-0.003
E_K	0.021	-0.006	-0.027	-0.043	0.055
E_F	0.005	0.086	-0.027	-0.087	0.023
E_I	-0.011	-0.010	0.097	0.064	0.002

Source: Derived from field survey data (2015)

Similarly, a variety of chemical fertilizers and pesticides are used in conventional farming. Their prices varied from farmer to farmer due to asymmetric information, but not much. Further, excessive advertising may have influenced their demand positively even in the presence of their rising prices. The own-price elasticity of demand for labor is significantly lower than unity in both types of farms and maybe inelastic. This can be explained by the nature of labor force supply in particular sample districts. As most of the farms, especially organic farms receive labor from their family members usually with very low opportunity cost in rural areas; its use typically changes little in response to changes in wage rate in another sector. Most of the estimates of the cross-price elasticity are less than one and have positive algebraic signs except land and labor. Further, their magnitudes for organic farms are smaller than those for conventional farms. Certain consistency in the results to a large extent indicates farmer's behavior conforming to the postulates of minimizing cost in producing farm output in sample area.

In conclusion, theoretically, a negative (positive) value of the partial elasticity of substitution indicates that the inputs/factors of a given pair are complements (substitutes) to each other. Under this criterion, land (N) and labor (L) are complements to each other in conventional farms and organic farms. Own-price elasticity is negative, whereas the cross-price elasticity of inputs is positive when given inputs are substitutes and negative when they are complementary in production. Similar sign holds for the elasticity of substitution. The own-price elasticity of all inputs in both types of farms is negative. While the cross-price elasticity of all five inputs has positive sign as theoretically expected. But in case of organic farms, only land (N) and labor (L) cross prices elasticity have negative signs. It means that the prices of land and labor are complementary to each other. Finally, the results of elasticity estimation and theoretical validity depend on the calculated value of inputs/factors parameters, data source, and sample size.

ACKNOWLEDGEMENTS

I would like to acknowledge my supervisor Prof. Indira Dutta, Central University of Gujarat, India, and Prof. Arup Mitra, Institute of Economic Growth, Delhi, India for their guidance on econometric estimation and modeling.

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ASIAN JOURNAL OF AGRICULTURE
Volume 5, Number 2, December 2021 E-ISSN: 2580-4537
Pages: 53-60 DOI: 10.13057/asianjagric/g050202

Identifying limiting factors for feasible productivity improvement for smallholder farmers in coffee sector in Indonesia

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Manuscript received: 19 May 2021. Revision accepted: 18 July 2021.

Abstract. *Tran HTM, Nathan S, Ilmma A, Burkiewicz M, Wisana IDGK. 2021. Identifying limiting factors for feasible productivity improvement for smallholder farmers in coffee sector in Indonesia. Asian J Agric 5: 53-60.* Coffee is a global commodity with significant value-addition and export potential for producing countries. The purpose of this study was to identify the important factors associated with increasing yields. Rather than prescribing theoretical solutions, our research purpose was to examine the prevailing agricultural practices that are used in the region and identify the top three factors that have a significant impact on yields. Using advanced data collection methods and controlling for regional characteristics and various farming practices, we found that higher yield was associated with the application of fertilizer, higher tree density, and shade level. The application of fertilizer was associated with an increase in yield of 98 kg/ha for Arabica and 124 kg/ha for Robusta. At the optimal density ranges, a higher yield can be obtained with the increase of trees. Lastly, the level of shade was negatively associated with yield for Arabica, but no significant difference was observed for Robusta. We found a lot of headroom to increase the yield, as the current fertilizer application was low especially for Robusta, a mismatch between optimum tree density for both Arabica and Robusta, and opportunities for better shade management to increase yield potential.

Keywords: Coffee, density, fertilizer, shade, yield

INTRODUCTION

Coffee is a global commodity with significant value-addition and export potential for producing countries, many of which are either poor or developing economies. In terms of the total area planted, Indonesia is the world's second-largest; but Indonesia ranks 4th in terms of coffee production with an average yield of 692 kgs of green bean per hectare. This is far below the yield of other leading coffee-producing countries such as Vietnam, Columbia, and Brazil (Ministry of Agriculture 2017). With a total production of 666,992 tons and 70% of them exported, coffee is a primary contributor to Indonesia’s export, raking in more than $1bn in export earnings (Indonesian Coffee Statistics 2017). Indonesia’s total coffee area is about 1.2 million hectares, and smallholder households numbering 1.8 million own and manage 96.26% of them. The two main species grown are Robusta, accounting for 73% (0.86 million ha), and Arabica accounting for 27% (0.31 million ha) (Ministry of Agriculture 2017). In the last few years, the demand for Arabica coffee is growing due to the rise in prices led by the global appetite for specialty coffee.

Smallholders, who produce most of the country’s coffee, often do not have access to quality processing facilities and thus resort to low-quality processing at a farm level. The adoption of good agricultural practices is also quite low, hampering yields. Such challenges, coupled with the fragmented landholding nature of smallholders do not bode well with the sustainable development of rural coffee-growing communities. Comparing the 692 kg ha^{-1} yield of Indonesia with neighboring Vietnam’s yield of 2,400 kg ha^{-1} sets a reasonable benchmark of the yields that are achievable through the right policy and development interventions.

Through this paper, we set out to identify the important factors associated with yield improvements. Rather than resorting to theoretical solutions, our research examines the prevailing agricultural practices in the key coffee-growing regions of Sumatra. By interviewing thousands of farmers and employing advanced statistical methodologies, we identified the top three factors that have a significant impact on yields.

We chose to research yields as Indonesia has significant headroom to increase per hectare yields. Also, the increased income a smallholder can derive from higher yields should help strengthen their livelihoods and build resilient rural communities. In the medium-to-long term, it should also pave the way for the nation’s inclusive growth and sustainable development.

MATERIALS AND METHODS

Data collection

The study uses data from The Enveritas Coffee Survey (ECS)* in 2018 that collected information about social, environmental, and economic aspects of coffee farming such as farming practices, productivity, coffee pricing, access to training and finance, relationship with workers, health and safety aspects, biodiversity, soil and water conservation, and chemicals usage. The ECS utilizes cutting-edge machine learning to identify coffee growing regions in seven provinces in Sumatra (Aceh, North Sumatra, West Sumatra, Bengkulu, Jambi, South Sumatra, and Lampung). Based on the population data from the Ministry of Agriculture (MoA) and National Statistics Office (BPS), we first mapped the population of coffee farmers of all districts in seven provinces in Sumatra. From this, we defined a new population unit called "supply units" (SU) which consisted of bordering districts in such a way that each supply unit contained approximately 10,000 coffee farmers (Figure 1.A). The formation of supply unit allowed us to better compare parameter estimates across regions, as it does not depend on the administrative boundaries that can be very different from region to region. In total, we had 68 supply units across seven provinces in Sumatra.

Through advanced data collection methods, ECS obtained representative samples of coffee farmers reaching out to even the remotest villages. For sample randomization, machine learning algorithms were applied to high-resolution satellite imagery to detect coffee-growing households. Our geo-randomization tool provided random drop pins across the supply units (Figure 1.B). Our field team of enumerators went to the drop pins location and looked for 5 coffee farmers within 2 km radius. Each randomized farmer household was interviewed in-person and on-site by the enumerators through a mobile application. Survey results and field observations underwent rigorous quality control and outlier detection process before acceptance.

We interviewed around 120 coffee farmers in each supply unit and achieved a less than 10% margin of error. Table 1 shows the overview of data collection of ECS survey. In total, ECS collected 8,236 survey data sets representing around 700,000 coffee farmers across seven provinces and 44 districts in Sumatra. The surveys were conducted during the harvest periods of respective regions that can provide more representative information regarding coffee farming activities (October-December 2018 for Northern Sumatra and April-July for Southern Sumatra). Backchecks on a sample size of around 8% were done to ensure data integrity. The average length of a survey was 62 minutes. The average age of farmer's interviewed was 47 years, of which 30% were female.

Table 1. Overview of the farm and household characteristics

Information	Description
Number of provinces	7
Number of districts	44
Total number of supply units	68
Total number of surveys:	8,236
Southern Sumatra (West Sumatra, Bengkulu, Jambi, South Sumatra, and Lampung)	2,914
Northern Sumatra (Aceh and North Sumatra)	5,322
Data collection period:	
Northern Sumatra	Oct-Dec 2018
Southern Sumatra	Apr-Jul 2018
Average number of surveys for each supply unit	121
Average survey length	62 minutes
Demographic information:	
Average coffee farmer's age	47 years old
Gender	30% of farmers interviewed are female

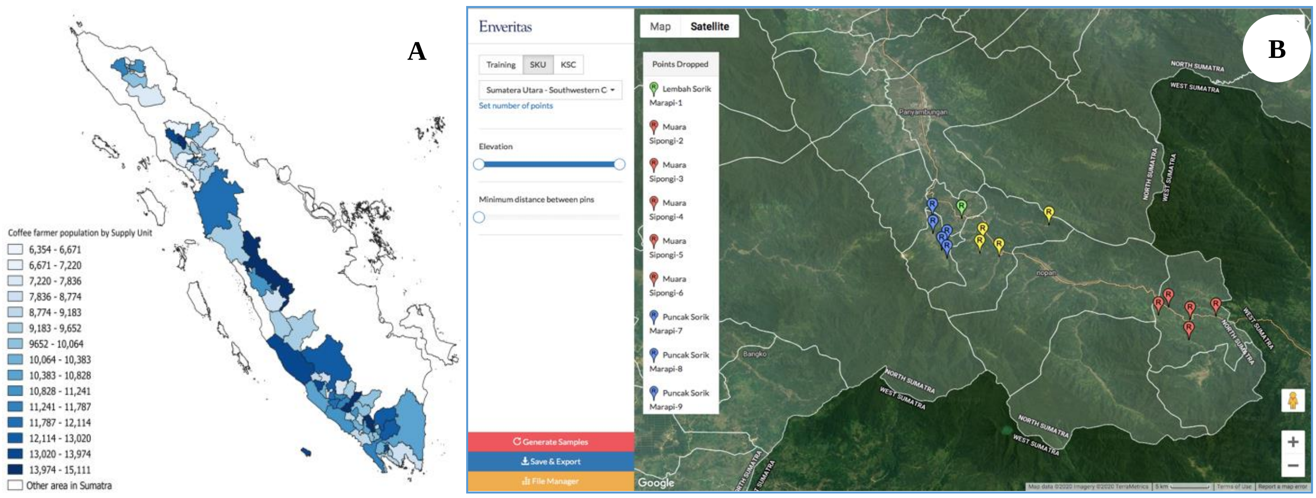


Figure 1. Identifying coffee growing location and sample randomization. A. Number of farmer by supply unit. B. Illustration of Enveritas' geo-randomization tools. The tools randomly drop a set of pins to which the enumerators will go to do the surveys.

Data analysis

Our research focused on finding several possible factors that correlated with yield including fertilizer application, tree density, levels of shade tree, chemical application, pruning, and replanting. Multiple linear regression was used by differentiating between Arabica and Robusta species. Farmer's characteristics such as farm size, exposure to farming-related training, experience of growing coffee, and hiring labor as well as provincial dummies were used as additional controls. In addition to yield, we also used yield per tree, total revenue, and revenue ha^{-1} as dependent variables to check factors that correlated with them. Controlling for those factors, we examined the association between yield and the application of (i) fertilizer or compost based on the use of soil or leaf testing; (ii) tree density, and (iii) shade level.

RESULTS AND DISCUSSION

For the seven provinces in Sumatra, 35% of the farmers grew Arabica which accounted for 18% of total coffee production. Most farmers in Northern Sumatra grew Arabica coffee (96%), while those who were in Southern Sumatra mostly grew Robusta (98%).

The survey found that an average smallholder coffee farmer had a coffee farm size of 1.15 ha, grew 2,427 trees, producing 645 kg of GBE (Green Bean Equivalent) coffee with a yield of 562 kg of GB ha^{-1}, and generating gross revenue of IDR 19.5 million per year. The provinces with the highest farm size were Bengkulu (1.61 ha) and South Sumatra (1.58 ha) and the lowest farm size were North Sumatra (0.41 ha) and West Sumatra (0.57 ha). The yields were quite comparable across provinces in Sumatra, which was around 500 kg of GBE ha^{-1}. Jambi and South Sumatra have relatively higher yields of 829 kg $ha^{-1}$and 631 kg ha^{-1}, respectively.

Comparing Arabica and Robusta farmers, on average Arabica farmers had smaller coffee farm size (0.68 vs 1.42 ha) and lower tree density (1,820 vs 2,143 trees ha^{-1}). In addition, despite having smaller total production (340 vs 812 kg of GBE) and lower yield (536 vs 577 kg ha^{-1}), Arabica farmers had an overall higher gross revenue (IDR 22 million year-^{1} vs IDR 18 million $year^{-1}$) than Robusta farmers due to higher price of Arabica coffee. The highest gross revenue from coffee farming was observed in Aceh (IDR 41 million $year^{-1}$) and the lowest was in West Sumatra (IDR 7.4 million $year^{-1}$). According to the Indonesian Ministry of Agriculture (2017), smallholders' production costs on average constitute 68.9% of the farm gate price. The reported earnings and expenses might put farmers in a vulnerable position to economic shocks such as in the event of drought, pest or disease infestation, or coffee price or production shocks. It is likely that this revenue was too low to cover the living expenses if the farmer's livelihood relies solely on coffee farming. It is in this scenario that improving yield takes utmost precedence. Despite this, when asked if their children would continue farming, majority of farmers (55%) said yes, which indicated their outlook towards future generations willingness to take up coffee farming as a profession.

In terms of the farming practices, there were more fertilizers used (86% vs 63%) but lower chemical used (68% vs 91%) among Arabica farmers compared to Robusta farmers (Figure 2). In terms of processing, Arabica farmers mostly sold their coffee as wet parchment (71%) and cherry (23%), while almost all Robusta farmers sold their coffee as green beans (97%).

When asked about the oldest coffee tree on the farm, many farmers (44%) reported having the oldest tree be between 11 to 20 years. In 2012, the Ministry of Agriculture estimated that 60% of Indonesia's coffee trees are more than 25 years old. The ministry allocated nearly IDR 143 billion (13 million USD) for Arabica expansion and Robusta rejuvenation (Neilson et al. 2015). The data collected through ECS should help the government to sharpshoot such investments where it is most needed.

Fertilizer use and soil conservation

Fertilizer is an important contributor to coffee yield. We found 14% of the Arabica farmers and 37% of the Robusta farmers did not apply fertilizer on their farm (Figure 2). The number of farms that used compost or organic fertilizer varies significantly between Arabica (66%) and Robusta (22%) (Figure 2). Other studies (Wahyudi and Jati, 2012; Saragih 2013) also reported that coffee yield in Indonesia was still relatively low, covering at 50-65% of potential production, possibly due to limited fertilizer application. Commonly cited causes for low yield also relate to the old age of the coffee trees.

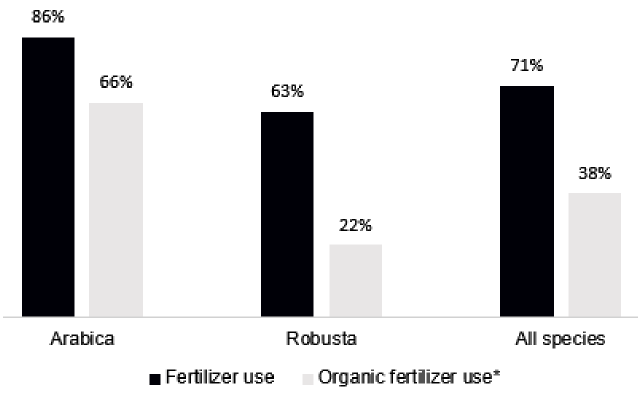


Figure 2. Percentage of farmers who use fertilizer and organic fertilizer by coffee species. Note: *For the use of organic fertilizer, percentage for Arabica is from Aceh and North Sumatra, percentage for Robusta is from the rest of Sumatra. The questions that identified the use of organic fertilizer was updated for surveys in Aceh and North Sumatra

This limited use of fertilizers could be a limitation in improving yields. The analysis showed that the use of fertilizer (including both organic and inorganic) was associated with an increase in yield of 98 kg of GBE ha^{-1} for Arabica and 124 kg of GBE ha^{-1} for Robusta (Table 2). These estimates were significant at α = 1% level. The use of fertilizer is also associated with higher yield per tree (0.058 kg/tree for both Arabica and Robusta). In terms of revenue per hectare, on average, both Arabica and Robusta farmers that applied fertilizer had higher gross revenue per hectare of IDR 6.9 million/year and IDR 2.8 million $year^{-1}$, respectively.

Neilson et al. (2015) highlighted the limited use of fertilizers (inorganic and organic) and inadequate attention towards maintaining soil fertility and conserving soil resources in Indonesia. Ibnu (2017) also stated that the production costs are relatively low, because most farmers make limited use of fertilizers. However, this turns out to also limit yields in Indonesia. Thus, it is necessary to educate the farmers to increase organic or chemical fertilizer application. Research results from the Coffee research unit at the Western Highlands Agriculture and Forestry Science Institute (WASI) in Vietnam, showed that applying fertilizers based on soil tests could save up to 30% of fertilizer while increasing yield up to 10% given the context that some farmers in Vietnam tend to overuse fertilizers (VCCB 2016). This will have an impact on input cost reduction, soil conservation, greenhouse gas, and sustainable production. The situation seems to be in contrast for Indonesia but the implication here is the benefits of soil tests in guidance of efficient fertilizer application.

In terms of sustainability, soil conservation is very critical in agriculture production. We found 79% of farmers did not apply any methods of soil conservation methods, 11% applied to mulch (i.e., coffee husk or peanut residue), 10% applied cover crops probably only for immature stage farms. Usually, mulching is not common for mature coffee, and not suitable for fertilization activities-farmers tend to rake and bury the tree residues. The most popular soil erosion control method was using natural barriers (12%), followed by contour planting, and replanting sloped areas (8% and 7%, respectively). Different techniques for soil conservation such as terracing, stabilizing grasses, etc. accounted for a small proportion.

Tree density

The average tree density we found in Sumatra varied for both Robusta and Arabica (Figure 3). For Robusta, we observed an average tree density of 2,143 trees ha^{-1}, and for Arabica 1,820 trees ha^{-1}. This tree density in Sumatra does not seem optimal for neither Arabica nor Robusta varieties.

Our research found that the two Arabica growing regions of Aceh and North Sumatra had a low tree density of 1,611 and 1,958 trees ha^{-1}, respectively. Significant yield improvements could be achieved by helping coffee farmers to reach optimal tree density. For Arabica, the optimal density varied from one variety to another. The open growth variety (i.e., Mundo Novo) is normally planted at low density (1,200-1,600 plants ha^{-1}). However, it can also be successfully grown at higher planting densities (3,000-4,000 plants ha^{-1}) (Eskes and Leroy 2004). Dwarf Arabica variety (i.e., Caturra) seems well adapted to the growing conditions that prevail in Colombia and Costa Rica, where it has served as a basis for high-density planting (5,000-10,000 plants ha^{-1}) (Eskes and Leroy 2004). In several countries, the best productivity results have been obtained with densities of 10,000 to 12,500 coffee trees ha^{-1} (Descroix and Wintgens 2004). Nevertheless, to secure sustainable, long-term production and to allow access to the plots for maintenance purposes, producers prefer to plant 4,000-7,000 trees ha^{-1}. This corresponds to a spacing between 2 m x 1.2 m and 1.7 m x 0.8 m (Descroix and Wintgens 2004). The density for Arabica that we found in our surveys, was far too low to this recommended range by other researchers. In Indonesia, the most popular varieties are Ateng which is a common name for Catimor coffees, followed by Sigara Utang-an improved Ateng selection of Timor variety with Bourbon, then Gayo (1, 2, 3) which is also a derived varietal of Catimor. Catimor is a hybrid of *C. Arabica* and *C. canephora* (Timor hybrid) with *C. Arabica* var. *catura*, and it is advised that Catimor with compact canopy should be planted at high density of at least 3,000-4,000 plants ha^{-1}.

Simultaneously, unlike the less-than-optimal tree density for Arabica, we found that the tree density for Robusta was higher than the optimal range. We found in the five Robusta growing provinces the tree density ranging from 1,364 trees ha^{-1} in West Sumatra to 2,455 trees ha^{-1} for Bengkulu. This is high for Robusta as the suggested density for Robusta worldwide can range from 1,250 to 2,220 coffee trees ha^{-1}. In full exposure to sunlight, the optimal density is approximately 2,000 plants ha^{-1}. Under shade, the density will be lower and will vary according to the density of the shade. The denser the shade, the lower the density of the coffee trees (1,250-1,660 trees/ha) (Descroix and Wintgens 2004). The density for Robusta found in our surveys was higher than the recommended range.

Our analysis shows that yield was positively correlated with tree density for Arabica coffee the correlation is 0.31 and for Robusta it is 0.67 (Figure 3). The regression analysis shows that 100 additional trees ha^{-1}were associated with higher yield by 9 kg $ha^{-1}$for Arabica and 15 kg ha^{-1} for Robusta (Table 2). Despite that, the yield per tree basis decreased as there were more trees ha^{-1}, showing the importance of planting an optimum number of tree densities for each species based on the research mentioned earlier.

