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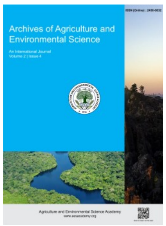

ORIGINAL RESEARCH ARTICLE

CrossMark

Genetic variability, character association and path analysis of yield and yield attributes of rice genotypes at Lalitpur, Nepal

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ABSTRACT

Rice is a staple for over half the world's population. Location-specific varietal trials help identify suitable genotypes with desirable traits. A study in Lalitpur, Nepal, evaluated 12 rice genotypes in a randomized complete block design (RCBD) with three replications to assess genotypic variability, character association, and path analysis for yield-related traits. Observations from five randomly selected plants per plot were analyzed statistically. Analysis of variance revealed significant differences among genotypes for most traits, indicating ample genetic variability. Grain yield (20.26) showed the highest genotypic coefficient of variation (GCV), while effective tillers (24.26%) had the highest phenotypic coefficient of variation (PCV), followed by grain yield, straw yield, and tiller number. High heritability and high genetic advance as percent of mean were noted for days to flowering (35.15), total grain per panicle (34.84), tiller number (33.39), and panicle weight (31.55), suggesting additive gene control and selection potential. Grain yield was positively correlated with panicle length (r = 0.47**), total grain per panicle (r = 0.40*), panicle weight (r = 0.43**), tiller number (r = 0.34*), and straw yield (r = 0.62*). Path analysis showed total grain per panicle (2.55) had the highest positive direct effect on yield, alongside days to flowering, plant height, effective tillers, unfilled grains per panicle, and straw yield. Khumal-4, Khumal-8, and Taichung-176 emerged as superior genotypes. Hence, it is strongly advised that these traits be chosen in rice breeding programs to further enhance production. Khumal-4, Khumal-8, and Taichung-176 were the most promising genotypes.

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INTRODUCTION

Rice is a staple food crop for more than half of the world's population (Bandumula, 2018). Approximately 510 million mt of rice had been produced worldwide in 2023, and Asian countries have the largest share of rice production in the world. The total area under rice cultivation in Nepal is 14, 77,378 ha, which is the highest among cereals with a production of 51, 30,625 mt and productivity of 3.47 mtha^{-1} (MoALD, 2023). It has contributed 13.60% to AGDP in fiscal year 2022/23 (MoALD, 2023). The rate of growth in rice productivity has been approximately 0.16% over the last 50 years, which is below the country's rate of population growth (IRRI, 2018). High-yielding rice cultivars with broad adaptation capabilities within diverse environmental conditions must be developed in countries where rice consumption has increased (Takai *et al.*, 2019). In Nepal, rice is mostly grown under rain-fed conditions, resulting in drought stress, which subsequently causes yield loss. The lack of suitable drought-tolerant varieties, disease and pest infestation, and timely unavailability of fertilizers are different factors for limiting rice production. To enhance rice productivity, the selection of superior genotypes with desirable agro-morphological and agronomical traits is essential. Genetic variability, heritability, and character association studies provide a scientific basis for crop improvement by identifying traits that contribute directly to yield performance. The success of any plant breeding activity depends entirely on the existence of genetic variability concerning the desired traits and the selection skill of the plant breeder (Adhikari *et al.*, 2018). Heritability is a measure of phenotypic variance due to the genotype. It has a predictive function for crop breeding. In general, heritability indicates the efficacy of selecting genotypes based on phenotypic performance (Tiwari *et al.*, 2019). According to Hossain & Haque Md (2016), knowledge of the correlation coefficients between grain yield and its attributing characteristics is crucial because grain yield in rice is heavily influenced by multiple component characters. Path coefficient analysis, on the other hand, divides the correlations, making it possible to distinguish between the direct effects and their indirect effects through other characters (Kiranmayee *et al.*, 2018). Conducting location-specific varietal trials is essential to recommend suitable genotypes with desired agro-morphological and agronomical traits (Tiwari *et al.*, 2019). This study aims to evaluate the genetic variability, heritability, character association, and path analysis of key yield-related traits in 12 rice genotypes under rainfed conditions in Lalitpur, Nepal. The findings will aid in identifying superior genotypes for breeding programs, contributing to varietal improvement.

