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Research Article

Selection criteria for culm strength in Kodo millet (*Paspalum scrobiculatum*L.) to suit mechanical harvesting

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Abstract

Kodo millet is an important small millet crop suited to dry land and subsistence farming in India. Due to scarcity of agricultural manpower, farm mechanization turns out to be inevitable to sustain the cultivation of millets. To facilitate mechanical harvesting the plant type should be non-lodging and sturdy. Hence, a thorough understanding of the basis for mechanical strength in kodo millet is a pre-requisite for identifying genotypes ideal for mechanical harvesting. Towards this objective, 297 kodo millet germplasm accessions were phenotyped for culm strength and other related traits. The study indicated that culm strength, measured in terms of pulling force, was positively correlated with culm diameter and plant height. But, it was independent of traits such as basal internode length, recovery angle after bending and degree of lodging. Thus, to identify non-lodging lines with sufficient culm strength to suit mechanical harvest, simultaneous selection for higher pulling force and recovery angle after bending, along with higher culm diameter and plant height appears to be relevant to identify genotypes suitable for mechanical harvest. Path analysis revealed that culm diameter is having the highest positive direct effect on pulling force followed by plant height and recovery angle after bending.

Key words:
Kodo millet, correlation, culm strength, pulling force, mechanical harvesting

Introduction:

Kodo millet (*Paspalum scrobiculatum* L), is a tropical small millet indigenous to India (de Wet *et al*., 1983) and grown for its grain and fodder. It is a traditional, long duration, hardy and drought resistant crop cultivated in about 9 lakh hectares in India with an annual production of 3.11 lakh tonnes (Bondale 1994; Singh 1994). The area under kodo millet cultivation is witnessing a declining trend in the post-green revolution period due to predominance of the major cereals such as rice and wheat. However, an intensified drive to increase the acreage of small millets is important because millets still contribute to the regional food security of the dry and marginal lands, where major cereal crops fail to yield. Nowadays, thrust to grow millets is given due to their nutritional superiority as compared to the major cereals. Kodo millet has been reported to have higher free radical quenching potential when compared to other millets (Hegde and Chandra, 2005). Besides, it provides low priced protein, minerals and vitamins in form of sustainable food (Yadava and Jain, 2006). Growing health consciousness among the consumers also creates demand for this type of nutri-cereals which are anti-diabetic and anti-oxidant in nature (Chandrasekara and and Shahidi, 2010). Hence, technological intervention in this crop is essential to boost the production on a profitable scale.

Kodo millet is predominantly grown as a pure crop and yields high net returns as compared to other dry land crops owing to its high unit area productivity and market price of the produce in addition to its fodder value. Due to scarcity of labour-, farmers use paddy combine harvesters to reap the crop. However, the spreading plant habit and poor culm strength of land races and high yielding varieties at present, leads to heavy lodging at maturity and therefore grain loss is more if harvested mechanically. Given the context, genotypes that are non-lodging with sufficient culm strength may be effectively cut by the blades of the mechanical harvester. Direct evaluation of each genotype for suitability to mechanical harvesting by raising them in large plots is not practicable. Hence, identifying traits that contribute for culm strength in kodo millet forms the premise of this investigation. Correlation gives an idea about the related traits which can be studied to identify superior lines with respect to specific phenome. Path analysis helps to partition the correlation coefficients into direct and indirect effects and provide a clear understanding of true relationships between associated traits. Therefore, this work attempts to identify the morphological traits contributing to culm strength in kodo millet and their nature of association.

Material and methods

A total of 297 germplasm accessions of kodo millet maintained by Small millets unit of Department of Millets were raised along with two checks, CO3 (a high yielding variety released by Tamil Nadu Agricultural University, India) and *Adari* (a local land race under cultivation in southern parts of India). The experiment was laid out during *kharif* (Aug – Dec), 2012 at Department of Millets, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University (TNAU), in Augmented Block Design (Federer,1956, 1961) with four blocks and the checks placed randomly in each block. Each accession was raised in a single row with 45 x 10 cm spacing and all the recommended package of practices was adopted. Observations were recorded on ten morphological traits as described in Table 1.

