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Research Article

Barnyard millet: A crop of promise elucidated through correlation and path analysis

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Abstract

With today's changing dietary demands and agricultural constraints, millets have become essential crops with significant agronomic and nutritional benefits. Among these, barnyard millet stands out for its resilience and nutritional richness. Despite its considerable nutritional and agronomic benefits, Barnyard millet suffers from a lack of recognition, relegating it to the status of a neglected and underutilized crop. The present study ventures into barnyard millet cultivation, utilizing correlation and path coefficient analysis to elucidate the complex interplay influencing its productivity and attributes. The study was conducted over two consecutive years and involved 172 genotypes with 23 yield-contributing traits under scrutiny. Panicle weight per plant (PWPP) (0.98), single panicle weight (0.81), biological yield per plant (0.79) and harvest index (0.71) exhibited strong positive correlations with grain yield per plant. While PWPP (0.82), PL (0.36), DSYPP (0.31) and HI (0.30) demonstrated high direct positive effects on grain yield per plant in the path coefficient analysis, emphasizing their significance in breeding programs. By improving these traits through selective breeding or genetic manipulation, researchers can potentially develop high-yielding varieties better adapted to varying environmental conditions. Conversely, days to maturity had a significant negative correlation with grain yield (-0.28) focusing on selecting early maturity genotypes. Panicle exertion (-0.30), biological yield per plant (-0.21) and flag leaf sheath length (-0.18) had the highest negative direct effects in the path analysis, suggesting their potential role as limiting factors in barnyard millet cultivation. Overall, these findings provide a roadmap for future research endeavours aimed at enhancing the productivity and resilience of barnyard millet, ultimately contributing to food security and agricultural sustainability in regions where this crop plays a vital role.

Keywords: Barnyard millet, Correlation coefficient, Food security, Path coefficient, Yield

INTRODUCTION

Amidst the dynamic agricultural landscape of modern times, the spotlight on millet intensifies, driven by the urgent need to fortify food systems against evolving challenges. Millets, often referred to as "miracle grains" or "crops of the future," offer numerous benefits that make them stand out in the realm of nutrition and agriculture (Laryea *et al.,* 2024). Nutritionally rich, millets surpass wheat and rice in protein content, boasting a more balanced amino acid profile (Nagaraja *et al.,* 2024). Among millets, Barnyard millet (*Echinochloa* spp.) is a resilient and nutritionally dense minor cereal that holds a crucial position in the agricultural landscapes of India (Renganathan *et al.,* 2020). It predominantly thrives in regions marked by limited rainfall and poor soil fertility. Known locally as 'Sanwa,' 'Oodalu,' or 'Kavadapullu,' it has been cultivated across various parts of India. India holds the top position in barnyard millet production, with a land area of 0.146 million hectares and a production of 0.147 million metric tons. Over the past three years, the average yield in India has been 1034 kilograms per hectare (Sahoo *et al.*, 2024). Barnyard millet offers exceptional nutritional value with high protein, fiber and micronutrient content, including iron and calcium (Bezbaruah and Singh, 2024). It is a crucial alternative in diets lacking sufficient nutrition or regions with challenging agricultural conditions for water-intensive crops (Mohanapriya *et al.,* 2024).

The crop's remarkable adaptability to adverse growing conditions—ranging from drought proneness to poor soil profiles—renders it a promising candidate in the arsenal against climate change (Krishnababu *et al.,* 2024). Furthermore, the escalating prevalence of life-style diseases necessitates a shift towards healthier dietary options, for which barnyard millet stands out due to its low glycemic index and substantial fiber content (Bangar *et al.,* 2024). Henceforth, research on barnyard millet assumes paramount importance in contemporary contexts, where the pursuit of sustainable and resilient crops is imperative.