MATERIALS AND METHODS

Twelve rice genotypes (Table 1) were collected from the National Plant Breeding and Genetics Research Centre (NPBGRC), Khumaltar, Lalitpur. The experiment was conducted in a randomized complete block design (RCBD) with three replications at the experimental field of Valley Krishi Campus, located in Godawari-11, Lalitpur, Nepal. Each experimental block measured 3m × 1m, with 20 cm × 20 cm spacing between rows and plants. The distance between two adjacent plots was 50 cm, while the distance between replications was 1m. Each hill contained 2–3 seedlings. Nitrogen (N), phosphorus (P), and potassium (K) were applied at 60 kg ha^{-1}, 20 kg ha^{-1}, and 20 kg ha^{-1}, respectively, following the general recommendations for rainfed conditions. A basal dose was applied at the time of transplantation, consisting of half the nitrogen dose and the full doses of phosphorus and potassium. The remaining nitrogen was split into two equal applications at 30 and 45 days after transplantation (DAT).

For data collection, five plants were randomly selected from each plot in each replication, and their mean values were used for statistical analysis. Observations were made on traits such as the number of tillers, flag leaf length (cm), flag leaf width (cm), plant height (cm), effective tiller, panicle length (cm), total grain weight (gm), total grain per panicle, unfilled grain per panicle, panicle weight (gm), days to flowering (days), sterility percentage (SP), straw yield (ton ha^{-1}), and grain yield (ton ha^{-1}).

The formula proposed by Burton & Devane (1953) was used to determine the phenotypic and genotypic coefficients of variation.

$$\text{Phenotypic coefficient of variation (PCV)} = \frac{\sqrt{\text{Phenotypic variance}}}{\text{Grand mean}} \times 100$$

$$\text{Genotypic coefficient of variation (GCV)} = \frac{\sqrt{\text{Genotypic variance}}}{\text{Grand mean}} \times 100$$

According to Sivasubramanian & Menon (1973), phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) values of more than 20% are regarded as high, whereas values less than 10% are considered to be low, and values between 10 and 20% to be moderate.

Heritability was estimated using the formula given by Falconer (1996) as follows:

$$H = \frac{Vg}{Vp} \times 100$$

Where, H=Broad sense heritability, V_p= phenotypic variance, and V_g=genotypic variance.

Robinson *et al.* (1949) classified the heritability percentage as low, moderate, and high, with corresponding percentages of 0–30%, 30–60%, and >60%.

Under selection, expected genetic advances for each character at 5% selection intensity were computed using the formula described by (Johnson *et al.*, 1955).

$$\text{Genetic Advance (GA)} = k.\sigma p.H$$

Where, k=constant (selection differential where k=2.056 at 5% selection intensity), σ_p= phenotypic standard deviation, H= broad-sense heritability.

Genetic advances as a percent of the mean were calculated to compare the extent of predicted advances of different traits under selection, using the formula (Falconer, 1996):

$$GAM = \frac{GA}{\bar{x}} \times 100$$

Where GAM= genetic advances as a percent of the mean, GA= genetic advances under selection, $\bar{X}$ = mean of the population in which selection will be employed.

Table 1. Rice genotypes used in the experiment.

S. No.	Genotypes (Promising lines)	S. No.	Genotypes	Release Year (AD)
1.	NR_10676-B-5-3	7.	Chandannath-3	2002
2.	IR_3K_190	8.	Khumal-4	1987
3.	NR_11345-B-B-15-1-2	9.	Khumal-8	2007
4.	NR_11271-B-B-6	10.	Khumal-10	2011
5.	NR_11321-B-B-7-3	11.	Khumal-12	2022
6.	NR_11301-B-B-1	12.	Taichung-176	1966

