Selection of major yield contributing traits by multiple linear regression model in finger millet (*Eleusine coracana* L.)

ABSTRACT

Yield improvement of finger millet through yield-based selection has plateaued in the last two decades. Hence, breeding efforts are required to prioritize trait-based improvement in addition to yield *per se*. Using the backward multiple linear regression, and path analysis, the independent parameters, mean ear-head weight (MEW), ear-head number/ plant (ENo.), and the threshing percentage, were found the highest contributors to grain yield. Genetic resources for the higher mean ear-head weight of >10.22g (GE-4683, GE-4596) and ear-head number >104.7m^{-2} (RAU-8, PR-202) were selected over the popular variety, GPU-28 (7.59g and 72.7, respectively). Theoretically, incorporating the higher MEW and ear-head number/plant from the identified lines into popular variety, GPU-28 (shy tillering) in multiple regression model has predicted the possibility of increasing yield of GPU-28 by 17.8% and 29.5%, respectively. Therefore, a shift towards trait-based improvement could be appropriate to break the yield plateau of finger millet.

KEY WORDS: Genetic resources, Path analysis, Multiple linear regression, Yield prediction

1. INTRODUCTION

Millets are gaining importance due to their higher capacity to adapt to harsh weather conditions. Finger millet accounts for 12% of the millet area, cultivated in more than 25 countries in Africa and Asia (http://icrisat.org). In India, finger millet was grown on 1.159 million hectares producing 1.988 million metric tonnes in 2020-2021 (http://apeda.). Compared to major rainfed millets, sorghum, and pearl millet, the finger millet productivity is considerably high (http://apeda). As a result, finger millet is more suitable for drought-prone areas in semi-arid regions (Thilakarathna and Raizada, 2015; Wafula *et al*., 2016; Nanja Reddy *et al*., 2021a) and cultivated as a rainfed crop by >90% of finger millet area (Davis *et al*., 2019). Additionally, finger millet has many dietary advantages with high calcium, iron, amino acids, fibre, and polyphenols (Upadhyaya *et al*., 2011; Chandra *et al*., 2016; Hiremath *et al*., 2018; Nanja Reddy et al., 2019a; Hassan *et al*., 2021). Livestock also prefers finger millet fodder (haulm) because it contains more than 60% of nutrients in digestible form (Baath *et al*., 2018).

Breeding efforts have increased the productivity from 1.5 to 2.0 t/ha (Cv. H-22 in 1919) to 4.0 to 4.5 t/ha (in popular variety like GPU-28 released in 1998) on research stations and innovative farmer's fields (Gowda *et al*., 2014), and still more or less in the same range. The success was attributed to the blast resistance and improved partitioning of the biomass towards grain (Megha *et al*., 2023). One of the most successful and popular varieties in varietal improvement was GPU-28, and it has 2.5 productive tillers per hill with an average ear-head weight of 7.5 g/ear (Nanja Reddy *et al*., 2019b). However, the rate of improvement of finger millet yield is in a declining trend in the last twenty years (Adugna *et al*., 2011; Saxena *et al*., 2018; Megha *et al*., 2023) because the selection was mainly towards yield only, in addition to increasing frequency of droughts coupled with high temperatures (Bennani *et al*., 2016; Krishna *et al*., 2021). Choosing additional yield-contributing traits would increase the grain yield further (Nanja Reddy *et al*., 2021b), and therefore, it would be appropriate to identify traits associated with yield andthe genetic resources for such characters.

For identification of appropriate traits, several strategies will be applied like correlations, path analysis, regression models. It is reported that the stepwise backward multiple linear regression (MLR) on one of the easy and appropriate method to identify the significant traits for yield contribution (Krishna *et al*., 2021). The identified lines with specific traits can be utilized in breeding programmes to achieve targeted higher grain yield in the background of popular varieties with blast resistance through the development of Multi-parent advanced generation inter-cross (MAGIC) population. Hence, the present study was conducted to emphasize the superior yield contributing traits and germplasm lines/ genotypes compared to popular variety, GPU-28 using MLR and path effects.

