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PATH ANALYSIS APPROACH TO ASSESS THE COMPENSATORY IMPACT OF YIELD ATTRIBUTES ON PEARL MILLET GRAIN YIELD IN SEMI-ARID AND ARID AREAS OF PUNJAB, PAKISTAN

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ABSTRACT

Yield gaps in agronomic crops are associated with grain number and per unit grain weight. These yield contributing components are interrelated and have compensatory effects on yield. Path coefficient analysis quantifies the direct influence of one yield component upon the other and allows for the separation of correlation coefficients into direct and indirect component effects with respect to various management options. Pearl millet fields with differing planting times (3rd week of June, 1st week of July, 3rd week of July, 1st week of August), with intra-row spacing (10 cm, 15 cm, 20 cm) and nitrogen rate (0, 150, 200, 250 kg ha^{-1}) in semi-arid (Faisalabad) and arid (Layyah) areas of Punjab, Pakistan were used during 2015-16 to examine relationships between yield and yield contributing components via Pearson correlation and path analysis. Correlations of kernels $panicle^{-1}$ and kernel weight $panicle^{-1}$ to pearl millet yield were more positive and had strong significance ($P \leq 0.001$) at both locations. Direct effects of panicle m^{-2} and kernel weight $panicle^{-1}$ on grain yield were found at both locations, however, indirect effects of kernels $panicle^{-1}$ on millet yield via kernel weight were higher at Faisalabad than Layyah (0.63). Kernels per panicle and kernel weight were positively associated with grain yield of pearl millet at both locations. Row spacing, and nitrogen regimes had higher indirect effects of kernels $panicle^{-1}$ on millet yield via kernel weight than planting time study. Similarly, kernel weight $panicle^{-1}$ showed higher yield compensation with intra row spacing and nitrogen variation than with planting time and row spacing changes. In conclusion, plant population per unit area and kernel grain weight are the important yield compensation indicators in pearl millet crop under optimum management options.

Keywords: yield compensation; correlation; path analysis; pearl millet.

INTRODUCTION

Yield variation in grains can be associated with changes in both grain number and weight per grain, and are determined by grain variety, environmental factors such as temperature (Ullah *et al*., 2018), edaphic factors (soil/nutrients), and water availability (Maman *et al*., 2004). Yield compensation potential occurs early in crop life cycle by adjustments in panicle m^{-2} and number of kernels $panicle^{-1}$, and later through adjustments in weight $kernel^{-1}$, so cereal grain yield in cereals is comparatively less sensitive to plant population density (Govintharaj *et al*., 2018).