Correlation coefficient analysis emerges as a potent tool in plant breeding, orchestrating the symphony of traits crucial for crop improvement (Kashyap *et al.*, 2024). Its role in unravelling the intricacies of barnyard millet physiology holds promise for tailored interventions to enhance its agronomic performance (Arya *et al.,* 2017; Joshi *et al.,* 2015). By discerning these relationships, breeders can more effectively select and improve desirable traits, thereby accelerating the development of superior cultivars. Path analysis offers a nuanced perspective in the landscape of plant breeding (Jyothsna *et al.,* 2016). By delineating the direct and indirect influences of traits on yield and quality parameters, path analysis provides a roadmap for prioritizing breeding objectives (Prabu *et al.,* 2020). In the context of barnyard millet, this analytical framework offers insights into the underlying physiological mechanisms governing its performance, thereby guiding breeders towards informed decision-making. This research paper embarks on a journey to explore the intricate dynamics of correlation and path coefficient analyses in the realm of barnyard millet breeding. It endeavors to illuminate novel pathways for enhancing crop resilience, productivity and nutritional quality.

MATERIALS AND METHODS

The present study used an augmented design for two consecutive years during Kharif 2019-2020 under rainfed conditions. The field study was performed at Research Farm Area, Department of plant breeding and genetics, CCS Haryana Agricultural University, Hisar, Haryana (latitude 290 10' North and longitude 750 46' East with an altitude of 215.2 m above the mean sea level) The experiment includes a large sample of 172 genotypes (Table 1) including 4 check Varieties (PRJ, DHBM-93, VL-172, CO-2) procured from Indian Institute of Millets Research (IIMR), Hyderabad, Telangana. The material was collected from diverse regions from all over the country and maintained by IIMR. The computational analysis and correlogram were done using R studio Software (R Core Team, 2021).

Data recording

The data on phenotypic traits were collected from five randomly chosen vigorous plants for each genotype except for DTFF and DTM on a plot basis. A total of 23 yield contributing traits abbreviated as FLBL-Flag leaf blade length, FLBW-Flag leaf blade width, FLSL-Flag leaf sheath length, PL-Peduncle length, PE-Panicle exertion, IL-Inflorescence length, IW-Inflorescence width, LRL-Lower raceme length, RPI-Number of racemes per inflorescence, NBT-Number of basal tillers, IPP-Number of inflorescences per plant, SPW-Single panicle weight, PWPP-Total Panicles weight per plant, DSYPP-Dry stem yield per plant, GYPP-Total grain yield per plant, BYPP-Biological yield per plant, HI-Harvest index, TW-Test weight (1000 grains weight), PH-Plant height, NPT-Number of nodes on primary tiller, DPT-Diameter of primary tiller, DTFF-Days to 50% flowering in total population, DTM-Days to 80% maturity in total population were studied.

Statistical analysis

The correlation coefficients among characters were estimated using the method suggested by Al-Jibouri *et al.* (1958). Path coefficient analysis was originally proposed by Wright (1921). However, it was later utilized in plant breeding by Dewey and Lu (1959). A standardized partial regression coefficient splits genotypic and phenotypic correlation coefficients into a series of direct and indirect effects.