2. MATERIAL AND METHODS

Field experiments were conducted in red-sandy loam soils in the rainy seasons over two consecutive years at the All-India Coordinated Small Millets Improvement Project, University of Agricultural Sciences, GKVK, Bengaluru, India. Experiments were conducted in a randomized complete block design with 30 medium (105-110 days) to long-duration (115 days) genotypes in three replications. Each genotype was sown in a plot size of 0.9 m width x 2.0 m long (3 rows of 2 m long each) in 2010 and 1.5 m width x 4.5m long (5 rows of 4.5 m long) in 2011, on 07-07-2010 and 22-07-2011, respectively and seedlings were thinned to one per hill within 20 days after sowing (DAS). The spacing between rows was 30 cm, and between hills within a row it was 10 cm. Fifteen days before sowing, the organic matter (FYM @ 7.5t/ha) was incorporated into the soil. The recommended fertilizer dose for finger millet is 50:40:25 kg of nitrogen, phosphorus, and potassium per hectare. At the time of sowing, half of the nitrogen, the entire P and K, was applied, and the remaining 50% nitrogen N was applied at 40 DAS. Whenever the rainfall did not occur continuously for 15 days, the plots were irrigated to field capacity. At crop harvest, from 30 hills constituting one square meter ground area, the observations on the number of ear-heads, strawweight, grain yield, and above-ground total dry matter (TDM) were recorded. The threshing percentage ((grain yield/total ear weight) x 100) and mean ear-head weight (total ear weight divided by total ear-head number) were calculated.

The parameters associated with grain yield were identified with the help of a regression equation using pooled data over two years. Combining the data over years is applicable only when the variances between the two years are homogeneous. If the variances are not homogeneous, the original observations need to be normalized to bring equal variances among the two years. Since the data pertaining to the two years in the present study, the F-test using Microsoft Excel software was performed to check the homogeneity of variances for each parameter between years (https://www.lexjansen.com). The F-ratio (F-statistic) was computed by dividing the large variance by the smaller, and F-critical values were taken from the statistical tables at P=0.05 at 29 degrees of freedom (n-1). The parameters with a lower F-statistic to that F-critical value indicate that the variances are similar (not significantly different), and such parameters are considered directly for the pooling of data for combined analysis. The F-statistic was higher than the F-critical for the number of ears/ hill and threshing percentage, where each observation was divided by the error mean sum of squares (MSSe) of that respective experiment analyzed in RCBD and obtained normalized values. The normalized values were used for combined analysis using OPSTAT statistical software (Sheoran *et al*., 1998). The coefficient of variation for each trait was calculated as, CV (%) = (Square root of error mean sum of squares in combined analysis divided by the mean of all observations) x 100.

Pearson’s correlations were measured using the Microsoft Excel ToolPak to study the relationship between traits. The path coefficients were arrived at using OPSTAT software to check for the direct and indirect effects of parameters on grain yield. The direct and indirect effects were negligible (0.00–0.09), low (0.10–0.19), moderate (0.20–0.29), high (0.30–0.99), and very high (>1.0) (Lenka and Mishra, 1973). The contribution of each or combination of traits to grain yield was measured by considering the residual values in the path analysis. The lower residual value indicates that the selected parameters through path coefficient analysis were appropriate (Amein *et al*., 2020). The traits contributing to grain yield were selected using multiple linear regressions (MLR) in stepwise backward selection using the Microsoft Excel ToolPak. In stepwise backward regression, the parameters showing P>0.05 were removed one by one until the significant parameters with P<0.05 remained to construct the final MLR equation. By employing the derived MLR equation, yield predictions were made and compared with the observed grain yields. Further, values of the specified parameters (10.31g, mean ear-weight of GE-4683, or 126.4 ear-heads per m^{-2} of cv. RAU-8) were incorporated into the final MLR equation to arrive at the predicted grain yield of popular variety, GPU-28.

3. RESULTS AND DISCUSSION

One of the principal approaches for identifying donor lines with specific traits could be the utilization of genetic resources (Upadhyaya *et al*., 2007) using appropriate statistical tools. Utilization of distinct donors for particular traits in hybridization, developing the MAGIC population, and the selection of transgressive segregants would increase productivity further (Upadhyaya *et al*., 2007; Krishnappa *et al*., 2009).

Genotypic variability for yield contributing parameters

For identifying the donors with specific parameters of yield contribution, the prerequisites are the availability of germplasm, genetic variability, heritability, and stability over the locations/ seasons (Upadhyaya *et al*., 2007). The parameters, mean ear-head weight, straw (haulm) weight, total dry matter (TDM), harvest index (HI), and grain yield were less influenced by the environment, confirmed through lower F-ratios (statistic) than the F-critical value, and thus these characters could be appropriate in the selection of donors (Table 1; Lule *et al*., 2012). While the ear-head number and threshing percentage had a higher F-ratio (3.37; 7.10, respectively)than the F-critical of 1.86 before transformation of data, depicting the higher influence of environmental conditions on these parameters (Table 1).