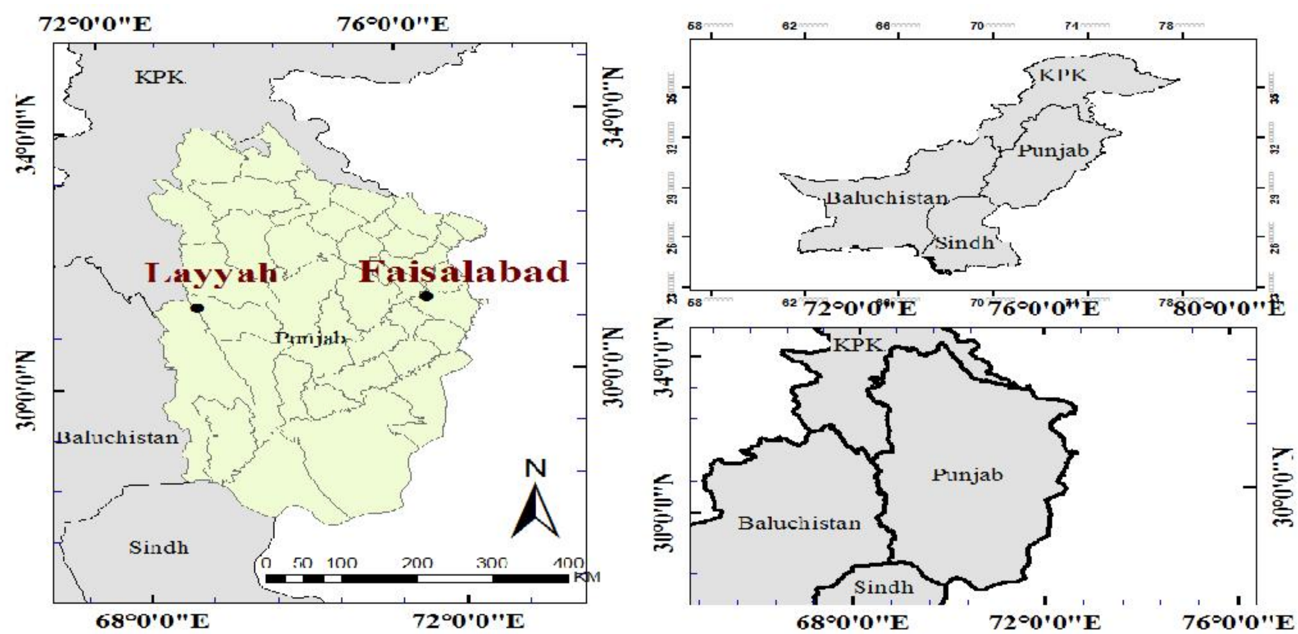
Kumar *et al* (2017) described developmental stages for pearl millet and sorghum (Aruna *et al*., 2015) and gave the concept of path analysis. For both cereals, potential grain number is set during GS_2 and grain weight is determined in GS_3 (Eastin *et al*., 1999; Bika *et al*., 2015). Water and temperature stress during late GS_1 and GS_2 can irreversibly reduce grain number (Maman *et al*., 2004; Bika *et al*., 2015). In pearl millet, high asynchrony of tiller development and flowering delay provide escape mechanisms during times of stress. Studies on yield components of pearl millet show strong associations between number of panicles per plant and yield. Because of profuse tillering, increase in planting density and reduction in intra-row spacing can be associated with either decrease (van-Osterom *et al*., 2002) or no change in panicles per square meter (Bidinger and Blummel, 2007; Ram *et al*., 2013; Govintharaj *et al*., 2018; Ullah *et al*., 2017).

In a study on the effect of planting time, seeding rate and phosphorus use in wheat, Blue *et al*. (1990) applied path coefficient analysis and found that kernel weight contributed a lot to yield estimation when there were low numbers of tillers, while under high tillering conditions, number of panicles per square meter was a better predictor of yield. Board *et al*. (1999) showed that although number of pods per productive node was the critical to yield through its effects on pod and kernel number, compensation between number of kernels and their size negated any positive effect on total yield. Maman *et al*. (2004) studied pearl millet and sorghum in the central Great Plains and found that pearl millet is more sensitive to environmental differences (across years and locations) than sorghum. They also found that among yield contributing components, kernel number per panicle and kernel weight were more associated with yield than panicle m^{-2}.

Yield contributing components are interrelated and have compensatory effects on yield. Path coefficient analysis allows the quantification of the direct influence of one yield component upon other and permits the separation of correlation coefficients into components of direct and indirect effects. This technique is traditionally used in breeding programs to improve knowledge of how yield components interact with each other at the phenotypic and genotypic level. However, the approach has been found to be useful for crop management in wheat (Blue *et al*., 1990; Edhdaie and Waines, 1993), soybean (Board *et al*., 1999) and physiological understanding of crop morphology (Garcia del Moral *et al*., 2003), tomato (Singh *et al*., 2017), Mazie (Jakhar *et al*., 2017), Chickpea (Tadesse *et al*., 2016), Rice (Ajmera *et al*., 2017) Cotton (Jawahar and Patil, 2017) and for pearl millet (Maman *et al*., 2004; Govintharaj *et al*., 2018), as it provides clear information than simple correlation. We estimated the effect of yield components of grain pearl millet to explore how yield contributing components influence yield of millet under contrasting environments.

MATERIALS AND METHODS

Site Description: Field experiments were conducted during summer season of 2015 and 2016 at two different locations in Punjab, Pakistan; Layyah (arid environment) and Faisalabad (semi-arid conditions, Fig. 1). The Agronomic Research Station (ARS), Karor Lal Eason, Layyah site is located at 31˚ 13´N, 70˚ 58´E and 158 m altitude 158 m, with 1916 and 1934 heat units in growing season 2015 and 2016, respectively, with Rangpur series soils (Sandy, mixed, hyper-thermic, typic torripsamments). The Faisalabad study site is located at 31˚26´N, 73˚04´Eand 184 m altitude and accumulated 1875 and 1940 heat units during growing season 2015 and 2016, respectively with a Lyallpur series soil (Fine, loamy, silik, therm).



