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Regression analysis to estimate enset (*Enset ventricosum* (Welw.) Cheesman) kocho yield from vegetative linear dimensions

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Abstract: The objective of this research was to develop multiple regression models which will enable to predict kocho yield from linear dimensions of enset considering different clones. The experiment was carried out at Areka Agricultural Research on-station site on a total number of 328 enset clones from the six major enset growing areas of Southern Ethiopia (59, 46, 49, 44, 49, and 81 from Gofa, Guragie, Wolaita, Sidamo, Dawro and Kembata respectively).Plant height and pseudostem circumference were found out to be the best non-destructive enset kocho yield predictors. The R^2 value for estimating fermented unsqueezed kocho yield was about 0.78 with the equation FUNK= -26.12 + 5.43 PH + 20.05 PSC describing the relationship of fermented un-squeezed kocho as a function of enset plant height and pseudostem circumference measurements. From the slope of linear relation line which was forced through the origin the amount of kocho in un-squeezed kocho is about 69% and the rest 31% will be the moisture. In an attempt to estimate fiber yield from measurements of the vegetative parameters, none of the regression relationships gave a significant result.

Keywords: Regression Model, Enset, Kocho, Moisture Content and Dry Matter

1. Introduction

Enset is single stemmed monocarpic perennial, herbaceous plant. The major parts of enset are corm, pseudostem, leaf, inflorescence, fruits and seeds. Pseudostem consists of a system of tightly or loose clasping and lax overlapping leaf-sheaths. The height and circumference of pseudostem are in the range of 1 - 2.8m and 0.77 - 1.7m respectively. At harvest time the average number of leaf per plant was 5 - 21. The length and width of matured leaf was in the range of 2 - 5m and 0.4 - 1m, respectively [1]. According to CSA and MoA report [2] about 183,765.87 hectares of land is cultivated with enset of which 57.38% is found in the southern parts of Ethiopia.

Enset propagated conventionally by vegetative means while growers rarely raise seedlings from seeds. Enset can also be propagated *in vitro* under aseptic condition on nutrient media [3]. Enset is processed into different products such as kocho (the main product) and bulla which are used as sources of food. Fiber is a by-product and has got importance for household and fiber factory use [4]. Kocho processing and care during fermentation is tedious and boring. Besides, it is kept in a pit prepared in enset field for a number of days for fermentation before yield data is taken, thus, it is exposed to theft. Kocho is also measured with varying amount of water content. These all have impacts on precision of the results when yield is evaluated.

Furthermore, assessment of crop yields is frequently carried out in the country to estimate balance (surplus/deficit) in production. Kocho is one of these yields being assessed. Kocho assessment is a difficult task as enset is a multiple year crop and also transplanted from nursery to nursery and then main field at ever wider spacing.

The FAO crop and food supply assessment mission [4] indicated that the contribution made by enset and other root crops should be investigated and a formula for its inclusion in the food balance needs to be determined. Regression model which, non-destructively, predicts yield of enset with better precision will simplify yield evaluation in experiments and will also solve difficulties in estimating kocho yield in the assessment of production balance in enset production region of the country.

According to Shank and Chernet [5], based on the data from sample size of 67 enset plants a positive relationship was obtained between measurements of plant pseudostem girth and height with plant kocho yield. By assuming an 80% correlation between these parameters and choosing the 90% confidence interval for the standard error of an estimate a model was constructed. They, however, explained that the model was developed without taking in to account the contribution of the other vegetative parameters, different types of clones and region of production; the model predicts no yield of the very small and very big plants.

Considering different enset clones and large number of samples plus the contribution of all the vegetative parameters as independent variables in the estimation has a paramount importance in constructing a more precise model which would serve as a non-destructive predictor of enset kocho yield.

Therefore, the objective of this research was to develop multiple regression models which take in to account large number of samples, different enset clones from low to high yielder and the other vegetative parameters to construct a more precise model which will enable to predict kocho and fiber yields non-destructively from linear dimensions of enset plants.