Table 1. Test of homogeneity between years for yield attributing traits, and pooled mean and variability statistics in finger millet genotypes in comparison with cv. GPU-28 (NS: Statistically Non-significant; *: Statistically significant at P<0.05)

Character	Test of homogeneity for variances between years	F-test	F-test	Across genotypes	GPU-28

	Variance 2010	Variance 2011	F-Critical	F-Statistic	for years	for genotypes	Mean	Min.	Max.	SD	Variance	CV (%)	Mean
Grain yield (gm-2)	4297	6859	1.86	1.60^{ns}	NS	*	399.3	288.5	548.3	67.3	4376	13.0	463.2
Mean ear weight (g)	4.90	3.32	1.86	1.42^{ns}	NS	*	7.06	3.43	10.3	1.97	3.75	8.5	7.59
Ear number (No.m-2)	644.8	191.2	1.86	1.24^{ns}	*	*	74.9	53.4	126.4	18.3	325.2	13.8	72.7
Threshing (%)	43.8	6.17	1.86	1.81^{ns}	*	*	81.1	68.3	86.8	4.39	18.6	2.6	84.8
Straw weight (gm-2)	9589	15830	1.86	1.61^{ns}	*	*	586.4	388.3	778.2	98.2	9322	14.8	597.2
Total dry matter (gm-2)	20229	29872	1.86	1.48^{ns}	*	*	1079	815.9	1323	131.8	16791	12.3	1145
Harvest index	0.002	0.002	1.86	1.31^{ns}	*	*	0.373	0.290	0.445	0.044	0.002	8.64	0.41

In the combined analysis, the genotypes were stable for mean ear-head weight and grain yield with no significant differences between the years (Table 1). Hence, the accessions/ genotypes shall be selected based on these two traits compared to the popular variety GPU-28 (Table 1). However, for grain yield, none of the genotypes was statistically superior to the popular variety, GPU-28,but, the mean ear weight was higher (>10.22 g/ear) in germplasm accessions GE-4596 and GE-4683 than in cv. GPU-28 (7.59 g.ear^{-1}). A higher ear-head number (>100 m^{-2}) was observed in cv. PES-110, PR-202, and RAU-8 compared to the popular cv. GPU-28 (72.7 m^{-2}). The majority genotypes had a higher threshing percentage of >80 % and were higher (84.5%) in cv. GPU-28. The popular variety, GPU-28, is a shy tillering variety with 2.5 tillers per hill with a higher mean ear-head weight (Nanja Reddy *et al*., 2019b). Integrating the higher productive tillers from selected donors into the background of popular variety, GPU-28 would increase finger millet productivity as GPU-28 occupies more than 60% of finger millet cultivation in India (Gowda *et al*., 2009).

Contribution of specific traits to grain yield

Although genetic variability exists for yield-contributing traits and selection could be possible, the nature and extent of interrelationships between the characters will provide additional support in selecting trait-specific donors (Nanja Reddy, 2023a & b). Pearson correlations revealed that the grain yield was positively and significantly correlated to the dependent (biomass, r=0.696**; and harvest index, r=0.680**), and independent traits (mean ear weight and threshing percentage; Table 2). The correlations suggest that mean ear-head weight would be a better trait for yield improvement, as mean ear-head weight and ear-head number are strongly and negatively correlated (r= - 0.817**, data not shown; Owere *et al*., 2015; Mujahid *et al*., 2020; Chaithra and Nanja Reddy, 2023).

Table 2 Direct and indirect effects of independent yield contributing traits on grain yield in finger millet

Character	MEW	EH No.	Th %	Str	Correlation coefficient with grain yield
Mean ear weight (MEW)	**1.364**	-0.740	0.020	0.009	0.653**
Ear number per hill (EHNo.)	-1.118	**0.902**	0.025	-0.006	-0.197*
Threshing percentage (Th%)	0.091	0.076	**0.298**	0.015	0.479**
Straw weight (Str.)	0.144	-0.064	0.053	**0.082**	0.215*
Residuals: 0.127					

In addition, dividing the correlation influence of traits into direct and indirect effects by path analysis will be more meaningful in selecting yield-contributing characters and provide a better understanding of their association with grain yield (Dhavaleshvar *et al*., 2019). Among the independent traits, the mean ear-head weight showed a very high direct positive effect (1.364; Lenka and Mishra, 1973) on grain yield, followed by a higher direct effect of ear-head number (0.902) and a moderate influence of threshing percentage (0.298; Table 2). A lower residual value of 0.127 of path analysis further confirmed that the mean ear-head weight could be the best trait for increasing finger millet yield (Table 2; Amein *et al*., 2020; Chaithra and Nanja Reddy, 2023). The highest contribution to grain yield was predicted by mean ear-head weight

(42.6%), followed by threshing percentage (23.0%), and ear-head number (3.9%; Table 3). The combination of ear-head number and mean ear-head weight increased the contribution to 77.5% (Table 3). Furthermore, the mean ear-head weight, ear-head number, and threshing percentage collectively contributed to the grain yield by 86.7%, with a low residual value of 0.133 (Table 3; Nanja Reddy *et al*., 2021b), and hence, these traits are collectively appropriate for selecting the donors in finger millet.