Air temperature and rainfall data for Faisalabad were retrieved from the Physiology section, Department of Agronomy, University of Agriculture, Faisalabad, 500m away from experimental site. For Layyah, temperature and rainfall data were collected from the Pakistan Meteorological Department (PMD) weather observatory in Karor (Layyah), 200 m distance from experimental site (Fig. 1).

Crop husbandry: At both sites, hybrid pearl millet, 86M86, a pioneer seed product developed for the climatic conditions of Punjab province, was grown in year 2015 and 2016 at both locations. For the two consecutive years, at each site, the millet was grown on different plots in adjacent fields. The previous crop, planted on these experimental sites was wheat during both years (2015 and 2016) at ARS, Karor and quinoa in 2015 and wheat in 2016 at Faisalabad.

In the first experiment, four sowing dates (3rd week of June, 1st week of July, 3rd week of July and 1st week of August; main plot) were laid out with three intra row spacing (0.10 m, 0.15 m, 0.20 m) in sub plots. In second field setting, three plant spacing (0.10, 0.15 and 0.20 m, main plots), and four nitrogen rates (0, 150, 200, 250 kg ha^{-1}, subplots) were compared in split plot design with three replicates. The plot size of each sub plot was 1.8 m × 3.6 m. The main plots were separated by 1 m non-experimental buffers and subplots by a 0.75 m buffer. The same treatments were applied to the same plots in each summer season during 2015 and 2016 at both locations.

Fields were prepared for sowing by cultivating, levelling, and basal irrigation of 80 mm to soil field capacity. Fungicide treated seeds were planted during the 1^{st} week of July in 2015 and 2016 in a single day at each site at a depth of 50 mm, with a row spacing of 0.45 m and plant spacing per treatments. The intra row spacing was maintained through thinning when the seedlings reached 0.15 m in height. All soils were analysed for its nutrients; soils at both locations were enough in potassium. Nitrogen and Phosphorus were applied at rates of 150 kg ha^{-1} and 57 kg ha^{-1}, respectively in all plots (except the nitrogen treatments (0, 150, 200, 250 kg ha^{-1} under study) in the form of Urea and TSP. All P and 1/3 of the N was applied at sowing, the second 1/3 of N was applied as side dressing at tillering, and the final 1/3 of N was applied as side dressing at panicle initiation with irrigation. Weeding and intercultural operations were undertaken as required for treatment maintenance, and the crop was harvested in the last week of September.

At maturity, the above ground parts of plants from the centre four rows (10.8 m^2) of each treatment were harvested in each replicate, and panicle m^{-2} was calculated via unit method. Ten plants from each replicate were selected for estimation of yield components i.e., kernel weight, kernels $panicle^{-1}$, grain weight $panicle^{-1}$.

Pearson correlation and Path Coefficient Analysis: Pearson correlations among yield and yield contributing components were calculated using replicate values. Direct path coefficients (p) were calculated using the CALIS procedure in SAS (SAS Inst., 1994) using the model of Dofing and Knight (1992) and standardized variables as described by Li (1975). Indirect path coefficients were determined by multiplying appropriate r (correlation coefficient between two yield components) and p values as described by Li (1975) and shown in Fig. 2 using following equations;

$$Y = P_1 + P_2X_2 + P_3X_3 + U_3 \quad (1)$$

$$X_3 = P_{13}X_1 + P_{23}X_2 + U_2 \quad (2)$$

$$X_2 - P_{12}X_1 + U_1 \quad (3)$$

For each yield component, the sum of direct and indirect coefficients via other yield components equals the correlation coefficient of this yield component with grain yield. The three criteria for identifying the importance of a specific yield component in affecting grain yield were based on Board *et al*. (1999). We used the criteria: (1) high positive($r > 0.50$) or intermediate ($r > 0.35$) correlation between the yield component and grain yield; (2) high positive ($p > 0.50$) or intermediate ($p > 0.35$) direct path coefficient by the yield component on grain yield; and (3) small or non-existent negative indirect effects (<-0.20) by the yield component on grain yield via others parameters (i.e., lack of yield component compensation). Presentation of path analysis results follow the guidelines described by Maman *et al*., (2004).