RESULTS AND DISCUSSION

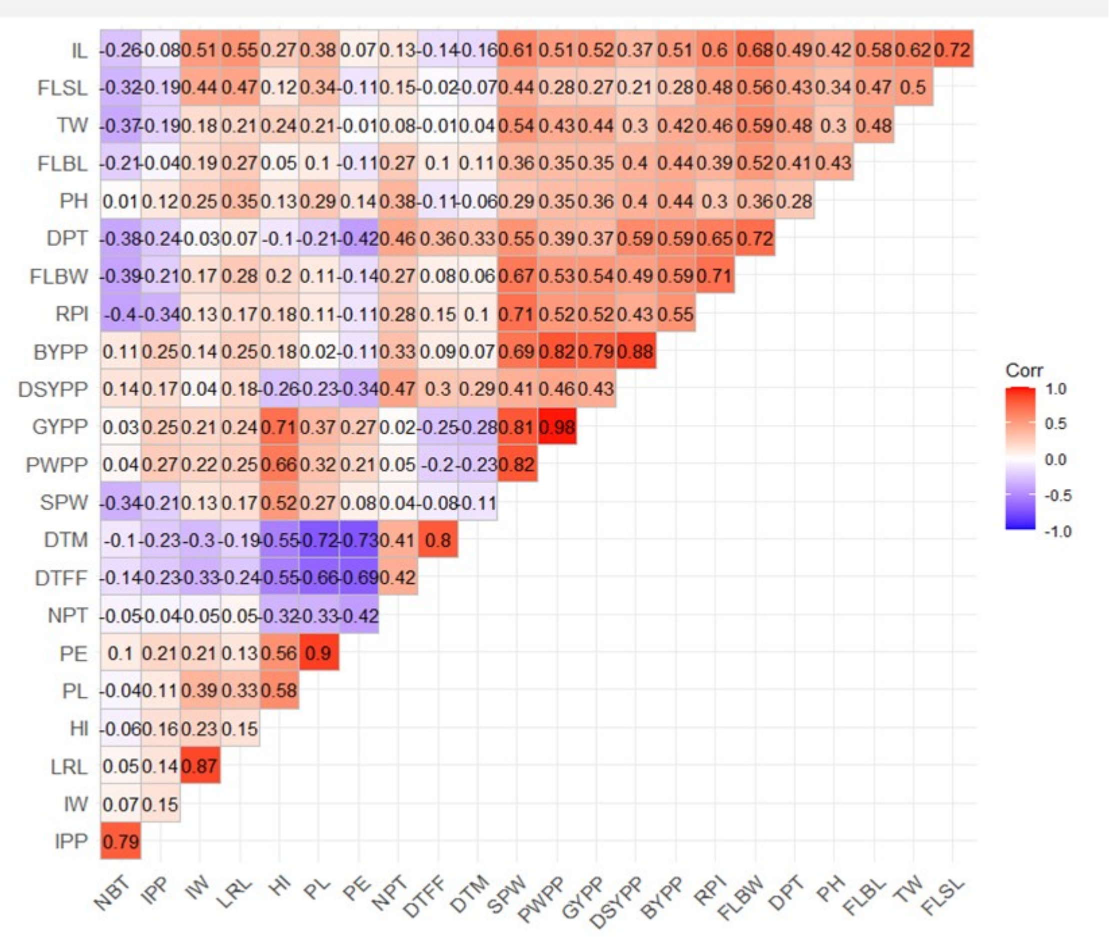
Correlation coefficient

The results showed that the highest positive significant correlation was observed between GYPP and PWPP (0.98), followed by PE and PL (0.90), BYPP and DSYPP (0.88), LRL and IW (0.87), PWPP and SPW (0.82), BYPP and PWPP (0.82), GYPP and SPW (0.81) as shown in Fig. 1. The figure depicts a correlogram, a graphical tool used to examine the correlation between every possible pair of variables within a dataset. In addition to these high correlations, the economic trait Grain yield per plant was seen to be positively correlated with BYPP (0.79), HI (0.71), FLBW (0.54), IL (0.52), RPI (0.52), TW (0.44), DSYPP (0.43), PL (0.37), DPT (0.37), PH (0.36), FLBL (0.35), and lastly with FLSL and PE each with 0.27 correlation coefficient. While a high negative significant correlation was seen between DTM and PE (-0.73), followed by DTM and PL (-0.72), DTFF and PE (-0.69) and DTFF and PL (-0.66). A negative significant correlation was also observed between DTM and GYPP (-0.28). Further low but significant correlation are depicted in Table 2

The present study highlighted the highest significant positive correlation between GYPP and PWPP. This could be because larger panicle weights often signify increased availability of assimilates from photosynthesis, which can support the development and filling of a greater number of grains. This cause is supported by the study of Zhang *et al.,* 2022 in rice. Additionally, a high positive correlation between GYPP and SPW suggests that larger individual panicles produce more grains, contributing to higher overall yield. Similar findings were observed by Arya *et al.* (2017) in 33 traditional genotypes and 5 improved varieties of barnyard millet. This aligns with previous research highlighting the crucial role of panicle architecture and grain size in determining yield potential in millet crops conducted by Panda *et al. (*2023); Singh *et al. (*2023) in finger millet and Zhi *et al*. (2021) in foxtail millet. Furthermore, the positive correlations between grain yield and traits related to plant vigor and biomass production, such as biological yield per plant and dry stem yield per plant observed in our study, emphasize the importance of robust vegetative growth in supporting reproductive success. The role of vegetative growth in supporting the reproductive growth of rice and wheat crops is also observed by Makino (2011). This suggests that optimizing plant growth and biomass accumulation during the vegetative phase can indirectly enhance grain yield potential in barnyard millet.