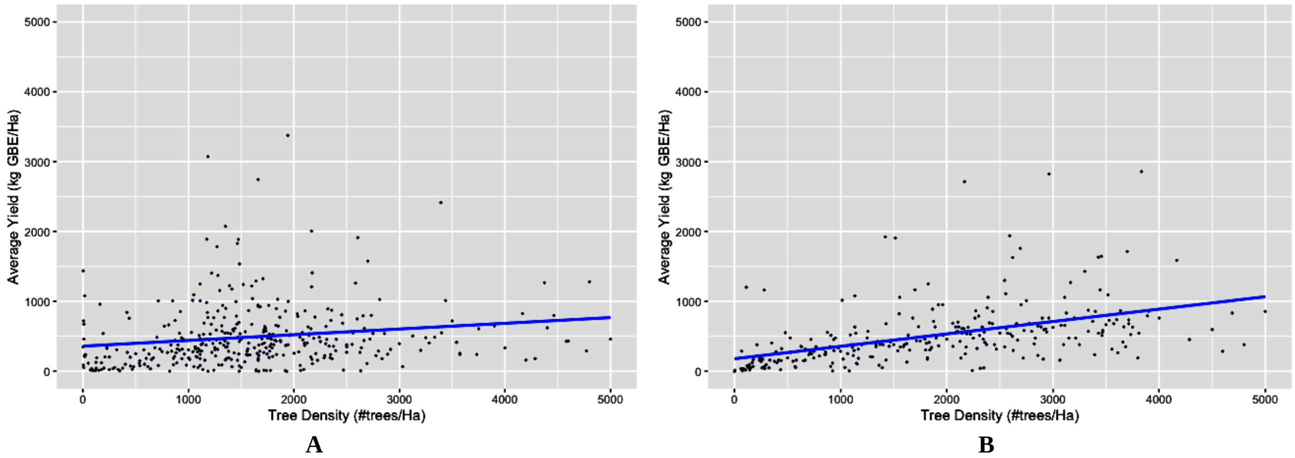


Figure 3. Scatterplot of yield and tree density for: A. Arabica, B. Robusta

Table 2. Regression analysis for several farming

	[1] Arabica	[2] Robusta	[3] Arabica	[4] Robusta	[5] Arabica	[6] Robusta	[7] Arabica	[8] Robusta
VARIABLES	Yield	Yield	Revenue (IDR 000)	Revenue (IDR 000)	Yield per tree	Yield per tree	Revenue/Ha (IDR 000)	Revenue/Ha (IDR 000)
Farming practices								
Type of shade = No shade (base category)								
Type of shade = Light/medium shade	-58.67***	-66.95	-1,731	10.24	-0.0349**	-0.012	-3,785**	-1,763
	[22.62]	[81.07]	[1,477]	[3,336]	[0.0142]	[0.0458]	[1,581]	[1,952]
Type of shade = Heavy shade	-94.84**	-114.9	1,737	-1,464	-0.0382	-0.0368	-6,807**	-3,018
	[41.54]	[82.84]	[2,715]	[3,409]	[0.0261]	[0.0468]	[2,905]	[1,995]
Tree density (trees/Ha)	0.0893***	0.149***	2.763***	3.629***	-8.49e-05***	-7.73e-05***	5.669***	3.271***
	[0.0113]	[0.00766]	[0.736]	[0.317]	[7.08e-06]	[4.33e-06]	[0.787]	[0.185]
Use fertilizer	97.75***	124.0***	6,455***	2,670***	0.0580***	0.0584***	6,976***	2,832***
	[28.11]	[14.53]	[1,836]	[600.4]	[0.0177]	[0.00822]	[1,964]	[351.4]
Do soil or leaf testing	-146	130.4***	-10,058*	8,525***	-0.102*	0.0446*	-8,927	3,762***
	[89.50]	[43.48]	[5,812]	[1,806]	[0.0562]	[0.0246]	[6,220]	[1,057]
Use chemicals	-7.907	-7.763	-1,386	647.7	-0.00333	0.000398	-1,569	121.9
	[19.12]	[24.77]	[1,249]	[1,032]	[0.0120]	[0.0140]	[1,336]	[603.8]
Do pruning	32.12	36.71	505.3	-133.7	0.00892	0.00413	3,996***	1,119**
	[21.05]	[23.23]	[1,372]	[965.1]	[0.0132]	[0.0131]	[1,468]	[564.8]
Do replanting	20.44	22.09	925.2	-411.6	0.0111	0.011	1,714	714.9
	[20.94]	[19.17]	[1,368]	[790.6]	[0.0132]	[0.0108]	[1,463]	[462.6]

Shade level

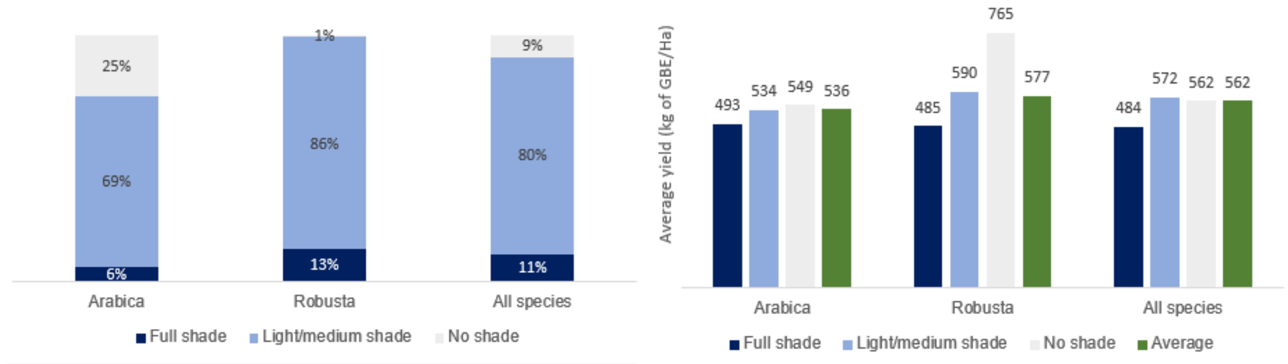
For this study, we defined light shade as 0-30%, medium shade as 30-60% and heavy shade as 60-100%. A predominant number (80%) of farms in Sumatra fell under light and medium shade, while 9% of the farms have almost no shade and 11% full shade. Leucaena, Albizia, and Gliricidia were the most popular shade trees in Sumatra accounting for 30%, 29% and 18% of farms, respectively.

We found the shade levels were not just appropriate but reverse. Arabica needs more shade, but 25% of farms surveyed had no shade, 69% of the farms have light and medium shade, and 6% of the farms had full shade. Robusta usually requires less shade than Arabica. However, among the Robusta farms, light and medium shade were observed in 86% of the farms, full canopy in 13% of the farms, and 1% of the farms had no shade (Figure 4.A). Other researchers such as Neilson et al. (2015) have found most coffee across Indonesia is grown under a relatively dense canopy of shade or as multi-strata coffee. The observed canopy levels in Indonesia where full canopy accounts for 11% was too high resulting in low production, and the medium shade of 46% was also high compared to the widely recommended level of shade.

We found the level of shade had a negative correlation with yield i.e., higher yield observed in less shade farms, especially in Robusta (yield of 765 kg/ha for no shade tree vs 485 kg/ha for having full shade tree) (Figure 4B). Saragih (2013) also found that shade trees have significant influence on coffee production in North Sumatra (at α = 10%). However, we also understand that shade management has its pros and cons. If the shade tree population increases, coffee production decreases due to reduced flowering and competition between species for nutrients. On the other end, shade trees have a positive role in improving the coffee quality and bean size (Muschler 2004), and biodiversity. Our analysis also showed the tree productivity is highest for lowest tree density and none for medium shading. It decreases with higher tree density and is significantly lower when heavy shading is observed (Figure 5).

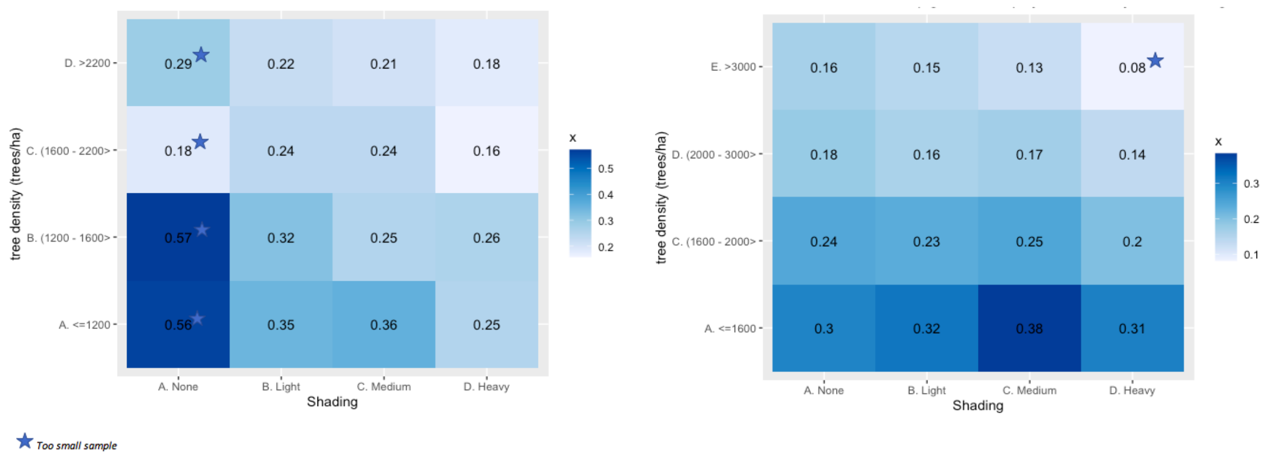
The best shade level varies with environmental conditions and production objectives. For low-altitude coffee zones (typically below 800 m. a.s.1.) with a pronounced dry season of 4-6 months, the suggested shade level was of 35-65%. Another study showed the rates of photosynthesis or growth of *C. Arabica* are highest at intermediate levels of shade, typically ranging from 30 to 50 % (reviewed by Muschler 2004). For Robusta, the shade should not exceed 40% as it will affect coffee production (Lambot and Bouharmont 2004). This level of shade would favor leaf retention in the dry season and reduce the incidence of some diseases and weeds. Higher shade levels should be avoided because of the potential increase of the Leaf Spot, which is encouraged by higher humidity, a condition accentuated by shade. Conversely, lower shade levels should be avoided because of the increased incidence of Brown Eye Spot disease and of the Coffee Leaf Miner under unshaded conditions (Muschler 2004). Leguminous shade trees are the most commonly used in coffee plantations (Lambot and Bouharmont 2004).

Shade management requires significant research, as the role played by other trees in a farm plays a crucial role in promoting biodiversity and environmental sustainability. We recommend no one-size-fits-all approach here and recommend interventions that are tailored factoring in the farm level context, without compromising any of the three pillars of sustainability: environmental, economic, and social.



A B

Figure 4. Shade tree level and yield. A. Distribution of shade tree level by coffee species. B. Average yield by shade tree level and coffee species (right)



A B

Figure 5. Tree yield by tree density and shade level for: A. Robusta and B. Arabica

Conclusion and policy recommendations

The Enveritas Coffee Survey is rigorous and possibly one of the largest studies conducted in Indonesia with an aim to promote coffee sector sustainability. Both the crop and the sector are of utmost importance to policymakers for the following key reasons: (i) coffee is one of the key export commodities; (ii) a significant portion of coffee producers are smallholder farmers vulnerable to economic shocks. Increasing the economic opportunities for coffee smallholders would lead to resilient rural communities, more export opportunities, poverty eradication, and importantly, to promote the inclusive and sustainable growth of the nation.

We started our analysis by exploring the variables that can have the maximum impact on the coffee producers. A comparative analysis of yield with other coffee-growing regions has given a clear indication that yield improvement is a priority. From the Enveritas Coffee Survey, we explored troves of data to understand the key variables that are associated with yields. We found three variables: (i) Fertilizer use was low among farmers, especially Robusta. There is scope to measure and improve soil health either through organic/inorganic fertilizer use and other soil conservation methods that can help increase yields; (ii) Coffee tree density: we found that there is a huge mismatch between the prevailing tree density in both Arabica and Robusta farms. By reviewing other literature, we have also presented the recommended tree density; (iii) Shade level: we also found that the shade levels among the coffee farms are not conducive to obtain optimal yield. We classified the farms into three shade categories and, after evaluating external research done on this topic, recommended best levels of shade. We also emphasized that shade management requires a farm-specific, tailored approach to increase yield potential without compromising biodiversity protection.

There are, however, limitations to our study. Our data collection and study focused more on the sustainability aspects of coffee farming, focusing largely on the social, economic, and environmental aspects. In-depth analysis of cultivation practices, soil, or climate are not part of the scope of this study. The factors, especially of nature, that influences a farm are hard to comprehend and will require years of research. Each farm is unique, and so is each farmer. By reaching out to thousands of farmers in some of the remotest places, we tried to present findings that could have a most positive impact. Using our research as a starting point, we would like to make the following recommendations as an area of future research or programs: (i) Conduct a rigorous study on each harvest to understand the yield figures across Indonesia's coffee-growing regions. Systematically understanding the progress on yields, preferably at a district level, will initially help understand the overall smallholder productivity landscape and later to implement and measure necessary interventions. (ii) Identify the prevailing prices of soil and leaf testing services and explore designing interventions to make such services affordable to farmers. (iii) Initiate a research program to understand the pathways to reach optimal tree density among both Arabica and Robusta growing smallholder's farms. (iv) Initiate a research study to understand the aspects of shade management that are suitable for the Indonesian context. Such research should focus not just on yields, but also the role of shade trees in biodiversity and the ecosystem services that comes with it.

Our findings have valuable insights for policymakers, development organizations, and anyone interested in coffee sectors sustainability. This is especially prudent in a time the national government has been planning initiatives to make 2019 as the year of the Indonesian farmers' revival. Our findings also have implications for coffee value chain actors that are committed to sustainable supply chains. We acknowledge that understanding the key factors that influence yields is just one step towards developing robust policy recommendations for creating inclusive employment opportunities. Effective dissemination of agricultural practices through programs such as farmer field schools or demo plots is also of utmost importance.

ACKNOWLEDGEMENTS

The authors thank Ade Amanullah from Enveritas for excellent assistance in data closeouts, all field coordinators, and enumerators for their efforts in collecting high-quality data.

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ASIAN JOURNAL OF AGRICULTURE
Volume 5, Number 2, December 2021
Pages: 61-71

E-ISSN: 2580-4537
DOI: 10.13057/asianjagric/g050203

Variation in winged bean (*Psophocarpus tetragonolobus*) growth parameters, seed yield, nodulation, and nitrogen fixation

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Manuscript received: 23 February 2021. Revision accepted: 14 August 2021.

Abstract. *Adegboyega TT, Abberton MT, Abdelgadir AH, Mahamadi D, Olaniyi OA, Ofodile S, Babalola OO. 2021. Variation in winged bean (*Psophocarpus tetragonolobus*) growth parameters, seed yield, nodulation, and nitrogen fixation. Asian J Agric 5: 61-71.* Underutilized legumes are widely distributed in tropical agriculture and associated with low yield. Thus they have not really been fully explored due to lack of research investment, breeding programs targeting crop improvement, marketing, and low awareness of nutritional benefits. This study was conducted to determine the variation in growth parameters, seed yield, nodulation, and nitrogen fixation in winged bean (*Psophocarpus tetragonolobus*) germplasms. High genotypic and phenotypic coefficients of variances were observed in traits evaluated. The combined analysis of variance for five variables of 25-winged bean accessions showed that replication by year interaction was statistically significant ($p \leq 0.0001$) for nodule parameters and dry shoot weight while it was not significant ($p = > 0.05$) for dry root weight, and total biomass. Significant variations ($p = \leq 0.05$) were observed among the accessions on some growth parameters. The genetic variability of winged beans could be carefully exploited to provide higher grain yield, as well as other economic and important traits to boost food security and conservation of the plant genetic materials.

Keywords: Crop improvement, genetic variability, nitrogen fixation, sub-Saharan Africa, winged bean

INTRODUCTION

Winged bean (*Psophocarpus tetragonolobus* (L.) DC.,) is a member of the underutilized or orphan legumes in the tropics but with proven ability for vigorous twining habit, Nitrogen fixation capacity and tuberous root system (Eagleton 2020; Vatanparast et al. 2016). It grows in the world's most common agro-ecologies (the hot, humid equatorial countries) (Afridatul and Syukur 2021; Lepcha et al. 2017). The United States Academy of Science gave the limelight to the crop in a 1975 publication and since then research attention has focused on the crop particularly on its agronomy, nutritional composition, and other aspects of crop improvements but subsequently, research interest dwindled but current evidence showed renewed interest at crop promotion and molecular breeding activities being exploited amongst other interventions (Eagleton 2020; Lepcha et al. 2017). The research could focus on germplasm characterization, exploration of genetic resources, employment of modern breeding tools/technologies and soil-related strategies (nodulation, nitrogen fixation, etc.).

The crop is a member of the Fabaceae family, Papilionoidea subfamily, a dicotyledonous plant consisting of a diploid genome and six pairs of long chromosomes estimated at around 1.22 Gb (Giga base pair) in size Vatanparast et al. (2016). Winged beans grow indeterminately, with intertwining vines and lateral branches to support plant growth (Schiavinato and Válio 1996). Certain variations exist in the seed coat color, ranging from cream to black, brown to purple, and mottled colors (Klu and Kumaga 1999; Mohanty et al. 2020). It's a multipurpose crop with extensive culinary uses with different plant parts (flowers, green pods, tubers, seeds, and leaves) (Massawe et al. 2016). It requires less input and produces reasonable amount of food to provide adequate dietary support from the plant parts (Lepcha et al. 2017).

In areas where winged bean is cultivated, particularly in India, New Papua Guinea, Thailand, Ghana, Indonesia, and Burma, various parts of the plant have been used for one meal preparation, confectionaries or the other to suit the need of the local communities (either as snack or whole meal) (Lepcha et al. 2017). Khalili et al. (2013) and Nazri et al. (2011) reported their antimicrobial efficacy in treating common bacterial infections. Wan et al. (2014) have also demonstrated that extracts from winged bean seeds could be useful for industrial applications.

In general, this crop is grown traditionally. It is very common to find winged beans associated with other crops as part of a farming system. It is also part of a rotation, especially with sweet potato (*Ipomoea batatas*) as an alternate crop. Rice, followed by winged bean and sugar cane, is a common rotation in Southeast Asia (Myanmar). In Papua New Guinea, it is very common to find winged beans in association with maize. The maize and bean are planted simultaneously, or the legume is planted later and uses the dry stalks for support. The winged bean is also associated with *Leucaena leucocephala* (Eagleton 2020; Rahman et al. 2014a). The nutrients, mineral composition, and physicochemical properties of winged bean have considerable potential. The seeds, pods, swollen roots, flowers, and foliage are rich in macronutrients (Makeri et al. 2017) and micronutrients (Lepcha et al. 2017). The seed oil content and fatty acids composition may be explored for different industrial uses. Oil obtained from winged beans has been described as better than soybean oil owing to its efficient heating capacity which makes it suitable for frying food. What needs to be done now is to scale up its utilization (Makeri et al. 2016). Winged beans are suitable for cultivation in soils with low fertility as it combines with and fixes nitrogen, useful as a cover crop, and is also used for intercropping systems (Wong et al. 2017). Adegboyega et al. (2019) and Esan et al. (2020) variable levels of nutrients and antinutrients were recorded in the seeds and tubers irrespective of the state in which samples were processed. The consumption of winged beans could help minimize malnutrition and provide alternative substitutes for other legumes. Consequently, there is an urgent need to support the increasing population of the world in the face of poor distribution and recycling of agricultural commodities to further boast food and agricultural sustainability (Tanzi et al. 2019).

This study investigated genetic variability for seed yield, nodulation, and N fixation of field-grown accessions of winged bean without application of fertilizers and inoculants, using ^{15}N and ^{13}C natural abundance to identify potential traits accessions for future breeding programs and farming systems.

MATERIALS AND METHODS

Study area

Field experiments were conducted at IITA (latitude 7°30'8"; longitude 3° 54'37") Ibadan, Southwest Nigeria, on an Alfisol soil of the Egbeda series (Omotoso and Aluko 2016). Every month, rainfall ranged between 0.05 and 86.5 mm, while the minimum and maximum temperatures ranged between 20 and 27°C and from 24 to 35.2 °C (Figure 1).

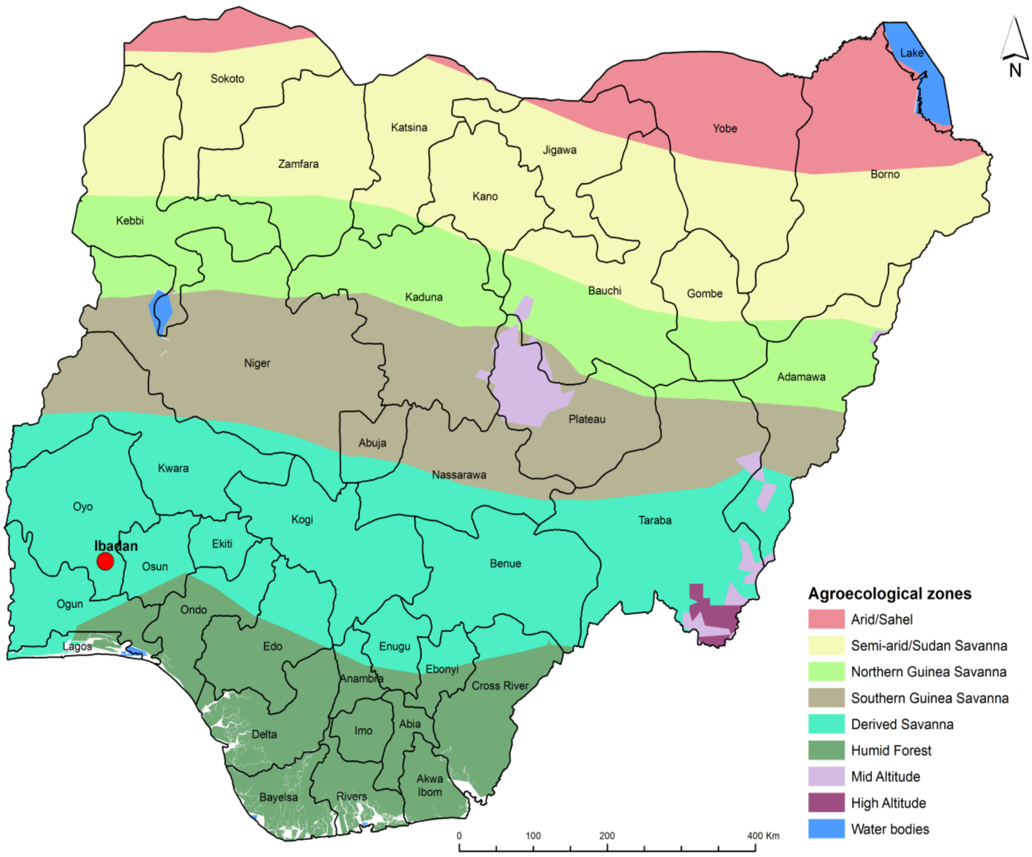

Figure 1. Map of Nigeria showing the various agroecological zones and the study location (Ibadan, in red). Source: Geospatial Information System (GIS) Unit, International Institute of Tropical Agriculture (IITA), Nigeria.

Planting materials and experimental design

Twenty-five accessions of the crop were obtained from the IITA germplasm collection center (Table 1). Soil samples were collected from a depth of less than 20 cm (0-15) analyzed (Table 2) according to Juo (1978). Seeds were planted with 1m spacing between plants on 5m long ridges using standard agronomic procedures for the field experiment conducted in randomized block design in three replicates. The seedlings were staked with plastic-coated stakes four weeks after planting. To keep the experimental field weed-free, manual weeding was done regularly. Neither fertilizers nor bacterial inoculants were applied. Morphological traits measured were terminal petiole length, leaf rachis, terminal leaf length and width, flower width and dry pod weight, and other seed parameters (seed length and thickness, 100-seed fresh weight, seed width, total seed) weight, and total number of seeds) including the pod length. The plant growth and nodulation parameters evaluated included nodule number per accession, nodule dry weight, dry shoot weight, dry root weight, and total biomass. Methuen Handbook of Color was used for seed coat description (Kornerup and Wanscher 1978).