3. Materials and Methods

3.1. Description of the Experimental Site

The experimental was carried out at Areka (the research center's experimental field) which is located 7^0 09' N latitude and 37^0 47' E longitudes and at an elevation range of 1750 and 1820 masl[6].

Based on five years data, the average annual rainfall is 1615.2 mm with a minimum/maximum mean air temperature of $13.9^0C/25.6^0C$ and 63% relative humidity [7,8]. The soil is silt clay loam with a pH value of 5.2 [9].

3.2. Method of Establishment

Mother plants of 2-3 years old were collected and stumped to 10 to 20 cm pseudostem height, and planted at 1.5 by 1.5 m spacing for sucker production. After one year, four suckers which had a similar size, from each clone were taken and planted in non-replicated permanent field between 1999-2006 at a spacing of 1.5 and 3 m between plants and rows respectively. Cultural practices including cultivation and weeding were done as required, Farm yard manure was applied to each plants at a rate of 5kg once in a year for the first two years. However, none of the treatments were applied with inorganic fertilizers.

3.3. Number of Clones in the Study

In the field, some clones were exposed to unfavorable environmental conditions including mole rate damage and corm rot so that, clones with less than 3 harvestable plants were not included in the study, Hence, a total number of 328 enset plants from the six major enset growing areas of Southern Ethiopia (59, 46, 49, 44, 49, and 81 from Gamo-Gofa, Guragie, Wolaita, Sidamo, Dawro/Waka and Kembata/Hadiya respectively) were considered for this experiment.

3.4. Harvesting Method

Plants were harvested within 5 days interval after flowering which is supposed to produce quality 'Kocho'. If harvesting is delayed after flowering, the plant parts could be affected due to the translocation of nutrient for fruit development [10]. At harvest, leaves and old leafsheath of the designated plants were cut off. The leafsheaths were separated from the true stem, and the true stem stumped from the corm. The leafsheaths were decorticated with locally prepared bamboo scraper. The corm was grated while it is in its original growing place, which is common practice in Wolaita enset growing Zone. The true stem was also grated. The grated corm and true stem were in a well lined pit then the decorticated leafsheath were placed on the top. The processed material was turned over, after 4-5 days to facilitate fermentation. Mixing and turning over were carried on for about a month at an interval of about eight days. The fermented 'Kocho' was squeezed manually to minimize the moisture content.

3.5. Measurements

3.5.1. Plant Height

Plant height was measured prior to harvesting by measuring it from ground level to the tip of the longest leaf using a tape meter.

3.5.2. Pseudostem Height

Pseudostem height was measured prior to harvesting by measuring it from ground level to the start of the leaf petiole using a tape meter.

3.5.3. Pseudostem Circumference

Pseudostem circumference was measured prior to harvesting by measuring the circumference at the middle height point using a tape meter.

3.5.4. Leaf Number

Leaf number was taken prior to harvesting by counting all the fully expanded and green leaves.

3.5.5. Leaf Length

Leaf length was taken prior to harvesting by measuring from the end point of the petiole to the tip edge of the leaf using a tape meter across the midrib.

3.5.6. Leaf Width

The leaf width was measured prior to harvesting by measuring at the middle wider point using a tape meter.

3.5.7. Fermented Un-Squeezed Kocho Yield (FUNK)

After the unfermented kocho yield is left in the pit for some time usually 20 to 30 days it will be fermented and this fermented kocho was directly measured for its weight before squeezing it to determine fermented un-squeezed kocho yield.

3.5.8. Fermented Squeezed Kocho Yield (FSQK)

The fermented un-squeezed kocho yield is squeezed usually by applying human force till it loses all its moisture content as much as possible.

3.5.9. Fiber

Fiber yield was measured by weighing all the fiber left, soon after decorticating the leafsheath.