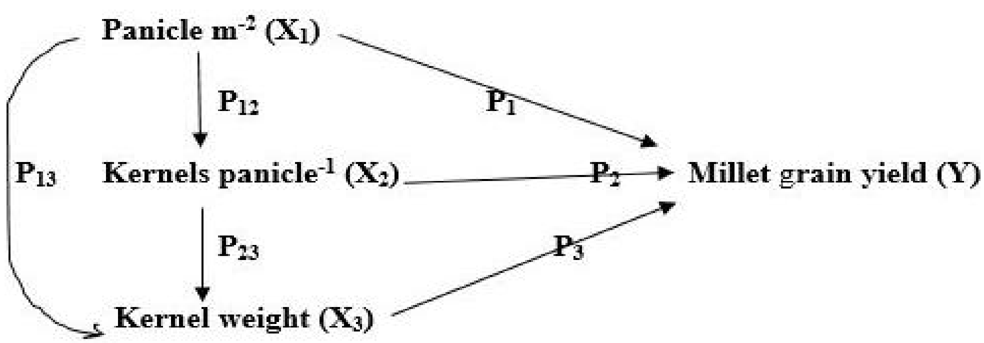


Fig. 2. Path diagram of three yield variables (X_1, X_2 and X_3) and grain yield as response variable (Y), Where P is the path for direct and indirect effects of variables on millet yield

RESULTS AND DISCUSSION

During 2015 and 2016, the observed monthly maximum temperature was higher (1.25°C and 0.29°C, respectively) in Layyah than Faisalabad during the millet growing season. As seen in Figure 3 (a, b), monthly growing season minimum temperatures were lower in Faisalabad for 2015 (by 0.45°C), and in Layyah in 2016 (by 0.89°C) Fig. 1 (a,b). In Faisalabad for both years, most of the rainfall occurred in the first sixty days of the growing season, but in 2016 Layyah's rainfall was scattered across the entire growing season. This type of variability in weather significantly hit the crop yield (Ullah *et al*., 2019)