Data collection and sample processing

Morphological measurements were taken from five individual plants from each accession. When the plants were at 50% flowering, shoots were cut off at the base with the roots specifically dug out and washed under flowing tap water. Nodule number, fresh and dry weights, fresh and dry shoot weights, fresh and dry root weights were recorded. Plant shoots were separated into leaves, stems, and petioles. The plant shoots and roots were then oven-dried at 60°C for 48 h. After that, they were measured, and processed to smooth powder in a 0.85-mm sieve to determine the amount of nitrogen fixed and estimates of the carbon and nitrogen ratio in the test plants. Mass spectrometry was carried out the investigation at the Department of Earth and Environmental Sciences, Katholieke Universiteit Leuven, Belgium. The non-fixing plant, *Eleusine indica,* was sampled concurrently from the field and processed for ^{15}N and ^{13}C isotope analysis as described above.

Measurement of N_2 fixation

This was carried out to determine the amount of N fixed by each accession plant. The milled material was carefully dispensed into aluminum tin capsules (0.5–1 mg) and analyzed for %N and $^{15}N/^{14}N$ ratio using a Thermo EA-1110 elemental analyzer (FORNO EA/NA ThermoQuest, Italia, S.P.A). Natural abundance of ^{15}N is expressed as δ (delta) notation and is the per mile deviation of the ^{15}N natural abundance of the sample from atmospheric (atm) N_2 (0.36637 atom % ^{15}N).

The isotopic composition ($\delta^{15}N$) was calculated as described by Unkovich et al. (2008).

$$\Delta^{15}N = \frac{(^{15}N/^{14}N)_{sample} - (^{15}N/^{14}N)_{atm}}{(^{15}N/^{14}N)\ atm} \times 1000$$

Where: $^{15}N/^{14}N$ is the abundance ratio of ^{15}N and ^{14}N in the shoot and root samples while the $^{15}N/^{14}Natm$ is the abundance ratio of ^{15}N and ^{14}N in the atmosphere.

The percentage N derived from atmospheric N_2 was calculated by the equation below Unkovich et al. (2008).

$$\%\ Ndfa = \frac{\delta^{15}N\ ref - \delta^{15}Nleg}{\delta^{15}N\ ref - B} \times 100$$

Where: $\delta^{15}N$ ref represents ^{15}N natural abundance of reference plants, $\delta^{15}N$ leg is the ^{15}N of the legume, and the B value is the ^{15}N of the test legume solely reliant on N_2 fixation. In this study, the B value used was −1.54 as Unkovich et al. (2008) explained.

The quantity of N-fixed was estimated as described by Unkovich et al. (2008);

$$N\ fixed = amount\ of\ N \times \%\ NdfA$$

Analysis of 13C/12C

This was carried out to determine the amount of C and N ratio in the plants of each tested accession. To analyze the $^{13}C/^{12}C$ ratio, shoot and root samples (0.5–1.0 mg) were used following the same procedures described for the $^{15}N/^{14}N$ isotopic ratio. The ratio of $^{13}C/^{12}C$ in the sample was used to calculate the ^{13}C ($\delta^{13}C$) as described by Stout and Rafter (1978).

$$\Delta^{13}C = \frac{((^{13}C/^{12}C)_{sample} - (^{13}C/^{12}C)_{standard-1})}{(^{13}C/^{12}C)_{standard}} \times 1000$$

Where: $^{13}C/^{12}C$ is the isotopic ratio of the sample, and $^{13}C/^{12}C$ standard is the isotopic ratio of the known universally accepted standard for C.

Table 1. Twenty-five accessions of winged bean sourced from Genetic Resources Center, IITA.

Accession	Origin	Seed color
Tpt2	No passport data	Light brown
Tpt4	Costa Rica	Dark brown
Tpt6	Indonesia	Light brown
Tpt10	Sri Lanka	Brownish grey
Tpt11	Nigeria	Greyish orange
Tpt12	Sri Lanka	Brown
Tpt14	No passport data	Brown
Tpt15	No passport data	Dark brown
Tpt16	Indonesia	Greyish orange
Tpt17	Trinidad and Tobago	Light brown
Tpt18	No passport data	Brown
Tpt19	Nigeria	Dark brown
Tpt30	No passport data	Brownish orange
Tpt32	Liberia	Brown
Tpt33	No passport data	Light brown
Tpt42	No passport data	Reddish-brown
Tpt43	Bangladesh	Dark brown
Tpt48	No passport data	Greyish yellow
Tpt51	Bangladesh	Greyish orange
Tpt53	Nigeria	Dark brown
Tpt125	No passport data	Light brown
Tpt126	Nigeria	Brown
Tpt154	No passport data	Greyish orange
Tpt15-4	No passport data	Reddish blond brownish orange
Tpt3-B	No passport data	Yellowish dark blond

Genotypic and phenotypic components of variance

These components of variance were carried out according to Burton and Devane (1953):

Genotypic Variance (σ^2g) = (MSg-Mse)/r

Where: MSg: Mean square of genotype, Mse: Mean square of error, r: number of replications

Phenotypic Variance, $\sigma^2p = \sigma^2g + \frac{\sigma^2 e}{r}$

Where: σ^2e: Mse and σ^2g: genotypic variance

Genotypic Coefficient of Variation (GCV)

$$\mathbf{GCV} = \frac{\sqrt{\sigma^2 \mathbf{g}}}{\bar{\mathbf{X}}} x\mathbf{100}$$

Where: σ^2g: genotypic variance and $\bar{x}$: mean of the character

Phenotypic Coefficient of Variance (PCV)

PCV = 100 (σ^2P) ^{½}/x

Where: σ^2P: phenotypic variance, and $\bar{x}$ = mean of a character

Broad Sense Heritability (h^2): This refers to the extent of the total phenotypic variation due to all genetic effects. This was calculated as recommended by Hanson et al. (1956) as follows:

$h^2 = 100 (\sigma^2g/\sigma^2p)$

Data analysis

Statistical Analysis System computer software version 9.4 (Institute 2015) was used for data analysis for the general linear model (GLM) procedure and least significant differences were estimated at $P \leq 0.05$ for mean separation with mean values obtained from two years of field data. Genotypic and phenotypic components of variance were calculated by the formula of Burton and Devane (1953), broad-sense heritability was computed as a percentage of the mean following the methods of Hanson et al. (1956). For principal component axis (PCA), eigenvalues (a measure of the extent of variation observed in variables), difference, cumulative variance, and principal scores (eigenvectors, which makes the understanding of the linear transformation in an easy way) of the first three components of genetic divergence in winged bean shoots and roots were also generated using SAS software as well as dendrogram.

RESULTS AND DISCUSSION

Results

In this study, a total of thirty-one (31) traits were measured, consisting of various agro-morphological characteristics using the standard winged bean descriptor and ^{15}N natural abundance for plant shoots and roots analysis. Table 1 describes the list of accessions used for the study in relation to number, origin, and seed color. Prominent seed colors were: light brown, brown, dark brown, reddish-brown, greyish brown, and reddish-blond brownish orange. Soil analysis results of the study site and map of the study location were given in Table 2 and Figure 1, respectively. The site had moderate levels of the nutrients measured. Table 3 shows the estimates of variance for yield characters. The pod length, dry pod weight, total seed weight, total number of seeds, seeds per pod, and 100-seed fresh weight exhibited high genotypic (s^2g) and phenotypic (s^2p) variances. The coefficient of variation guide provides a quantification of the variance among the different traits and accessions studied. The total number of seeds per accession, total seed weight, terminal leaf length, terminal leaf width, pod length, dry pod weight, and number of seeds per pod exhibited a high genotypic (GCV) and phenotypic (PCV) coefficient of variances. The phenotypic coefficient of variation (PCV) values were 7.14 for flower width to 71.82, for dry pod weight while the GCV values were from 2.22 for flower width to 43.12 for dry pod weight. Furthermore, PCV values were observed to be more than the GCV for all the traits evaluated. Based on the classification, the PCV value was low for flower width; medium for terminal leaf length, leaf rachis, and seed parameters (seed length, seed thickness, seed width, and 100-seed fresh weight). It was high for terminal leaf length, terminal leaf width, pod length, dry pod weight, and number of seeds per pod, total seed weight, and total number of seeds.

The GCV values were low for terminal petiole length, leaf rachis, terminal leaf length, flower width, seed length, seed thickness, and 100-seed fresh weight; no trait was in the medium range. However, values were high for dry pod weight, number of seeds per pod, pod length, total seed weight, and total number of seeds. The high GCV values of these characters may imply that the traits mentioned above can be improved through selection. The PCV values were low for flower width; medium for terminal leaf length, leaf rachis and seed parameters (seed length, seed thickness, seed width and 100-seed fresh weight).

Table 2. Soil analysis of study site.

Soil parameters	Value
Sand (%)	78.00
Silt (%)	9.00
Clay (%)	13.00
pH (H_2O)	7.30
Organic carbon (%)	1.97
Total N (%)	0.04
Available nutrient (mg kg^{-1})	
P [1]	2.36
Ca^{2+}	472.00
Mg^{2+}	82.80
K^+	54.60
Na^+	131.10
Zn	5.10
Cu	1.35
Mn	168.95
Fe	31.40

It was high for terminal leaf length, terminal leaf width, dry pod weight, number of seeds per pod, pod length, total seed weight, and total number of seeds (Table 3). The broad-sense heritability ranged from 83.05% for total seed weight to 1.64% for leaf rachis (Table 3). However, for traits with low heritability, 40% or less, selection may be difficult due to environmental influence. Based on these criteria, the broad-sense heritability estimate was high for total seed weight (83.05); moderate (75-55) for total number of seeds, seed per pod, and pod length; low with less for 55 for dry pod weight, seed length, and other traits.

The mean number of nodules was 359.62, with mean nodule dry weight being 3.69 g and the dry shoot weight was 239. 97 g. While the dry root weight g and total biomass were 19. 38 g and 250.93 g, respectively. The combined analysis of variance for five variables of 25-winged bean accessions show that replication by year interaction was statistically significant ($P \leq 0.0001$) for number of nodules per accession (NON), nodule dry weight (NDW) and dry shoot weight (DSW) while it was not significant p = > 0.05 for dry root weight (DRW), and total biomass (TBM) (Table 4).

The interaction of the year of planting and weeks after planting showed highly significant results for all traits measured while the accession by year interaction was not statistically significant (p = > 0.05) for the traits measured. Significant differences (p =) were observed among the accessions on nodulation parameters of winged beans. Tpt15 had a significantly (p= ≤ 0.0001) higher number of nodules (607.42) than other accessions while Tpt3-B had the lowest (207.33). Tpt126 had the highest nodule dry weight at 5.03 g and Tpt3-B had the lowest at 2.54 (Table 5). Significant differences existed among the accessions (Tpt15, Tpt126, Tpt18, Tpt42, and Tpt154) on some growth parameters of winged bean, as shown in Table 5. The highest and the least total biomass were found in Tpt18 (428.83 g) and Tpt19 (168.07 g), respectively. Statistically significant (p = ≤ 0.05) variations were recorded in the dry root weights among the accessions with Tpt42 (36.47 g) and Tpt154 (11.32 g) having the highest values. The means of % N derived from the atmosphere (Ndfa) and N fixed of the studied accessions are shown in Table 6. The amount of N fixed (Kg ha^{-1}) in the shoots varied among the accessions with Tpt32 fixing 25.76 Kg ha^{-1}, followed by Tpt15-4 (24.23 Kg ha^{-1}). The accession fixing the least N was Tpt30 (9.02) with considerably lower amounts fixed in the roots. The amount of N derived from the atmosphere also ranged from 24.97% (Tpt30) to 62.13% (Tpt32). This result suggested that winged beans derived a fair quantity of Nitrogen from the atmosphere (Table 6).

Table 3. Estimates of variance for seed yield and its component characters in winged bean.

Traits	s^2g	s^2p	GCV (%)	PCV (%)	h^2 (%)
Terminal petiole length (cm)	0.90	10.07	7.11	23.78	8.94
Leaf Rachis	0.19	11.60	2.41	18.82	1.64
Terminal leaf length (cm)	0.40	4.61	5.62	18.97	8.79
Terminal leaf width (cm)	0.00	5.76	0.00	24.66	0.00
Flower width (cm)	0.01	0.06	2.22	7.14	9.64
Dry pod weight (g)	11455.07	31779.21	43.12	71.82	36.05
No of Seeds/pod	17.47	24.18	28.50	33.54	72.23
Seed Length (mm)	0.40	1.29	6.90	12.40	30.97
Seed Thickness (mm)	0.29	1.32	7.07	15.22	21.59
Pod Length (cm)	20.43	36.66	28.02	37.54	55.74
100-Seed Fresh Weight (g)	1.38	20.60	3.59	13.86	6.69
Seed Width (cm)	0.18	1.07	4.88	11.97	16.63
Total seed weight (g)	1,097,451.14	1321501.84	41.99	46.07	83.05
Total Number of seeds	8,568,620.93	11484969.33	37.73	43.68	74.61

Note: s^2g: Genotypic variance; s^2p: Phenotypic variance; GCV: Genotypic coefficient of variation, PCV: Phenotypic coefficient of variation; h^2: Broad sense heritability

Table 4. Summary of combined analysis of variance for 5 variables of 25 accessions of winged bean accessions.

Parameter	NON	NDW (g)	DSW (g)	DRW (g)	TBM (g)
Mean	359.62	3.69	239.97	19.38	250.93
Minimum	42.00	0.01	6.52	1.06	10.78
Maximum	1032.00	19.24	2195.04	207.11	2237.34
DF	291.00	291.00	279.00	290.00	270.00
Rep (Year)	762542.29***	42.59***	103339.74*	447.78^{ns}	68981.54^{ns}
WAP (Year)	546630.91***	762.27***	350379.82***	7956.37***	363741.64***
Year	15215065.31***	76.79***	4528622.964***	2245.70*	4293374.95***
Accession	92292.92*	4.55^{ns}	28871.50^{ns}	328.28^{ns}	29143.77^{ns}

Note: NON: Number of nodules; NDW: Nodule dry weight; DSW: Dry shoot weight; DRW: Dry root weight; TBM: Total biomass. DF: Degree of freedom; WAP: Weeks after planting; Rep: Replicate; ns: not significant *** and *Significant probability level at $P \leq 0.0001$ and 0.05 respectively.

Table 5. Means of nodulation and plant growth characteristics of winged bean accessions.

Accession	NON	NDW (g)	DSW (g)	DRW (g)	TBM (g)
Tpt10	290.67	3.29	253.93	19.71	275.38
Tpt11	401.55	4.21	226.80	19.52	246.33
Tpt12	352.17	4.15	188.92	15.45	204.49
Tpt125	312.08	2.86	177.49	24.00	200.85
Tpt126	469.42	5.03	285.72	20.22	303.79
Tpt14	322.73	3.21	232.87	24.11	246.31
Tpt15	607.42	4.54	329.38	17.06	346.44
Tpt15-4	400.50	3.10	285.17	16.61	254.13
Tpt154	239.18	3.45	163.40	11.32	176.61
Tpt16	326.83	3.79	260.47	14.85	275.32
Tpt17	293.25	3.00	192.91	14.20	207.96
Tpt18	477.75	4.14	403.23	25.60	428.83
Tpt19	381.08	4.20	163.34	16.98	168.07
Tpt2	332.17	3.54	275.99	18.32	281.80
Tpt3-B	207.33	2.54	168.49	28.75	198.15
Tpt30	464.50	4.77	279.37	19.50	298.87
Tpt32	434.92	3.67	223.81	16.79	239.45
Tpt33	329.36	3.48	259.36	19.46	209.34
Tpt4	427.73	4.11	258.72	20.98	279.70
Tpt42	320.83	2.90	209.39	36.47	248.85
Tpt43	288.58	4.06	256.50	16.77	273.27
Tpt48	392.09	3.25	255.10	16.22	252.07
Tpt51	251.07	3.48	183.06	20.36	181.04
Tpt53	301.27	3.86	165.39	14.98	180.64
Tpt6	357.27	3.69	229.51	15.05	211.37
C.V	94.71	85.73	87.70	103.52	83.50
F value	4.08***	4.27***	3.12***	1.48**	3.26***

Note: NON: Number of nodules; NDW: Nodule dry weight; DSW: Dry shoot weight; DRW: Dry root weight; TBM: Total biomass. Mean values of accessions are significantly different at $P \leq 0.05$, ns: not-significant and ***Significant probability level at $P \leq 0.0001$.

Table 6. Means of % N derived from the atmosphere and N fixed in shoots and roots of winged bean accessions.

Accession	RNfAT (%)	RTN (Kg/ha)	SNfAT (%)	STN (Kg/ha)
Tpt10	27.79	1.67	43.49	15.77
Tpt11	28.11	2.81	47.43	18.14
Tpt12	34.01	1.57	58.86	24.11
Tpt125	33.12	2.99	54.17	20.11
Tpt126	29.67	2.79	32.43	11.72
Tpt14	47.56	5.46	54.09	19.29
Tpt15	16.66	1.51	30.75	13.64
Tpt15-4	26.59	1.82	60.03	24.23
Tpt154	42.58	1.02	54.85	21.09
Tpt16	44.04	3.61	41.59	14.97
Tpt17	40.57	1.56	32.93	13.81
Tpt18	35.11	3.18	24.31	9.34
Tpt19	59.19	0.79	51.15	19.29
Tpt2	27.86	0.90	42.06	17.47
Tpt3-B	39.35	2.30	62.81	21.13
Tpt30	27.01	2.77	24.97	9.02
Tpt32	69.54	3.21	62.13	25.76
Tpt33	31.03	2.77	33.09	12.95
Tpt4	23.57	2.44	47.34	17.88
Tpt42	42.34	3.61	35.67	13.77
Tpt43	49.90	3.65	45.56	18.69
Tpt48	32.09	2.52	51.26	19.28
Tpt51	26.48	1.47	55.07	21.96
Tpt53	46.84	2.91	52.88	22.68
Tpt6	24.67	2.57	32.04	12.63
C.V	72.56	77.64	37.13	38.93
F value	1.54^{ns}	1.66^{ns}	1.69*	1.54^{ns}

Note: RNfAT: Root N derived from the atmosphere; RTNfixed (kg/ha): Root N fixed; SNfAT: Shoot N derived from the atmosphere; STNfixed (kg/ha): Shoot N fixed

The principal component analysis (PCA) is a statistical procedure that can provide a summary of large data into a form that can easily be observed. The PCA derived from the analysis of the plant growth and nodulation revealed differences in eigenvalues were 4.23 (PC I), 2.23 (PC II) and 2.15 (PC III) indicating the first three PCAs when the cut-off was at 10%; other components 4-8 were less than 4% (Table 7) while the total contribution of the principal component was 72%. The first PCA contributed the most towards variability and was highly related to plant growth parameters. The second PCA was related to variation among accessions owing to total N fixed in roots, shoot C/N and shoot δ^{13}C while the third PCA showed variation in the S δ^{15}N and shoot N.

The results showed that Tpt15, Tpt18, Tpt126, Tpt30, Tpt32, and Tpt15-4 all had a very high mean number of nodules, important for N fixation and nodulation. The significant mean squares of numbers of nodules indicated variability among the accessions regarding nodulation potentials. Tpt18 had the highest biomass production, which was reflected in its high value for dry shoots and dry roots weights. A comparison of growth between the studied accessions showed differences in shoot and root dry weights, but these were not statistically ($p = > 0.05$) different. The dry shoot weight ranged from 403.23g in Tpt18 to 163.40 g in Tpt15-4.

The carbon and nitrogen ratio (C/N ratio) indicates the C and N relationships in plants used in measuring plant water use capacity. Significant differences ($p = \leq .05$) were recorded in C and N ratio among the accessions studied.

Overall, the C/N ratio ranged from 15.87 (Tpt3-B) to 11.97 (Tpt15) for the shoots; it ranged from 14.03 (Tpt4) to 18.33 (Tpt12) for the roots (Table 8). The $\delta^{15}N$ value varied from 3.34 (Tpt18) to 0.86 (Tpt3-B) in the shoots and from 3.07 (Tpt15) to 0.49 (Tpt32) for roots (Table 8). The $\delta^{13}C$ of C3 plants explained their water-use ability (Lawson and Pike 2017). Analysis of variance of $\delta^{13}C$ from shoots and roots revealed highly significant variation (p= ≤.0001.) among accessions under investigation. The $\delta^{13}C$ values of shoots were higher, while the values for the roots also varied considerably. Therefore, the $\delta^{13}C$ values of shoots ranged from -30.60 (Tpt48) to -29.62 (Tpt19) and from -30.17 (Tpt53) to -19.19 (Tpt6) for the roots (Table 8) could indicate variations in the pattern of water use potential of the studied accessions.

Clustering analysis produced three clusters at a similarity index of 0.6 (Figure 2). Cluster I contained 10 accessions (41.6 %) followed by cluster II with 8 accessions (33.4 %) and cluster III contained 6 accessions (25.0%). Of the 25 accessions, Tpt32 was observed not to belong to any of the three clusters formed. Accessions with high values of the parameters measured in the roots and shoots were grouped in Cluster I while other Clusters (II and III) contained relatively low values. The clustering relationship also corresponds to the nodulation, plant growth parameters (Table 5), Ndfa and estimated amount of Nitrogen fixed (Table 6). If accessions from derived clusters are crossed, it may produce a desirable genetic diversity in subsequent generations (Figure 2). Three of the 15 principal components generated explained more than 72% of the variations encountered (Table 7). The PC I accounted for 28.0% of the variation and illustrated primarily the variations in shoot N; shoot and root N fixed. The PC II accounted for an additional 23.0% of the total variation and primarily described the variation patterns in root C/N, ď13 C Corr, ď^{15}N, Ndfa and shoot ď^{15}N. The PC III emphasized the root N (Table 7). The PCA showed that the first three PCs accounted for more than 72% of the total variation; 54.0% was contributed by the first two PCs (PC I and PC II) (Figure 3).

Table 7. Eigenvalues, difference, cumulative variance, and principal scores (eigenvectors) of the first three components of genetic divergence in winged bean shoots and roots.

Characters	Component score		
	PC I	PC II	PC III
RCN	0.327	–	–
Rd13Ccorr	–	–	–
Rd15N	–0.368	–	–
RN	–0.310	–	–
RNfAT (%)	0.368	–	–
RTNfixed (kg/ha)	–	0.348	–
SCN	–	0.552	–
Sd13Ccorr	–	0.247	–
Sd15N	–	–	0.282
SN	–	–	0.347
SnfAT (%)	0.41		–
STNfixed (kg/ha)	0.405	–	–
Eigenvalue	4.23	2.23	2.15
Proportion (%)	0.35	0.19	0.18
Cumulative (%)	0.35	0.54	0.72

Note: RnfAT: Root N derived from the atmosphere; RTNfixed (kg/ha): Root N fixed; SnfAT: Shoot N derived from the atmosphere; STNfixed (kg/ha): Shoot N fixed, PCs: Principal components

Table 8. Means estimation of C/N, ď13 Corr, ď15N and %N in shoots and roots of winged bean.