3.6. Simple Linear Regression

In this study simple linear model was involved to analyze the relationship of one independent variable with one dependent variable to state changes that the true mean of the dependent variable assumes at a constant rate as the value of the independent variable increases or decreases.

$$E(Yi) = \beta_0 + \beta_1 X_i + e_i$$

Thus, the functional relationship between the true mean of *Yi*, denoted by *E*(*Yi*), and $X_i$is the equation of a straight line: β_0 is the intercept, the value of *E*(*Yi*) when *X* = 0, and β_1 is the slope of the line, the rate of change in *E*(*Yi*) per unit change in *X*., and $e_i$is the residual.

3.7. Multiple Regressions

Multiple regressions was also employed in this study where several predictors used to model a single response variable.The linear additive model for relating a dependent variable to*p* independent variables is indicated below:

$$Yi = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_p X_{ip} + e_i.$$

The subscript *i* denote the observational unit from which the observations on *Y* and the *p* independent variables were taken. The second subscript designates the independent variable. The sample size is denoted with n, $i = 1, \ldots, n$, and *p* denotes the number of independent variables. There are (*p* + 1) parameters βj, $j = 0, \ldots, p$ to be estimated when the linear modelincludes the intercept β_0.

3.8. Predicted Values and Residuals

The regression equation from the above can be evaluated to obtain estimates of the mean of the dependent variable *Y* at chosen levels of the independent variable. The validity of such estimates is dependent on the assumed model being correct, or at least a good approximation to the correct model within the limits of data ranges observed in the study.

Each quantity computed from the fitted regression line $\widehat{Y\imath}$is used as both (1) the estimate of the population mean of *Y* for that particular value of *X* and (2) the prediction of the value of *Y* one might obtain on some future observation at that level of *X*.

Hence, the observed values *Yi* in the data set are compared with their corresponding values $\widehat{Y\imath}$ computed from the regression equation, to obtain the residual which is a measure of the degree of agreement between the fitted model and the data and providing information regarding assumptions about error terms and the appropriateness of the model as indicated by the equation below.

$$\hat{e}_i = Y_i - \widehat{Y\imath}$$

Plots of residuals verses other quantities are used to find failures of the assumptions. The most common plot, especially useful in linear regression, is the plot of êversus the fitted values $\hat{Y}_i$. Systematic features in this plot are of interest. Residuals that seem to increase or decrease in average magnitude with $\hat{Y}_i$ might indicate non-constant residual variance. A few relatively large residuals may be indicative of outliers' cases for which the model is somehow inappropriate. On the other hand if the plot of $\hat{e}_i$ verses $\hat{Y}_i$shows no systematic features, then one can have little reason to suspect that the fitted model was inappropriate for the data.

3.9. Correlation Analysis

In the regression analysis the Correlation Matrix is the one that involves the relationship between one dependent and many independent variables. This analysis identifies those independent variables that significantly affect the dependent variable *Y*. Correlation measures the strength of the linear relationship between two variables. A correlation of 0 means, that there is no linear association between the two variables. A correlation of 1 (-1) means that there is an exact positive (negative) linear association between the two variables. Therefore, inspection of the correlation matrix was carried outto identify the values of the coefficient of determination in the multiple regression, if *Y* were regressed on all the independent variables (plus an intercept).

3.10. Statistical Analysis

All data and parameters were subjected to analysis of multiple and simple linear regression using the SAS Software system version 9and SigmaPlot 10.0.

4. Results and Discussion

4.1. Estimation of Fermented Un-Squeezed Kocho from Vegetative Measurements

The vegetative parameters plant height, pseudostem height, pseudostem circumference, leaf number, leaf length and leaf width can easily be measured in enset fields and can be used as non-destructive estimators of kocho yield of an enset plant [5]. In this experiment a sample size of 328 enset plants from the six major enset growing areas of Southern Ethiopia (59, 46, 49, 44, 49, and 81 from Gamo-Gofa, Guragie, Wolaita, Sidamo, Dawro/Waka and Kembata/Hadiya respectively) were used to develop the model which will enable to predict the kocho yield of an enset plant from the vegetative measurements.