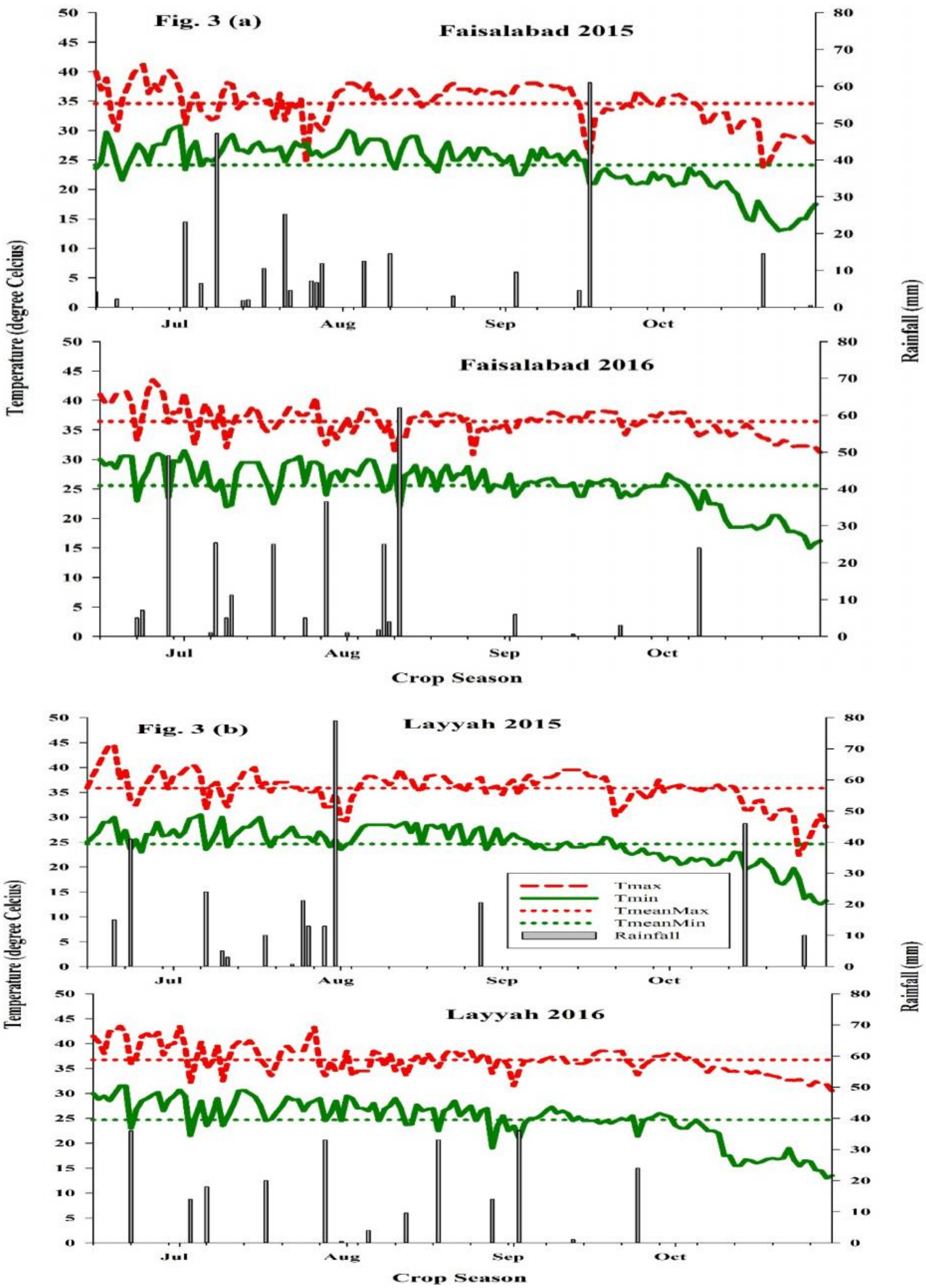


Fig. 3 Seasonal weather conditions at Layyah (a) and Faisalabad (b)

Correlations: As hypothesized, pearl millet yields were positively correlated with panicle m^{-2}, kernels $panicle^{-1}$ and kernel weight $panicle^{-1}$ at both locations for all treatments. These results were in consistent with findings of Maman *et al*. (2004), who found a positive high correlation of kernel weight with grain yield of pearl millet. In our first study, we found a higher correlation of kernel weight $panicle^{-1}$ (0.78) to yield of millet at both locations, followed by correlation of kernels $panicle^{-1}$ with kernel weight $panicle^{-1}$ at Faisalabad (0.58) and Layyah (0.52) at significance value of $P\leq 0.001$ (Table 1). No relationship between panicle m^{-2} and kernels $panicle^{-1}$ were found for pearl millet at either location. The kernel weight $panicle^{-1}$ associated with millet grain yield was observed in line with Badinger *et al*., 2007 and Maman *et al*., 2004. However, Govintharaj *et al*. (2018) found that always there was a relative constant correlation of kernel $panicle^{-1}$ with millet grain yield.

In our second experiment, the strength of correlations among millet yield and its components were also estimated. The effects of intra-row spacing and nitrogen application on millet yield components showed highly significant correlations. The strongest positive relationships were found between kernels $panicle^{-1}$ and kernel weight $panicle^{-1}$ (0.80) and grain yield (0.85, 0.86) at P≤ 0.001, followed by kernels $panicle^{-1}$with grain yield (0.74, 0.65) at Faisalabad and Layyah, respectively (Table 2). A positive correlation was also found between panicles m^{-2} and grain yield (0.51, 0.52) at Faisalabad and Layyah, respectively. Ong and Monteith (1985), likewise Maman *et al*. (2004) and Kumar *et al*. (2017) found reduction in millet kernels $panicle^{-1}$.

Table 1. Pearson correlation coefficient among pearl millet yield and its components, studying planting time and intra-row spacing at Faisalabad and Layyah during 2015 and 2016.

		Pearl millet		
Faisalabad		**Grain yield**	**Panicle m^{-2}**	**Kernels $panicle^{-1}$**
	Panicle m^{-2}	0.44**		
	Kernels $panicle^{-1}$	0.26*	0.09	
	Kernel weight	0.78**	0.28*	0.58**
Layyah	**Panicle m^{-2}**	0.50**		
	Kernels $panicle^{-1}$	0.23	0.04	
	Kernel weight	0.78**	0.35**	0.52**

P ≤0.05 (*), P ≤ 0.01 (**)

Table 2. Pearson correlation coefficient among pearl millet yield of and its components, studying intra row spacing and nitrogen rate at Faisalabad and Layyah in 2015 and 2016.