Interestingly, the present results also revealed positive correlations between grain yield and traits related to photosynthetic efficiency and nutrient utilization, such as flag leaf blade width and peduncle length. This suggests that maximizing photosynthetic capacity and nutrient uptake during the vegetative and reproductive stages may contribute to higher grain yields in barnyard millet. Joshi *et al.* (2015) and Prabu *et al.* (2020) found similar results of a positive correlation of flag leaf width and flag leaf length with grain yield in Barnyard millet. Similarly, Arya *et al.* (2017) found a positive correlation of peduncle length with grain yield in their study on barnyard millet genotypes.

The strong negative correlations observed in the present study between DTM and DTFF, PL and PE suggest that plants with longer maturity and flowering periods tend to exhibit reduced peduncle lengths and panicle exertion levels. This may be attributed to delayed reproductive development in plants with longer maturity and flowering times, leading to slower peduncle elongation and reduced panicle emergence. The present results are supported by the study conducted on barnyard millet by Kuraloviya *et al.* (2022), who emphasized



	NBT	IPP	IW	LRL	HI	PL	PE	NPT	DTFF	DTM	SPW	PWPP	GYPP	DSYPP	BYPP	RPI	FLBW	DPT	PH	FLBL	TW	FLSL
IL	-0.26	-0.08	0.51	0.55	0.27	0.38	0.07	0.13	-0.14	-0.16	0.61	0.51	0.52	0.37	0.51	0.6	0.68	0.49	0.42	0.58	0.62	0.72
FLSL	-0.32	-0.19	0.44	0.47	0.12	0.34	-0.11	0.15	-0.02	-0.07	0.44	0.28	0.27	0.21	0.28	0.48	0.56	0.43	0.34	0.47	0.5	
TW	-0.37	-0.19	0.18	0.21	0.24	0.21	-0.01	0.08	-0.01	0.04	0.54	0.43	0.44	0.3	0.42	0.46	0.59	0.48	0.3	0.48		
FLBL	-0.21	-0.04	0.19	0.27	0.05	0.1	-0.11	0.27	0.1	0.11	0.36	0.35	0.35	0.4	0.44	0.39	0.52	0.41	0.43			
PH	0.01	0.12	0.25	0.35	0.13	0.29	0.14	0.38	-0.11	-0.06	0.29	0.35	0.36	0.4	0.44	0.3	0.36	0.28				
DPT	-0.38	-0.24	-0.03	0.07	-0.1	-0.21	-0.42	0.46	0.36	0.33	0.55	0.39	0.37	0.59	0.59	0.65	0.72					
FLBW	-0.39	-0.21	0.17	0.28	0.2	0.11	-0.14	0.27	0.08	0.06	0.67	0.53	0.54	0.49	0.59	0.71						
RPI	-0.4	-0.34	0.13	0.17	0.18	0.11	-0.11	0.28	0.15	0.1	0.71	0.52	0.52	0.43	0.55							
BYPP	0.11	0.25	0.14	0.25	0.18	0.02	-0.11	0.33	0.09	0.07	0.69	0.82	0.79	0.88								
DSYPP	0.14	0.17	0.04	0.18	-0.26	-0.23	-0.34	0.47	0.3	0.29	0.41	0.46	0.43									
GYPP	0.03	0.25	0.21	0.24	0.71	0.37	0.27	0.02	-0.25	-0.28	0.81	0.98										
PWPP	0.04	0.27	0.22	0.25	0.66	0.32	0.21	0.05	-0.2	-0.23	0.82											
SPW	-0.34	-0.21	0.13	0.17	0.52	0.27	0.08	0.04	-0.08	-0.11												
DTM	-0.1	-0.23	-0.3	-0.19	-0.55	-0.72	-0.73	0.41	0.8													
DTFF	-0.14	-0.23	-0.33	-0.24	-0.55	-0.66	-0.69	0.42														
NPT	-0.05	-0.04	-0.05	0.05	-0.32	-0.33	-0.42															
PE	0.1	0.21	0.21	0.13	0.56	0.9																
PL	-0.04	0.11	0.39	0.33	0.58																	
HI	-0.06	0.16	0.23	0.15																		
LRL	0.05	0.14	0.87																			
IW	0.07	0.15																				
IPP	0.79																					