RESULTS AND DISCUSSION

Mean performance of different traits of rice genotypes

The mean comparison of agronomic traits of the 12 different genotypes (Table 3) suggests that there was a significant result observed for 12 different agronomic traits. A research conducted at Dolakha, Nepal also revealed highly significant differences in traits like plant height, panicle length, no. of tillers/plant, thousand grain weight and grain yield (Shrestha *et al.*, 2021). Similarly, significant differences in agro-morphological traits was reported in rice genotypes by Shrestha *et al.* (2021) and Abebe *et al.* (2017). In this experiment, Khumal-8 produced the highest grain yield of 8.41 tonha^{-1} followed by Khumal-4 with a grain yield of 7.06 tonha^{-1}. Khumal-12 was found to be superior to others in straw yield with a yield of 12.51 tonha^{-1} followed closely by Khumal-8 with a yield of 12.50 tonha^{-1}. Likewise, Khumal-12 was also found to be significantly superior in terms of total grain per panicle, number of tillers, and panicle weight (238, 19, and 4.76 g, respectively). Khumal-4 had the same number of tillers. Khumal-4 also produced a significant result and was superior to the others in traits such as effective tillers (12), flag leaf length (41.83 cm), and panicle length (30.65 cm). Khumal-12, Khumal-8, Chandannath-3, and NR-11301-B-B-1 had 10 effective tillers. Khumal-10 and Khumal-8 had flag leaf lengths and plant height of 39.14 cm and 30.47 cm, respectively. Taichung-176 had the highest average plant height and average thousand-grain weight, with heights and weight of 150.30 cm and 26.12 g, respectively. This was followed by IR-3K-190 and Chandannath-3, with heights and weight of 140.40 cm and 25.16 g, respectively. Chandannath-3 was also significantly superior to the other genotypes in terms of days of flowering, with 125 days of flowering.

Table 2. Mean performance of rice genotypes.

Name of genotypes	NTR	ET	FLL	DF	PH	PL	TGW	TGPP	PW	SY	GY
Chandamnath-3	17^{abcd}	10^{ab}	37.59^{abcd}	125^{a}	127.97^{bcd}	28.55^{abc}	25.16^{ab}	174^{cd}	3.82^{bcd}	11.33^{a}	5.28^{bc}
IR_3K_190	15^{abcd}	7^{bc}	32.14^{bcd}	101^{e}	140.40^{ab}	26.07^{cd}	22.83^{abcde}	153^{d}	2.87^{abce}	11.45^{a}	5.22^{bc}
Khumal-10	18^{abc}	9^{ab}	39.14^{ab}	100^{e}	133.07^{bcd}	28.40^{abc}	22.39^{abcde}	212^{ab}	4.27^{a}	10.08^{ab}	5.69^{bc}
Khumal-12	19^{a}	10^{ab}	36.38^{abcd}	101^{e}	131.10^{bcd}	30.13^{ab}	20.20^{de}	238^{a}	4.76^{ab}	12.51^{a}	5.82^{bc}
Khumal-4	19^{ab}	12^{a}	41.83^{a}	105^{d}	133.43^{bcd}	30.65^{a}	24.37^{abc}	234^{a}	4.58^{abc}	12.10^{a}	7.06^{ab}
Khumal-8	18^{ab}	10^{ab}	29.22^{d}	114^{b}	121.57^{cd}	30.47^{ab}	21.57^{bcde}	190^{bc}	4.35^{de}	12.50^{a}	8.41^{a}
NR_10676-B-5-3	9^{e}	5^{c}	29.67^{d}	99^{e}	119.40^{d}	23.80^{d}	19.33^{e}	156^{cd}	3.02^{e}	8.13^{ab}	5.19^{bc}
NR_11271-B-B-6	12^{de}	7^{bc}	29.85^{cd}	101^{de}	119.8^{d}	27.19^{bcd}	23.80^{abcd}	149^{d}	2.83^{cde}	7.77^{ab}	4.22^{c}
NR_11301-B-B-1	15^{abcd}	10^{ab}	28.69^{d}	102^{de}	138.47^{abc}	26.21^{cd}	20.86^{cde}	154^{d}	3.50^{de}	8.05^{ab}	4.19^{c}
NR_11321-B-B-7-3	14^{bcd}	6^{bc}	29.24^{d}	103^{de}	125.93^{bcd}	24.83^{d}	22.80^{abcde}	148^{d}	3.19^{de}	8.19^{ab}	4.47^{c}
NR_11345-B-B-15-1-2	13^{cde}	7^{bc}	31.17^{bcd}	102^{de}	118.20^{d}	25.77^{cd}	21.87^{bcde}	165^{cd}	3.31^{cde}	6.62^{b}	3.79^{c}
Taichung-176_242	13^{cde}	8^{abc}	38.71^{abc}	110^{c}	150.30^{a}	25.73^{cd}	26.12^{a}	150^{d}	3.58	11.78^{a}	6.17^{bc}
SEM (±)	1.47	1.29	2.71	1.15	5.25	1.05	1.16	10.98	0.28	1.39	0.71
LSD (=0.05)	4.32***	3.79*	7.94*	3.37***	15.40**	3.08***	3.41*	32.19***	0.81***	4.09*	2.08**
F value	4.58	2.46	3.07	41.8657	3.50	4.79	2.99	9.33	5.96	2.38	3.43
CV (%)	16.77	26.81	13.95	1.89	6.99	6.65	8.91	10.74	13.06	24.04	22.48
Grand mean	15.23	8.36	33.64	105.19	129.97	27.32	22.61	176.99	3.67	10.04	5.46

