Leaf Area Estimation Models for Ginger (*Zingibere officinale* Rosc.)

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Abstract: The study was carried out to develop leaf area estimation models for three cultivars (37/79, 38/79 and 180/73) and four accessions (29/86, 30/86, 47/86 and 52/86) of ginger. Significant variations were observed among the tested genotypes in leaf length (L), leaf width (W) and actual leaf area (ALA). Leaf area was highly correlated with L × W, followed by L + W, L and W. Regression equations developed for the aforementioned cultivars and accessions were $Y = 13.6 + 1.204X$, $Y = 4.244 + 1.349X$, $Y = 0.516 + 1.428X$, $Y = -54.627 + 2.201X$, $Y = 1.811 + 1.421X$, $Y = -2.386 + 1.489X$ and $Y = -4.614 + 1.831X$ respectively, where Y is estimated leaf area (ELA) and X is L × W, and have R^2 ranged between 0.916 and 0.942. Simple constants (K) were also derived from L × W and have the values of 1.454, 1.458, 1.396, 1.626, 1.433, 1.586 and 1.429 for the respective genotypes. On all cultivars and accessions, the correlation coefficients (r) computed between ALA and ELA [K (L × W)] were positive and significant ($p < 0.01$). Hence both the regression models and K developed are employed equally for estimating the areas of intact ginger leaves.

Keywords: Correlation; Ginger; Leaf Area; Regression

1. Introduction

Ginger (*Zingibere officinale* Rosc.) 'Zingible' is the rhizomatous slender perennial herb (30-100 cm tall), usually grown annually, and has been cultivated in tropical Asia since ancient times. It has been known in Ethiopia since the beginning of the 13th century and cultivated in wider environments than any other spices (Borget, 1993). It is popular in the daily dishes of every Ethiopian and used alone or together with other spices for flavoring a variety of foods and local drinks.

Leaf area is an index to measure the growth, development and yield of a plant (Ramkhelawan, 1992; Rajan, 2003). It is a noble parameter in agronomic and physiological studies like photosynthetic efficiency and rate of individual leaves in a crop community (Uzun and Celik, 1999; Rajan, 2003; Pinto e*t al*., 2004). Various methods have been reported for measuring the leaf area of crops. Some well-known methods include tracing an individual leaf on paper and determining the area by planimeter or by the weight of the cut paper; using sensitized photopaper, photoelectric cells, or glass sheets divided into 1 cm^2 sections; and measuring roughly by direct calculation (Planiswamy and Gomez, 1974), and photocopying and leaf printing in a dye solution (Willims and Joseph, 1970). However, most of the methods require complex and sophisticated tools, which are costly and not easily available in most developing countries. Besides, others require leaves to be removed from the plant, which reduces the photosynthetic surface area of plants, and tiresome and time-consuming tracing on square paper. Hence, exploring simple, rapid and non-destructive methods that could estimate the area of intact plant leaves with modest precision is imperative.

The use of regression models and simple constants (adjustment factors) for estimating leaf area can provide simple, quick, accurate, reliable, inexpensive and non-destructive methods to within 0.05 accuracy (Raju *et al*., 1991; Uzun and Celik, 1999). In addition to the fact that the methods can allow the replication of measurements during the growth period, it reduces variability in experiment as compared to destructive sampling (NeSmith, 1992). They are very useful in studying plant activities, which require a non-destructive method of measuring leaf area and also when the number of available plants is limited (Pinto *et al*., 2004).

The usual procedure of the methods involves measuring lengths, widths and areas of a sample of leaves and then calculating several and/or common (pooled) regression equations and/or constants to estimate areas of subsequent leaf samples (Pouono *et al*., 1990; Ramkhelawan, 1990; Yacob *et al*., 1993; Fanthaun and Anteneh, 1995; Pinto *et al*., 2004). Developing mathematical models and/or constants eliminate the need for leaf area meters and also save time as compared to cumbersome geometric reconstructions (NeSmith, 1992; Yacob *et al*., 1993; Fanthaun and Anteneh, 1995). However, such models have not yet been established for estimating the leaf area of ginger in Ethiopia and elsewhere. The present study was, therefore, undertaken with the objective of developing the best matching regression equation and constants for estimating areas of intact ginger leaf from measurements of leaf length and leaf width and to test for homogeneity of regression equations among different ginger cultivars and accessions using the best matched model.

2. Materials and Methods

Three cultivars (37/79, 38/79 and 180/73) and four accessions (29/86, 30/86, 47/86 and 52/86) of ginger grown at Tepi Agricultural Research Sub-center, Ethiopia,

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with a spacing of 30 cm * 15 cm on well-prepared ridge and in the recommended planting time (April) were selected for leaf area measurements. Samples of 90 leaves per cultivar and accession were collected from three replications (30 leaves per replication) in September 2005. The sampled leaves represented the full spectrum of measurable leaf size and did not present any damage and deformation caused by diseases, insects or other external factors.