Accession	RCN	Rď13Ccorr	Rď15N	RN	SCN	Sď13Ccorr	Sď15N	SN
Tpt10	14.94	–29.29	2.52	2.75	15.07	–29.94	2.10	2.69
Tpt11	15.08	–28.99	2.51	2.65	14.12	–30.18	1.85	2.84
Tpt12	18.33	–28.84	2.22	2.19	12.98	–30.00	1.11	3.09
Tpt125	15.41	–29.60	2.26	2.60	14.58	–30.41	1.42	2.75
Tpt126	15.77	–29.10	2.43	2.55	14.68	–30.03	2.82	2.73
Tpt14	16.37	–28.93	1.56	2.55	14.90	–30.06	1.42	2.68
Tpt15	14.31	–29.23	3.07	2.82	11.97	–30.11	2.93	3.34
Tpt15-4	14.21	–29.65	2.58	2.85	13.21	–30.24	1.04	3.03
Tpt154	17.41	–29.21	1.80	2.33	13.91	–30.43	1.37	2.88
Tpt16	15.64	–29.61	1.73	2.61	14.87	–30.39	2.23	2.70
Tpt17	17.47	–29.20	1.90	2.31	12.50	–30.12	2.79	3.21
Tpt18	15.38	–29.19	2.17	2.60	13.84	–29.95	3.34	2.89
Tpt19	15.68	–29.08	0.99	2.56	14.22	–29.62	1.61	2.82
Tpt2	14.81	–29.54	2.52	2.71	12.84	–30.16	2.20	3.15
Tpt3-B	17.66	–29.39	1.96	2.33	15.87	–30.20	0.86	2.53
Tpt30	14.95	–29.67	2.56	2.69	14.57	–30.03	3.30	2.77
Tpt32	16.57	–29.17	0.49	2.47	12.84	–30.19	0.90	3.12
Tpt33	15.58	–29.22	2.37	2.60	13.20	–29.83	2.78	3.11
Tpt4	14.03	–29.26	2.73	2.85	14.11	–30.32	1.86	2.85
Tpt42	15.31	–29.61	1.81	2.62	13.78	–30.22	2.61	2.91
Tpt43	15.34	–29.63	1.44	2.62	13.11	–30.46	1.97	3.09
Tpt48	14.88	–29.70	2.31	2.69	14.18	–30.60	1.60	2.82
Tpt51	14.31	–29.38	2.59	2.80	13.44	–30.36	1.36	2.98
Tpt53	17.83	–30.17	1.59	2.26	12.70	–30.59	1.50	3.18
Tpt6	15.55	–28.79	2.68	2.58	13.49	–30.15	2.84	2.97
C.V	12.47	–1.97	60.75	11.91	9.61	–1.06	54.39	9.7
F value	1.21^{ns}	2.75**	1.54^{ns}	1.08^{ns}	1.74*	2.03*	1.69*	1.77*

Note: RCN; Root Carbon Nitrogen; Rď^{13}Ccorr: Root ď^{13}Carbon correlation; Rď^{15}N: Root ď^{15}N; RN: Root Nitrogen; SCN; Shoot Carbon Nitrogen; Sď^{13}Ccorr: Shoot ď^{13} Carbon correlation; Sď^{15}N: Shoot ď^{15}N; SN: Shoot Nitrogen ***Significant probability level at $P \leq .0001$.

Discussion

The pod length, dry pod weight, total seed weight, total number of seeds, number of seeds per pod, and 100-seed fresh weight exhibited high genotypic (s^2g) and phenotypic (s^2p) variances. The total number of seeds per accession, total seed weight, terminal leaf length, terminal leaf width, pod length, dry pod weight, and number of seeds per pod also exhibited a GCV and PCV. The outcome from the current study was like previous work in winged bean accessions (Afridatul and Syukur 2021; Kant and Nandan 2018; Mohamadali et al. 2010; Prasanth et al. 2016; Rajeshwar et al. 2009). Furthermore, PCV values were observed to be higher than GCV for all the traits evaluated. Based on this classification, the PCV value was low for flower width; medium for terminal leaf length, leaf rachis, seed length, seed thickness, seed width, and 100-seed fresh weight. It was high for terminal leaf length, terminal leaf width, pod length, dry pod weight, and number of seeds per pod, total seed weight, and total number of seeds.

The GCV values were low for terminal petiole length, leaf rachis, terminal leaf length, flower width, seed length, seed thickness, and 100-seed fresh weight; no trait was in the medium range. Values were high for dry pod weight, number of seeds per pod, pod length, total seed weight, and total number of seeds. The high GCV indicates the choice of trait improvements that may be possible through selection. In a study on winged beans by Rajeshwar et al. (2009) high genetic advance was observed for almost all the characters under study. The results obtained herein are in line with Prasanth et al. (2016) who recorded substantial differences among accessions of different genotypes evaluated for variability.

In the accessions studied, the PCV value was low for flower width; medium for terminal leaf length, leaf rachis and seed parameters (seed length, seed thickness, seed width, and 100-seed fresh weight). It was high for terminal leaf length, terminal leaf width, dry pod weight, number of seeds per pod, pod length, total seed weight, and total number of seeds. The broad-sense heritability ranged from 24.13% for 100-seed fresh weight to 50.98% for dry pod weight. Singh (2001) believed that if the heritability of a character is very high, 80% or more, selection for such a character would be done with ease. This is because there would be a close correspondence between the accession and the phenotype due to the relatively small contribution of the environment to the phenotype. However, for characters with low heritability, 40% or less, selection may be considered difficult because of environment. Based on these criteria, the heritability values were moderate (31-50) for terminal petiole length, leaf rachis, dry pod weight, seeds per pod, and seed length, and low at less than 30 for terminal leaf length, terminal leaf width, flower width, and seed thickness.

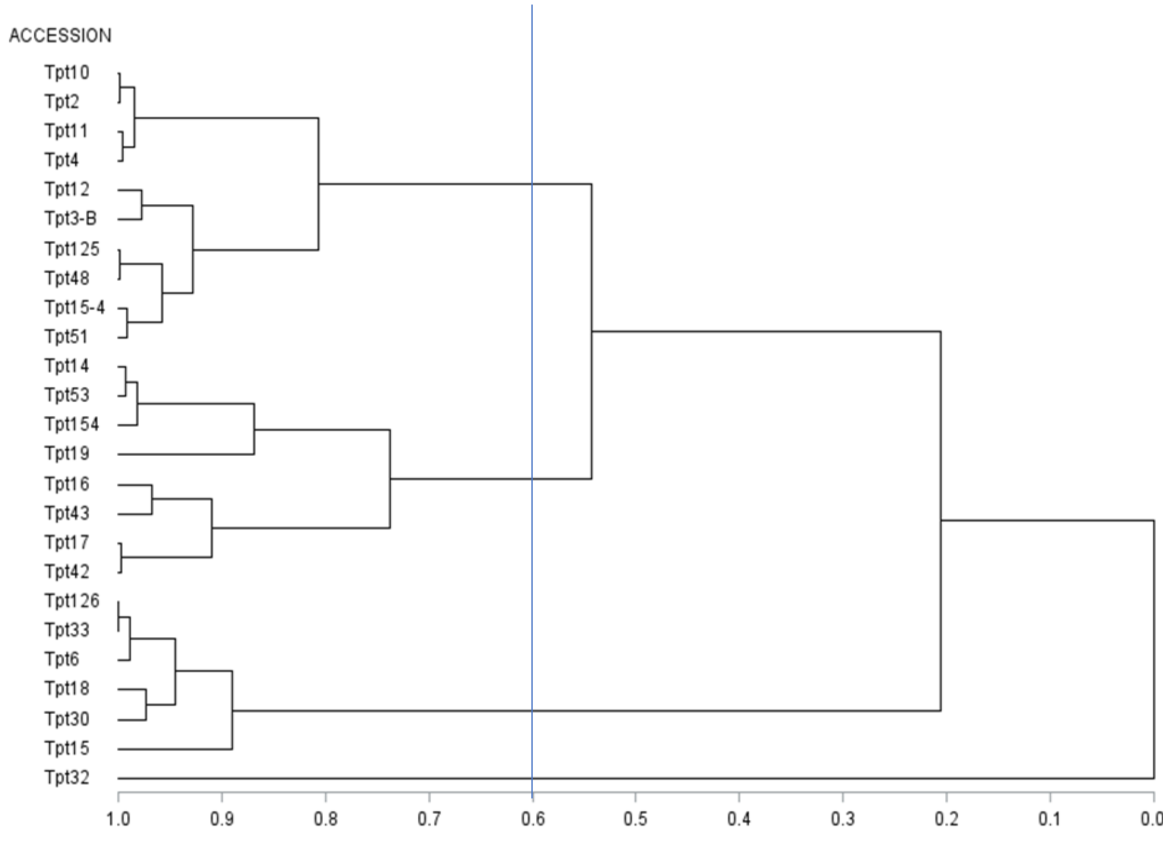

Figure 2. Dendrogram showing the hierarchical structure of winged bean shoots and roots.

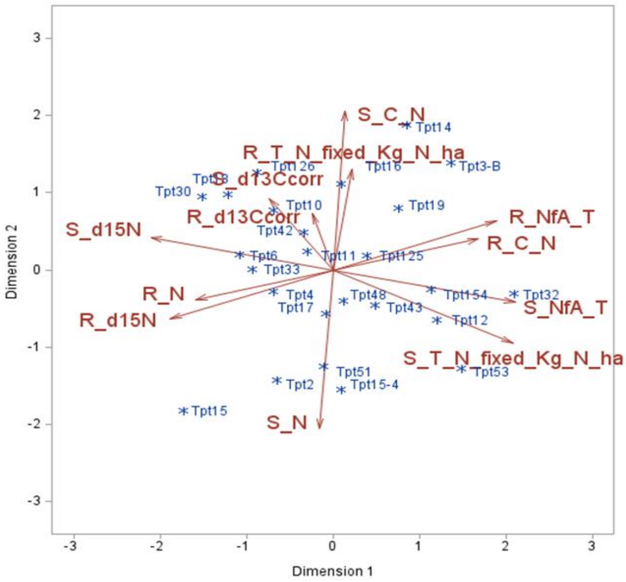

Figure 3. Mean performance of characters and stability of 25 accessions of winged bean as measured by principal components.

This study revealed that the nodulation ability of winged beans were high compared with other legumes previously reported (Abaidoo et al. 2017; Waluyo and Lie 2016). Consequently, an increase in N could be attributed to the high number of nodules as the bacteria in the nodules could be freely fixing N (Boddey et al. 2017; Kumar et al. 2016; Tampakaki et al. 2017). Therefore, high N content may position winged bean as the desired crop for the future providing the needed protein and other nutritional values to the ever-growing global population (Martin 2017).

N fixation by winged beans could be comparable to that of other legumes capable of producing ureide (such as cowpea, desmodium and soybean to mention but a few) (Yoneyama 2017). Furthermore, due to its capacity to fix N, some studies (Anugroho et al. 2010; Hikam et al. 1991; Hikam et al. 1992; Rahman et al. 2014b) have demonstrated that winged beans could contribute significantly to the amount of N available for plant growth and development either when intercropped or planted solely.

The amount of N fixed (Kg/ha) in the shoots varied among the accessions with Tpt32 fixing 25.76 Kg/ha, followed by Tpt15-4 at 24.23 Kg/ha. The accession fixing the least was Tpt30 that measured 9.02 Kg/ha with considerably lower amounts fixed in the roots. Similar results involving other legumes were obtained by other researchers further elucidating the potential role of N fixation in modern agriculture (Abaidoo et al. 2017; Chalk 2016; Foyer et al. 2016; Kermah et al. 2018; Kumar et al. 2016; Li et al. 2017; Singh et al. 2016). Therefore, winged beans can be described as a good N fixer and could serve as a good constituent of sustainable agricultural practices.

Water use efficiency by plants has been reported to decrease with water in the soil and increase with the soil water decline (Fang et al. 2010; Hartman and Danin 2010; Lawson and Pike 2017; Mapope and Dakora 2016). In this present study, the values obtained show these accessions could be stable in their expression of water use. The extent of C in plants is compared to photosynthetic activity (Belane et al. 2011). The values of Carbon concentrates for winged bean was not more than 40 % which was in agreement with previous reports for other legumes (Mohale et al. 2014; Polania et al. 2016).

A higher C content indicates presence of large amount of plant biomass (Mohale et al. 2014). The lower C content in plants could be moderated by N nutrition. The C and N ratio may undoubtedly be a viable tool to estimate N condition (Mohale et al. 2014). The non-legume grass used as a reference plant had over 24 gg^{-1} while accessions of winged bean exhibited C and N ratios below 24 gg^{-1}. This finding is similar to outcomes from previous researches (Murray et al. 2017). In all cases, the C and N ratio value increased with decreasing $\delta^{15}N$ values. These outcomes support the opinion that photosynthetic activities in winged beans could have been mediated by N nutrition, as accessions producing low C and N-fixed ratios yielded high N (Adams et al. 2016; Ulm et al. 2017; Yoneyama 2017). Future research is needed in all areas of germplasm improvement and may focus on studies where winged bean is intercropped with different legumes or cereals to measure how significant its contribution to food and farming systems in different agroecological zones. The study investigated the variability of growth, seed yield, nodulation, and N fixation in accessions of winged beans. Results indicated there are great opportunities for the selection of promising accessions from current germplasm collections for improvement programs for seed yield and other characters. The understanding of the genetic variability of winged beans could be carefully exploited to provide higher grain yield as well as other economic and important traits. Winged beans can be improved based on the genetic variability observed in the selected accessions from the germplasm collections to boost food security and conservation of the plant genetic materials. Winged bean accessions could fix atmospheric Nitrogen and nodulate well which may help reduce dependence on microbial inoculants and chemical N fertilizer application.

ACKNOWLEDGEMENTS

The authors wish to thank the leadership and entire staff of the Genetic Resources Center (GRC), IITA, Ibadan, Nigeria for the award of doctoral research fellowship through the Global Crop Trust, Germany. We are grateful to Prof. Bouillon, Katholieke Universiteit Leuven, Belgium for the use of his laboratory in the sample analysis of the ^{15}N and ^{13}C. We are also deeply grateful to the assistants who helped with fieldwork and the staff of the Soil Microbiology Laboratory of IITA.

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ASIAN JOURNAL OF AGRICULTURE
Volume 5, Number 2, December 2021
Pages: 72-83
E-ISSN: 2580-4537
DOI: 10.13057/asianjagric/g050204

Production system and breeding practice of indigenous chickens in selected districts of Dawro zone and Konta special district, Southern Ethiopia

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Manuscript received: 4 May 2021. Revision accepted: 14 September 2021.

Abstract. *Melak A, Kenfo H, Aseged T, Hailu A. 2021. Production system and breeding practice of indigenous chickens in selected districts of Dawro zone and Konta special district, Southern Ethiopia. Asian J Agric 5: 72-83.* This study was conducted to understand the production system, breeding practices, selection criteria, and production constraints of chickens to have a baseline for future production strategies in the study area. The data was collected through individual interviews, focus group discussions, and personal observations. A semi-structured questionnaire using Food and Agriculture Organization Guidelines was used to avail the views of the respondents. Based on chicken population, production potential, and road accessibility, a total of 90 households from six kebeles were considered for an individual interview. The data was analyzed using SPSS software version 23.0 and an index was calculated for all ranked variables like the importance of livestock, purpose of keeping chicken, selection criteria, culling criteria, and constraints of chicken production. The index value of meat production and income generation in midland agroecology were 0.28 and 0.26 respectively. Also, the index value of income generation and meat production in lowland agroecology were 0.31 and 0.25 respectively. It is concluded that both female and male chickens are maintained mainly for income generation followed by meat sources. A variable that was given a higher priority in breeding selection was body size and health conditions, for male and female chickens respectively. Most of the respondents select their breeding hen in health, egg production, and age with an index value of 0.44 and 0.36 and 0.15 respectively; while their breeding cock in body size, disease resistance, and color with an index value of 0.36, 0.29, and 0.28 respectively. Disease and predators were the major constraints of chicken production mentioned in the study area. Therefore, addressing these constraints is important to design a successful genetic improvement scheme.

Keywords: Constraints, Ethiopia, identification, indigenous chicken, selection criteria, trait preference

INTRODUCTION

It is believed that the livestock population in Ethiopia is the largest in Africa (Tsegay and Gebreegziabher 2016). Livestock is an important source of income for the agricultural communities, and one of Ethiopia's major sources of foreign currency through the exportation of live animals, meat, and skin (Habtamu 2015). Climate change and livestock issues have been only modestly considered, even though livestock production is the most important sector (Niemi 2013). Livestock production and productivity are negatively affected by climate change, and it needs justification on the need to conserve and sustainably use local animal genetic resources. Conservation and sustainable utilization of local Animal Genetic Resource (AnGR) requires information on their morphology and production system (Osei-Amponsah 2017).

In Ethiopia, indigenous chickens are largely kept by the rural society and have large variations in body conformation, plumage color, and comb-type (Moges 2009 and Halima 2007). The naturally or farmer-selected indigenous chickens that have adaptive fitness to a specific area, are often poor in their egg production and characterized by long broodiness as well as late maturation (Moges 2010 and Negasa 2014).

The economic contribution of indigenous chickens is not proportional to their large population, this is because of their low genetic potential, the prevalence of diseases and predators, limited feed resources, constraints related to institutional, socio-economic, and infrastructural practices.

Besides these indigenous chickens are good scavengers and foragers, being well adapted to harsh environmental conditions. Their minimal space requirements make chicken rearing a suitable activity and an alternative income source for the rural Ethiopian farmers. Besides, the local chicken sector has been playing a significant role in poverty alleviation, food security, and economic empowerment for vulnerable groups, women, and children (Moreki 2010; Negassa 2014).

The mean annual egg production of indigenous chickens has not exceeded 60 eggs/hen with an average egg weight of 40gm (Abegaz and Gemechu 2016; Hunde et al. 2016; FAO 2019). However, when compared to commercial chickens, the production potential of indigenous chickens is low due to adapting to harsh environments and are recognized for their ability to survive and reproduce in these conditions, they have added advantages of sustainable development (Fisseha et al. 2010; Wong et al. 2017). Indigenous chickens maintained under the traditional system contributed about 94.31% of the total national poultry products (eggs and meat), while the remaining 2.49% is obtained from an intensively kept exotic breed of chickens, and 3.21% are obtained from hybrids (CSA 2016/2017).

Information on production environments, breeding practices, breeding objectives, and farmers' trait preferences require for designing, planning, and implementing agroecological friendly and sustainable genetic improvement programs of indigenous chickens can then be used to help small-scale farmers. Particularly by ensuring sustainable improvement, utilization, and conservation of indigenous chicken genetic resources and uplift their contributions on the livelihoods of small-scale farmers. However, to date in the Dawro zone and Konta special district of the southern nation nationality and people (SNNP) region, very little effort has been made to identify breeding objectives and farmer’s chicken breeding practices and production system of indigenous chicken ecotype before genetic improvement is made through cross and breeding selection. Therefore, the main objective of this study is to characterize the production system, describe the production objectives and breeding practices of the chicken producers, generate information on the chicken ecotypes and breeding systems, and provide baseline information for designing breeding programs for indigenous chicken in Dawro zone and Konta special district.

MATERIALS AND METHODS

Description of the study area

The study was conducted in the Dawro zone and Konta special district of SNNP in Southern Ethiopia (Figure 1). The districts were selected for it is known as the center of distribution for chicken ecotypes. Dawro zone is in the SNNPR of Ethiopia, about 500 km southwest of Addis Ababa, the capital city of Ethiopia. Tarcha is located about 535 km south of Addis Ababa and the study area's elevation ranges from 1000 to 2300 meters above sea level. The rainfall distribution is bimodal with the highest fall at the wet season (April to September) and lowest fall at the last half of the dry season (February to March). The mean annual rainfall ranges from 650 to 1100 mm, and the mean daily temperature ranges between 18 - 23 °C (TZWOA, 2018). According to agro-ecological classification criteria, the district is partitioned into three agro-ecological zones, namely highland (Dega), midland (Woinadega), and lowland (Kola) with the total land holds of 53%, 30%, and 17%, respectively. The major crops are maize, teff, *enset* (*Ensete ventricosum*), and sweet potato and to a lesser extent other crops (Tarcha Zuria Agricultural Office 2018).

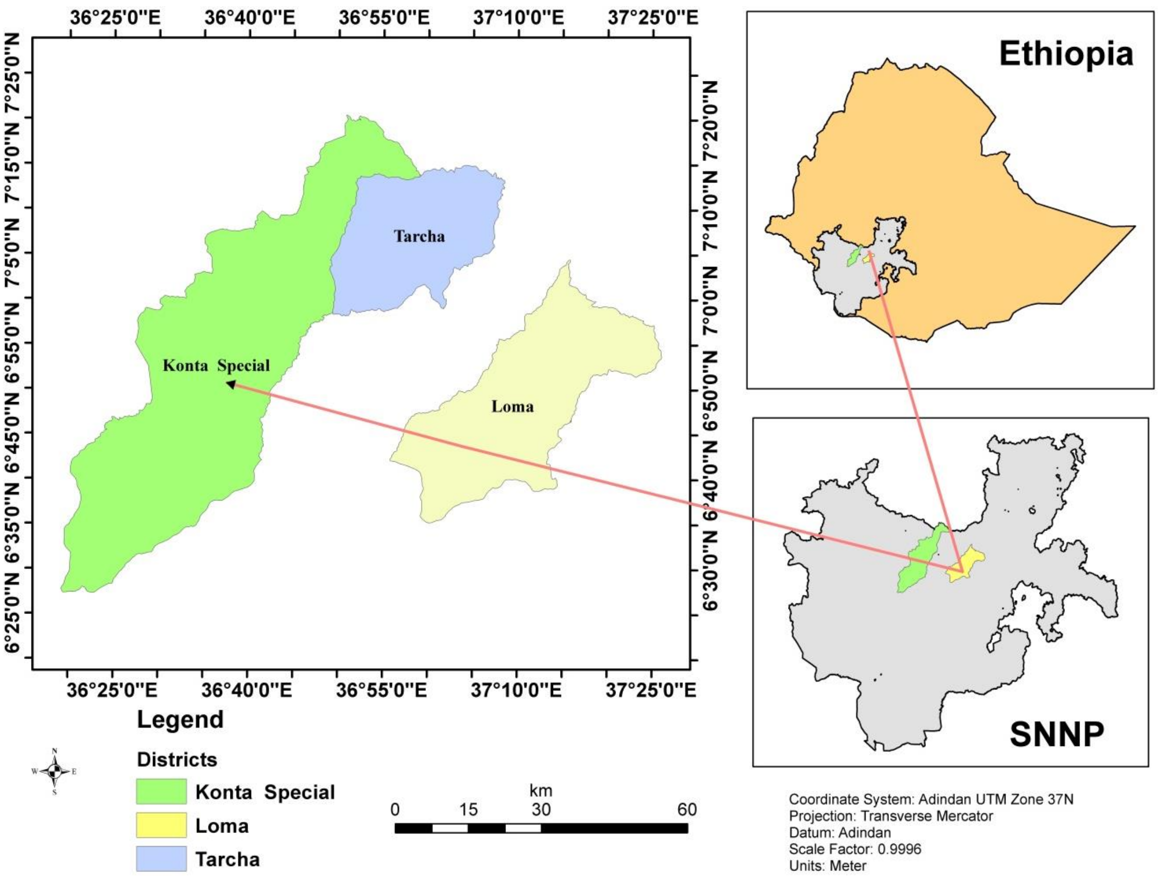

Figure 1. Map of the study area in the Dawro zone and Konta special district of SNNP, Southern Ethiopia.