Analysis of variance for augmented block design was done using the online statistical tool available at Indian Agricultural Statistics Research Institute (IASRI) website (http://www.iasri.res.in/spadweb/default.aspx). Pearson's linear correlation coefficient (r) was calculated for all the combinations of traits. Since the trait 'degree of lodging' was recorded as a categorical data, Point biserial correlation coefficient (r_{pb}) (http://vassarstats.net/pbcorr.html) Das Gupta 1960) was used to estimate the correlation between degree of lodging and other continuous data. Microsoft office excel 2007 was used to draw the polynomial regression curves. Correlation coefficients were partitioned into direct and indirect effects using path analysis suggested by Dewey and Lu (1959). Schonbrodt and Perugini (2013) reported that the sample size should approach 250 for stable estimates of correlation. In this study, the sample size is 299 including checks hence the correlation can be highly relied upon.

Results and Discussion

The analysis of variance was observed to be significant for all the traits studied (Table 2). The range of variability present for each trait in the germplasm is given in Table 3. The pulling force, which quantifiably represents the culm strength, exhibited the high positive correlation with culm diameter (0.544), plant height (0.379), number of productive tillers per plant (0.324), grain yield per plant (0.219) and days to 50% flowering (0.155). But, pulling force has no correlation with internode length, recovery ability after bending and degree of lodging. Plant elasticity represented by recovery angle after bending had negative correlation with internode length (-0.392) and degree of lodging (-0.470). The correlation between internode length and degree of lodging is positive and highly significant (0.490). Grain yield per plant had positive correlation with plant height (0.465), number of productive tillers per plant (0.191), culm diameter (0.206), internode length (0.250), degree of lodging (0.240) and pulling force (0.219), and negative association with recovery ability after bending (-0.316) (Table 4).

In this study, path analysis was carried out to find out the direct and indirect effects of associated traits with pulling force (Table 5). Path analysis revealed that culm diameter (0.378) had highest positive direct effect on pulling force followed by plant height (0.292) and recovery angle after bending (0.255).

Traits related to Culm strength:The correlation of pulling force with other traits indicated that the lines with high culm strength are taller with thicker culm, more productive tillers and yield, but are late in flowering. This result corroborated with the findings of Kashiwagi et al. (2008), who reported that the stem diameter was positively correlated with pushing resistance in rice. The insignificant correlation of pulling force with recovery angle after bending is in accordance with the earlier findings of Torro et al. (2011) in rice, who reported that culm strength and elasticity are two independent traits. The correlation between degree of lodging and recovery angle is negative, i.e., the plants which recovered better seldom lodged. Hence, to assess lodging resistance alone recovery angle would be the ideal trait for screening as reported by Torro et al. (2011). But to identify non-lodging genotypes with good culm strength to suit mechanical harvesting, simultaneous selection for high pulling force and recovery angle has to be done as evidenced from this study.

Traits related to lodging

Recovery angle after bending had high negative correlation with degree of lodging, plant height, internode length and grain yield per plant. This reveals that lines which are tall with more grain weight and longer basal internodal length will have poor recovery after bending. Degree of lodging was negatively associated with days to flowering and days to maturity. This suggests that short duration lines are more prone to lodging which may be due to shorter time window available for strengthening and lignification of culm which is needed for culm strength (Li *et al.*, 2000). But the correlation between degree of lodging and plant height is positive. This could be due to the fact that, lodging happens in short duration lines because of its poor culm strength, which is decided by its genetic makeup. On contrary, the tall plants with sufficient culm strength normally stand erect, but any adverse environmental conditions like high plant density, heavy rain or wind lodges the plant, the recovery to original position demands more force. Hence the tall plants fail to recover after lodging. Moreover, there is no correlation between degree of lodging and culm diameter, which reinstates the above statement that both weaker and strong culms may tend to lodge, the former for its inherent weakness in culm and inability to stand erect and the latter because of its inability to recover upon lodging. So the ideal plant type has to be medium tall with sufficient culm strength which can stand while being cut by the blades of the mechanical harvester and can also recover better if lodged because of any adverse environmental conditions.

Internode length was positively correlated with plant height and degree of lodging and negatively with recovery angle after bending, but its correlation with culm diameter is insignificant. This confirms the earlier work of Aliaga *et al.* (1986), who reported that the culm elasticity is correlated with internode length, but not with culm thickness in rice. Internode length also is negatively correlated with days to 50% flowering and days to maturity. This suggests that the short duration lines are with longer basal internodes giving them the elasticity to bend.

Traits related to grain yield

Grain yield per plant is the most important trait which should also be given due consideration, because increased return is the ultimate goal of any study. Though the grain yield increases with plant height, it becomes static beyond a height of 60 cm (Fig. 1). Likewise if the pulling force and culm diameter increases beyond 6 Newton (Fig. 2) and 4 mm (Fig. 3), respectively, there is no corresponding increase in the grain yield, this could be because of diversion of source to strengthen the culm at the cost of yield. Moreover, the grain yield decreases with days to maturity. Hence an ideal cultivar should be medium tall and medium duration with optimal pulling force and culm diameter.