Note: ** Significant at 1% level; *significant at 5% level; NTR= Number of tillers; ET= Effective tillers; FLL= Flag leaf length; FLW= Flag leaf width; PH= Plant height; PL= Panicle length; TGW= Thousand-grain weight; TGPP= Total grain per panicle; UGPP= Unfilled grain per panicle; PW= Panicle weight; SY=Straw yield; GY= Grain yield; SP= Sterility Percentage; DF= Days to flowering.

Table 3. Genetic parameter for yield and yield components in rice.

Traits	Range	GMS	EMS	VG	VP	GCV%	PCV%	h^2_b	GA	GAM
Number of tillers	8.666-19.100	29.89	6.52	7.79	9.96	18.33	20.73	0.7819	5.08	33.39
Effective tillers	4.933-11.633	12.34	5.02	2.44	4.11	18.68	24.26	0.5929	2.48	29.63
Flag leaf length (cm)	28.693-41.833	67.64	22.01	15.21	22.55	11.60	14.12	0.6746	6.60	19.62
Plant height (cm)	119.400- 150.300	289.57	82.75	68.94	96.52	6.39	7.56	0.7142	14.46	11.12
Thousand grain weight (gm)	19.333-26.116	12.12	4.06	2.69	4.04	7.25	8.89	0.6650	2.75	12.18
Total grain per panicle	147.666-238.300	3373.00	361.60	1003.80	1124.33	17.90	18.94	0.8928	61.67	34.84
Panicle length (cm)	23.800-30.653	15.80	3.30	4.17	5.27	7.47	8.40	0.7911	3.74	13.69
Panicle weight (gm)	2.826- 4.760	1.37	0.23	0.38	0.46	16.79	18.41	0.8321	1.16	31.55
Days to flowering	99.333-124.667	166.09	3.97	54.04	55.36	6.99	7.07	0.9761	14.96	35.15
Straw yield (tonha^{-1})	6.620-12.508	13.92	5.83	2.70	4.64	16.65	21.44	0.5812	2.58	25.67
Grain yield (tonha^{-1})	3.792-8.408	5.18	1.51	1.22	1.73	20.26	24.06	0.7091	1.92	14.22

Note: GMS=Genotypic mean sum of squares; EMS= Error mean sum of squares; VG= Genotypic Variance, VP= Phenotypic Variance, GCV= Genotypic coefficient of variation; PCV= Phenotypic coefficient of variation; h^2_b = Broad sense heritability, GA= Genetic advance; GAM= Genetic advance as percentage of mean.

Character association studies

Genetic variability

To improve the breeding of any field crops, the degree of variability of a trait is crucial. Estimates of genotypic variation (VG), phenotypic variation (VP), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (h^2 b), genetic advance (GA), and genetic advance as percentage of mean (GAM) for different characteristics are presented in Table 2. Grain yield (20.26) had the highest GCV, suggesting a high degree of genetic heterogeneity among the rice genotypes for that trait, whereas, effective tillers (18.68), number of tillers (18.33), total grain per panicle (17.90), Panicle weight (16.79), and straw yield (16.65) had moderate GCV. The highest PCV was recorded for effective tillers (24.26), followed by grain yield (24.06), straw yield (21.44), and number of tillers (20.73). High PCV and GCV for grain yield were also recorded by Abebe *et al.* (2017) and Adhikari *et al.* (2018). This indicates that the traits can be further improved through selection. PCV was found higher than GCV for all the characters analyzed, which could be due to the environment's role in the phenotypic expression of the characteristics to some extent. Similar findings were found to be reported by Singh *et al.* (2021), Rashid *et al.* (2017), and Adhikari *et al.* (2018). Greater differences between GCV and PCV were observed in grain yield (20.26 and 24.06), straw yield (16.65 and 21.44), and number of effective tillers (18.68 and 24.26), indicating that these traits were more influenced by their growing environment and thus, can be improved if we provide optimum growing environments. Likewise, smaller differences in GCV and PCV were observed in the number of tillers, flag leaf length, plant height, thousand-grain weight, total grain per panicle, panicle length, panicle weight, and days to flowering. This indicates a lesser environmental influence on these traits and cannot be improved by providing a favorable environment.

