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PATH COEFFICIENT ANALYSES OF INTRODUCED RICE VARIETIES UNDER DIFFERENT PLANTING DISTANCES

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SUMMARY

Five rice (*Oryza sativa* L.) cultivars (N22, Amber, Moroberekan, Kinandang Patong, and Azucena) underwent path coefficient analysis across three plant spacings (15 cm × 15 cm, 20 cm × 20 cm, and 25 cm× 25 cm) in the summer of 2017 at the College of Agricultural Engineering Sciences, University of Baghdad, Al-Jadriya, Iraq. The experiment proceeded in a randomized complete block design (RCBD) with a split-plot arrangement and three replications. The main plots included three planting distances, and the subplot comprised five varieties. The traits studied were plant height, flag leaf area, number of tillers, panicle number, length and branches, grains per panicle, 1000-grain weight, and the percentage of unfilled grains. The results showed significant ($P \leq 0.05$) differences between direct and indirect and total effects. The studied traits provided negative values for the total effects except for the number of tillers and the number of panicles per plant, as these two traits reached 1.0938 and 1.0798, respectively. With the second plant spacing of 20 cm × 20 cm, the traits: plant height, number of tillers, number of panicles, and panicle length, showed the total positive effects, ranging from 0.2803 to 0.6606, with the remaining traits enunciated negative values. For the third plant spacing of 25 cm × 25 cm, the traits: panicle length, number of tillers, grains per panicle, and 1000-grain weight, exhibited positive values for the total effects, ranging from 0.623 to 1.1593.

Keywords: Rice (*Oryza sativa* L.), path coefficient analysis, correlation coefficient, genetic variability, plant spacing, morphological and yield-related traits, grain yield

Key findings: Significant variations among direct and indirect effects of various rice traits indicate that the panicle length, number of tillers, grains per panicle, and 1000-grain weight with a plant spacing of 25 cm × 25 cm could serve as vital selection criteria for improving the grain yield in rice.

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INTRODUCTION

Global rice production is not enough to meet the food demand of the bulging population, and increasing the yield to 800 million tons is a must to meet the demand in 2025 (Cassman, 1999). The required additional increase could come mainly from the irrigated areas of Asia (Alhassan and Musa, 2021). However, for horizontal improvement, the extent of

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expansion in cultivating new lands is usually limited (Hadi *et al.,* 2019; Khan *et al*., 2022; Sakinah *et al*., 2022). The land cultivated with rice is shrinking in several Asian countries due to urbanization and industries. Therefore, vertical improvement, like yield per unit area, should be increased, with the scope to improve the genetic potential by using genetic resources to enhance rice productivity (Chowdhury *et al*., 2023).

Knowledge about the genotypic and phenotypic correlations is vital in diagnosing the traits most closely related to grain yield(Shrestha *et al*., 2014; Al-Shugeairy *et al*,2014; Len *et al*., 2015). The correlation of morphological traits with the yield is of great importance in determining the components of the yield; however, it does not reveal the direct and indirect effects of each trait on the yield, so the path coefficient analysis provides for further assessment (Alhassan and Musa, 2021; Zayed *et al*., 2023). The path analysis is critical in studying the direct and indirect effects of the various yield components to determine the importance of these traits as selection criteria in managing the grain yield (Nadali *et al*., 2011; Dutt *et al*., 2020). Path coefficient analysis is a statistical tool used to organize and find the causal relationships among the causative variables and the response variable through pathways that depend on the results obtained from a series of research concerning the application of the pathway coefficient in genetic issues (Dutt *et al*., 2020).

Mervat *et al.* (2019) revealed that it is possible to improve the grain yield by selecting one of the yield components based on the correlation coefficients between the yield and its related traits and dividing it into direct and indirect effects by analyzing through path coefficient analysis. After knowing the direct and indirect effects of the yield components on grain yield by analyzing through pathway coefficient, the traits undergo diagnosis and selection to increase the yield. The path coefficient analysis approach in various crop experiments helped diagnose the desired traits as selection criteria to increase productivity (Srijan *et al.,* 2018).

Path analysis depends on the existence of causal models, as it assumes the existence of a linear causal relationship (Kalyan *et al.,* 2017). Nandan and Singh (2010) concluded the correlation coefficient between cause and effect is often equal to its direct effect, and the correlation showed the true relationship between them, and direct selection through those traits will be effective. A conclusion also stated the correlation coefficient was positive, but the direct effect was negative or negligible, and the indirect effects could be the reason for this relationship. In such cases, the indirect causative factors need simultaneous consideration when choosing that trait (Hadi *et al.,* 2019a, b).