Fig. 1. *Correlogram, graphical representation of correlation matrix (R software using GGplot package); Color intensity is directly proportional to the correlation coefficient (Blue color depicts a negative correlation while red color shows a positive correlation)*

Table 1. List of 172 barnyard millet genotypes used in the study

S.No.	Genotypes	S.No.	Genotypes	S.No.	Genotypes	S.No.	Genotypes	S.No.	Genotypes	S.No.	Genotypes
1	BAR-14	30	BAR-75	59	BAR-178	88	BAR-223	117	BAR-1406	146	BAR-1464
2	BAR-26	31	BAR-78	60	BAR-180	89	BAR-226	118	BAT-1407	147	BAR-1465
3	BAR-27	32	BAR-79	61	BAR-183	90	BAR-227	119	BAR-1409	148	BAR-1466
4	BAR-28	33	BAR-80	62	BAR-189	91	BAR-228	120	BAR-1411	149	BAR-1467
5	BAR-29	34	BAR-81	63	BAR-190	92	BAR-229	121	BAR-1412	150	BAR-1470
6	BAR-30	35	BAR-84	64	BAR-191	93	BAR-230	122	BAR-1413	151	BAR-1472
7	BAR-31	36	BAR-87	65	BAR-193	94	BAR-232	123	BAR-1414	152	BAR-1473
8	BAR-32	37	BAR-91	66	BAR-195	95	BAR-234	124	BAR-1417	153	BAR-1474
9	BAR-34	38	BAR-111	67	BAR-196	96	BAR-235	125	BAR-1418	154	BAR-1475
10	BAR-35	39	BAR-119	68	BAR-197	97	BAR-236	126	BAR-1420	155	BAR-1476
11	BAR-36	40	BAR-123	69	BAR-198	98	BAR-237	127	BAR-1425	156	BAR-1478
12	BAR-37	41	BAR-131	70	BAR-199	99	BAR-238	128	BAR-1430	157	BAR-1480
13	BAR-38	42	BAR-148	71	BAR-200	100	BAR-239	129	BAR-1441	158	BAR-1482
14	BAR-39	43	BAR-151	72	BAR-203	101	BAR-240	130	BAR-1442	159	BAR-1483
15	BAR-40	44	BAR-152	73	BAR-204	102	BAR-241	131	BAR-1443	160	BAR-1484
16	BAR-41	45	BAR-154	74	BAR-205	103	BAR-242	132	BAR-1445	161	BAR-1486
17	BAR-42	46	BAR-157	75	BAR-206	104	BAR-243	133	BAR-1446	162	BAR-1487
18	BAR-43	47	BAR-158	76	BAR-207	105	BAR-244	134	BAR-1448	163	BAR-1489
19	BAR-45	48	BAR-160	77	BAR-208	106	BAR-245	135	BAR-1450	164	BAR-1490
20	BAR-46	49	BAR-161	78	BAR-209	107	BAR-247	136	BAR-1451	165	BAR-1508
21	BAR-47	50	BAR-162	79	BAR-210	108	BAR-248	137	BAR-1454	166	BAR-1512
22	BAR-50	51	BAR-163	80	BAR-211	109	BAR-249	138	BAR-1455	167	BAR-1515
23	BAR-52	52	BAR-165	81	BAR-213	110	BAR-250	139	BAR-1456	168	BAR-1517
24	BAR-53	53	BAR-167	82	BAR-214	111	BAR-251	140	BAR-1457	169	PRJ
25	BAR-54	54	BAR-168	83	BAR-215	112	BAR-252	141	BAR-1458	170	DHBM-93
26	BAR-60	55	BAR-170	84	BAR-216	113	BAR-253	142	BAR-1459	171	VL-172
27	BAR-63	56	BAR-172	85	BAR-219	114	BAR-254	143	BAR-1460	172	CO-2
28	BAR-64	57	BAR-173	86	BAR-220	115	BAR-255	144	BAR-1461		
29	BAR-71	58	BAR-175	87	BAR-222	116	BAR-256	145	BAR-1462		

selecting early maturing genotypes. Furthermore, days to maturity significantly negatively correlated with grain yield (-0.28). Similar results of negative correlation of days to maturity with dry root yield were observed in a recent study conducted by Nehru et al. (2024). These findings can guide breeders in selecting early-maturing and early-flowering varieties with desirable reproductive structures, ultimately leading to improved barnyard millet cultivars with enhanced yield and productivity, as suggested by Vanniarajan *et al.* (2018) while studying the stability of high-yielding early-maturity variety in barnyard millet. The findings of Eric *et al.* (2016) concluded, based on their study in finger millet that late maturing accessions have lower 1000 grain weight and yield due to limited moisture at the grain filling stage and excessive shading due to high leafiness.