Table 3 Contribution of yield attributing traits towards grain yield of finger millet in pooled data

Parameters (Grain yield Vs other traits)	Residual	Contribution (%)	% Increase
1) Total dry matter (g m-2)	0.516	48.4	
2) Harvest index (HI)	0.536	46.4	
3) Mean ear-head weight (MEW) (g ear-1)	0.574	42.6	
4) Threshing percentage (Thr. %)	0.770	23.0	
5) Straw weight (Str. Wt.; gm-2)	0.954	4.6	
6) Ear-head number (ENo.; No. m-2))	0.961	3.9	
7) Mean ear-head weight + Ear number	0.225	77.5	34.9
8) Mean ear-head weight + Threshing percent	0.383	61.7	38.7
9) Mean ear-head weight + Straw weight	0.552	44.8	40.2
10) Mean ear-head weight + ENo. + Straw weight	0.208	79.2	1.70
11) Mean ear-head weight + ENo. + Thr. %.	0.133	86.7	9.20
12) MEW + ENo. + Thr. % + Str. Wt.	0.127	87.3	0.60
Residual: 0.133			

Yield prediction by MLR using specific traits

To predict the grain yield by using the selected traits, a multiple linear regression (MLR) model was computed (Y = -589.1 + (49.5 x MEW) + (3.56 x Ear-head number/ m^{-2}) + (4.59 x Th. %). The relationship between observed and predicted grain yield in MLR was statistically significant, with 8.85% deviation between observed and expected grain yield suggesting that the model is appropriate (Fig. 1). However, the grain yield of popular cultivars is already high over the germplasm accessions (Fig. 2). Therefore, direct selection for a given location or across locations for the grain yield is not advisable (Simion et al., 2020; Nanja Reddy *et al*., 2021b). Hence, trait-specific donor selection could be a better approach for improving the grain yield of finger millet, using the available genetic resources for independent traits such as mean ear-head weight and productive tillers (Owere *et al*., 2015; Kandel *et al*., 2019).

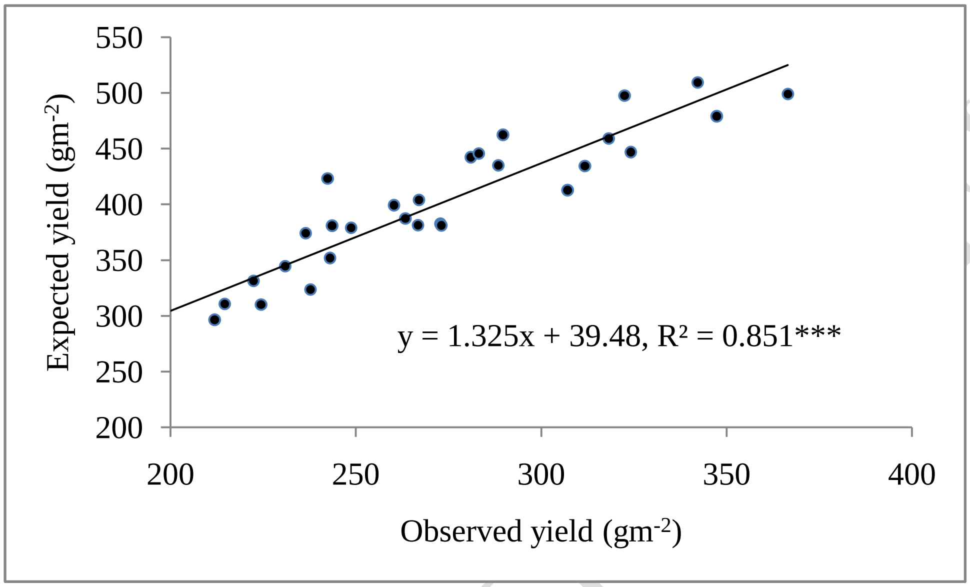

Fig. 1 Relationship between observed and expected grain yield calculated using three variables in linear regression model