Previous studies comprising path coefficient analysis in rice revealed that the number of panicles per plant had the greatest direct effects and a vital role in managing grain yield (Rao *et al.,* 2014). Nagaraju *et al.* (2013) analyzed the grain yield through path coefficient analysis. Their findings exhibited that the number of grains per panicle had the highest direct effect on rice grain yield. The analysis of the genetic path coefficient showed that the number of panicles had the highest direct effect on grain yield. Alhassan and Musa (2021) noted from the pathway coefficient analysis that the number of panicles and grains per plant had direct and indirect positive effects on grain yield.

Path coefficient analysis in maize showed the traits, plant height and leaf area in spring, and plant height and the number of ears in autumn had the highest direct positive effects on the grain yield in maize, with the researchers concluding that these traits could serve as essential selection criteria in future breeding to improve the crop yield (Wuhaib *et al.,* 2018). Mervat *et al.* (2019) analyzed the genetic pathway coefficient while studying the rice genotypes and the characteristics, viz., the number of panicle m^{-2} and the number of grains per panicle have direct positive effects on the grain yield. Meanwhile, the number of grains in the panicle also had a negative indirect effect through the number of panicle m^{-2} and panicle length.

Sarker *et al*. (2013) concluded that the number of panicles m^{-2} has a direct positive effect on the grain yield, followed by the number of grains per panicle. Findings of Srijan *et al*. (2018) revealed that 1000-grain weight has the highest values of direct positive effects on grain yield in *Oryza sativa* L. Genetic path coefficient analysis by Nandan and Singh (2010) found that the number of grains in the panicle has the highest direct effect on grain yield, followed by 1000-grain weight in rice.

MATERIALS AND METHODS

A field experiment transpired in the summer of 2017 to determine the genetic variation among the rice cultivars affected by plant spacing at the College of Agricultural Sciences, University of Baghdad, Al-Jadriya, Iraq. The experiment employed a randomized complete block design (RCBD) with a split-plot arrangement and three replications. The experiment evaluated five rice cultivars (N22, Amber, Moroberekan, Kinandang Patong, and Azucena) with three plant spacing (15 cm × 15 cm, 20 cm × 20 cm, and 25 cm × 25 cm) for various morphological and yield-related and other traits.

The experiment comprised 45 experimental units of four m^2 (2 m × 2 m). Sowing of five rice genotype seeds in the nursery began on 15 May and 01 June 2017. Transplanting the two-week-old seedlings of the five varieties proceeded manually at one plant per hill in the field using the square planting method with three different plant spacing. Adding nitrogen fertilizer was at the rate of 280 kg N ha^{-1} as urea (46% N). The added fertilizer was in two split doses, i.e., the first dose was applied after one month, while the second was after two months from transplanting (NPDRC, 1996). All the recommended crop cultivation operations ensued as needed.

Traits studied and statistical analysis

Random sampling from all experimental units occurred, with the data recorded on the traits, viz., plant height, flag leaf area, number of tillers per m^2, panicle number per m^2, grain number per panicle, 1000-grain weight, and the percentage of unfilled grains. The percentage of unfilled grain calculation followed the formula below:

Percentage of unfilled grain = (number of empty grains/number of grains) × 100

Determining genetic correlation with their direct and indirect effects used the path coefficient analysis (Singh and Chaudhry, 1987).

RESULTS AND DISCUSSION

Path coefficient analysis with a plant spacing of 15 cm × 15 cm

The results of path coefficient analysis of the correlation coefficient among various variables affecting the total grain yield of the rice genotypes with a plant spacing of 15 cm × 15 cm appear in Table 1. Most of the total effects values showed the highest negative, except for the number of tillers m^{-2} and panicles m^{-2}, for which the said effects were the highest positive. The trait plant height showed a direct positive effect (0.0698), with its total effect negative (-0.1178). Said negative value resulted from the indirect negative effects through the traits, viz., number of panicles, length of the panicle, 1000-grain weight, and the percentage of unfilled grains (-1.1666, 0.0612, -0.0256, and -0.1274, respectively).

Table 1. Direct and indirect effects of some traits on rice grain yield with a plant spacing of 15 cm × 15 cm.