Loma is one of the administrative districts in the Dawro zone of SNNPR. The total surface area is 116,320 ha. The agro-ecology of the district comprises 45.6% lowland (less than 1500 m.a.s.l), 41.4% midland (between 1500 and 2300 m.a.s.l), and 13% highland (more than 2300 m.a.s.l). The mean annual temperature ranges between 15.1 and 29.5°C, and the mean annual rainfall is between 900 and 1800 mm. The land use pattern followed is 50,701 ha cultivated; 36,172.17 ha covered by bush shrubs; 16, 202 ha under settlement; 120,60 ha for grazing; 852.33 ha covered with forest; and the rest is 332.50 ha covered by others. The district is comprised of 34 rural and five urban *kebeles* (the lowest administrative region) (SNNPRS-BoFED 2012).

Konta special district is located 464 km to the south of Addis Ababa. It is situated at an altitude ranging from 870 to 2850 meters above sea level, and latitude 7 0 42 N and 360 50'E. The area has a mean annual rainfall ranging from 500 mm – 2200 mm. The rainfall is bimodal, with the long rain happening from the beginning of June to the end of September, and the short rainfall from the beginning of March to the end of April, with more rainfall measures from July to August. The mixed crop-livestock production system is common in the district (Konta special district livestock and fishery office, unpublished data).

Sampling procedure and data collection

Data was collected through interviews with 90 randomly selected chicken owners from Tarcha zuria, Loma, and Konta special districts. Two different agro-ecologies (mid-altitude and lowland) of the districts were purposively selected based on their poultry population and accessibility. To check on the clarity of the questionnaire to respondents and the appropriateness of the questions, the questionnaire was designed, pre-tested, and modified before the commencement of the actual administration. Staff from the Ethiopian Biodiversity Institute administered the modified and finalized questionnaire. The questionnaire gathered information on socio-demographic characteristics of the households (age, gender, educational background, family size), livestock holding, flock characteristics (number and composition), source of income, livestock and their importance, farming system characteristics, the purpose of keeping, selection criteria, culling criteria, reproductive characteristics, and constraints of chicken production in the study area.

Data analysis

The entered data was transported and analyzed using descriptive statistics of statistical package for social sciences (SPSS version 23.0, 2015). Descriptive statistics of SPSS 23.0.0.0 software were used to describe the survey. An index was calculated to provide an overall ranking of the importance of livestock, the purpose of keeping chickens, selection criteria, culling criteria, and constraints of chicken production, according to the formula: Index = Σ of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] given for particular qualitative variables divided by Σ of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] for all-qualitative variables. The rank was calculated by Microsoft Excel 2010. X^2 test was calculated to evaluate the relationship among the categorical variables. The map of the study area was mapped with arc GIS (arc map 10.8).

RESULTS AND DISCUSSION

Individual and household characteristics of the respondents

Most of the indigenous chicken-owning households were male-headed (60%) while the remaining (40%) were headed by females (Table 1). The number of male respondents in the lowland agroecology is significantly higher than the number of male respondents in midland agroecology. There was a significant difference ($P < 0.05$) among agro-ecologist. As the results revealed that farmer respondents are significantly higher in the midland agroecology than the lowland agroecology ($P<0.05$). The educational status of the respondents was 32.2% illiterate, 22.2% read and write, 12.2% grade (1-4), 21.1% grade (5-8), 8.9% grade (9-12), and 3.3% others, and there was no variation ($P > 0.05$) among the agro-ecologies (Table 1).

Livestock holding and composition, chicken ownership, and flock structure

The average reported livestock holding in the household is presented in Table 2. The mean (±SEM) number of cattle, sheep, goat, chicken, donkey and bee hives per household were 4.31±0.28, 1.90±0.32, 2.79±0.20, 8.90±0.52, 1.44±0.18, 6.00±1.23, respectively. The respondents do not have a horse, mule, and camel. Mostly the household head (husband) and spouse jointly, are flock owners. The number of chicks per household was 4.79±0.46 which was followed by layers (3.28±0.15). In the case of livestock holding and flock structure, there was no difference ($P > 0.05$) among the agro-ecologies (Table 2).

Gender involvement in village chicken management

Decision-making and division of labor on chicken production in the households are provided in Table 3. Most activities like chicken feeding, buying, treating, house cleaning, and egg collection were significantly ($P<0.05$) occupied by females above 18 years old. The women play a primordial role in brooding eggs (61.1%), cleaning chicken pens (47.8%), treating sick chicken (48.8%), selling eggs (61.1%), and feeding (61.1%) of the household. The results showed buying chicken, disease treatment, collecting of egg, feeding the chicken, cleaning house was significantly higher in the age group above 18 years of female (Table 3).

Housing materials and conditions of chickens

The results showed most of the respondents (77.8%) replied that their chickens spend the night inside perch trees and the remaining 13.3% and 8.9 % spent the night in the basket and the house with the households, respectively (Table 4).

Table 1. Household characteristics.

Variable		Mid altitude N=45		Low altitude N=45		Overall N=90		X^2	p-value
Age of household		38.29±1.45		33.49±1.59		35.89±1.10		36.616^a	0.081
Family size		5.31±0.37		6.04±0.43		5.68±.28		8.887^a	0.713
Landholding		1.86±0.17		1.67±0.19		1.76±0.13		27.600^a	0.539
		Frequency	Percent	Frequency	Percent	Frequency	Percent		
Sex	Male	22	48.9	32	71.1	34	60	4.630^a	0.031
	Female	23	51.1	13	28.9	36	40		
Job	Farmer	40	88.9	39	86.7	79	87.8	11.013^a	0.026
	Merchant	0	0	5	11.1	5	5.6		
	G/employee	3	6.7	0	0	3	3.3		
	Student	2	4.4	0	0	2	2.2		
	Carpenter	0	0	1	2.2	1	1.1		
Education	Illiterate	16	35.6	13	28.9	29	32.2	7.278^a	0.201
	Read and write	10	22.2	10	22.2	20	22.2		
	Grade (1-4)	4	8.9	7	15.6	11	12.2		
	Grade (5-8)	12	26.7	7	15.6	19	21.1		
	Grade (9-12)	1	2.2	7	15.6	8	8.9		
	Others	2	4.4	1	2.2	3	3.3		

Table 2. Mean (±SEM) livestock holdings.

	Livestock	Mid altitude (N=45)	Low altitude (N=45)	Overall Mean ± SEM (N=90)	X^2	P-value
	Cattle	4.50±0.37	4.12±0.44	4.31±0.28	9.407^a	0.58
	Sheep	1.92±.46	1.86±0.40	1.90±0.32	3.234^a	0.52
	Goat	2.40±0.19	3.22±0.35	2.79±0.20	11.594^a	0.072
	Chicken	8.51±0.66	9.29±0.80	8.90±0.52	13.097^a	0.79
	Donkey	NA	1.44±0.18	1.44±0.18	NA	A
	Beehive	5.67±1.36	6.67±2.68	6.00±1.23	3.150^a	0.68
Flock structure	Layer	3.52±0.21	3.05±0.22	3.28±0.15	10.556^a	0.10
	Pullet	1.58±0.13	2.11±0.44	1.81±0.21	4.252^a	0.37
	Female grower	1.56±0.22	1.93±0.34	1.73±0.20	1.402^a	0.84
	Male grower	1.44±0.20	2.42±0.51	1.86±0.26	6.477^a	0.17
	Cock	1.71±0.18	1.87±0.24	1.79±0.14	3.147^a	0.68
	Chicks	5.46±1.06	4.46±0.44	4.79±0.46	10.730^a	0.30

Note: N: number of respondents; SEM: standard error of the mean; A: no statistics were computed; NA: Not available

Table 3. Division of labor in percent.

	Buying chicken	Selling chicken	Disease treatment	Collecting egg	Feeding	Selling egg	Brooding egg	Cleaning house	Other activities
< 18 years male	1.1	16.7	16.7	16.7	0	0	0	0	0
< 18 years female	31.1	5.6	5.6	35.6	30.0	31.1	30.0	43.3	0
> 18 years male	24.4	28.9	28.9	0	8.9	7.8	8.9	8.9	0
> 18 years female	43.3	48.9	48.9	47.8	61.1	61.1	61.1	47.8	17.8
X^2	2.698^a	8.493^a	18.788^a	23.624^a	11.798^a	2.735^a	3.978^a	16.480^a	A
P value	0.44	0.037	0	0	0.03	0.26	0.14	0	A

Note: A: no statistics were computed

Table 4. Housing material and type of chicken house.

Materials		Iron steel	Grass	Wood	Plastic	Mud	x^2	p-value
Housing material for roof	Frequency	75	15	0	0	0	13.520^a	0.00
	%	83.3	16.7	0	0	0		
Housing material for wall	Frequency	0	0	76	14	0	16.579^a	0.00
	%	0	0	84.4	15.6	0		
Housing material or floor	Frequency	0	0	29	26	35	2.133^a	0.344
	%	0	0	32.2	28.9	38.9		
Housing type		Inside house	Inside perch trees	Basket house	Total			
	Frequency	8	70	12	90		14.914^a	0.001
	%	8.9	77.8	13.3	100			

The results showed that there was a highly significant difference in housing types (P=0.001) between the midland and lowland agro-ecologies. Results also showed that houses/night shelters were made using locally available materials such as grass, wood, plastic, and mud. There was a significant difference between the housing material for the roof of the chicken and most of the respondents constructed their chicken roof from iron steel. There was also a significant difference between the housing material for the wall of the chicken and most of the respondents construct their chicken wall from wood (P<0.05) (Table 4).

Livestock and their importance

The uses of livestock are presented in Table 5. The results showed that cattle are the leading livestock species used for the lives of the respondents. Cattle were significantly higher than other livestock species in the study area (P<0.05). Chickens and goats were the second and third important livestock species, respectively.

Purpose of keeping chicken

The results in Table 6 present the purpose of keeping chicken in the area. Male chickens were mainly kept for meat (43% and 42%), cash generation (29% and 34%), and for production (breeding) 20% and 15% in the mid and low land, respectively. Whereas females were kept mainly for egg production (49% and 50%) followed by income generation 23% and 28% in mid and low land areas, respectively.

Selection of breeding chickens and trait preferences

The result showed the selection of breeding cock by size, color, disease resistance was significantly higher at midland agroecology. Selection by the performance of breeding cock was not significantly different between the midland and lowland agro-ecologies. The selection of breeding hen by egg production was significantly high in the lowland rather than in the midland. On the other hand, the selection of breeding hen by health and non-broodiness was significantly higher in the midland than in the lowland. Selection by age of breeding hen was not significantly different between the midland and lowland agro-ecologies. The selection criteria for chicken in Tarcha, Loma, and Konta special districts with corresponding index values are presented in Table 7.

Most of the respondents select their breeding cock based on body size (index = 0.38, and 0.33 in the midland, and lowland agro-ecologies, respectively) being the most important cock selection trait followed by disease resistance (index = 0.33, and 0.25 in the midland, and lowland agro-ecologies, respectively), and the next selection criteria that the respondents prefer were color (index = 0.29, and 0.27 in the midland, and lowland altitude, respectively) and performance with an index value of 0.15 in the lowland altitude (Table 7).

Table 5. Importance of livestock.

Livestock breeds	Rank1	Rank2	Rank3	Index
Cattle	76	5	3	0.48
Sheep	1	3	7	0.03
Goat	0	43	11	0.19
Chicken	11	34	38	0.28
Donkey	0	0	0	0.00
Beehives	0	1	4	0.01
Others	0	0	0	0.00
Total	88	86	63	1.00

Table 6. Purposes of keeping chicken.

Item		Male				Female				
		Rank1	Rank2	Rank3	Index	Rank1	Rank2	Rank3	Index	AVI
Mid land	Meat	25	20	0	0.43	3	12	0	0.12	0.28
	Egg	0	0	0	0.00	42	2	0	0.49	0.24
	For breeding	0	24	6	0.20	0	0	31	0.12	0.16
	Manure	0	0	0	0.00	0	0	0	0.00	0
	Saving	0	0	3	0.01	0	0	12	0.05	0.03
	Wealth status	0	0	15	0.06	0	0	0	0.00	0.03
	Culture	0	0	0	0.00	0	0	0	0.00	0
	Income generation	17	2	23	0.29	0	30	0	0.23	0.26
	Others	0	0	0	0.00	0	0	0	0.00	0
	Total	42	46	47	1.00	45	44	43	1.00	1
Low land	Meat	25	20	0	0.42	1	4	12	0.09	0.25
	Egg	0	0	0	0.00	44	1	0	0.50	0.25
	For breeding	5	5	16	0.15	0	0	15	0.06	0.1
	Manure	0	0	0	0.00	0	0	0	0.00	0
	Saving	0	2	18	0.08	0	4	11	0.07	0.08
	Wealth status	0	0	1	0.00	0	0	2	0.01	0.01
	Culture	0	0	0	0.00	0	0	0	0.00	0
	Income generation	14	23	6	0.34	0	36	4	0.28	0.31
	Others	0	0	0	0.00	0	0	0	0.00	0
	Total	44	50	41	1.00	45	45	44	1.00	1

Note: AVI: average index

Most of the respondents select their breeding hen in which health (index = 0.44, and 0.36 in the midland, and lowland agro-ecologies, respectively) was the most important male chicken selection trait followed by egg production (index = 0.28, and 0.45 in the midland, and lowland agro-ecologies, respectively), and the next selection criteria that the respondents prefer were age (index = 0.19, and 0.11 in the midland, and lowland altitude, respectively) and non-broodiness with an index value of 0.09 and 0.08 in the midland and lowland altitude, respectively.

Culling reasons for chickens

Culling criteria for chickens in Tarcha, Loma, and Konta special districts with corresponding index values are presented in Table 8. Most of the respondents cull their chickens in which body disease (index = 0.54, and 0.27 in the midland, and lowland altitude, respectively), and decrease production (index = 0.21, and 0.44 in the midland, and lowland altitude, respectively) were the most important chicken culling criteria followed by age (index = 0.13, and 0.27 in the midland, and lowland altitude, respectively), and the next culling criteria were comb-type with an index value of 0.07, and 0.02 in the midland and lowland altitude, respectively. The results showed that the culling of chickens by decrease production was significantly high at lowland agro-ecology than the midland agro-ecology. On the other hand, the culling of chickens by disease was significantly high at midland agro-ecology than lowland agro-ecology, but the culling of chickens by comb type and age has no significant difference among the agro-ecologies in the study area (Table 8).

Mortality of chicken

The mortality of chickens by age is presented in Table 9. Most of the respondents (84.4%) reported that there was chicken mortality for the last year. There is no significant difference ($P<0.05$) in average chicken mortalities among different age groups.

Traits of adaptive and economic importance

According to a survey conducted, farmers identify traits of preference mainly on brooding ability, feed consumption, mothering ability, egg production, meat quality growth performance, disease resistance, and scavenging ability (Table 10).

Mothering and brooding ability

The results showed that the mothering and brooding ability of chickens in the study area is highly significant (Table 7). In the case of brooding ability and mothering ability, there was a significant difference among the agro-ecologies. Brooding ability was high at the midland agro-ecology in the medium intensity preference. Mothering ability was high at the lowland agro-ecology at high-intensity preference. In the case of brooding ability and mothering ability, there was a significant difference among the agro-ecologies. Brooding ability was high at the midland agro-ecology in the medium intensity preference. Mothering ability was high at the lowland agro-ecology at high-intensity preference.

Table 7. Ranked selection criteria for breeding males and females.

	Item	Agro-ecological zones								Average index	X^2	p-value
		Midland				Lowland						
		R1	R2	R3	Index	R1	R2	R3	Index			
Selection criteria of cock	Size	15	29	1	0.38	26	6	0	0.33	0.36	17.366[a]	0
	color	15	2	28	0.29	1	26	18	0.27	0.28	34.955[a]	0
	Performance	0	0	0	0.00	13	0	0	0.15	0.07	A	A
	Disease resistance	15	14	16	0.33	5	13	27	0.25	0.29	7.851[a]	0.020
	Total	45	45	45	1.00	45	45	45	1.00	1		
Selection criteria of hen	Egg production	16	14	0	0.28	40	0	0	0.45	0.36	23.333[a]	0
	Age	0	6	39	0.19	0	0	30	0.11	0.15	1.008[a]	0.315
	Health	29	16	0	0.44	5	40	0	0.36	0.4	27.227[a]	0
	Non-Broodiness	0	10	5	0.09	0	3	15	0.08	0.09	8.567[a]	0.003
	Total	45	46	44	1.00	45	43	45	1.00	1		

Note: R: rank, A: no statistics were computed

Table 8. The culling reason for male and female chicken in Tarcha, Loma, and Konta special district, Southern Ethiopia

Item	Agro-ecological zones								Average index	X^2	p-value
	Mid altitude				Low altitude						
	R1	R2	R3	Index	R1	R2	R3	Index			
Decrease production	1	21	5	0.21	27	15	2	0.44	0.33	23.718[a]	0
Age	0	5	22	0.13	4	29	0	0.27	0.20	3.676[a]	0.055
Disease	39	6	0	0.54	4	29	0	0.27	0.40	42.769[a]	00
Broodiness	0	0	14	0.06	0	0	0	0.00	0.03	a	a
Color	0	0	0	0.00	0	0	0	0.00	0	0	0
Comb	0	6	4	0.07	0	2	1	0.02	0.04	0.043[a]	0.835
Temperament	0	0	0	0.00	0	0	0	0.00	0	0	0
Shape	0	0	0	0.00	0	0	0	0.00	0	0	00
Total	40	38	45	1.00	35	75	3	1.00	1		

Disease resistance

Disease resistance was also found to be very important. The results showed that there was a significant difference among the agro-ecologies. Disease resistance of indigenous chicken ecotypes was high at the midland agro-ecology at high-intensity preference.

Scavenging ability

The results showed that the scavenging ability of chickens was not significant among the agro-ecologies. Based on this, the local breeds were appreciated by the local farmers for their scavenging ability irrespective of the agro-ecological zones (Table 10).

Chicken breeding and reproduction performances

Age at sexual maturity

The average age at sexual maturity for male and female chickens varies from breed to breed. Reproductive performances of the studied chicken population are summarized in Table 11.

Egg production and hatchability

The egg production and hatchability of the female chicken population are summarized in Table 11. The average reported age at sexual maturity for studied chicken ecotypes were 5.33±0.13 and 6.14±0.15 months for males and females, respectively (Table 11). The present study showed that the average number of eggs laid by indigenous hens was 10.81±0.31 eggs per hen per clutches and the mean annual egg production was 61.70±0.95 eggs per hen per year (Table 11). The average age at sexual maturity of female chicken, the maximum brooding interval in weeks, average market age of males in months, average market age of females in months, number of hatches per year, low yield number of eggs produced annually, number of hatches per year, medium yield number of egg produced annually, have a significant difference between the midland and lowland agro-ecologies. Whereas average age at sexual maturity, the minimum brooding interval in weeks, average brooding interval in weeks, hatched number per one natural incubation, number of chicks surviving, the average number of eggs laid in a single clutch, and maximum number of eggs produced annually were not significant in the studied agro-ecologies (Table 11). The result showed the average number of egg/clutch/hen was 11.17±0.31 and the average number of times a hen hatches in a year was 2.80±0.13 with an estimated average egg number of 61.70±0.95 per year.

Major constraints of chicken production

The major constraints of chicken production as mentioned by the households were disease, predator, unknown causes, and drought (decreased in both size and productivity) (Table 12). The result showed in the case of chicken production constraints there was no significant difference between the midland and lowland agro-ecologies (P>0.05). Most of the respondents' major cause of loss of chicken identified in this study was a disease with an index value of 0.44 (Table 12).

Table 10. Trait preference of chicken ecotypes by agro-ecology (%)

Variables	Intensity of preference	Agro-ecological zones		X^2	p-value
		Mid altitude	Low altitude		
Brooding ability	High	0	44.4		
	Medium	100	55.6	34.615[a]	0.000
	Low	0	0		
Feed consumption	High	0	53.3		
	Medium	100	46.7	32.727[a]	0.000
	Low	0	0		
Mothering ability	High	56.6	91.1		
	Medium	44.4	8.9	14.545[a]	0.000
	Low	0	0		
Egg production	High	51.1	60		
	Medium	48.9	40	0.720[a]	0.396
	Low	0	0		
Meat quality	High	46.7	35.6		
	Medium	44.4	62.2	3.809[a]	0.149
	Low	8.9	2.2		
Growth performance	High	33.3	55.6		
	Medium	57.8	42.2	3.487[a]	0.062
	Low	8.9	2.2		
Disease resistance	High	80	57.8		
	Medium	20	42.2	5.184[a]	0.023
	Low	0	0		
Scavenging ability	High	100	97.8		
	Medium	0	2.2	1.011[a]	0.315
	Low	0	0		

Note: X^2: chi-square test

Table 9. Mortality of chicken within one year period and chicken age category.

Mortality by age	Mean ± SEM		Frequency	%	X^2	p-value
Mortality in the last 12 months		Yes	76	84.4	1.353[a]	0.245
		No	14	15.6		
Less than 1 week	1.48±0.26				12.024[a]	0.150
1 week-2 month	1.63±0.23				13.931[a]	0.084
2-5 months	1.46±0.19				11.429[a]	0.076
More than 5 months	2.10±0.28				21.116[a]	0.032

Table 11. Production and productivity of chicken (Mean and SD, N=90).