Among the characters studied, the highest heritability was observed in days to flowering (0.97), followed by total grain per panicle, panicle weight, panicle length, number of tillers, plant height, grain yield, thousand-grain weight, and flag leaf length (Table 3). These high-heritability traits indicated a high response to selection. However, heritability comprises of the effects of both additive and non-additive genes. Thus, genetic advancement is a more useful indicator to achieve expected results on the trait of interest of a population after selection. Genetic advancement as percent mean was categorized as low (0-10%), moderate (10-20% and high (≥20%) (Adhikari *et al.*, 2018). Genetic advancement as percent of mean was highest for days to flowering, followed by total grains per panicle, number of tillers, panicle weight, effective tiller, and straw yield. High heritability coupled with high genetic advance as percent mean was observed for days of flowering, total grain per panicle, panicle weight, and number of tillers, which indicates the control of additive genes of action and a greater scope of selection for these traits. Similar findings have been reported for the number of tillers, panicle weight, total grain per panicle, and days of flowering (Bhargava *et al.*, 2021; Kulsum *et al.*, 2022; Rashid *et al.*, 2017).

Correlation analysis

Crop grain yield is a quantitative characteristic influenced by interactions between many component characteristics. Hence, knowledge about the nature and association among different traits is a prerequisite for yield improvement. If the characters are correlated, the selection of one character will bring changes to another character (Noatia *et al.*, 2021). The results of the correlation analysis among the various characteristics of the rice genotypes used in the study are shown in Figure 1. The results showed that grain yield was positively correlated with panicle length (r = 0.47**), total grain per panicle (r = 0.40*), panicle weight (r = 0.43**), tiller number (r = 0.34*), and straw yield (r = 0.62*). This indicates that grain yield can be influenced by improvements in these rice traits. Bhandari *et al.* (2019) reported similar results for panicle length and straw yield were reported by Bhandari *et al.* (2019). Panicle length was highly significant and had a strong positive correlation with total grain per panicle (r = 0.73***), panicle weight (r = 0.61***), and number of tillers (r = 0.63***); moderately strong positive correlation with grain yield (r = 0.47**); and weak positive correlation with effective tiller (r = 0.34*), straw yield (r = 0.38*), and flag leaf length (r = 0.36*). The results conform to those of Akinwale *et al.* (2011) for the number of tillers and Dhurai *et al.* (2016) for panicle weight and total grain per panicle. The total grain per panicle was positively and highly correlated with panicle weight (r = 0.78***), panicle length (r = 0.73***), and number of tillers (r = 0.60***). Straw and grain yields were positively and strongly correlated (r = 0.82***), indicating that higher straw yield would also result in higher grain yield.

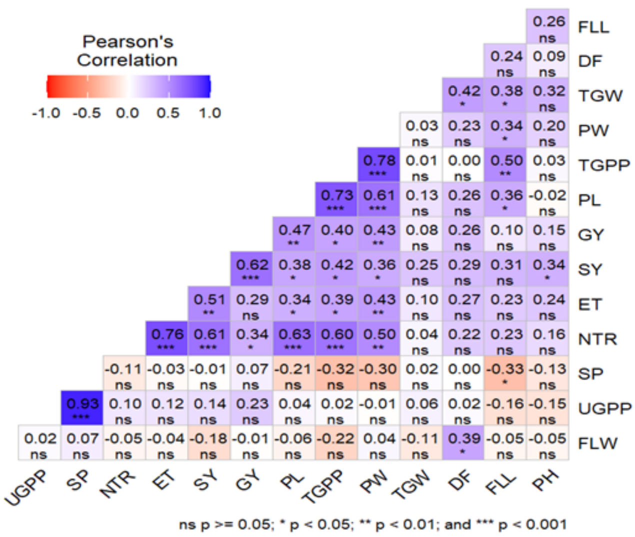

Figure 1. *Correlation matrix for yield and yield component of traits in rice.* Note: ET= Effective tillers; FLL= Flag leaf length; FLW= Flag leaf Width; GY= Grain yield; NTR= Number of tillers; PH= Plant height; PL= Panicle length; SY=Straw yield; SP= Sterility percentage; PW= Panicle weight TGW=Thousand-grain weight; TGPP= Total grain per panicle; UGPP= Unfilled grain per panicle.