Studied traits	Plant height	Flag leaf area	Number of tiller	Panicle number	Panicle length	Panicle branches	Grains panicle^{-1}	1000-grain weight	Unfilled grain %	Total effects
Plant height	0.0698	0.0160	1.0206	-1.1666	-0.0612	0.0463	0.1102	-0.0256	-0.1274	-0.1178
Flag leaf area	-0.0269	-0.0416	3.8750	-5.0839	0.0091	0.0122	0.1377	0.3573	-0.1398	-0.9010
Number of tillers	-0.0160	0.0362	-4.4590	5.8911	0.0367	-0.0540	-0.1469	-0.4573	0.2630	1.0938
Panicle number	-0.0138	0.0359	-4.4585	5.8918	0.0352	-0.0567	-0.1510	-0.4682	0.2650	1.0798
Panicle length	0.0531	0.0047	2.0335	-2.5784	-0.0804	0.0209	0.0175	0.2791	-0.1995	-0.4497
Panicle branches	0.0324	-0.0051	2.4170	-3.3511	-0.0168	0.0997	0.1768	0.2549	-0.2499	-0.6422
Grains per panicle	0.0432	-0.0322	3.6802	-4.9991	-0.0079	0.0990	0.1780	0.1769	-0.2535	-1.1153
1000-grain weight	-0.0032	-0.0267	3.6682	-4.9618	-0.0404	0.0457	0.0566	0.5559	-0.2685	-0.9742
Unfilled grains %	0.0310	-0.0203	4.0910	-5.4464	-0.0559	0.0869	0.1574	0.5207	-0.2867	-0.9224
Residual	0.034									

However, the positive and indirect effect was unaffected by the traits, viz., flag leaf area, number of tillers, panicle branch number, and number of grains per panicle (0.0160, 1.0206, 0.0463, and 0.1102, respectively).

The trait flag leaf area showed a direct negative effect (-0.0416), with its total effect the highest negative (-0.9010). Also, the said trait had indirect negative effects through the traits, viz., plant height, number of panicles, and percentage of unfilled grains (-0.0269, -5.0839, and -0.1398, respectively). However, it was unaffected by the indirect positive effect through the traits, i.e., number of tillers, length of panicle, number of branches per panicle, grains per panicle, and 1000-grain weight (3.8750, 0.0091, 0.0122, 0.1377, and 0.3573, respectively). The total highest positive effect of the tillers per plant (1.0938) resulted despite the negative indirect effects of the traits, i.e., plant height, panicle branch number, grains per panicle, and 1000-grain weight (-0.0160, -0.0540, -0.1469, and -0.4573, respectively). Although, among the indirect positive effects traits, viz., leaf area, number of panicles, length of panicle, and percentage of unfilled grains (0.0362, 5.8911, 0.0367, and 0.2630, respectively), gave a direct negative effect of -4.4590.

The trait number of panicles showed the highest direct positive effect (5.8918) and total effects (1.0798), which resulted from the indirect positive effects of the traits. i.e., flag leaf area, length of the panicle, and the percentage of unfilled grains (0.0359, 0.0352, and 0.2650, respectively). However, the said trait was unaffected by the indirect negative effects of the traits, i.e., plant height, number of tillers, panicle branch number, grains per panicle, and 1000-grain weight (-0.0138, -4.4585, -0.0567, -0.1510, and -0.4682, respectively). The panicle length behaved oppositely to the trait number of tillers as its direct effect was negative, despite the positive indirect effects of the traits, viz., plant height, leaf area, number of tillers, panicle branches, grains per panicle, and 1000-grain weight (0.053, 0.0047, 2.0335, 0.0209, 0.0175, and 0.2791, respectively).

The trait number of branches per panicle showed a direct positive effect, with its total effects negative due to the negative indirect effects of the traits, i.e., leaf area, number of tillers, panicle length, and percentage of unfilled grains (-0.0051, -3.3511, -0.0168, and -0.2499, respectively). However, the said trait had other indirect positive effects from plant height, number of tillers, grains per panicle, and 1000-grain weight (0.0324, 2.4170, 0.1768, and 0.2549, respectively). The trait grains per panicle^{-1} achieved a direct positive effect (0.1780) and a positive indirect effect with the traits, i.e., plant height, number of tillers, branches per panicle, and the 1000-grain weight (0.0432, 3.6802, 0.0990, and 0.1769, respectively); sequentially and negative indirect effects through the traits, viz., flag leaf area, number of tillers, panicle length, and percentage of unfilled grains (-0.0322, -4.9991, -0.0079, and -0.2535, respectively). Nonetheless, the overall effects were the highest negative (-1.1153). The trait of 1000-grain weight achieved the highest total negative effect (-0.9742) because of the indirect negative effects of plant height, flag leaf area, number of tillers, panicle length, and percentage of unfilled grains (-0.0032, -0.0267, -4.9618, -0.0404, and -0.2685, respectively).