With a larger pool of germplasm lines, there's a greater chance of capturing the full spectrum of genetic variation within the population. This diversity allows for more comprehensive assessments of trait relationships and interactions. With more diverse genotypes, it becomes possible to identify subtle associations that may not be apparent in smaller sample sizes. Similarly, Mackay and Anholt (2024); Mohammadi and Prasanna (2003) emphasized a large population size for better results for diversity and association studies. This makes our current research more efficient. Furthermore, yield, a polygenic trait, necessitates an indirect approach to enhance its productivity by selecting traits that exhibit high correlations with yield. Nandini *et al.* (2020); Vikram *et al.* (2020) also used correlation analysis as a statistical tool to improve grain yield in barnyard millet. This strategy leverages the interplay between these correlated traits and yield, allowing for targeted selection and breeding efforts to enhance overall productivity. Correlation analysis lays the foundation for targeted breeding strategies by deciphering the interplay between various traits, optimizing yield, resilience and nutritional quality. Additionally, these findings provide valuable insights into the physiological mechanisms underlying grain production as the work conducted by Kulundžić *et al.* (2022) in soyabean in which they studied the metabolic pathways responsible for yield production.

Path coefficient analysis

Direct effects

The path coefficient analysis revealed high direct and positive effects of PWPP (0.82), PL (0.36), DSYPP (0.31), and HI (0.30), highlighting the significance of their association with grain yield per plant. Furthermore, PE (-0.30) and FLSL (-0.18) negatively affected GYPP.

The present PWPP research findings indicate that higher panicle weight per plant favours grain production per plant, as evidenced by the strong direct impacts found. Vishnuprabha and Vanniarajan (2018) observed similar results. Prakash and Vanniarajan (2015) and Ganesamoorthi (2012) continuously emphasized the crucial importance of panicle size and weight in influencing the prospective grain production in millet crops. Larger panicle weights frequently result in enhanced flower output and grain set, which raises the overall grain yield per plant. Sood *et al.* (2015) confirm this reasoning. Furthermore, in the present study, the positive direct effects observed for PL and DSYPP suggest that longer peduncle lengths and higher dry stem yields per plant positively influence grain yield per plant. Longer peduncles provide better support for developing panicles, facilitating optimal grain development and filling, while higher dry stem yields may indicate greater plant vigor and biomass production, supporting enhanced grain yield. The positive direct effect observed in the current research for HI indicates that a higher harvest index, reflecting efficient resource utilization and partitioning towards grain formation, positively impacts grain yield per plant. These findings collectively emphasize the importance of PWPP, PL, DSYPP and HI in enhancing grain yield and productivity in barnyard millet.

Similarly, Vikram *et al.* (2020) observed the significant role of peduncle length and panicle weight in achieving high grain yield. Prakash and Vanniarajan (2015) confirmed the results of our study by depicting the highest direct effect of panicle weight, straw yield and peduncle length on grain yield in barnyard crop. Dhanalakshmi *et al.* (2019) observed high positive direct effect of peduncle length on grain yield. Furthermore, in present study as mentioned above, FLSL and PE traits had a positive correlation on GYPP, which is a seemingly contradictory relationship with their negative direct effect on GYPP. It may be explained by indirect effects or confounding factors that are not captured by the correlation analysis alone. For example, FLSL and PE may positively correlate with GYPP due to their association with other favorable traits, such as plant vigor or biomass production. However, their direct negative effects on GYPP may reflect specific physiological limitations or trade-offs that directly affect grain yield. Sood *et al.* (2015) found positive direct effect of flag leaf sheath length on grain yield in barnyard millet.