Path analysis

Path analysis separates the effects of grain yield into direct and indirect ones. The direct effect directly increases yield, but the indirect effect affects yield via other qualities. The direct and indirect effects of several features are depicted in Table 4. The highest positive direct effect was observed for the total grain per panicle (2.55), which was accompanied by days to flowering (0.81), plant height (0.58), effective tillers (0.43), unfilled grains per panicle (0.30), and straw yield (0.30). Similarly, the most negative direct effects on grain yield were panicle weight (-1.61), flag leaf length (-0.60), number of tillers (-0.56), thousand-grain weight (-0.27), flag leaf width (-0.23), and panicle length (-0.04). The highest indirect positive effect was found for effective tillers through total grains per panicle (2.61), and the highest indirect negative effect was shown by effective tillers through panicle weight (-1.97). The number of tillers showed the highest positive indirect effect on grain yield through total grains per panicle (2.36) and the highest negative indirect effect through panicle weight (-1.78). Effective tillers and flag leaf length both showed the highest positive indirect effects via total grains per panicle (2.61) and (1.94), respectively. They also showed the highest negative indirect effects through panicle weight (-1.97) and (-1.33). Flag leaf width had a positive indirect effect on all traits, except the number of tillers (-0.48), total grains per panicle (-0.26), thousand-grain weight (-0.24), plant height (-0.23), unfilled grain per panicle (-0.06), and plant length (-0.02). Panicle height showed the highest positive indirect effect through straw yield (0.20), and the highest negative indirect effect through flag leaf length (-0.45). Panicle length had a negative indirect effect on all traits, except total grain per panicle (2.31), effective tillers (0.63), days to flowering (0.35), straw yield (0.33), flag leaf width (0.13), and plant height (0.01). Furthermore, thousand-grain weight showed positive indirect effects on all traits except total grain per panicle (-0.67) and flag leaf length (-0.45). Days to flowering showed the highest positive indirect effect through flag leaf width (0.26) and a negative indirect effect through panicle weight (-0.43). The total grain per panicle showed the highest indirect positive effect through effective tiller (0.44) and a negative effect via panicle weight (-1.60). Unfilled grain per panicle showed a negative indirect effect on all characteristics except flag leaf length (0.25), panicle weight (0.22), thousand-grain weight (0.15), days to flowering (0.11), and flag leaf width (0.05). Panicle weight and straw yield both showed the highest positive indirect effect through total grain per panicle (2.52) and (1.96), respectively, whereas panicle weight showed the highest negative effect via the number of tillers (-0.61), and straw yield showed the highest negative effect via panicle weight (-1.60).

In our experiment, effective tillers showed a direct positive effect on grain yield. Effective tillers enhance the quantity of grains and sink capacity in rice, which is essential for yield improvement, (Singh *et al.*, 2020) and (Kavya *et al.*, 2023) had the similar findings. Grain yield was positively impacted by plant height, which is consistent with studies by (Priya *et al.*, 2017) and (Bhargava *et al.*, 2021). Plant height is an essential agronomic trait of rice that directly affects rice yield. If the plants are too short, it will lead to insufficient growth and ultimately affect the yield potential of the rice (Zhang *et al.*, 2017). The days to flowering also had a positive direct effect on grain yield. According to (Asilo *et al.*, 2019), leaf area index (LAI) is crucial during the reproductive phase, especially during the heading stage when it reaches its maximum, which improves the photosynthesis rate and is directly correlated with grain yield. Similar results were obtained by Muthuramu & Thangaraj, (2023) and Azhar *et al.* (2024) but Fentie *et al.* (2021) contradicted these findings. The total grains per panicle showed the highest positive effect on grain yield. The quantity of grains in each panicle is a crucial characteristic that influences yield; longer panicles can hold more grains. Abbas, (2024) and Sudeepthi *et al.* (2020) also found the similar results. A positive direct effect on grain yield was observed for unfilled grains per panicle. However, the positive direct effect of unfilled grains was nullified by the negative indirect effects of plant height, total grain per panicle, effective tillers, and straw yield, which is in accordance with the findings of Kiran *et al.* (2023) and Islam *et al.* (2021). In rice, reduced biomass is linked to inadequate grain-filling (Fentie *et al.*, 2021). Furthermore, a reduced straw yield indicates fewer tillers, which reduces the amount of grains produced. Therefore, grain yield was directly positively impacted by straw yield. Similar results were also obtained for straw yield by Chavan *et al.* (2022) and Barhate *et al.* (2021). Each of these characteristics contributed to improved grain yield and grain filling. These traits, which directly affect grain production in a positive way, may be subject to additional yield improvements. However, other characteristics such as the flag leaf length, flag leaf breadth, number of tillers, plant length, thousand-grain weight, and panicle weight should be excluded from selection because they have a negative direct effect on grain yield. After analyzing this data, it was found that the variables looked at in this experiment explained 60.53 percent of the variability in grain production, with a modest residual impact (0.3947). This suggests that characteristics other than those under study also contribute to grain yield.