Most enset growing areas prefer dry seasons for harvesting. This may be due to the convenience of dry season for harvesting processing and fermentation [11]. Enset after flowering stops its vegetative growth, therefore, soon after flowering is the best time to harvest and process an enset plant [10]. After harvesting an enset plant, the decorticated leaf sheath will be mixed with the grated true stem and corm and left in the pit for fermentation. Usually, after one month of time the buried mixture ferments and will be ready for consumption and this first yield is the fermented un-squeezed kocho [12].

In this experiment the measurements of all the six vegetative parameters were considered in estimating the fermented un-squeezed kocho yield. The R-square value was about 0.79 with the equation indicated below describing the relationship of fermented un-squeezed kocho yield as a function of enset plant height, pseudostem height, pseudostem circumference, leaf number, leaf height and leaf width measurements.

$$FUNK = -25.98 + 5.44PH - 2.31PSH + 18.63PSC + 0.31LN + 0.92LH - 1.32LW$$

Where, FUNK is fermented un-squeezed kocho yield (in kg), PH is plant height (in m), PSH is pseudostem height (in m), PSC is pseudostem circumference (in m), LN is leaf number, LH is leaf length (in m) and LW is leaf width (in m)

However, considering the correlation of each of the vegetative parameters with fermented un-squeezed kocho yield, the highest correlation values were attributed by plant height followed by pseudostem circumference and that of leaf height respectively (Table 1). This is in contradiction with previously developed enset yield predictor model by Shank and Chernet [5] which considers pseudostem height and pseudostem circumference as best predictors of enset kocho yield. As indicated in (Table 1), pseudostem height alone predicts kocho yield of enset plant with correlation coefficient value 0.46. However, leaf height alone predicts kocho yield with the correlation coefficient value (0.78) followed by that of pseudostem circumference (correlation coefficient=0.75), which actually leads us to the conclusion that higher yield of an enset plant is acquainted more with the measurements of leaf height rather than pseudostem height. Therefore, from this research finding, considering plant height (which includes the height measurements of both pseudostem and leaf) along with pseudostem circumference can be taken as the best non-destructive predictors of enset kocho yield, unlike the previously developed model which considers pseudostem height along with pseudostem circumference as the best yield estimators.

Table1. *Correlation of the vegetative parameters with fermented un-squeezed kocho (FUNK), fermented squeezed kocho (FSQK) and dry matter (DM) yield of enset plant*

VARIABLES	PSH	PSC	LN	LH	LW	FUNK	FSQK	DM
PH	0.72	0.50	0.38	0.88	0.57	0.78***	0.69***	0.70***
PSH		0.25	0.19	0.57	0.33	0.46**	0.42	0.41**
PSC			0.37	0.54	0.52	0.75***	0.74***	0.63***
LN				0.42	0.37	0.45***	0.33	0.33
L H					0.59	0.75	0.70***	0.67
LW						0.56	0.52	0.44

***, and ** are significant at 1 percent, and 5 percent probability level, respectively.

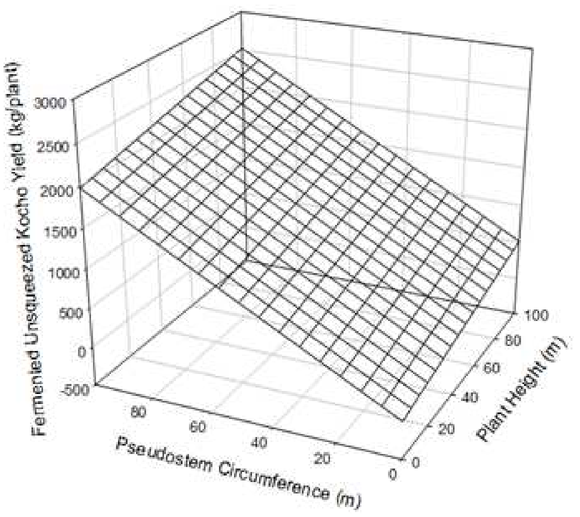

Figure 1. *Fermented Unsqueezed Kocho Yield (kg/plant) for various pseudostem and plant height sizes derived from the regression equation FUNK= -26.12 + 5.43 PH + 20.05 PSC (R^2=0.78 and P<0.0001)*