Item	Agro-ecological zones		Overall	X^2	p-value
	Mid altitude	Low altitude			
Average ASM of male	5.33±1.02	5.33±1.41	5.33±1.23	10.511[a]	0.105
Average ASM of female	6.29±1.09	5.99±1.65	6.14±1.40	22.554[a]	0.007
minimum BI in weeks	8.16±5.53	5.38±1.66	6.77±4.29	17.977[a]	0.082
Average BI in weeks	10.06±6.73	6.3±1.37	8.18±5.19	24.133[a]	0.087
Maximum BI in weeks	12.61±8.70	7.46±1.77	10.03±6.76	25.400[a]	0.031
Average MA of males in months	8.99±2.52	6.33±1.67	7.66±2.51	38.984[a]	00
Average MA of females in months	9.69±2.58	7.04±1.55	8.37±2.50	36.781[a]	00
HA per one natural incubation	11.64±2.85	10.69±3.0	11.17±2.99	14.349[a]	0.350
No- of chicks surviving	6.87±3.67	6.38±2.55	6.62±3.15	17.624[a]	0.128
Average NoEL in a single clutch	11.44±2.89	10.18±2.8	10.81±2.90	18.130[a]	0.201
No- of hatches per year	2.64±1.52	2.96±.74	2.80±1.20	14.121[a]	0.015
NoEP annually low yield	47.07±8.75	50.78±7.0	48.92±8.10	41.940[a]	0.002
NoEP annually medium yield	59.93±9.75	63.47±7.9	61.70±9.00	33.203[a]	0.044
NoEP annually maximum yield	72.82±9.67	77.53±11.08	75.18±10.61	25.081[a]	0.244

Note: ASM: age at sexual maturity, BI: Brooding interval, MA: market age, HA: hatched number, NoEL: Number of eggs laid, NoEP: number of eggs produced

Table 12. Major Chicken production constraint in Tarcha, Loma, and Konta special district, Southern Ethiopia.

Causes of mortality	Agro-ecological zones								Av. index	X^2	P-value
	Mid land				Low land						
	R1	R2	R3	Index	R1	R2	R3	Index			
Predator	14	24	0	0.42	14	22	0	0.40	0.41	0.033[a]	0.856
Disease	23	14	0	0.45	22	13	0	0.43	0.44	0.004[a]	0.951
Drought	0	0	0	0.00	0	0	13	0.06	0.03	A	A
Unknown	0	1	25	0.13	0	0	23	0.11	0.12	1.217[a]	0.270
Total	37	39	25	1.00	36	35	36	1.00	1		

Note: Av: average

Discussion

The small proportion of female respondents in this study, was not in line with Halima et al. (2007) where households were predominantly headed by females and that most livestock farmers are of old age which is a common phenomenon in most developing countries. The proportion of female-headed households in the present study was lower than the 47.7% for Hawassa town (Haile et al. 2012). This indicated that most of the time the men, whether in male-headed or female-headed households, are responsible for chicken rearing while the women are responsible for crop cultivation and other household chores. The average family size of the households was 5.68±.28 (ranging from 1-14) and this result is higher than the report of Demographic Health Survey (2016) which is 4.8 persons. Large family size was considered very important for chicken production activities. Many members within the family seem to be considered as an asset and security in times of retirement. The current study showed that many of the respondents had formal education and is important to understand extension messages and to realize the importance of new technologies within a short time. According to Ofukou et al. (2009), farmers with high educational levels usually adopt new technologies more rapidly than lower educated farmers.

The current study described and documented indigenous chicken production systems in the traditional sector of Tarcha zuria, Loma, and Konta special districts as an essential step towards the development of a sustainable breed improvement program.

Flock structure is described in terms of the number and proportion of the different age groups and sex in a flock. The number of chicks in this study was like that of the Gantaafeshum district of Eastern Tigray as reported by Gebresilassie et al. (2015) that was reported as 4.29 and 3.17 for chicks and layers per household, respectively. This indicates that the proportion varies between places and with time due to various reasons.

Results of focus group discussions indicated that the household heads provided chickens for children if they request and mostly, children share the responsibility of chicken feeding and watering that they have the ownership of chicken. This finding is similar to the observation of Gebresilassie et al. (2015) from the Gantaafeshum district of Eastern Tigray, Ethiopia.

The ownership pattern was usually related to decision-making in the selling and consumption of chicken meat and eggs. It was noted that women, followed by men, play the major decision-making role in the selling and consumption of chicken meat and eggs, and the purchase of chickens. This agreed with the report of Aklilu et al. (2007) from Tigray, Northern Ethiopia who reported that live birds and egg sales were decided by women who would serve them as immediate income to meet household expenses instead of expecting their husband to provide the cash.

Women were further responsible to perform most of the activities in chicken rearing except in the construction of chicken pens perch or partitions, which is mainly carried out by the men and youth males. Results of this study showed that adult women have a significant contribution to poultry farming and related activities. The results obtained in this study agree with the reports of Gebresilassie et al. (2015) from the Gantaafeshum district of Eastern Tigray, Ethiopia.

Solomon Zewdu et al. (2013) also reported chicken houses are constructed with locally available materials such as bamboo for making ceilings (86.7%), mud blocks and hat (11.1%), a house made of iron sheet roof (1.5%), and basket made of bamboo (0.7%). The sites are secure overnight places to protect from predators.

One aim of this study was to document information that would be useful when formulating a breeding program for indigenous chickens in the Dawro zone and Konta special district. The results showed that chicken was commonly used as a family income, source of meat, and egg. These could be opportunities that farmers can exploit to better utilize their indigenous chickens. The other use mentioned by our respondents was saving and wealth status. The result showed that both hen and cock are maintained mainly for income generation followed by meat source and egg production (Table 6). This builds financial capital and allows the sale of animals for cash that can be used for other agricultural enterprises, school fees, and medical bills, etc. Functions like saving and wealth status received a lower ranking among chicken breeders. Chickens are a highly valued livestock species in the study area, next to cattle, and are reared to fulfill diverse socio-cultural needs. Chicken production plays a great role as a prime supplier of eggs and meat in rural and urban areas and as a source of income, especially to women (Geleta et al. 2013). The purpose of keeping chicken for culture and manure is zero, due to the beliefs of the society restricting not to believe in such kinds of things and due to ignorance of chicken manure. Dikinya and Mufwanzala (2010) reported the utilization of chicken manure as an organic fertilizer is essential in improving soil productivity and crop production.

The most common way of selecting chickens as parents for the coming generations is to use the offspring of a chosen parent. A linear index is the best strategy for selecting replacements in the livestock industries (Chawala 2019). Therefore, the selection criteria used for breeding hen in this study is not in line with Fitsum (2017) who reported that the selection criteria used for breeding hen were egg size, plumage color, broodiness, disease resistance, and hatchability with an average index value of 0.067, 0.064, 0.062, 0.054, and 0.042, respectively. The highest selection criteria used for breeding cock were egg number of the dam, comb type, plumage color, and disease resistance, with an index value of 0.053, 0.052, 0.045, and 0.044, respectively.

Livestock keepers need to evaluate each animal and decide whether that animal is productive or not, with decreasing production costs. Nonproductive chickens should not be maintained in the flock. The best way to increase the efficiency of the chicken ecotypes is culling. The culling of cocks for sale or family consumption is another possible factor contributing to the high proportion of hens per flock in this study. Our study showed the respondents cull their chickens mostly through sale and slaughter. As reported by Abera (2014) the respondents cull their chickens by selling and consuming at home and they sell the chicken at an early age. The sale of a chicken at an early age is common in other areas too. Thus, the sale of young animals negatively influenced flock productivity that fast-growing and good-looking pullets and male growers could be removed out from the flock before reaching breeding age and replacing themselves (Abera 2014), and therefore drains the genetic pool of the flock. However, the practice can be taken as an efficient method of culling less productive and unselected animals out of the system, if properly managed. Therefore, care should be taken to maintain the productivity of animals while removing those with unwanted traits.

Most of the respondents considered the scavenging ability as the most important trait followed by mothering ability and egg production. This study is not in line with the report of Abdelqader et al. (2007) where village farmers considered egg production as the most important criterion, followed by mothering ability and body weight, for selecting their breeding stock in Jordan. Identification of traits of economic importance is vital in the development of breeding objectives.

In this regard, the local chicken ecotypes are well noted for their good mothering and brooding ability. This implies that the local chickens can serve considerably in hatching eggs for breeding/reproduction purposes to increase the flock size. Their mothering ability can contribute more to the better survival of the chickens. However, brooding can reduce the egg production of local chickens. The mothering and brooding ability of the chickens were irrespective of agro-ecological zones (Gebremariam 2017).

The disease resistance of indigenous chickens was high in the midland agroecology at high preference. The importance of disease resistance on preference for traits of chickens and other livestock species is mentioned in the previous studies. (Ouma et al. 2007; Kassie et al. 2009; Faustin et al. 2010). The trait "disease resistance" is maybe a consequence of the economic importance of poultry diseases in rural Ethiopia and the lack of poultry health services. This finding is in line with previous studies in African countries including Benin, Somalia, Cameroon, and Zambia (Guèye 2000; Faustin et al. 2010).

The age at sexual maturity of a male chicken in this study is shorter than the finding of Assefa et al. (2019) who reported that the average sexual maturity of chicken in the shaka zone was 22.4 and 25. 2 weeks (5.6 and 6.3 months) for male and female chickens, respectively. Also, the age at sexual maturity in this study is not in agreement with Yadessa et al. (2017) who reported that average sexual maturity was 19.6 and 20.8 weeks (4.9 and 5.2 months) for male and female chickens, respectively. The variation in age at sexual maturity may be due to the variation in environmental factors (temperature and nutrition) in the study districts.

The results of the average number of eggs laid in this study was higher than the mean annual egg production of 50.8 eggs per hen per year reported by Nebiyu et al. (2013) and lower than 65 eggs reported by Yitbarek and Zewudu (2014). The significant difference in the estimated annual egg for local chickens in the different ecological zones might be due to different climate conditions associated with the zones. The differences in annual egg production might also be due to differences in how the birds were managed by the caretakers and the availability of scavenging feed resource base in the various locations. Or it may be due to the types of husbandry practices provided by the households to the chickens as well as the quality and quantity of the feed available in the respective locations. Hence, the development agents in the study area need to appraise the poultry keepers about improved practices and packages of poultry husbandry aimed at poverty alleviation.

The findings of the average eggs/clutch/hen in the current study is lower than the report of Fisseha et al. (2010) who reported 15.70 and 14.90 eggs/clutch with estimated total egg production/birds/year of 60 and 55 eggs in Bure and Dale districts, respectively. The average number of chicks surviving to adulthood and number of chicks hatched per brood in the study districts were 10.54±0.51 and 7.95±0.58, respectively. This indicates that poor husbandry practices cause loss of one-quarter of the chicken in the study area. The current findings are in line with Fisseha et al. (2010), who reported the average number of chicks survived from the average number of eggs hatched (11 and 10.2) were 6.7 and 7.6 in Bure and Fogera districts, respectively. The different results on indigenous chicken ecotypes showed that good poultry husbandry practices could improve the percentage of survivability of hatched chicken and the income of the households.

The major cause of loss of chicken identified in this study, concurred with findings by Addis (2014) who reported that the major cause of chicken mortality is a disease in Bahir Dar Zuria district and ensured that poor health is the key limiting factor to the productivity of chicken raised by most rural farmers in the study area. As reported by Addis (2014) most farmers interviewed depended on drug suppliers for veterinary help. This raises some doubts about the accuracy of the diagnosis of diseases. Maximum productivity in each system of production emerges when disease control is optimal (Edea 2012). Thus, healthcare is an important problem to consider before the genetic program can be seriously contemplated. Community-based animal health programs may be one way forward and wider utilization of indigenous breeds tolerant to disease another predator was identified as the second constraint for the chicken producers in the study area (Mirkena et al. 2012). Causes of predators were due to the scavenging nature of the chickens, going here and there to search for feed, which will push for the predator. Whereas unknown causes and drought were ranked lowly in the study area (Table 12). Drought as the cause of mortality might be due to the lowland agroecology of the area.

In conclusion, this study provides insight into agricultural production systems, breeding practices, and major production constraints encountered in chicken farming in the study area, which are preconditions in developing breeding programs. Midland agroecology is the most suitable as compared with that of the lowland areas for most parameters. Documenting the productive and reproductive performance of local chicken at different agro-ecologies could be considered as playing a pivotal role as a base for further research. Chicken has a great role in the livelihoods of the community. Indigenous chicken ecotypes in the study area are the most promising for their better adaptability under low input extensive production environments where disease and predator are the two major constraints. Chicken is a highly valued animal by the Southern people next to cattle reared to fulfill diverse socio-cultural needs. Body size and growth performance are given high priority in selecting breeding males among their mates. Similarly, for breeding females, good health conditions, egg production, and age are among the most considered criteria for selection. The study indicated that most of the women actively participate in poultry production using indigenous ecotypes and traditional knowledge of poultry management to generate income. Chickens support food security at the household level through not only direct consumption, but also creating an enabling economic environment that enables farmers to have better purchasing power or better access to purchase food. It also can provide financial support for the schooling of children. The most dominant chicken production systems in the study area were the backyard extensive systems based on the local indigenous birds and scavenging with occasional supplementary feeding of homegrown grains and household food refusals. Most of the respondents have not accessed regular vaccination programs and proper prevention mechanisms for their chickens.

To avoid the early disposal of breeding males, a strong extension service is required to convince farmers and to develop an interest in the benefits of better genotypes or incentives that might be provided for those keeping their best males for breeding purposes. Owing to the small flock size in the study area, reasonable genetic gain demands the formation of breeders' groups or co-operatives, which in turn require full participation and long-term commitment of chicken keepers and other livestock development actors. To realize the full benefits of breeding programs, approaches should be holistic, and a concurrent improvement in the non-genetic factors (disease and feed) is central. To minimize the loss of chickens, the government as well as the concerned bodies need to give attention to the main constraints.

ACKNOWLEDGEMENTS

The authors would like to thank everyone who has contributed to this study, especially Tarcha, Loma, and Konta special district farmers and livestock experts. Also, we would like to thank Tadese Hunduma for his support in the preparation of the map of the study area, and the Ethiopian biodiversity institute for the support of the research fund.

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ASIAN JOURNAL OF AGRICULTURE
Volume 5, Number 2, December 2021 E-ISSN: 2580-4537
Pages: 84-89 DOI: 10.13057/asianjagric/g050205

Leaves and bark of *Albizia* shade trees in tea plantation shows both insect attractant and pesticidal properties: a GC-MS based investigation

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Manuscript received: 7 August 2021. Revision accepted: 13 October 2021.

Abstract. *Ghosh A, Majumder S, Saha S, Chakraborty S, Bhattacharya M. 2021. Leaves and bark of* Albizia *shade trees in tea plantation show both insect attractant and pesticidal properties: a GC-MS based investigation. Asian J Agric 5: 84-89.* Tea is the major plantation crop of sub-Himalayan region. The bushes are grown under a partial canopy cover of leguminous plants to protect them from scorching sun rays. The shade plants are primarily beneficial but attract several pests. Metabolites present in four *Albizia* trees were detected by GC-MS, and insect attracting and/or repelling phytochemicals were pointed out. A total of thirty-two compounds exhibiting semiochemical properties were detected. 15.84%, 2.52%, 2.61% of semiochemicals are exclusively present in leaves of *Albizia odoratissima*, *Albizia chinensis,* and *Albizia procera.* While in bark 10.73% and 13.35% semiochemicals were exclusively present in *Albizia odoratissima* and *Albizia lebbeck*. A total of nine semiochemicals are exclusively present in AO, out of which seven semiochemicals viz., caryophyllene, epoxide; longiborneol; longifolene; methyl linolenate; methyl linoleate; methyl cis-jasmonate; tonalid are present in leaf and five semiochemicals viz. longiborneol; methyl cis-jasmonate; camphor; isopropyl myristate; tonalid are present in bark. A total of five semiochemicals viz. alpha-santalol; bisabolol oxide A; gamma-Sitosterol; glycidyl oleate (as oleic acid); oleoyl chloride (as oleic acid) are found exclusively in the bark of *Albizia lebbeck.* There were only three semiochemicals that were exclusively found in the leaf of AC, these were 2-decen-1-ol; cyclohexanol, 5-methyl-2-(1-methyl ethyl); acetophenone. In the leaf of AP, a total of five semiochemicals were found to be exclusive, these being dehydro-beta-ionone; oleamide; beta-amyrin; isopropyl linoleate; stigmasterol. GC-MS analysis explored metabolites from shade trees like caryophyllene, epoxide; beta-amyrin; 1, 8-cineol etc. which serve as both attractant and pesticidal components while compounds like longiborneol; longifolene; linalyl acetate, etc. are exclusively pest attractants and compounds like isopropyl myristate are exclusive pest repellants. This cumulative property of shade trees can be utilized to trap insect pests and destroy them with pesticidal activity. Isolation of these metabolites from shade trees, and their utilization as semiochemical/pheromone trap and green pesticides, will control pests by eco-friendly measures along with reducing the production cost.

Keywords: *Albizia*, attractant, GC-MS, insect, pesticide

Abbreviations: AO: *Albizia odoratissima;* AC: *Albizia chinensis;* AP: *Albizia procera*; AL: *Albizia lebbeck*; GC-MS: Gas chromatography-mass spectrometry

INTRODUCTION

Tea, in the sub-Himalayan region, is grown under a canopy of trees which provides partial shade that is quite essential for good tea leaf production by minimalizing burns or damage to the young tea leaves from sun-scorch. A good number of trees are planted mainly to provide shade but, at the same time, can also be beneficial for reducing soil erosion, enriching soil fertility and organic matter content through leaf litter and nitrogen fixation (leguminous plants only) (Kalita et al. 2014; Ghosh et al. 2020). Among the shade trees *Albizia* spp. trees are considered as the best by planters for besides providing shade, as being leguminous they can fix nitrogen and can add huge amount of organic matter by shedding their leaves once a year (Anim-Kwapong 2003). Moreover, because of pinnation in leaves, the amount of sunlight under their canopy gets reduced but not blocked completely which is essential for tea bushes. Besides these benefits, tea plantations suffer some disadvantages from these big nutrition suckers. One of the deadliest effects is occurrence of pest and disease infestations (Beer 1987). Several factors are behind these infestations; like reduced air movement and increased humidity to favor fungal diseases and provide good breeding grounds for different insects, etc.

Positive and negative attributes of shade trees on tea bushes and quality of manufactured tea have been the center of attraction by researchers. But one of the ignored areas is studying insect pests attracting properties by shade trees. A semiochemical is a chemical substance or mixture released by plants and other organisms that affect the behaviors of other individuals. Plants contain such chemicals in the form of pheromones, attractants, allomones, kairomones, and synomones. They occur mainly in the outer part or cuticle in plants and thus are easily released into the air to attract other organisms to facilitate pollination (Majumder et al. 2020). In this research, we intended to study the occurrence of semiochemicals in shade tree leaves and bark to find whether they can play a role in attracting tea pests and pollinators. Considering this objective, a GC-MS based study was conducted to detect semiochemicals of four tea plantation-shade trees belonging to *Albizia* spp and make a comprehensive study on probable semiochemical based interaction between them and pests.

MATERIALS AND METHODS

In this study, leaves and bark of four tea plantation shade trees viz., *Albizia odoratissima* (L.f.) Benth, (AO), *Albizia lebbeck* (L.) Benth (AL), *Albizia chinensis* (Osbeck)Merr. (AC) and *Albizia procera* (Roxb.) Benth (AP) was considered.

Crushed fresh sample (1g) of leaf and bark from each plant was dissolved in acetone to extract components prior to GC-MS analysis. Acetone, being polar and aprotic solvent, was used.

The GC-MS analysis was done following the methodology of Majumder et al. (2020) and Chakraborty et al. (2021). Acetone extract of bark and leaves of four shade trees was used for GC-MS. One microliter of extracts was injected in split mode in the instrument (GCMS-QP2010 Plus). Injection temperature was 260 °C and the interface temperature was set to 270°C. Ion source temperature was adjusted to 230 °C. Helium was used as carrier gas. Total flow rate was 16.3 ml min^{-1} and the column flow rate was 1.21 ml min^{-1}. Mass spectra were recorded at 5 scan s^{-1} with a scanning range of 40-650 m/z. Quantification of compounds was done based on their peak areas. The data obtained from GCMS analysis were further analyzed from available literature. The detected metabolites were screened from available database (El-Sayed 2019) to analyze semiochemical properties.

RESULTS AND DISCUSSION

A total of thirty-two compounds exhibiting semiochemical property viz., longifolene, dehydro-beta-ionone, methyl linolenate, methyl linoleate; cumene; acetophenone; methyl palmitate; phenol; squalene etc. were detected by GC-MS analysis. A greater number of semiochemicals were detected in leaves of shade trees compared to bark. Only thirteen semiochemicals (camphor, alpha-santalol, phenol, gamma-sitosterol, etc.) were detected in the bark samples of which five were identical with compounds of leaf extracts (longiborneol; methyl palmitate; methyl cis-jasmonate; phenol and tonalid). Names of the semiochemicals previously reported as pheromones, kairomones, allomones, attractant for pests like ants, mites, moths, flies, etc. are provided in Table 1.