Table 4. Path coefficient analysis demonstrating the influence of several traits on grain yield, both directly (bold) and indirectly.

	NTR	ET	FLL	FLW	PH	PL	TGW	DF	TGPP	UGPP	PW	SY
NTR	**-0.56**	0.43	-0.51	0.19	0.16	-0.05	-0.06	0.31	2.36	-0.00	-1.78	0.24
ET	-0.55	**0.43**	-0.65	0.12	0.25	-0.06	-0.09	0.44	2.61	0.11	-1.97	0.22
FLL	-0.48	0.47	**-0.60**	-0.16	0.43	-0.03	-0.20	0.23	1.94	0.12	-1.33	0.31
FLW	-0.48	0.23	0.43	**-0.23**	-0.23	-0.02	-0.24	0.92	-0.26	-0.06	0.16	0.43
PH	-0.16	0.19	-0.45	-0.09	**0.58**	-0.00	-0.15	0.02	-0.02	0.18	-0.12	0.20
PL	-0.63	0.63	-0.40	0.13	0.01	**-0.04**	-0.04	0.35	2.31	-0.16	-1.61	0.33
TGW	-0.13	0.15	-0.45	0.20	0.33	-0.00	**-0.27**	0.51	-0.67	0.16	0.21	0.11
DF	-0.22	0.23	-0.17	0.26	0.01	-0.02	-0.17	**0.81**	0.03	-0.04	-0.43	0.19
TGPP	-0.52	0.44	-0.46	-0.02	-0.00	-0.04	0.07	0.01	**2.55**	0.02	-1.60	0.23
UGPP	-0.00	-0.16	0.25	0.05	-0.35	-0.02	0.15	0.11	-0.18	**0.30**	0.22	-0.08
PW	-0.61	0.53	-0.49	-0.02	0.04	-0.04	0.03	0.21	2.52	0.04	**-1.61**	0.30
SY	-0.44	0.32	-0.61	0.32	0.39	-0.05	-0.10	0.51	1.96	0.08	-1.60	**0.30**

Residual: 0.3947; Note: NTR= Number of tillers; ET= Effective tillers; FLL=Flag leaf length; FLW= Flag leaf width; PH= Plant height; TGW= Thousand-grain weight; DF= Days to flowering; TGPP= Total grain per panicle; UGPP= Unfilled grain per panicle; PW= Panicle weight; SY= Straw yield.

Conclusion

There was sufficient genetic variability and potential for selection and further improvement among the rice genotypes. A greater scope of selection was observed for the trait days of flowering, total grain per panicle, panicle weight, and number of tillers due to control of the additive gene of action. Correlation analysis showed that panicle length, total grain per panicle, panicle weight, number of tillers, and straw yield could be considered for further yield improvement programs. Path analysis revealed positive direct effects of total grain per panicle, days to flowering, plant height, effective tillers, unfilled grain per panicle, and straw yield on grain yield. Only the total grain per panicle and straw yield demonstrated a strong positive correlation and a positive direct effect on grain yield. Thus, it is strongly advised that these traits be chosen in rice breeding programs to further enhance production. Khumal-4, Khumal-8, and Taichung-176 were the most promising genotypes. These findings provide a basis for selecting high-yielding, adaptable varieties for rainfed conditions in Nepal.

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DECLARATIONS

Author contribution statement

Conceptualization: R.S. and S.K.; Methodology: N.S. and R.D.; Software and validation: S.K., S.N., and N.S.; Formal analysis and investigation: R.S. and R.D.; Resources: S.K.; Data curation: S.N. and N.S.; Writing—original draft preparation: N.S., R.D., R.S., S.N.; Writing—review and editing: S.K., R.S., R.D.; Visualization: N.S. and S.N.; Supervision: S.K.; Project administration: N.S., R.D., R.S., S.N.; Funding acquisition: S.K. All authors have read and agreed to the published version of the manuscript.

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