		Pearl millet		
Faisalabad		**Grain yield**	**Panicle m^{-2}**	**Kernels $panicle^{-1}$**
	Panicle m^{-2}	0.51**		
	Kernels $panicle^{-1}$	0.74**	0.40**	
	Kernel weight	0.85**	0.53**	0.80**
Layyah	**Panicle m^{-2}**	0.52**		
	Kernels $panicle^{-1}$	0.65**	0.32**	
	Kernel weight	0.86**	0.54**	0.73**

P ≤0.05 (*), P ≤ 0.01 (**)

Path Coefficient (P) Analysis: Planting time, intra row spacing and nitrogen application strongly influence the grain yield at Faisalabad and Layyah, Punjab Pakistan (Tables 3,4). Planting time and intra row spacing in pearl millet showed weaker relationships (0.65, 0.69) than for intra row spacing and nitrogen rate (0.76, 0.75) at Faisalabad and Layyah, respectively.

In our first study, effect of planting time and intra-row spacing were checked on important yield attributes during year 2016-16. It was observed that panicles m^{-2} and kernel weight $panicle^{-1}$ were found to directly affect millet grain yield at both locations (Table 3), but overall kernel weight direct effects were more strongly related to yield (0.87, 0.80) than to panicles m^{-2} (0.22, 0.23) at Faisalabad and Layyah, respectively. Kernels $panicle^{-1}$ was negatively correlated with pearl millet yield at both locations. This suggests that panicle with more of kernels may reduce the yield through reductions in weight per kernel. Several studies (Maman *et al*., 2004; Egharevba, 1977; Mahalakshmi and Bidinger, 1986) similarly found negative direct effects of panicle m^{-2} on yield of pearl millet at several locations. In our study, kernels $panicle^{-1}$ showed wide yield compensation with a larger number of indirect effects, while panicles m^{-2} showed only limited yield compensation with a smaller number of indirect effects.

In our second field experiment, while studying effect of intra-row spacing and nitrogen application on pearl millet yield in year 2015-16, no significant direct effects of panicle m^{-2} and kernel per panicle were observed on millet yield at either location (Table 4). Significant and strong direct effects of kernel weight $panicle^{-1}$ (0.69, 0.77) were found at Faisalabad and Layyah, respectively. Indirect effects of panicle m^{-2} via kernels per panicle and kernel weight per panicle on millet yield were significant at both locations. Likewise, indirect effects of kernel per panicle on millet yield via kernel weight (0.70, 0.63) were significant at both locations. The strength of indirect effect of kernel $panicle^{-1}$ on millet yield via kernel weight was higher at Faisalabad (0.70) than Layyah (0.63). Correlation and path analysis at both locations showed a positive association between both kernels' $panicle^{-1}$ and kernel weight and grain yield of pearl millet in both studies at both locations. However, our study of row spacing, and nitrogen regimes showed strong indirect effects of kernels $panicle^{-1}$on yield via kernel weight. Thus, kernel weight $panicle^{-1}$ showed high yield compensation across differing intra row spacing and nitrogen regimes.

Table 3. Path coefficient (P) analysis of millet yield and yield components, studying planting time and intra row spacing at Faisalabad and Layyah, Punjab PK, in 2015 and 2016.

	Pearl millet	
Pathway	**Faisalabad**	**Layyah**
Multiple correlation (R^2)	0.65	0.69
Panicle m^{-2} vs. grain yield		
Direct effect	0.22**	0.23**
Indirect effect via kernels $panicle^{-1}$	0.09	0.04
Indirect effect via kernel weight	0.23*	0.33**
kernels $panicle^{-1}$ vs. grain yield		
Direct effect	-0.26**	-0.19*
Indirect effect via kernel weight	0.55**	0.50**
kernel weight vs. grain yield		
Direct effect	0.87**	0.80**
Residual	0.62**	0.63**
P ≤0.05 (*), P ≤ 0.01 (**)		

Table 4. Path coefficient (P) analysis of millet yield and yield components, studying intra row spacing and nitrogen rate at Faisalabad and Layyah, Punjab PK, in 2015 and 2016.