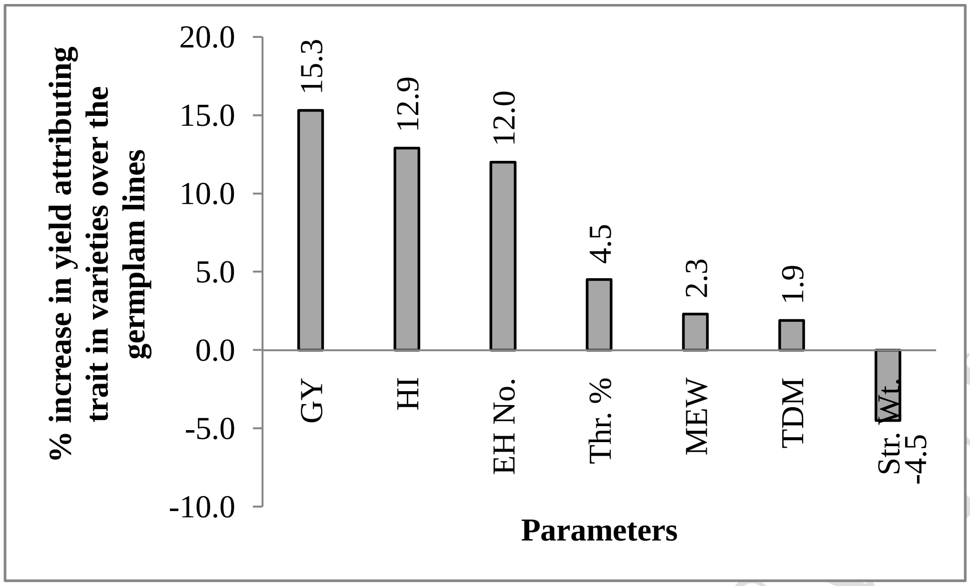

Fig. 2 Performance of released varieties over the germplasm accessions in finger millet in pooled data (varieties, 11 and germplasm, 19)

Superior accessions / genotypes for the mean ear-head weight (>10.22 g/ear-head, GE-4683, and GE-4596), and ear-head number per hill (>104.7 m^{-2}, RAU-8, PR-202, PES-110) were selected in comparison with cv. GPU-28 (7.59 g/ear-head, and 72.7 tillers m^{-2}). The theoretical model predicted the possibility of grain yield of popular variety, GPU-28 with the incorporation of higher ear-head number (by 29.5%), or mean ear-head weight (by 17.8%)from the selected donors (Table 4). In the similar lines, an increase in 1 tiller per plant found to increase the yield by 54.5%, and an increase in 2 g per ear-head by 29.5% (Nanja Reddy, 2023a), by 52.9 and 47.1% with PT and MEW, respectively (Nanja Reddy, 2023b), and by 31.3 and 35.9% respectively (Krishna *et al*., 2021). The mean threshing percentage of the GPU-28 (84.8%) is already high. Therefore, the re-validated study, reiterates that the integration of higher productive tillers could be a better approach because of the GPU-28 which has a shy tillering habit with relatively a higher mean ear-head weight, and the backward MLR can be effectively used to select traits in finger millet and can be applied to other crops as well.

Table 4 Selected traits with multiple linear regression by backward selection of traits

Parameter		Coefficient	T-statistic	Prob.	Observed yield of GPU-28 (gm-2)	Expected increase in grain yield of GPU-28 by trait introgression
Adj. R2	0.846					
Intercept	-589.1					
Mean ear weight (g/ ear)		49.5	10.50	***	483.3	569.3 (17.8%)
Ear-number (No.m-2)		3.56	7.06	***	483.3	625.8 (29.5%)
Threshing (%)		4.59	4.00	***	483.3	443.8 (NS)
Straw weight (g. m-2)				NS		
Y= -589.1 + (49.5 x MEW) + (3.56 x PT/ Ear number) + (4.59 x Th.%)						

4. CONCLUSIONS

Finger millet yield improvement could be possible by improving ear-head size and productive tillers per hill in the popular cultivar, GPU-28. However, the integration of traits depends on the background of the variety that needs improvement. For instance, if a genotype has shy tillering habit, it should be integrated with a higher productive tiller number and a high tillering genotype with a large ear-head size. Furthermore, using the identified genetic resources for specific traits, a MAGIC population can be developed to achieve a potential grain yield of finger millet. The present statistical analysis model can be derived for other crops also. The selection of traits can be carried out by the backward MLR.

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