Therefore, with the consideration of only the two most important enset yield predictors the model can be rewritten with the R-square value of about 0.78 and with the equation indicated below describing the relationship of fermented un-squeezed kocho yield as a function of enset plant height and pseudostem circumference as indicated in (Figure 1).

$$FUNK = -26.12 + 5.43\,PH + 20.05\,PSC$$

Where, FUNK is fermented un-squeezed kocho yield (in kg), PH is plant height (in m) and PSC is pseudostem circumference (in m).

As indicated in Shank and Chernet [5], one of the factors that could change the model might be if plant measurements were taken while the enset was under moisture stress. Therefore, to make the model valid, measurements should be carried out at favorable time for enset growth which is just after the rainy season. Assessment should also be made on healthy plants which are matured or nearly matured and free from vigorous leaf removal.

Previously developed enset yield predictor model by Shank and Chernet [5], also lacked taking in to account different types of clones; the model also predicts no yield of the very small and very high plants. In this experiment however, because of the larger number of enset samples (collected from the six major enset growing areas of Ethiopia) considered, it took in to account enset plants with various growth as well as yielding ability ranging from the smallest to highest values (Table 2).

Table 2. *Measured value range of lowest and highest values for the different growth and yield parameters of the different enset clones*

No	Measured parameters	Acronyms	Measured value ranges	
			Lowest	Highest
1	Plant height (m)	PH	3.0	8.0
2	Pseudostem height (m)	PSH	0.7	3.6
3	Pseudostem circumference (m)	PSC	0.55	2.27
4	Leaf number	LN	4	19
5	Leaf height (m)	LH	0.70	4.82
6	Leaf width (m)	LW	0.17	0.97
7	Fermented unsqueezed kocho yield (kg/plant)	FUNK	4.0	53.0
8	Fermented squeezed kocho yield (kg/plant)	FSQK	2.0	45.0

Table 3. *Estimation of Fermented un-squeezed kocho yield per plant from measurements of various plant heights and pseudostem circumferences by application of the multiple regression equation FUNK= -26.12 + 5.43 PH + 20.05 PSC*

PSC PH	0.55	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00
3.00	1.3	5.3	10.3	15.3	20.3	25.3	30.3	35.3	40.3	45.3	50.3	55.3	60.3	65.3	70.3
3.50	4.0	8.0	13.0	18.0	23.0	28.0	33.0	38.0	43.0	48.0	53.0	58.0	63.0	68.0	73.0
4.00	6.6	10.6	15.7	20.7	25.7	30.7	35.7	40.7	45.7	50.7	55.7	60.7	65.7	70.7	75.7
4.50	9.3	13.3	18.3	23.3	28.3	33.3	38.3	43.3	48.3	53.3	58.3	63.3	68.4	73.4	78.4
5.00	12.0	16.0	21.0	26.0	31.0	36.0	41.0	46.0	51.0	56.0	61.0	66.0	71.0	76.0	81.0
5.50	14.7	18.7	23.7	28.7	33.7	38.7	43.7	48.7	53.7	58.7	63.7	68.7	73.7	78.7	83.7
6.00	17.3	21.3	26.4	31.4	36.4	41.4	46.4	51.4	56.4	61.4	66.4	71.4	76.4	81.4	86.4
6.50	20.0	24.0	29.0	34.0	39.0	44.0	49.0	54.0	59.0	64.0	69.0	74.0	79.1	84.1	89.1
7.00	22.7	26.7	31.7	36.7	41.7	46.7	51.7	56.7	61.7	66.7	71.7	76.7	81.7	86.7	91.7
7.50	25.4	29.4	34.4	39.4	44.4	49.4	54.4	59.4	64.4	69.4	74.4	79.4	84.4	89.4	94.4
8.00	28.0	32.0	37.1	42.1	47.1	52.1	57.1	62.1	67.1	72.1	77.1	82.1	87.1	92.1	97.1
8.50	30.7	34.7	39.7	44.7	49.7	54.7	59.7	64.7	69.7	74.7	79.7	84.7	89.8	94.8	99.8
9.00	33.4	37.4	42.4	47.4	52.4	57.4	62.4	67.4	72.4	77.4	82.4	87.4	92.4	97.4	102.4
9.50	36.1	40.1	45.1	50.1	55.1	60.1	65.1	70.1	75.1	80.1	85.1	90.1	95.1	100.1	105.1
10.00	38.7	42.7	47.8	52.8	57.8	62.8	67.8	72.8	77.8	82.8	87.8	92.8	97.8	102.8	107.8