Indirect effects

BYPP (0.67), SPW (0.67), HI (0.54), FLBW (0.44), RPI (0.43), IL (0.42) and DSYPP (0.38) via PWPP had the highest indirect effect on Grain yield per plant. The observed indirect effects through PWPP, as seen by Sreenivasulu and Schnurbusch (2012) implied that plants with higher BYPP and SPW allocate more resources towards panicle development, bolstering panicle weight and consequently enhancing grain yield. This suggests that greater resource allocation towards reproductive structures during the critical stages of pan-

Table 2. Path coefficient analysis of 23 yield contributing traits studied in diverse 172 barnyard millet genotypes

	FLBL	FLBW	PL	FLSL	PE	IL	TW	IW	LRL	PH	NPT	RPI	DPT	NBT	IPP	SPW	PWPP	DSYPP	BYPP	HI	DTFF	DTM
FLBL	0.02	0.01	0.04	-0.09	0.03	0.02	0.00	-0.01	0.00	0.00	0.00	0.01	0.02	-0.01	0.00	-0.02	0.29	0.12	-0.09	0.02	0.00	0.00
FLBW	0.01	0.01	0.04	-0.10	0.04	0.03	0.00	-0.01	0.01	0.00	0.00	0.02	0.04	-0.02	0.01	-0.05	0.44	0.15	-0.12	0.06	0.00	0.00
PL	0.00	0.00	**0.36**	-0.06	-0.27	0.01	0.00	-0.02	0.01	0.00	0.01	0.00	-0.01	0.00	-0.01	-0.02	0.26	-0.07	0.00	0.17	-0.01	0.01
FLSL	0.01	0.01	0.12	**-0.18**	0.03	0.03	0.00	-0.02	0.01	0.00	0.00	0.01	0.02	-0.02	0.01	-0.03	0.23	0.06	-0.06	0.04	0.00	0.00
PE	0.00	0.00	0.33	0.02	**-0.30**	0.00	0.00	-0.01	0.00	0.00	0.01	0.00	-0.02	0.01	-0.01	-0.01	0.17	-0.10	0.02	0.17	-0.01	0.01
IL	0.01	0.01	0.14	-0.13	-0.02	0.04	0.00	-0.03	0.01	0.00	0.00	0.01	0.03	-0.01	0.00	-0.04	0.42	0.11	-0.11	0.08	0.00	0.00
TW	0.01	0.01	0.08	-0.09	0.00	0.02	0.00	-0.01	0.00	0.00	0.00	0.01	0.03	-0.02	0.01	-0.04	0.35	0.09	-0.09	0.07	0.00	0.00
IW	0.00	0.00	0.14	-0.08	-0.06	0.02	0.00	-0.05	0.02	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.18	0.01	-0.03	0.07	0.00	0.00
LRL	0.01	0.00	0.12	-0.09	-0.04	0.02	0.00	-0.04	0.02	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.21	0.06	-0.05	0.05	0.00	0.00
PH	0.01	0.00	0.11	-0.06	-0.04	0.02	0.00	-0.01	0.01	-0.01	-0.01	0.01	0.01	0.00	-0.01	-0.02	0.29	0.12	-0.09	0.04	0.00	0.00
NPT	0.01	0.00	-0.12	-0.03	0.13	0.00	0.00	0.00	0.00	0.00	-0.02	0.01	0.02	0.00	0.00	0.00	0.04	0.14	-0.07	-0.10	0.00	-0.01
RPI	0.01	0.01	0.04	-0.09	0.03	0.02	0.00	-0.01	0.00	0.00	-0.01	0.02	0.03	-0.02	0.02	-0.05	0.43	0.13	-0.11	0.05	0.00	0.00
DPT	0.01	0.01	-0.08	-0.08	0.13	0.02	0.00	0.00	0.00	0.00	-0.01	0.02	0.05	-0.02	0.01	-0.04	0.32	0.18	-0.12	-0.03	0.00	-0.01
NBT	0.00	0.00	-0.01	0.06	-0.03	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01	-0.02	0.05	-0.04	0.02	0.03	0.04	-0.02	-0.02	0.00	0.00
IPP	0.00	0.00	0.04	0.03	-0.06	0.00	0.00	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.04	-0.06	0.01	0.22	0.05	-0.05	0.05	0.00	0.00
SPW	0.01	0.01	0.10	-0.08	-0.02	0.02	0.00	-0.01	0.00	0.00	0.00	0.02	0.03	-0.02	0.01	-0.07	0.67	0.13	-0.14	0.16	0.00	0.00
PWPP	0.01	0.01	0.12	-0.05	-0.06	0.02	0.00	-0.01	0.00	0.00	0.00	0.01	0.02	0.00	-0.02	-0.06	**0.82**	0.14	-0.17	0.20	0.00	0.00
DSYPP	0.01	0.01	-0.08	-0.04	0.10	0.01	0.00	0.00	0.00	0.00	-0.01	0.01	0.03	0.01	-0.01	-0.03	0.38	**0.31**	-0.18	-0.08	0.00	0.00
BYPP	0.01	0.01	0.01	-0.05	0.03	0.02	0.00	-0.01	0.00	0.00	-0.01	0.01	0.03	0.01	-0.01	-0.05	0.67	0.27	-0.21	0.05	0.00	0.00
HI	0.00	0.00	0.21	-0.02	-0.17	0.01	0.00	-0.01	0.00	0.00	0.01	0.00	-0.01	0.00	-0.01	-0.04	0.54	-0.08	-0.04	**0.30**	-0.01	0.01
DTFF	0.00	0.00	-0.24	0.00	0.21	-0.01	0.00	0.02	0.00	0.00	-0.01	0.00	0.02	-0.01	0.01	0.01	-0.16	0.09	-0.02	-0.17	0.01	-0.01
DTM	0.00	0.00	-0.26	0.01	0.22	-0.01	0.00	0.02	0.00	0.00	-0.01	0.00	0.02	-0.01	0.01	0.01	-0.19	0.09	-0.01	-0.17	0.01	-0.02