In *path analysis*, the culm diameter, which registered high positive direct effect on pulling force, is the best selection index for assessing culm strength. Following this, plant height and recovery angle after bending also have the true positive association with pulling force. So, to identify genotypes with good culm strength in kodo millet, culm diameter, plant height and recovery angle after bending could be the candidate traits upon which selection has to be imposed.

Though this study aims to identify traits related to mechanical strength, traits related to yield and lodging resistance were also included to arrive at a plant type suitable for machine harvest without compromising on yield. This could be the reason for high *residual effect* (Table 5). Moreover, apart from the morphological traits studied, polysaccharides (Cellulose, Hemi-cellulose), lignin (Li *et al.*, 2003) and other elemental (Silicon, Potassium) composition (Datta and Mikkelsen, 1985; Idris *et al.*, 1975; Ma and Yamaji, 2006) of the culm may have a direct bearing on culm strength. Hence these traits need to be explored in kodo millet for better understanding of the culm strength.

Thus, culm diameter which recorded the highest estimate of correlation and direct effect with pulling force is the most important morphological trait to assess the culm strength followed by plant height and recovery angle after bending. Selection strictly for maximum culm strength may be only at the cost of yield. Therefore, as a trade off, selection of medium tall and medium duration with sufficient pulling force, culm diameter and recovery angle after bending should be considered to identify lines to suit mechanical harvest. However, further study of the culm biochemistry and anatomy can throw more light on the features that could impart high strength to the culm of kodo millet.

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Table 1. Description of the traits studied

Sl. No	Trait	Description
1	Days to 50% flowering (DF)	Counted as days from sowing to 50% of the plants in flowering
2	Plant height (cm) (PH)	Taken from base of the plant to tip of the panicle in the main tiller
3	Number of productive tillers (Ptil)	Total number of productive tillers in the plant
4	Culm diameter (mm) (CD)	The machine cut the plant at the base of the plant approximately at a height of 20 cm. Hence, the culm diameter is measured at middle of the second internode from the base of the plant on the main tiller, using digital vernier caliper. The cross section of the internode is elliptical, hence, the shorter diameter is measured. (Fig 4)
5	Internode length (cm) (IntL)	The length of the second internode from the base of the plant on the main tiller is measured
6	Pulling Force (Newton) (PF)	The force required to bend the whole plant to an angle of 45^0 from the ground level measured using force gauge (Torro *et al.*, 2011) after setting the gauge to read the force at peak-hold. This setting will give the maximum force required from erect position to 45^0 angle. (Fig 5)
7	Recovery angle after bending (degrees) (RA)	The angle of recovery made by the plant after bending it to the ground level by holding the tip of the plant (this is a slight modification of the trait described by Torro *et al*. (2011) in rice). Instead of tiller angle difference, the angle of recovery is taken into account here. To read the angle, a protractor is kept behind the plant. (Fig 6)
8	Days to maturity (DM)	Number of days taken from sowing to physiological maturity of 50% of the main tillers
9	Grain yield per plant (gm) (GY)	Mean yield of three random plants.
10	Degree of lodging (DL)	0: non lodging; 1: lodging

*Except days to 50% flowering all the traits have been measured at physiological maturity of the crop.

Table 2. Anova for Augmented Block Design I

		Mean sum of squares				
Sl.No	**Source**	**Treatments (df =298)**	**Checks (df =1)**	**Test entries (df =296)**	**CheckxTest entries (df =1)**	**Error (df =6)**
1	Days to flowering	83.05*	465.12**	77.42*	1369.13**	14.79
2	Plant height	110.62**	269.93**	101.79**	2565.39**	11.86
3	Numbers of productive tillers	6.77**	8.14*	6.78**	2.25	0.87
4	Culm diameter	0.37*	0.75*	0.34*	7.65**	0.07
5	Basal internode length	5.77*	2.21	5.79*	3.13	0.84
6	Pulling force	1.30**	0.35	1.30**	2.35**	0.08
7	Recovery angle after bending	121.23*	153.12*	120.95*	172.79*	18.40
8	Days to maturity	91.05**	512.00**	84.31**	1664.03**	7.90
9	Grain yield per plant	62.72*	49.21	61.86*	331.04**	10.01