	Pearl millet	
Pathway	**Faisalabad**	**Layyah**
Multiple correlation (R^2)	0.76	0.75
Panicle m^{-2} vs. grain yield		
Direct effect	0.09	0.09
Indirect effect via kernels $panicle^{-1}$	0.40**	0.32**
Indirect effect via kernel weight	0.25**	0.34**
kernels $panicle^{-1}$ vs. grain yield		
Direct effect	0.16	0.06
Indirect effect via kernel weight	0.70**	0.63**
kernel weight vs. grain yield		
Direct effect	0.69**	0.77**
Residual	0.31**	0.35**
P ≤0.05 (*), P ≤ 0.01 (**)		

Conclusion: Path coefficient analysis is a useful tool for exploring the direct effects of yield components upon one another, and for partitioning correlation coefficients into direct and indirect component effects. The yield traits viz., kernel weight $panicle^{-1}$ and kernels $panicle^{-1}$ showed higher compensation due to a high number of direct and indirect effects on yield, while panicle m^{-2} showed a small number of indirect effects with limited yield compensation at semi-arid (Faisalabad) and arid (Layyah) climates of Punjab, Pakistan.

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REFERENCES

Ajmera, S., S.S. Kumar and V. Ravindrababu (2017). Path Coefficient Analysis for Grain Iron and Zinc contents and other traits in Rice Genotypes. Bull. Env. Pharmacol. Life Sci. 6(1): 160-163

Aruna, C., M. Swarnalatha, P.P. Kumar, V. Devender, M. Suguna, M. Blümmel and J.V. Patil (2015). Genetic options for improving fodder yield and quality in forage sorghum. Tropical Grasslands. 3:49–58.

Bidinger, F.R. and M. Blummel (2007). Determinants of ruminant nutritional quality of pearl millet [Pennisetum glaucum (L) R. Br.] stover. I. Effects of management alternatives on stover quality and productivity. Field Crops Res. 103: 119-128.

Bika, N.K. and S.S. Shekhawat (2015). Character association studies in pearl millet [Pennisetum glaucum (L.) R. Br.] for green fodder yield and related traits. Agric. Sci. Digest. 35(3): 191-194.

Blue, N.E., S. C. Mason and D. H. Sander (1990). Influence of planting date, seeding rate, and phosphorus rate on wheat yield. Agron. J. 82:762-768.

Board, J.E., M.S. Kang and B.G. Harville (1999). Path analysis of the yield formation process for late-planted soybean. Agron. J. 91:128-135.

Dofing, S.M. and C.W. Knight (1992). Alternate model for path analysis of small-grain yield. Crop Sci. 32:487–489.

Eastin, J.D., C.L. Petersen, F. Zavala-Garcia, A. Dhopte, P. K. Verma, V. B. Ounguela M. W. Wit, H. G. Gonzalez, M. Livera, T.J. Gerik, G. I. Gandoul, M. R. A. Hovney and O. L. Mendoza (1999). Potential heterosis associated with developmental and metabolic processes in sorghum and maize, p. 205–229. In J.G. Coors and S. Pandey (ed.) The genetics and exploitation of heterosis in crops. ASA, CSSA, and SSSA, Madison, WI.

Egharevba, P.N. (1977). Tiller number and millet grain productivity. Cereal Res. Commun. 5:235–247

Edhdaie, B. and J.G. Waines (1993). Variation in water use efficiency and its components in wheat. I. Well-watered pots experiment. Crop Sci. 33:294-299.

Garcıa del Moral, L.F., Y. Rharrabti, D. Villegas and C. Royo (2003). Evaluation of grain yield and its components in durum wheat under Mediterranean conditions: An ontogenic approach. Agron. J. 95:266–274.