The collected leaf samples were immediately taken to the laboratory in paper bags for measurements of length (L), width (W), and area. The length and width of each lamina was measured along the midrib, from the apex to the base of the lamina and perpendicularly to the midrib at the widest part of the leaf respectively. Actual leaf area (ALA) of each lamina was determined by tracing an individual leaf onto square paper with a dimension of 0.25 cm^2 per square and counting the number of squares covered by the leaf and multiplying it by the dimension of a square. In this case, peripheral squares with an area greater or equal to 0.125 cm^2 were considered as full squares. The collected data was then summarized and arranged for statistical analysis using randomized complete block design with three replications to investigate the variability in leaf dimension variables. To this end, the data were subjected to analysis of variance using the SAS software program (SAS Institute, 1990). Results were presented as means and compared using Duncan's New Multiple Range Test at $p < 0.05$ probability level (Mandefero, 2005).

Correlation coefficients (r) were computed between the dependent variable, ALA, and the independent variables *viz.* L, W, L + W and L × W for individual cultivars and accession separately. Leaf dimension variables strongly related to ALA, regression equation, which is represented by $Y = a + bX$, where Y = ALA; a = Intercept; b = Regression coefficient and X = regressor highly correlated with ALA (L or W or L + W or L × W), were computed separately for each cultivar and accession. The coefficient of determination (R^2), which measures the contribution of the linear function of independent leaf dimension variables to the variation in leaf area, was also worked out. Subsequently, homogeneity tests of the various regression coefficients developed for the cultivars and accessions were carried out to determine whether a single pooled regression equation was to be used to estimate the leaf area for the studied genotypes.

Likewise, intact leaf area estimation constant (K) were computed for individual cultivar and accession using the regressor strongly correlated to the ALA following the procedure adopted by Raju *et al.* (1991), Yacob *et al.* (1993) and Fanthaun and Anteneh (1995). Finally, r were computed between ALA and estimated leaf area [K (L × W)] to investigate the reliability of estimating ALA by using simple constants. All the regression equations and correlation coefficients were computed using the Microsoft Excel computer program.

3. Results and Discussion

There were significant differences among ginger cultivars and accessions in leaf lengths, leaf widths, and actual leaf area (Table 1). The mean leaf length was found to be maximum in 30/86 followed by 29/86, 180/73, 37/79, 47/86, 38/79 and 52/86. However, the mean leaf width ranged from 2.31 - 2.63 cm with the maximum in 30/86 followed by 37/79, 180/73, 29/86 and 52/86, 38/79, and 47/86. Similarly, leaf area was found to be maximum in 30/86 and minimum in 52/86. Except for accession 30/86, which consistently register the highest leaf length, width and area, no definite trend could be observed among the remaining cultivars and accessions for the parameter tested.

Table 1. Mean leaf length, width and leaf area of ginger cultivars and accessions.

Cultivar and accession	Length (cm)	Width (cm)	Area (cm^2)
Cultivar			
37/79	23.14^{b}	2.45^{b}	81.81^{bc}
38/79	22.41^{b}	2.35^{b}	75.88^{d}
180/73	23.71^{ab}	2.44^{b}	83.29^{b}
Accession			
29/86	25.20^{b}	2.40^{b}	78.62^{bcd}
30/86	25.24^{a}	2.63^{a}	96.27^{a}
47/86	22.96^{b}	2.31^{b}	77.12^{cd}
52/86	22.20^{b}	2.40^{b}	74.67^{d}
F-test	*	*	**
SE (±)	0.39	0.05	0.66
CV (%)	4.42	3.51	3.55

Means within a column followed by the same superscript (s) are not significantly different from each other at p < 0.05 probability level.

, Significant at p < 0.05 and 0.01 probability level, respectively.*

The correlation coefficients computed between ALA and L, W, L + W and L × W were significant ($p < 0.01$) in all cultivars and accessions (Table 2). However, only the relationships between leaf area and L × W consistently gave the highest r values ranging from 0.957 to 0.970, indicating the strong relationship between these variables. The present investigation corroborates the earlier works in cacao (Pouono *et al.*, 1990), sour orange (Ramkelawn, 1990), Arabica coffee (Raju *et al.*, 1991; Yacob *et al.*, 1993), black pepper (*Piper nigrum* L.) (Fantahun and Anteneh, 1996), summer squash (NeSmith, 1995), *Zinnia* spp and 'profusion cherry' (Pinto *et al.*, 2004).