Table 3: Variability observed in the genotypes

Sl.No	Traits	Min	Max	Mean±SE
1	Days to flowering (days)	64.00	127.00	78.21±3.85
2	Plant height (cm)	20.33	70.20	40.83±3.44
3	Numbers of productive tillers	3.33	20.00	7.12±0.94
4	Culm diameter (mm)	1.72	5.45	2.92±0.28
5	Internode length (cm)	3.25	19.50	9.38±0.92
6	Recovery angle after bending (degrees)	20.00	80.00	54.89±4.29
7	Days to maturity (days)	102.00	172.00	121.23±2.81
8	Grain yield per plant (gm)	1.11	57.55	17.39±3.16
9	Pulling force (Newton)	0.86	7.78	2.54±0.30

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Table 4. Simple correlation coefficients between pulling force and other traits

Characters	**Days to flowering (days)**	**Plant height (cm)**	**Numbers of productive tillers**	**Culm diameter (mm)**	**Internode length (cm)**	**Recovery angle after bending (degrees)**	**DL**	**Days to maturity (days)**	**Grain yield per plant (gm)**
Plant height (cm)	0.088								
Numbers of productive tillers	-0.113	0.416**							
Culm diameter (mm)	0.351**	0.521**	0.257**						
Internode length (cm)	-0.359**	0.556**	0.369**	-0.024					
Recovery angle after bending (degrees)	0.095	-0.432**	-0.176**	-0.135*	-0.392**				
DL	-0.250**	0.390**	0.100*	0.010	0.490**	-0.470**			
Days to maturity (days)	0.857**	-0.09	-0.320**	0.193**	-0.453**	0.160**	-0.290**		
Grain yield per plant (gm)	-0.107	0.465**	0.191**	0.206**	0.250**	-0.316**	0.240**	-0.190**	
Pulling force (Newton)	0.155*	0.379**	0.324**	0.544**	-0.026	0.103	-0.090	0.036	0.219**

*significant at 5% level; **significant at 1% level

Table 5. Direct and indirect effects of different traits on pulling force

Traits	DF	PH	Ptil	CD	IntL	RA	DL	DM	GY	**Correlation with pulling force**
DF	**-0.054**	0.026	-0.021	0.133	0.061	0.024	0.017	-0.020	-0.011	0.155*
PH	-0.005	**0.292**	0.078	0.197	-0.094	-0.110	-0.026	0.002	0.046	0.379**
Ptil	0.006	0.121	**0.188**	0.097	-0.063	-0.045	-0.007	0.007	0.019	0.324**
CD	-0.019	0.152	0.048	**0.378**	0.004	-0.034	-0.001	-0.004	0.020	0.544**
IntL	0.019	0.162	0.069	-0.009	**-0.170**	-0.100	-0.033	0.010	0.025	-0.026
RA	-0.005	-0.126	-0.033	-0.051	0.067	**0.255**	0.032	-0.004	-0.031	0.103
DL	0.013	0.114	0.019	0.004	-0.083	-0.120	**-0.067**	0.007	0.024	-0.068
DM	-0.046	-0.026	-0.060	0.073	0.077	0.041	0.019	**-0.023**	-0.019	-0.090
GY	0.006	0.136	0.036	0.078	-0.042	-0.081	-0.016	0.004	**0.099**	0.219**

Residual effect = 0.759

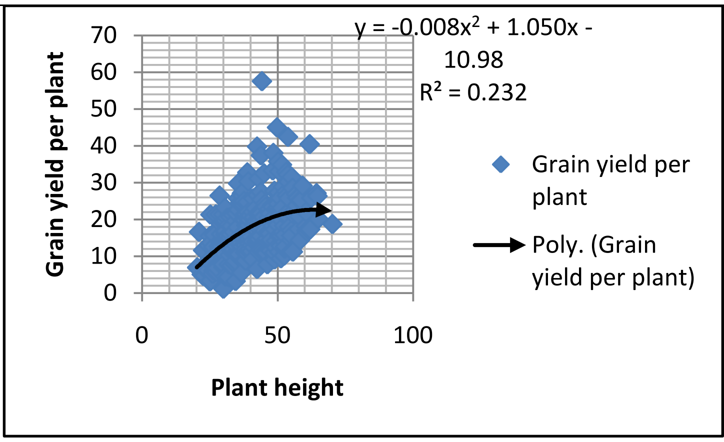

Figure 1: The polynomial regression of plant height with grain yield per plant (Note: The grain yield reaches a static beyond 60cm height**)**