Govintharaj, P., S.K. Gupta, M. Maheswaran, P. Sumathi and D.G. Atkari (2018). Correlation and path coefficient analysis of biomass yield and quality traits in forage type hybrid parents of pearl millet, Int. J. Pure App. Biosci. 6(1): 1056-1061. doi: http://dx.doi.org/10.18782/2320-7051.5992

Jakhar, D.S., R. Singh and A. Kumar (2017). Studies on Path Coefficient Analysis in Maize (Zea mays L.) for Grain Yield and Its Attributes. Int. J. Curr. Microbiol. App. Sci. 6(4): 2851-2856

Kumar, S., C. Babu, S. Revathi and P. Sumathi (2017). Estimation of genetic variability, heritability and association of green fodder yield with contributing traits in fodder pearl millet [*Pennisetum glaucum* (L.)]. Int. J. Advanced Biological Research. 7(1): 119- 26.

Li, C.C. (1975). Path analysis - a primer. Boxwood Press Pacific Grove, CA.

Mahalakshmi, V.and F. R. Bidinger (1985). Water stress and time to floral initiation in pearl millet. J Agric. Sci., Cambridge. 105:437-445.

Mahalakshmi, V.and F. R. Bidinger (1986). Water deficit during panicle development in pearl millet: Yield compensation by tillers. J. Agric. Sci. (Cambridge) 1986:113–119.

Maman, N., S. C. Mason, T. Galusha and M. D. Clegg (1999). Hybrid and nitrogen influence on pearl millet in Nebraska: yield, growth, and nitrogen uptake and nitrogen use efficiency. Agron. J. 91:737-743.

Maman, N., S. C. Mason, D. J. Lyon and P. Dhungana (2004). Yield components of pearl millet and grain sorghum across environments in the central great plains. Crop Sci. 44:2138–2145.

Ong, C.K. (1983). Response to temperature in a stand of pearl millet (*Pennisetum typhoides*) Final number of spikelets and grains. J. Exp. Bot. 34:337-338.

Ong, C.K. and J. L. Monteith (1985). Response of pearl millet to light and temperature. Field Crops Res. 11:141–160.

Pearson, C.J. (1985). Editorial: Research and development for yield of pearl millet. Field Crop Res. 11:113-121.

Ram, G., K.C. Sharma, M.L. Jakhar, E.V.D. Sastry, and R. Mundiyar (2013) Correlation and path coefficient analysis in pearl millet for green fodder yield and its components. J. Plant Science Research. 29: 185-190.

SAS. Institute Inc. (2011). Base SAS® 9.3 Procedures Guide. Cary, NC: SAS Institute

Singh, A.K., C.N. Ram, G.C. Yadav, R.K. Srivastava, C. Deo, J.K. Rao, D.K. Gautam, and P. Kumar (2017). Studies on Correlation and Path Coefficient Analysis in Tomato [Solanum lycopersicon (Mill.) Wettsd.], Int. J. Pure App. Biosci. 5(2): 931-936. doi: http://dx.doi.org/10.18782/2320-7051.2807

Tadesse, M., A. Fikre, M. Eshete, N. Girma, L. Korbu, R. Mohamed, D. Bekele, A. Funga and C.O. Ojiewo (2016). Correlation and Path Coefficient Analysis for Various Quantitative Traits in Desi Chickpea Genotypes under Rainfed Conditions in Ethiopia. J. Agricultural Science; 8(12):112-118

Ullah, A., A. Ahmad, T. Khaliq and J. Akhtar (2017). Recognizing production options for pearl millet in Pakistan under changing climate scenarios. J. Integrative Agriculture. 16(4): 762-773. DOI: 10.1016/S2095-3119(16)61450-8.

Ullah, A., N. Salehnia, S. Kolsoumi, A. Ahmad and T. Khaliq (2018). Prediction of effective climate change indicators using statistical downscaling approach and impact assessment on pearl millet (Pennisetum glaucum L.) yield through Genetic Algorithm in Punjab, Pakistan. Ecological Indicators, 90C (2018): 569-576. https://doi.org/10.1016/j.ecolind.2018.03.053.

Ullah, A., I. Ahmad, A. Ahmad, M. H. Rahman, T. Khaliq, U. Saeed and G. Hoogenboom (2019). Assessing climate change impacts on pearl millet under contrasting environments using system analysis approach. Environmental Science and Pollution Research.(2019): 1-13 https://doi.org/10.1007/s11356-018-3925-7

Van-Oosterom, E.J., G. J. O'Leary, P. S. Carberry and P. Q. Craufurd (2002). Simulating growth, development, and yield of tillering pearl millet. III. Biomass accumulation and partitioning. Field Crops Res. 79:85–106.