The strong correlations between the ALA and L × W in the present investigation indicate the possibility of estimating leaf area by using regression analysis pertaining to L × W compared to other independent leaf dimension variables (L, W and L + W). Accordingly, the regression equations along with the coefficient of determinations (R^2) for different cultivars and accessions are summarized in Table 3. The R^2, a measure of predictive ability of the model, ranged between 0.916 to 0.942 for different cultivars and accessions, indicating that 91.6 to 94.2% of the variability in the ALA has been explained by L × W. On the other hand, homogeneity tests of regression lines developed for the studied genotypes revealed significant ($p < 0.01$) differences between them. Hence, a single pooled regression equation based on the L × W should not be used to estimate leaf area for the studied genotypes. Each cultivar and accession should have its own regression equation. Similar results have been reported for cacao (Pouono *et al.*, 1990), Arabica coffee selections (Raju *et al.*, 1991) and black pepper (*Piper nigrum* L.) (Fantahun and Anteneh, 1996).

Table 2. Correlation coefficient (r) for actual leaf area (ALA) vs leaf length (L), leaf width (W), L + W and L × W for different ginger cultivars and accessions.

Cultivar and accession	Correlation coefficient (r)*			
	ALA vs L	ALA vs W	ALA vs L + W	ALA vs L × W
Cultivar				
37/79	0.491	0.702	0.606	0.957
38/79	0.857	0.731	0.895	0.961
180/73	0.800	0.801	0.862	0.970
Accession				
29/86	0.450	0.754	0.458	0.958
30/86	0.696	0.667	0.771	0.966
47/86	0.747	0.608	0.802	0.961
52/86	0.747	0.608	0.802	0.961

* *All 'r' values are significant at $p < 0.01$ probability level.*

Table 3. Regression equations and coefficient of determination (R^2) of different cultivars and accessions of ginger for estimating actual leaf area (Y).

Cultivar and accession	Regression equation	R^2
Cultivar		
37/79	$Y = 13.6 + 1.204X$[b]	0.916
38/79	$Y = 4.244 + 1.349X$	0.924
180/73	$Y = 0.516 + 1.428X$	0.942
Accession		
29/86	$Y = -54.627 + 2.201X$	0.918
30/86	$Y = 1.811 + 1.421X$	0.934
47/86	$Y = -2.386 + 1.489X$	0.930
52/86	$Y = -4.6143 + 1.483X$	0.925

[b] *X is the product of L and W.*

In addition to the regression equations, simple constants (*K*) were computed for each cultivar and accession and are given in Table 4. The *K* obtained for different cultivars and accessions were 1.454, 1.458, 1.396, 1.326, 1.433, 1.486 and 1.429 for 37/79, 38/79, 180/73, 29/86, 30/86, 47/86 and 52/86 respectively. However, Raju *et al.* (1991), Yacob *et al.* (1993) and Fanthaun and Anteneh (1995) stated that accurate estimates of leaf area by constants require a strong correlation between ALA and the L × W. Likewise, a high and significant correlation evident between the ALA and L × W in all cultivars and accessions (Table 2) in this study confirms the possibility of estimating ginger leaf area accurately by using these constants. A positive and significant ($p < 0.01$) r value evident between the ALA and ELA [*K* (L × W)] (r = 0.925 - 0.996) (Table 4) indicate that these constants can be used for estimating areas of ginger leaves accurately. Similarly, Raju *et al.* (1991) and Yacob *et al.* (1993) developed simple constants and regression equations for leaf area estimation of Arabica coffee cultivars from L × W. The work of Fantahun and Anteneh (1996) also corroborated L × W to nearly accurately estimate leaf area of black pepper (*Piper nigrum* L.) cultivars with an appropriate constant.

In conclusion, both regression equations and simple constants involving L × W compared to other independent leaf dimension variables, *viz*. L, W and L + W, are found to be equally suitable in estimating the area of intact ginger leaves without destroying the assimilatory organs and could be used as potential indicators of the yield performance of ginger planted in macro and micro climates. However, simple constants are easier than the regression equations for estimating leaf area since the calculations involved are very simple.

Table 4. Simple constants (*K*) and correlation coefficients (r) between ALA and estimated leaf area [*K* (L × W)].

Cultivar and accession	K[c]	r[d]
Cultivar		
37/79	1.454	0.976
38/79	1.458	0.979
180/73	1.396	0.996
Accession		
29/86	1.326	0.987
30/86	1.433	0.995
47/86	1.486	0.979
52/86	1.429	0.925

[c] $K = \frac{ALA}{L \times W}$

[d] *All 'r' values are significant at p < 0.01 probability level.*

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