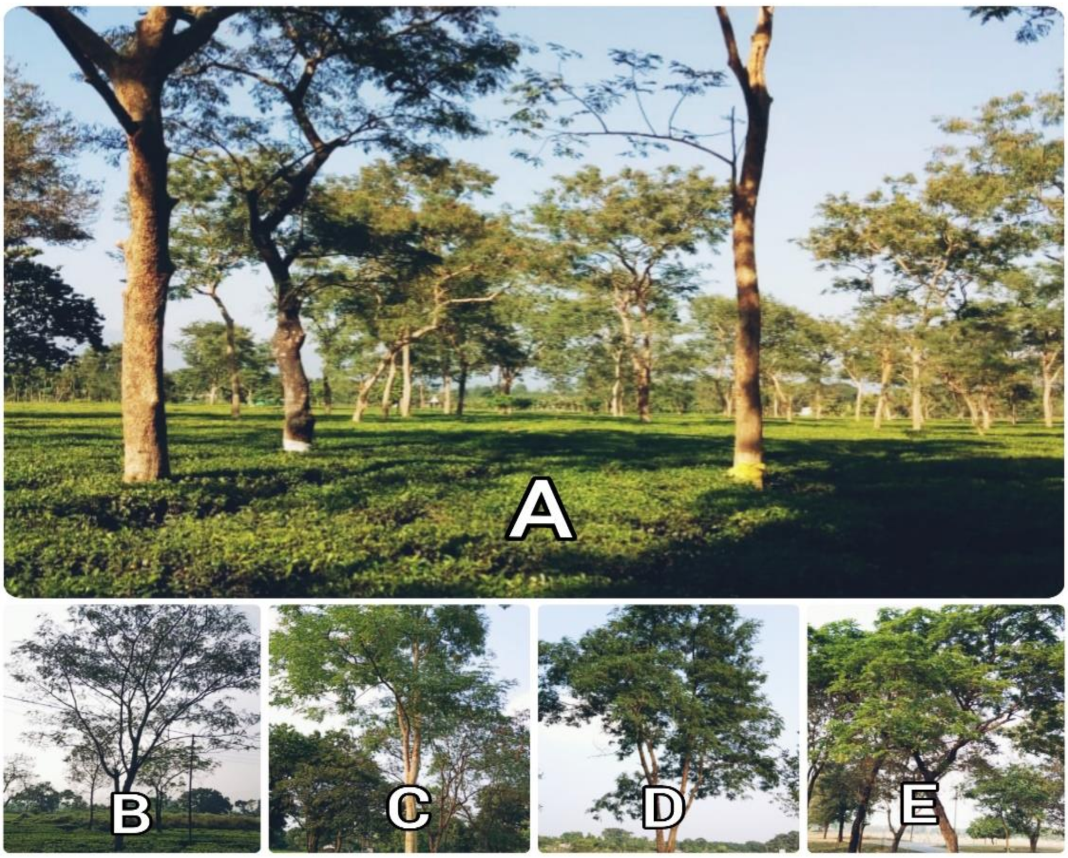

Figure 1. A- Tea Garden of North Bengal University, B- *Albizia chinensis* (AC), C-*Albizia procera* (AP), D-*Albizia odoratissima* (AO), E-*Albizia lebbeck* (AL).

Table 1. Semiochemicals present in four *Albizia* spp. to target wide range of pests.

Metabolites	**Type of pests**	**Attractant and/or insecticidal**
Caryophyllene, epoxide	Honeybee, moth, and butterfly (*Papilio* sp.)	Attractant, pheromone, antifeedant, fungi stat, larvicidal, insectifuge pesticidal activity
Longiborneol	*Monochamus alternatus* (Japanese pine sawyer)	Kairomone
Longifolene	Beetle, and pine sawyer	Attractant and pheromone
Linalyl acetate	Butterfly and cockroach	Attractant and pheromone
2-decen-1-ol	Bugs	Nematocidal activity
4,8,12,16-tetramethylheptadecan-4-olide	Crimson-patched longwing	Pheromone
Dehydro-beta-ionone	Beetle, whitefly, and spider mite	Attractant
Oleamide	*Lysmata boggessi* or Peppermint shrimp	Pheromone
Methyl linolenate	Mite, beetle, fly, honeybee, and butterfly	Pheromone, kairomone and allomone
Methyl linoleate	Mite (*Dermatophagoides* sp.), Queen honeybee, bumblebee, leaf-cutting ant, butterfly and leafroller	Attractant and pheromone
Benzene, (1-methylethenyl)	Floral compound or semiochemical	No report
Cumene	Floral compound or semiochemical	Pheromone, kairomone and allomone
Beta-amyrin	*Melanoplus sanguinipes* or Lesser migratory grasshopper	Pheromone and mosquitocidal, larvicidal activity
Cyclohexanol, 5-methyl-2-(1-methylethyl)	*Pogonomyrmex rugosus*-or Rough harvester ant	Pheromone
Acetophenone	Wasp, tick, Dendroctonus beetles and locust	Pheromone, kairomone, attractant and allomone
Methyl palmitate	Spider, mite, thrip, beetle, fruit fly, bumblebee, ant, wasp, butterfly, leafroller, spider, Housefly, Olive fruit fly and leafroller	Pheromone, kairomone, attractant and allomone
Isopropyl linoleate	*Pseudomyrmex ferruginea* or Acacia ant	Pheromone
Methyl cis-jasmonate (Methyl dihydrojasmonate)	Fruit moth	Pheromone and attractant
Neophytadiene	Heliconius sara or Sara longwing	Pheromone
Phenol	Beetle, cockroach, Screwworm fly, tick (*Amblyomma americanum*), moth, beetle, weevil, cockchafer (*Melolontha melolontha*), Blowfly, midge, house mosquito, honeybee Myrmecocystus ants, Locust, and grasshopper	Pheromone, kairomone, attractant and allomone
Phytol	Moth, beetle, and butterfly	Pheromone, attractant and allomone
Squalene	Mites (*Tyrophagus* sp.), seed borer, Tick (*Amblyomma* sp.) weevil, fruit fly, bumblebee, ant, and butterfly	Pheromone, attractant, allomone and pesticidal activity
Stigmasterol 1, 8-cineol	Bee and wood wasp Moth, ant, thrips, weevil, beetle, bug, looper and spider	Pheromone, attractant, allomone, kairomone and acaricidal, nematocidal, insectifuge, pesticidal activity
Camphor	Chafer, weevil, and moth	Attractant and allomone
alpha-Santalol	Fragrance	Mite repellent and acaricidal activity
Bisarbolol oxide A	Floral compound (semiochemical)	Insecticidal activity
gamma-Sitosterol	*Lacerta* sp., *Psammodromus algirus* and *Blanus cinereus*	Pheromone
Glycidyl oleate (as Oleic acid)	Mite, ant, tick (*Amblyomma americanum*), moth, booklouse, honeybee, bumblebee, bee, stem borer and grasshopper	Insectifuge
Oleoyl chloride (as Oleic acid)	Mite, ant, tick (*Amblyomma americanum*), moth, booklouse, honeybee, bumblebee, bee, stemborer and grasshopper	Insectifuge
Isopropyl myristate	Psyllids, beetles, bee, and moths.	Pesticidal activity
Tonalid	Fragrance	No report
Vitamin E	*Blanus cinereus*	Pheromone

Some secondary metabolites exhibiting semiochemical properties are exclusively present in the four *Albizia* spp. (Table 2). Leaf extracts of AO, AC and AP contained 15.84%, 2.52% and 2.61% (nil in AL) area of exclusive semiochemicals while AO and AL contained 10.73% and 13.35% (nil in AC and AP) area of semiochemicals exclusively in bark. A total of nine semiochemicals were exclusively present in AO, out of which seven semiochemicals viz., caryophyllene, epoxide; longiborneol; longifolene; methyl linolenate; methyl linoleate; methyl cis-jasmonate; tonalid were present in leaves and five semiochemicals viz., longiborneol; methyl cis-jasmonate; camphor; isopropyl myristate; tonalid were present in bark.

Table 2. Percentage of exclusive semiochemicals present in *Albizia* shade trees.

Semiochemicals	AO		AL		AC		AP	
	Leaf	Bark	Leaf	Bark	Leaf	Bark	Leaf	Bark
Caryophyllene, epoxide	1	0	0	0	0	0	0	0
Longiborneol	3.14	3.45	0	0	0	0	0	0
Longifolene	1.04	0	0	0	0	0	0	0
2-decen-1-ol	0	0	0	0	0.46	0	0	0
Dehydro-beta-ionone	0	0	0	0	0	0	0.1	0
Oleamide	0	0	0	0	0	0	0.25	0
Methyl linolenate	3.96	0	0	0	0	0	0	0
Methyl linoleate	2.13	0	0	0	0	0	0	0
beta-amyrin	0	0	0	0	0	0	0.45	0
Cyclohexanol, 5-methyl-2-(1-methylethyl)	0	0	0	0	0.79	0	0	0
Acetophenone	0	0	0	0	1.27	0	0	0
Isopropyl linoleate	0	0	0	0	0	0	0.75	0
Methyl cis-jasmonate	2.31	3.06	0	0	0	0	0	0
Stigmasterol	0	0	0	0	0	0	1.06	0
Camphor	0	0.53	0	0	0	0	0	0
alpha-Santalol	0	0	0	0.32	0	0	0	0
Bisabolol oxide A	0	0	0	0.88	0	0	0	0
gamma-Sitosterol	0	0	0	9.98	0	0	0	0
Glycidyl oleate	0	0	0	1.37	0	0	0	0
Oleoyl chloride	0	0	0	0.8	0	0	0	0
Isopropyl myristate	0	2.41	0	0	0	0	0	0
Tonalid	2.26	1.28	0	0	0	0	0	0

A total of five semiochemicals viz., alpha-santalol; bisabolol oxide A; gamma-Sitosterol; glycidyl oleate (as oleic acid); oleoyl chloride (as oleic acid) are found exclusively in the bark of AL. Only three semiochemicals have exclusively been found in the leaf of AC, these are 2-decen-1-ol; cyclohexanol, 5-methyl-2-(1-methylethyl); acetophenone. In the leaves of AP, a total of five semiochemicals were exclusive; these were: dehydro-beta-ionone; oleamide; beta-amyrin; isopropyl linoleate; stigmasterol.

Discussion

Semiochemicals like pheromones, allomones, kairomones, attractants, etc. are signaling compounds that can create responses even in minute amounts. But, in our samples, some of the semiochemicals were found to be present in high amounts which made our study more interesting to establish the shade trees as relevant pest attractants. As major components, benzene, (1-methylethenyl)-; cumene; neophytadiene; phytol; squalene; and vitamin E are semiochemicals present in leaf extracts. While phenol and gamma-sitosterol, are two of the prime bark components that are also potent contenders as semiochemicals (Table 1). According to results of this research, leaves of *Albizia* are found to contain more quantity of semiochemicals compared to bark (Figure 2). Summative area percentage of semiochemicals from all the four shade tree leaves amount to 159.59 while that of bark is 34.35.

Comparative analysis among leaf extracts of four shade trees, AO, AC, AL, and AP are depicted in Figure 2. It is observed that the leaves of AO (47.66%), AL (42.29%) and AC (49.34%) contain more amounts of semiochemicals based on area percentage than AP (20.3%). Surprisingly, in bark, the result is quite different. In AC, semiochemical content of leaf shows highest quantity but in bark sample, AL showed highest percentage of semiochemicals (18.27%). In AO, AL, and AC the quantity of semiochemicals in bark is 15.36%, 18.36% and 0.72% respectively.

According to "The Pherobase" (El-Sayed 2019) some of our compounds that have these properties are the following; caryophyllene, epoxide works as pheromone for honeybee and as attractant for moth; longifolene is pheromone for beetle; methyl linolenate is kairomone for mite and pheromone for honeybee; beta-amyrin is a pheromone for grasshopper; methyl palmitate is allomone for flies, thrips, ants, wasp and also attractant as well as kairomone for mites; isopropyl linoleate is a pheromone for ants; methyl cis-jasmonate is pheromone of moth; phytol works as pheromone for moth, and works allomone as well as attractant for beetles; squalene works as attractant and allomone of ticks, etc. Being leguminous, shade trees of *Albizia* sp. generally shed their leaves and other arial parts once in a year (spring/winter) so there is a chance to attract soil pests by their exudates even after shedding of leaves.

In our study, a few compounds were reported to have pest repellent and/or pesticidal properties besides their pest attracting properties (Figure 3). Isopropyl myristate has pesticidal activity and is found in AO (2.41% in bark) (Sharmila et al. 2019); Squalene is found in AO (5.59% in leaf), AL (11.39% in leaf), AC (8.7% in leaf) and AP(1.65% in leaf) having pesticidal activity (Arora and Kumar 2018), (Elakkiya and Murugaiah 2015); Caryophyllene, epoxide has antifeedant, fungistat, pesticidal, larvicidal, insectifugal activity (Duke 1992) and is found 1% in leaf extract of AO . 2-decen-1-ol found in AC (0.46% in leaf), has nematicidal activity. Beta-amyrin has mosquitocidal and larvicidal activity which is found in AP (0.45% in leaf) (Duke 1992); Methyl palmitate, found in AO (2.1% in leaf), has Acaricide and insect (ant) repellant activity (Wang et al. 2009), AL (0.45% in bark); Aphicide compound phytol (Benelli et al. 2020) is found in AO (5.64% in leaf), AL (2.83% in leaf), AC (1.77% in leaf) and AP (3.94% in leaf). Stigmasterol has insecticidal effect and is found in AP (1.06% in leaf) (Nong et al. 2017); 1,8 cineol has acaricidal, nematocidal, insectifugal and pesticidal activities (Duke 1992) that is found in both AL (0.49% in bark) and AC (0.72% in bark); alpha-santalol has acaricidal activity (Misra and Dey 2013) and mite repellant activity against *Tetranychus urticae* and is found in AL (0.32% in bark) (Roh et al. 2012); Bisabolol oxide A has insecticidal activity (de Andrade et al. 2004) and is found in AL (0.88% in bark); glycidyl oleate (1.37%) and oleoyl chloride (0.80%) which are both derivatives of oleic acid is found in the bark extracts of AL, works as insectifuge (Duke 1992).

Besides having both insect attracting and pesticidal properties for pests, some of the metabolites are specifically important for tea plantations as they specifically attract pests of tea bushes. Methyl palmitate and methyl linolenate function as pheromone, kairomone, attractant and allomone for spider, mite, thrip, beetle, ant, wasp, and leaf roller; longifolene functions as pheromone to attract beetles; dehydro-beta-ionone attract beetle, whitefly, spider mite. Spider mites, especially red spider mites cause much damage in tea plantations of sub–Himalayan West Bengal (Roy 2019). Acetophenone act as pheromone, kairomone, attractant and allomone for wasp, tick, beetles, and locust. Phenol is a pheromone, kairomone, attractant and allomone for beetle, cockchafer (*Melolontha melolontha*), locust and grasshopper, while phytol is a pheromone, attractant and allomone for moth and beetle. Camphor is attractant and allomone for moth.

The metabolites of leaf and bark also reduce insect pests. Caryophyllene epoxide is insectifuge with larvicidal and pesticidal activity; 2-decen-1-ol has nematocidal activity specifically on bugs; squalene has pesticidal property on mites, seed borers, ants; beta-amyrin acts on lesser migratory grasshopper. Also, it is mosquitocidal and larvicidal for *Melanoplus sanguinipes* or lesser migratory grasshopper (Duke 1992; El-Sayed 2019). Alpha -santalol has mite repellent and acaricidal activity. Bisabolol oxide A is an insecticide. Glycidyl oleate and oleoyl chloride are insectifuge while isopropyl myristate has pesticidal activity.

Some metabolites have interesting properties; they act as both, attractant and has pesticidal effect on pests. 1,8-cineol is a pheromone, attractant, allomone, kairomone and has acaricidal, nematocidal, insectifugal, pesticidal activity against moth, ant, thrips, weevil, beetle, bug, looper, spider while stigmasterol acts as pheromone and have insecticidal activity. So, considering the beneficial properties of the metabolites, this study suggests that these shade tree organs can be utilized profitably to trap pests in tea plantations and as natural biopesticides.

Shade trees are inseparable partners of tea bushes in tea plantations of sub-Himalayan region. Leguminous trees are the first and foremost choice for providing shade but, non-leguminous trees like neem are planted too for their pesticidal secondary metabolites. Shade tree metabolites serve as insect or pest attractant as revealed by GC-MS analysis, but several metabolites have been reported to exhibit pesticidal activity. So, this dual property established shade trees as insect-attracting plants with insecticidal properties. Moreover, isolation of metabolites from shade trees and their utilization as semi chemical/pheromone trap and green pesticides will not only help in controlling pest in an eco-friendly and profitable aspect, but also will reduce the use of chemical pesticides in tea plantations.

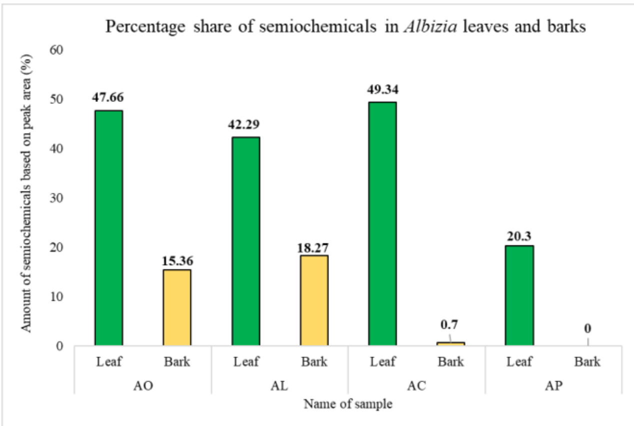

Figure 2. Semiochemicals contents of insect related properties in *Albizia* leaf and bark extracts.

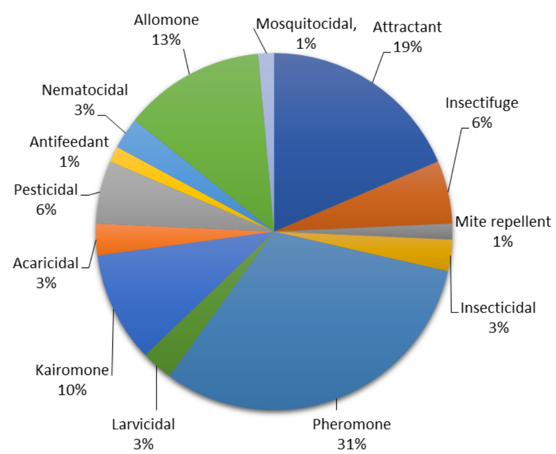

Figure 3. Proportion of insect-related semiochemical activities in *Albizia* extracts revealed by GC-MS.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the scientific team of Molecular Biology and Tissue Culture Laboratorymates, University of North Bengal, India. The authors declare no conflict of interest.

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ASIAN JOURNAL OF AGRICULTURE
Volume 5, Number 2, December 2021
Pages: 90-97
E-ISSN: 2580-4537
DOI: 10.13057/asianjagric/g050206

Impact of corm size and phosphorous on growth and floral characteristics of gladiolus (*Gladiolus grandiflorus*)

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Manuscript received: 15 September 2021. Revision accepted: 3 December 2021.

Abstract. *Hossain TM, Pitol MNS, Mannan MA, Khan SAKU. 2021. Impact of corm size and phosphorous on growth and floral characteristics of gladiolus (*Gladiolus grandiflorus*). Asian J Agric 5: 90-97.* The present study was conducted to investigate the impact of corm size and phosphorus levels on the growth, flowering, corm, and cormel production of gladiolus (*Gladiolus grandiflorus* L.). The experiment was laid out in Randomized a Complete Block Design (RCBD) with three replications, three corm sizes, viz. S1 (31-40 g), S2 (21-30 g), S3 (10-20 g), and four phosphorus levels, viz. P0 (Control), P1 (200 kg ha^{-1} Triple Super Phosphate (TSP), P2 (300 kg ha^{-1} TSP), P3 (400 kg ha^{-1} TSP). The observations were recorded for various vegetative, floral, and corm parameters. Corm size significantly impacted plant height, number of leaves, number of tillers, size of the leaf, number of spikes, spike length, and number of florets. Corm size also significantly impacted all yield contributing characters and yield of corm and cormel. Large (S1) and medium-size (S2) corms were found superior to small-size (S3) corms concerning all the parameters. At 60 days after planting (DAP), the highest plant (83.53 cm), the maximum number of leaves (10.00), the utmost number of the tiller (3.00), the highest number of the spike (10.00), the largest spike (87.03 cm), the maximum number of floret (13.80), the greatest number of corm and cormel (154.67), the maximum size of corm (44.16 mm) and the highest weight (2,706.7 gm) of corm was obtained from the treatment combination of S1 (31-40 g) treated with P3 (400 kg ha^{-1}) TSP under this observation. The obtained result will guide the farmers on what types of planting materials and how much fertilizer to use to cultivate gladiolus commercially successfully.

Keywords: Corm, cormel, florets, floriculture, gladiolus, spike

INTRODUCTION

Floriculture is becoming a promising enterprise in Bangladesh. The economic importance of ornamentals has been increasing day by day. Gladiolus (*Gladiolus grandiflorus* L.) is an essential bulbous ornamental plant and queen amongst the flowers (Gil et al. 2000). It belongs to the family Iridaceae. It is believed to have originated in South Africa, but its cultivation in the Indian subcontinent began in the 19th century (Bose and Yadav 2003). Gladiolus occupies fourth place next to the tulips in the international cut flower trade (Ogale et al. 2005). It is highly priced for its bright, beautiful, and vivid colored flowers for garden displays such as beds, herbaceous borders, pots, and indoor ornamentation. The spike of gladiolus is viral in Bangladesh and used in different social and religious ceremonies. It has domestic and international markets, as no flower surpasses its beauty in the cut flower industry (Halevy et al. 2007). Their cultivation is getting popular for its striking colors occurring naturally in the stripes, dots, and splashed bicolored and multicolored florets. This flower has a longer shelf life than cut flowers. Their sweet inflorescence, various colors, and several pretty florets have made them gorgeous for spread use in the garden (Chandra et al. 2000). Moreover, the cut flower market continuously looks for alternatives to traditional genera such as rose, tuberose, marigold, and chrysanthemum. Bulbous flowers like gladiolus, tuberose, cyclamen, resurrection lily, spider lily, etc., make up a considerable part of the cut flower market.

Gladiolus is prized for its showy flowering stem and relative production case (Sarek et al. 2004). Still, Having elegance and long vase life of gladiolus, its value is increasing in our daily lives. Recently it has been viral in Bangladesh, and its demand is increasing daily. But modern technology of gladiolus production demands the production of healthy corms every year, which is essential for quality flower production. An insufficient supply of planting material is the major constraint in gladiolus farming (Malter 2005). Gladiolus is propagated mainly by its corms and cormels. The new corm produces several small cormels around it during its growth, serving as a future propagule source (Ginsburg 2003). Reports indicated that growth, flowering, and corm production in gladiolus are affected by various factors, of which size of the corm planted and chemical treatment of corms before planting essential play roles (Mohanty et al. 2004). The diameter and weight of corms have also influenced the yield and quality of cut flowers in gladiolus. Increased floret length and, thus, longer bloom life by planting large corms have been reported by Bankar and Mukhopadhyay (1980). Arora et al. (1992) reported better performance of large corms concerning corm and cormel production than smaller or medium ones. Several factors, such as agro-techniques, nutrition, phosphorus level, etc., influenced the productivity, quality of spikes, corms, and cormels production. So, it is imperative to deliver more evidence to the cultivators for higher productivity and quality. However, the number of spikes, corms, and cormels produced per plot was greatly influenced by corm size (Singh and Bijimol 2003). The growth, flowering, and yield of daughter bulbs in gladiolus have been affected by corm size. (Mukhopadhyay and Bankar 1986). The larger size of the corm benefits in obtaining good quality cut flowers and better land utilization for next crop production and quality (Sindhu and Verma 2007).