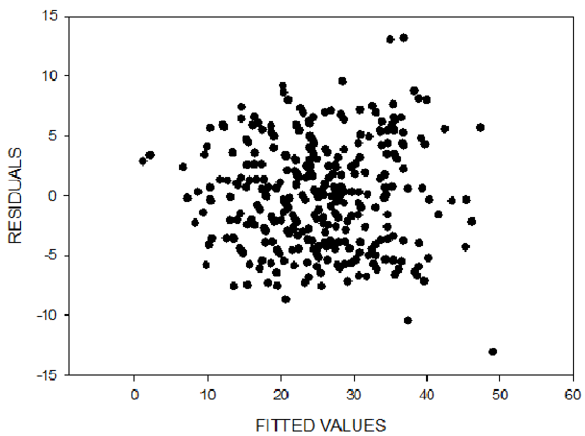

Figure 2. *Plot of the fitted values and the residuals*

Considering validation test of the model, the observed values Yi in the data set are compared with their corresponding values $\widehat{Yi}$ computed from the regression equation, to obtain the residual which is a measure of the degree of agreement between the fitted model and the data. The fitted values and the residuals are plotted against each other as indicated in Figure 2. The residual are generally small compared to the $\hat{Y}_i$'s and that they do not suggest anydistinct pattern therefore, indicating the appropriateness of the fitted model to the data.

Hence, this multiple regression model in the future will enable the prediction of yield from the measurements of plant height and pseudostem circumference of enset plants with various growth and yielding abilities ranging from lowest to highest values as compared to the formerly developed one (Table 3).

4.2. Linear Relationship between Fermented Un-Squeezed and Squeezed Kocho Yields

From the data of this experiment the fermented squeezed kocho yield could have been easily estimated directly from the measurements of plant height and pseudostem circumference with R^2 value of 0.69. The correlation of each of the vegetative parameters in estimating the fermented squeezed kocho yield had a similar pattern with that of the above in that plant height along with pseudostem circumference is more important predictors of enset squeezed kocho yield rather than using pseudostem height with pseudostem circumference (Table 1). The model indicated below could easily be used in estimating the fermented squeezed kocho yield directly from the two most important parameters.

$$FSQK = -19.91 + 3.35PH + 17.10PSC$$

Where, FSQK is fermented squeezed kocho yield (in kg), PH is plant height (in m) and PSC is pseudostem circumference (in m).

However, predicting the fermented un-squeezed kocho yield from the two vegetative parameters, followed by the prediction of fermented squeezed kocho yield from the fermented un-squeezed kocho yield will have more importance in knowing the relationship between the two.