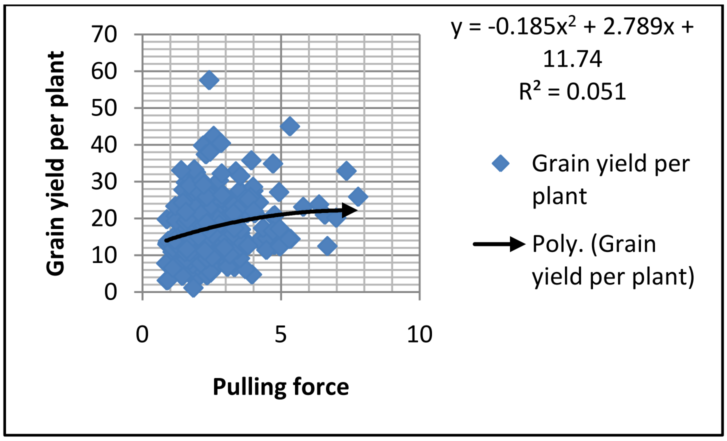

Figure 2: The polynomial regression of pulling force on grain yield per plant (Note: Beyond a pulling force of 6 newton there is no corresponding increase in grain yield)

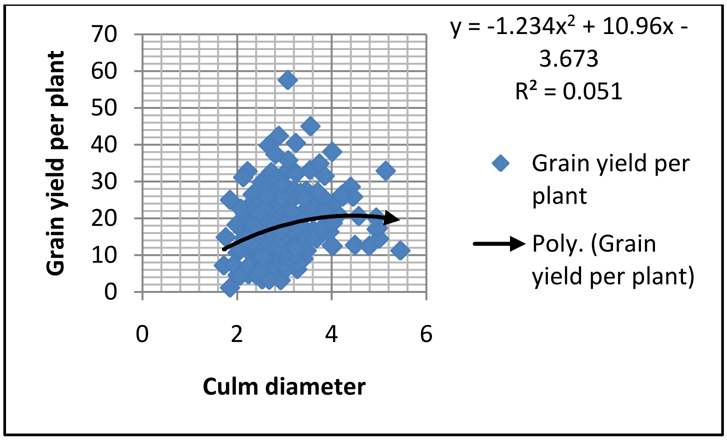

Figure 3: The polynomial regression of culm diameter with grain yield per plant (Note: Culm diameter more than 4mm has no positive effect on grain yield per plant)

Figure 4. Culm diameter measurement using vernier caliper

Figure 5. Pulling force measured force gauge.

6a 6b 6c

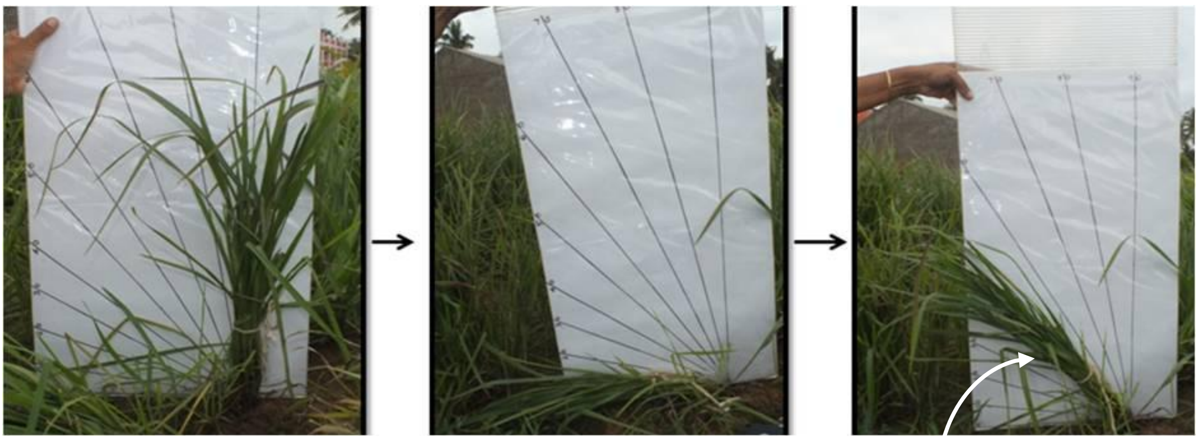

Figure 6. Measurement of recovery angle after bending,
6a: Plant at normal position, 6b: Plant bend to the ground level gently by holding the tip of the plant, 6c: The plant slowly released. Now the angle made by the plant from the ground level is measured.