On the other hand, modification of growth and flowering of gladiolus due to phosphorous has been reported by many authors (Bose and Yadav 2003; Bleasdale 2004; Mohanty et al. 2004). The influence of corm and cormel growth by using different corms is also reported by Mukhopadhyay and Bankar (2003). Bhattacharjee (2004) observed increased vegetative growth, cormel production, and improved flowering using phosphorous. Halevy et al. (2007) and Ginsburg (2003) reported an increase in the yield and weight of corm and cormel due to phosphorous treatment. Some studies have been done in Bangladesh regarding the corm size and phosphorous effect. But research work is still lacking in the country, especially in the southwestern region. So, the present study was designed to determine the impact of corm and cormel size and phosphorous levels on gladiolus' growth and flower production.

MATERIALS AND METHODS

Field experiment

The study was conducted on the Khulna University campus, Khulna, Bangladesh, to investigate the effects of corm size and phosphorus levels on gladiolus' growth and floral characteristics. The experiment's locality has three distinct seasons: the monsoon or rainy season extending from May to October, the winter or dry season from November to February, and the pre-monsoon period or hot season from March to February April (Edris et al. 2009). The experimental plot was a medium-high land having proper drainage and irrigation facilities. The soil of the observed area was Sandy loam in texture under the Agroecological zone (AEZ) 13. The treatment details were as follows (Table 1). The two-factor experiment was laid out in Randomized Complete Block Design (RCBD) with three treatment replications.

Factor A and B expressed the corm size and phosphorus level, respectively. The land was divided into three blocks with 12 block treatment combinations at each block. The unit plot size was 1.5 m × 3.0 m, with a spacing of 50 cm × 30 cm. The corms and cormels used in the present study were collected from Gadkhali, Jhikorgacha, and Jessore.

Cultural practices

The land selected for the experiment was opened during mid-November 2016 and thoroughly prepared by several ploughings and cross ploughings with a power tiller followed by laddering to obtain a good tilth. The weeds and debris were removed from the field, and the soils were pulverized before final land preparation. The basal doses of manures and other fertilizers were applied during the final land preparation, and all types of fertilizer (Triple Super Phosphate-TSP, Mop-130 kg ha^{-1}, Zypsum-120 kg ha^{-1}, Cow dung 10 t ha^{-1}) were applied except urea. Urea was used at 30 days, 45 days, and 60 days of planting. The corms were planted at a depth of 6 cm in furrows maintaining a row-to-row distance of 50 cm and plant-to-plant distance of 30 cm. Weeding was done periodically whenever necessary. The soil was mulched with rice straw to conserve soil moisture. The experimental plots were irrigated weekly in the dry season during the plant growth following the sprinkler method. Two earthing up at 25 and 50 days of planting were done throughout the growing period. The gladiolus spikes were harvested at the tight bud stage when three basal flower buds showed color so that these may easily open indoors one by one (Bose and Yadav 2003). Corms and cormels were harvested when 25 percent of cormels had become brown, and the leaves also started yellowing (Webster 2002).

Data collection

Data on the following parameters were recorded from ten randomly selected plants as representatives of a unified plot and yield per plot where all the plants were considered. All the data were recorded at an interval of 15 days, from 15 days after planting (DAP) to 60 days after planting. Plant height was determined from the ground level to the large leaf's apex and expressed in centimeters. All the leaves, spikes, florets per spike and tillers were counted. The total number of corm and cormel was counted after harvest, and the mean was calculated at 180 DAP. The length and breadth of leaves, spikes, corms, and cormels were measured, and the means were calculated (at cm). The total weight of the corm and cormel per plot was calculated at 180 DAP, while the mean was in kilogram (kg).

Table 1. Treatments and combinations

Treatment	Combination	Treatment	Combination	Treatment	Combination
T1	S1 and P0	T5	S2 and P0	T9	S3 and P0
T2	S1 and P1	T6	S2 and P1	T10	S3 and P1
T3	S1 and P2	T7	S2 and P2	T11	S3 and P2
T4	S1 and P3	T8	S2 and P3	T12	S3 and P3

Note: S1 (31-40 g), S2 (21-30 g), S3 (10-20 g), P0 (Control), P1 (200 kg ha^{-1} (TSP), P2 (300 kg ha^{-1} TSP), P3 (400 kg ha^{-1} TSP)

Statistical analysis

The collected data for various characters were statistically analyzed using Statistical Tool for Agricultural Research (STAR) computer package program. The mean for all the treatments was calculated, and the F-test analyzed variance for each character. Duncan's New Multiple Range Test (DMRT) evaluated the difference between the treatment means at 1% or 5% probability wherever applicable.

RESULT AND DISCUSSION

Impact of corm size and phosphorous levels on plant height of gladiolus

Plant height was significantly influenced by corm size but no significant variation between the phosphorus level and the combination treatment of corm size with a phosphorous level regarding plant height. At different DAP, the taller plant (80.60 cm) was obtained from S1 (31-40 g), and the shorter plant (60.43 cm) was observed from S3 (10-20 g) (Table 2). That might be because the early emergence of the crop from a large corm and higher reserve food resulted in better growth and ultimately gave maximum plant height compared to the small corm. Similar results were found by Bankar and Mukhopadhyay (1980), Misra et al. (1985), Azad (1996), Gil et al. (2000), Singh et al. (2000), and Hossain et al. (2011) from their earlier experiments. However, the taller plant (70.87 cm and 83.53 cm) at 60 DAP was obtained from P3 (400 kg ha^{-1}) and S1xP3 (31-40 g with 400 kg ha^{-1}), where the shorter plant (68.67 cm and 59.73 cm) was obtained from the control (P0) and S3xP0 (10-20 g with 0 kg ha^{-1}) respectively (Table 2). Rabbani and Azad (1996) stated that large and medium corms were superior to small ones. Anil et al. (2000) and Bazwaja et al. (2001) reported that growth increased with increasing phosphorous doses.

Impact of corm size and phosphorus levels on the number of leaves of gladiolus

The number of leaves was significantly influenced by corm size, and there was no significant variation among the phosphorus level and combination treatments. The highest number of the leaf (9.83) was obtained from the plant grown from S1 (31-40 g), and the lower number (5.91) was recorded from S3 (10-20 g) (Table 3). Similar results were found by Gowda (1987), Mohanty et al. (1994), Kalasareddi et al. (1997), and Hossain et al. (2011). However, the highest number of the leaf at (8.33 and 10.00) was obtained from P3 (400 kg ha^{-1} TSP) and S1xP3 (31-40 g with 400 kg ha^{-1}). In contrast, the lower number of the leaf (7.56 and 5.67) at 60 DAP was obtained from P0 (the control) and S3xP0 (10-20 g with 0 kg ha^{-1}), respectively (Table 3).

Table 2. Impact of corm size and phosphorous levels on plant height of gladiolus

Corm size (cm)	Plant height(cm) at			
	15 DAP	**30 DAP**	**45 DAP**	**60 DAP**
S1	41.60 a	55.91 a	66.53 a	80.60 a
S2	34.09 b	43.50 b	54.53 b	67.03 b
S3	30.50 c	38.67 c	50.41 c	60.43 c
Level of significance	**	**	**	**
Level of phosphorous (kg ha^{-1})				
P0	34.66	45.31	56.87	68.67
P1	35.57	46.39	57.35	68.92
P2	35.64	46.60	57.38	68.88
P3	35.92	46.80	57.42	70.87
Level of significance	NS	NS	NS	NS
Treatment combination				
S1 P0	40.53	55.06	66.20	79.93
S1 P1	41.83	57.16	66.80	80.43
S1 P2	41.36	54.80	66.20	79.53
S1 P3	42.67	56.60	66.90	83.53
S2 P0	34.63	44.67	55.06	66.36
S2 P1	34.76	43.67	53.80	65.13
S2 P2	34.30	41.00	54.53	66.76
S2 P3	36.30	44.67	54.70	69.86
S3 P0	25.80	34.67	49.00	59.73
S3 P1	30.10	38.33	50.00	60.47
S3 P2	30.67	41.00	51.33	59.99
S3 P3	40.80	41.67	51.33	60.20
Level of significance	NS	NS	NS	NS
CV	9.41	7.76	3.78	4.02

Note: **: Significance 0.01, NS: non-Significant

Table 3. Impact of corm size and phosphorus levels on the number of leaves of gladiolus

Corm size (cm)	Number of the leaf at			
	15 DAP	**30 DAP**	**45 DAP**	**60 DAP**
S1	8.59 a	9.25 a	9.83 a	9.83 a
S2	7.00 b	7.58 b	7.83 b	7.91 b
S3	6.33 c	5.75 c	5.75 c	5.91 c
Level of significance	**	**	**	**
Level of phosphorous (kg ha^{-1})				
P0	6.77	7.11	7.44	7.56
P1	7.44	7.22	7.55	7.67
P2	7.44	7.77	8.00	8.00
P3	7.55	8.00	8.22	8.33
Level of significance	NS	NS	NS	NS
Treatment combination				
S1 P0	9.00	9.66	9.67	9.67
S1 P1	9.00	9.33	10.00	10.00
S1 P2	8.33	9.00	9.67	9.67
S1 P3	8.33	9.00	10.00	10.00
S2 P0	7.67	8.33	8.33	8.33
S2 P1	7.67	8.00	8.67	8.67
S2 P2	6.67	6.67	7.00	7.33
S2 P3	6.00	7.33	7.33	7.33
S3 P0	5.31	5.33	5.33	5.67
S3 P1	5.67	6.00	6.00	6.33
S3 P2	5.33	5.67	5.67	6.67
S3 P3	5.31	5.33	5.33	6.67
Level of significance	NS	NS	NS	NS
Cv	12.70	9.37	7.86	9.53

Note: **: Significance 0.01, NS: non-Significant

Impact of corm size and phosphorus levels on tiller number of gladiolus

Plants grown from large corms had the highest number of tiller (3.0), and the lowest number of tiller (1.92) was observed from small corms used as planting material (Table 4). That might be because the large corms were about four times larger than the small corm having more reserve food, which enhanced the vegetative growth quickly and resulted in a maximum number of tillers. Similar results were reported by Vinceljak-Toplak (1990). However, a highest number of tillers (2.44 and 3.00) was obtained from the P3 (400 kg ha^{-1} TSP) and S1xP3 (31-40 g with 400 kg ha^{-1}). In contrast, the lower number of tillers (2.22 and 1.67) was obtained from P0 (the control) and S3xP0 (10-20 g with 0 kg ha^{-1}) at 60 DAP, respectively (Table 4).

Impact of corm size and phosphorus levels on the number of spike gladiolus

The number of spikes was significantly influenced by corm size. At different DAPs, the highest (43.75) and lowest (23.00) number of the spike was obtained from the treatment S1 (31-40 g) and S3 (10-20 g), respectively (Table 5). Similar results were reported by Mukhopadhyay and Bankar (2003). At all the growth stages, the number of spikes increased with time advancement. However, a highest number of spikes (8.33 and 10.00) was obtained from P3 (400 kg ha^{-1} TSP) and S1xP3 (31-40 g with 400 kg ha^{-1}). In contrast, the lower number of spikes (7.56 and 5.67) were obtained from P0 (the control) and S3xP0 (10-20 g with 0 kg ha^{-1}) at 60 DAP, respectively (Table 5).

Effect of corm size and phosphorous levels on spike length of gladiolus

At 60 DAP, the large corm produced the highest spike length (84.80cm.), and the small corm produced the lowest spike (66.38) (Table 6). Similar results, i.e., the increased spike length due to large corm, were reported by Dod et al. (2007). However, no significant effect was observed due to the variation in phosphorus level. At all the stages of growth, spike length was increased with the advancement of time. Numerically, the longest spike (76.10cm) was obtained from P3 (400 kg ha^{-1} TSP). At the same time, the shortest spike (73.34cm) was obtained from P0 (the control) at 90 DAP. However, the maximum spike length (87.03cm) was observed in the treatment combination of large corms with 400 Kg/ha TSP, and the minimum spike (65.46cm) was obtained from the most undersized corms treated with the control (Table 6). Gil et al. (2000), Bhattacharjee (2001), and Makay et al. (2001) stated that spike length, floret number, flower diameter, and size and weight of corms increased with the increase in corm size.

Table 4. Impact of corm size and phosphorous levels on the number of tillers of gladiolus

Corm size (cm)	Number of the tiller at			
	15 DAP	**30 DAP**	**45 DAP**	**60 DAP**
S1	3.00 a	3.00 a	3.00 a	3.00 a
S2	2.00 b	2.00 b	2.08 b	2.08 b
S3	1.92 c	1.91 c	1.92 c	1.92 c
Level of significance	**	**	**	**
Phosphorous (kg ha^{-1})				
P0	2.22	2.22	2.22	2.22
P1	2.22	2.22	2.33	2.33
P2	2.33	2.33	2.33	2.33
P3	2.44	2.44	2.44	2.44
Level of significance	NS	NS	NS	NS
Treatment combination				
S1 P0	3.00	3.00	3.00	3.00
S1 P1	3.00	3.00	3.00	3.00
S1 P2	3.00	3.00	3.00	3.00
S1 P3	3.00	3.00	3.00	3.00
S2 P0	2.33	2.33	2.33	2.33
S2 P1	2.00	2.00	2.00	2.00
S2 P2	2.00	2.00	2.00	2.00
S2 P3	2.00	2.00	2.00	2.00
S3 P0	1.67	1.67	1.67	1.67
S3 P1	2.00	2.00	2.00	2.00
S3 P2	2.00	2.00	2.00	2.00
S3 P3	2.00	2.00	2.00	2.00
Level of significance	NS	NS	NS	NS
CV	12.89	12.89	10.55	10.55

Note: **: Significance 0.01, NS: non-Significant

Table 5. Impact of corm size and phosphorous levels on the number of spikes of gladiolus

Corm size (cm)	Number of the spike at			
	45 DAP	**60 DAP**	**75 DAP**	**90 DAP**
S1	10.00 a	26.33 a	38.17 a	43.75 a
S2	2.92 b	11.67 b	22.08 b	27.00 b
S3	2.42 c	9.83 c	18.08 c	23.00 c
Level of significance	**	**	**	**
Phosphorous (kg ha^{-1})				
P0	5.33	13.56	23.67	29.33
P1	5.33	15.67	24.78	29.89
P2	5.55	16.78	27.67	32.66
P3	6.22	17.77	28.33	33.11
Level of significance	NS	NS	NS	NS
Treatment combination				
S1 P0	9.33	21.33	33.33	40.33
S1 P1	6.67	25.67	37.33	43.00
S1 P2	10.67	27.00	38.67	43.33
S1 P3	13.33	31.33	43.33	48.33
S2 P0	4.67	10.00	19.67	25.33
S2 P1	3.33	13.33	22.67	27.00
S2 P2	2.97	12.00	23.67	28.33
S2 P3	2.83	11.33	22.33	27.33
S3 P0	2.89	9.33	18.00	22.33
S3 P1	2.00	8.00	14.33	19.67
S3 P2	2.07	11.33	20.67	26.33
S3 P3	1.97	10.67	19.33	25.67
Level of significance	NS	NS	NS	NS
CV	48.96	35.69	26.79	20.84

Note: **: Significance 0.01, NS: non-Significant

Table 6. Impact of corm size and phosphorous rate on spike length of gladiolus

Corm size (cm)	Spike length (cm)
	90 DAP
S1	4.80 a
S2	2.77 b
S3	6.38 c
Level of significance	**
Phosphorous (kg ha^{-1})	
P0	73.34
P1	74.16
P2	74.99
P3	76.10
Level of significance	NS
Treatment combination	
S1 P0	85.06
S1 P1	84.53
S1 P2	82.57
S1 P3	87.03
S2 P0	72.70
S2 P1	71.40
S2 P2	72.00
S2 P3	74.97
S3 P0	65.46
S3 P1	66.57
S2 P2	66.46
S3 P3	66.30
Level of significance	NS
CV	74.65

Note: **: Significance 0.01, NS= non-Significant

Table 7. Impact of corm size and phosphorous levels on the number of florets of gladiolus

Corm size (cm)	Number of florets at
	90 DAP
S1	3.30 a
S2	1.17 b
S3	0.39 c
Level of significance	**
Phosphorous (kg ha^{-1})	
P0	11.41
P1	11.53
P2	11.69
P3	11.83
Level of significance	NS
Treatment combination	
S1 P0	13.80
S1 P1	13.20
S1 P2	12.97
S1 P3	13.80
S2 P0	11.00
S2 P1	11.10
S2 P2	11.06
S2 P3	11.50
S3 P0	10.20
S3 P1	10.73
S3 P2	10.20
S3 P3	10.20
Level of significance	NS
CV	5.52

Note: **: Significance 0.01, NS: non-Significant

Effect of corm size and phosphorous levels on the number of florets of gladiolus

At 90 DAP, the highest (13.30) and lowest (10.39) number of floret was obtained from S1 (31-40 g) and S3 (10-20 g), respectively (Table 7). The present results are in agreement with the findings of Bhattacharjee (2001), Dod et al. (2007), and Gowda (2008), who obtained a highest number of florets per spike in plants grown from a large corm. At all the stages of growth, the number of florets increased with time. However, numerically the maximum number of floret (11.83) was obtained from the P3 (400 kg ha^{-1}). On the other hand, the minimum number of floret (11.41) was obtained from P0 (the control). Moreover, the combined effect of corm size and phosphorus level was insignificant.

Effect of corm size and phosphorous levels on the number of corm and cormel of gladiolus

The corm size significantly influenced the number of corm and cormel. At 180 DAP, the highest (144.50) and lowest (77.17) number of corm and cormel were observed from the treatment of S1 and S3, respectively (Table 8). The present finding is in agreement with the reports of Hong et al. (1989), Vincetjak-Toplak (1990), and Ogale et al. (2005). However, the result showed that the highest number of corm and cormel (113.11, 154.67) was obtained from the P3 (400 kg ha^{-1} TSP) and S1xP3 (31-40 g with 400 kg ha^{-1}) where the lowest (83.22, 67.33) were obtained from P0 (the control) and S3xP0 (10-20 g with 0 kg ha^{-1}) at 180 DAP, respectively (Table 8).

Table 8. Impact of corm size and phosphorous on the number of corm and cormel

Corm size (cm)	Number of corm and cormel at
	180 DAP
S1	44.50 a
S2	0.67 b
S3	7.17 c
Level of significance	**
Phosphorous (kg ha^{-1})	
P0	83.22
P1	98.78
P2	108.00
P3	113.11
Level of significance	NS
Treatment Combination	
S1 P0	151.67
S1 P1	133.67
S1 P2	138.00
S1 P3	154.67
S2 P0	72.00
S2 P1	48.67
S2 P2	82.00
S2 P3	106.00
S3 PO	67.33
S3 P1	67.33
S3 P2	76.33
S3 P3	78.67
Level of significance	NS
CV	42.22

Note: **: Significance 0.01, NS: non-Significant

Table 9. Impact of corm size and phosphorous rate on the size of corm of gladiolus

Corm size (cm)	Size of corm (cm) at	
	Length	Breath
S1	2.83 a	0.90 a
S2	6.90 b	3.95 b
S3	5.93 c	3.58 c
Level of significance	**	**
Phosphorous (kg ha^{-1})		
P0	39.27	37.36
P1	38.83	36.22
P2	38.42	35.54
P3	37.70	35.44
Level of significance	NS	NS
Treatment combination		
S1 P0	44.16	42.40
S1 P1	42.93	41.57
S1 P2	42.57	40.27
S1 P3	41.67	39.37
S2 P0	33.90	31.80
S2 P1	35.47	32.23
S2 P2	37.50	34.63
S2 P3	40.87	37.13
S3 P0	33.77	37.90
S3 P1	34.70	32.83
S3 P2	35.30	31.43
S3 P3	33.97	32.16
Level of significance	NS	NS
CV	9.67	9.95

Note: **: Significance 0.0, NS: non-Significant

Table 10. Impact of corm size and phosphorous levels on the weight of corm of gladiolus

Corm size (cm)	Weight of corm (gm) at
	180 DAP
S1	2505.80 a
S2	1287.50 b
S3	1162.5 c
Level of significance	**
Phosphorous (kg ha^{-1})	
P0	1316.70
P1	1594.40
P2	1846.70
P3	1850.00
Treatment combination	
S1 P0	2583.30
S1 P1	2333.30
S1 P2	2400.00
S1 P3	2706.7
S2 P0	1266.7
S2 P1	750.20
S2 P2	1333.3
S2 P3	1800
S3 P0	866.7
S3 P1	1006.87
S3 P2	1050.00
S3 P3	1033
Level of significance	NS
CV	44.96

Note: **: Significance 0.01, NS: non-Significant

Effect of corm size and phosphorous rate on the size of corm of gladiolus

Corm size significantly influenced the size of the corm. The longest number of sizes of corm (42.83 mm) was found in the plant grown from a large corm. On the other hand, the shortest corm size (35.93 mm) was discovered when a small corm was used as planting material (Table 9). The present experimental results regarding the size of the corm agree with the findings of Singh and Singh (1998). However, there was no significant variation between the phosphorus level and the combined treatment regarding the size of the corm.

Effect of corm size and phosphorous levels on the weight of corm of gladiolus

Corm size significantly influenced the weight of the corm. At 180 DAP, the maximum weight of the corm (2,505.80 g) was obtained from the plant grown from a large corm. On the other hand, the minimum weight of the corm (1,162.50 g) was observed when a small corm was used as planting material (Table 10). The increased weight of corms from large corms was probably due to the stored food materials present during planting, which contributed towards better vegetative growth and higher corm weight. Misra et al. (1985) also reported similar results. However, the highest weight of the corm (1,850 gm) was obtained from the treatment P3 (400 kg ha^{-1}). In contrast, the lowest weight of the corm (1,316 .80 gm) was obtained from the P0. Moreover, the maximum weight of corm (2706.7 gm) was observed in the treatment combination of large corm treated with 400 Kg/ha TSP, and the minimum weight of corm (866.7 gm) was obtained from the most undersized corms treated with the control (Table 10). Prakash et al. (2008) found the maximum production using phosphorus in 500 kg/ha, whereas Auge (1982) found 300 Kg/ha TSP and 600 Kg/ha TSP by Roychoudhuri et al. (1985). Mukhopadhyay and Bankar (1986) and Nilimesh and Roychowdhury (1989) obtained tremendous results from 500 Kg/ha TSP.

In conclusion, the experiment results revealed that corm size significantly influenced all parameters studied, and no significant effect was observed due to variation in phosphorus level and combined treatment. Plant height, spike length, and the number of leaves, florets, tillers, corm, and cormel were significantly increased with the increase in the size of the corm and the advancement of time. This result will be helpful for those farmers who are interested in plants gladiolus for commercial cultivation. However, there are some significant limitations to our study. We did not consider how production changes with temperature, rainfall, and seasonal changes. More extensive research is needed to successfully obtain the desired results from the commercial cultivation of gladiolus.

ACKNOWLEDGEMENTS

The authors first thank Agrotechnology Discipline, Khulna University, Bangladesh, for providing care in the field during data collection and analysis. However, this research did not take any financial aid.

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