Residual Effect^2 = 0.02

icle development increases grain production in proso millet (Gomashe *et al.,* 2017). Prakash and Vanniarajan, 2015 showed a positive indirect effect of panicle weight and straw yield on grain yield in barnyard millet. Prabu et al. (2020) observed similar findings to the present research for the positive indirect effect of number of racemes and inflorescence length on grain yield in barnyard millet. Traits such as FLBW, RPI, IL and DSYP are associated with enhanced photosynthetic efficiency, reproductive output, and biomass production. The observed indirect effects through PWPP suggest that these traits contribute to increased panicle weight by facilitating optimal assimilate production, allocation, and utilization during critical reproductive stages, ultimately leading to higher grain yield.

Residual effect

The residual effect, calculated to be 0.20, suggests that a significant portion of variation remains unexplained in the association between seed yield and dependent traits. This indicated that approximately 80% of the variability in grain yield per plant can be attributed to the component traits studied, highlighting their substantial contribution to grain yield. A higher residue value of 0.3943 was seen by Prabu *et al.* (2020) with 17 traits. Since the traits and germplasm were much higher in present study, less residual value was seen.

Conclusion

In conclusion, the highest positive correlation was observed between GYPP and panicle weight per plant in barnyard millet, indicating that larger panicle weights are associated with increased grain yield. Peduncle length and dry stem yield per plant could be key strategies for improving grain yield. Additionally, photosynthetic efficiency and nutrient utilization traits, such as flag leaf blade width and peduncle length, were positively correlated with grain yield, highlighting the importance of optimizing these traits for better productivity. Negative correlations between days to maturity and days to flowering with peduncle length and panicle exertion suggest that early-maturing and early-flowering varieties tend to have desirable reproductive structures, which can improve yield. The path coefficient analysis further supported the importance of PWPP, PL, dry stem yield per plant and harvest index in influencing grain yield, with these traits showing high direct effects on GYPP. The residual effect analysis indicated that approximately 80% of the variability in grain yield could be attributed to the studied traits, underscoring their substantial contribution. The findings suggest that targeted breeding strategies focusing on these key traits could effectively enhance grain yield in barnyard millet, ultimately leading to improved cultivars with higher productivity. Further research is warranted to explore the genetic basis of these trait associations for grain yield enhancement in barnyard millet.

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Conflict of interest

The authors declare that they have no conflict of interest.

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