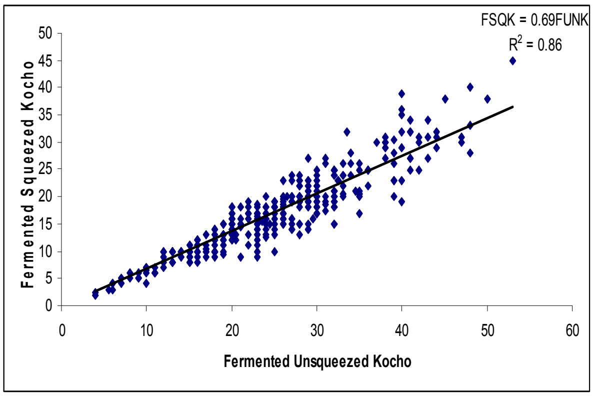

Figure 3. *Slope of the linear regression showing the relationship of fermented squeezed kocho and fermented un-squeezed kocho yield values. Symbols: observed data; lines: fitted lines. The regression line is forced through the origin.*

The fermented squeezed kocho yield is the final step which is ready for consumption. Usually, the kocho after fermentation, it will be removed out of the pit and squeezed with the application of hand squeezing force, which leads to un-standardized and misleading result. Assessing the relationship between fermented un-squeezed kocho and fermented squeezed kocho has an importance in determining the moisture content in fermented unsqueezed kocho enabling the estimation of fermented squeezed kocho yield without squeezing the fermented un-squeezed kocho with R-square value of 0.86. The linear regression line between fermented un-squeezed and squeezed kocho yield was plotted by forcing the line through the origin with the equation indicated below (Fig. 3).

$$FSQK = 0.69FUNK$$

Where, FSQK is fermented squeezed kocho yield (in kg) and FUNK is fermented un-squeezed kocho yield (in kg).

In this experiment, using the equation the moisture content in a 100 kg fermented un-squeezed kocho yield was calculated and found out to be around 31% and about 69% is the squeezed kocho.

4.3. Estimation of Fiber Yield from Measurements of enset Vegetative Parameters

In estimating fiber yield from measurements of the vegetative parameters, none of the regression relationships gave a significant result. The R-square value was always around 1% even using a logarithmic transformation of the fiber data. This could be due to the great variability in moisture and fiber content in the different enset clones observed in this experiment. However, using a single type enset clone to estimate fiber content from its vegetative performance may yield in a significant result, for example, wild enset clones are known for their high fiber content as compared to cultivated enset clones (which are having high moisture content and lower fiber content) which attributed the wild enset clones for their higher diseases resistance especially to enset bacterial wilt disease as compared to the cultivated ones. From the experiment it can be concluded enset fiber content is highly genotype specific trait. In the future by using a large number of samples from a single type of enset clone plus a specific harvesting time after flowering, there could be a possibility to develop a model to estimate enset fiber content from the linear dimensions.

5. Conclusion and Recommendations

Generally, Regression model which, non-destructively, predicts yield of enset with better precision will simplify yield evaluation in experiments and will also solve difficulties in estimating kocho yield in the assessment of production balance in enset production region of the country.

Considering, the correlation of the different enset vegetative parameters with the fermented un-squeezed and squeezed kocho yields, plant height and pseudostem circumference have the highest correlation coefficient followed by leaf height, leaf width, pseudostem height and leaf number respectively. Hence, plant height and pseudostem circumference were found out to be the best non-destructive enset kocho yield predictors.

The R-square value for estimating fermented un-squeezed kocho yield was about 0.78 with the equation FUNK= -26.12 + 5.43 PH + 20.05 PSCdescribing the relationship of fermented un-squeezed kocho as a function of enset plant height and pseudostem circumference measurements.

This research finding recommends the prediction of fermented squeezed kocho yield from the linear relationship with the fermented un-squeezed kocho yield with the equation FSQK (kg/plant) = 0.69FUNK (kg/plant) (with R^2=0.86). From the slope of linear relation line which was forced through the origin the amount of kocho in un-squeezed kocho is about 69% with the rest 31% moisture content.

In this experiment the variation in fiber yield was very high which was due to the intrinsic fiber content of the different enset clones. None of the regression types could fit for estimation of fiber yield.Even with the logarithmic transformation of the fiber data the R-square value was still very small which, was less than 1%. Therefore, for the future, it is recommended that by using a large number of samples from specific enset clone having similar fiber content, fiber yield could be estimated from linear dimensions of enset plant.

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