The trait of the percentage of unfilled grain showed a direct negative effect; however, its total effects were the highest negative due to the negative indirect effects of the traits, viz., flag leaf area, number of panicles, and panicle length (-0.0203, -5.4464, and -0.0559, respectively). Inversely, its indirect positive effects were unaffected by the traits, viz., plant height, number of tillers, branches per panicle, grains panicle^{-1}, and 1000-grain weight (0.0310, 4.0910, 0.0869, 0.1574, and 0.5207, respectively). The presented results also got support from the past findings of Bhatia *et al*. (2013) as they analyzed the coefficient of the genetic path analysis and recorded direct positive effects of the trait, viz., plant height, number of panicles, panicle branches, grains panicle^{-1}, and 1000-grain weight on the grain yield in rice (*Oryza sativa* L.). Rangare *et al*. (2012) also obtained the highest direct and positive effects of the trait 1000-grain weight on grain yield in Indian rice. Dutt *et al*. (2020) also recorded the highest direct and positive effects of the traits, i.e., number of panicles, number of tillers, plant height, 1000-grain weight, and the percentage of unfilled grains on the grain yield in rice genotypes. Table 1 also denotes that the percentage of influence of other unstudied factors amounted to 0.034. However, the studied traits contributed a lot to explore the largest part of the variance, which amounted to 0.966 for the plant spacing of 15 cm × 15 cm. Previous studies showed the highest positive effects of the plant height and 100-grain weight on grain yield in various populations of maize (Wuhaib *et al*., 2017, 2018; Hadi and Hassan, 2021) and durum wheat (Almajidy *et al*., 2017).

Table 2. Direct and indirect effects of some traits on rice grain yield with a plant spacing of 20 cm × 20 cm.

Studied traits	Plant height	Flag leaf area	Number of tillers	Panicle number	Panicle length	Panicle branches	Grains panicle^{-1}	1000-grain weight	Unfilled grain %	Total effects
Plant height	0.2035	-0.0012	0.5289	-0.2973	0.2685	-0.0010	0.1551	-0.5036	0.1394	0.4922
Flag leaf area	0.0061	-0.0407	-1.0268	0.7306	-1.2037	0.0448	-0.1898	-0.6001	1.6030	-0.6766
Number of tillers	-0.0204	-0.0079	-5.2858	6.2148	-0.5241	0.0232	-0.3398	-0.8216	1.4221	0.6606
Panicle number	-0.0097	-0.0048	-5.2829	6.2182	-0.5166	0.0228	-0.3344	-0.8589	1.4489	0.6825
Panicle length	0.0569	0.0509	2.8827	-3.3430	0.9610	-0.0214	0.1917	0.6139	-1.1123	0.2803
Panicle branches	0.0069	0.0590	3.9791	-4.5844	0.6669	-0.0309	0.2805	0.6327	-1.3341	-0.3243
Grains per panicle	0.0923	0.0226	5.2565	-6.0863	0.5391	-0.0253	0.3417	0.5898	-1.2705	-0.5400
1000-grain weight	-0.0979	0.0233	4.1509	-5.1049	0.5639	-0.0187	0.1926	1.0462	-1.3794	-0.6240
Unfilled grains %	0.0193***0***	0.0445	5.1272	-6.1452	0.7291	-0.0281	0.2961	0.9844	-1.4661	-0.4775
Residual	0.045									

Path coefficient analysis with a plant spacing of 20 cm× 20 cm

Path coefficient analysis of the correlation coefficient of the various variables affecting the grain yield of the rice genotypes with a plant spacing of 20 cm × 20 cm reveals in Table 2. The plant height showed the positive shares of direct and total effects (0.2035 and 0.4922, respectively), with the said trait was unaffected by indirect negative effects of the traits, i.e., flag leaf area, number of tillers, panicle branches, and the 1000-grain weight (-0.0012, -0.2973, -0.0010, and -0.5036, sequentially). The flag leaf area showed a negative direct effect (-0.0407), with its total effects also the highest negative (-0.6766), which might be due to indirect negative effects of the traits, viz., number of tillers, panicle length, grains panicle^{-1}, and 1000-grain weight (-1.0268, -1.2037, -0.1898, and -0.6001, respectively). The indirect positive effects were not affected by the traits, viz., plant height, number of panicles, panicle branches, and percentage of unfilled grains (0.0061, 0.7306, 0.0448, and 1.6030, respectively).

The number of tillers had the highest direct negative effect (-5.2858), yet, its total effects were positive (0.6606) due to the positive indirect effects of the number of panicles, panicle branches, and percentage of unfilled grains (6.2148, 0.0232, and 1.4221, respectively), despite the negative indirect effects of the traits. i.e., plant height, flag leaf area, panicle length, grains panicle^{-1}, and 1000-grain weight (-0.0204, -0.0079, -0.5241, -0.3398, and -0.8216, respectively). The number of panicles showed the highest direct positive effect (6.2182), with its total effect (0.6825) not affected by the indirect negative effects of the traits. i.e., plant height, flag leaf area, number of tillers, panicle length, grains per panicle^{-1}, and 1000-grain weight (-0.0097, -0.0048, -5.2829, -0.5166, -0.3344, and -0.8589, respectively). The trait panicle length behaved similarly with the trait number of panicles, as its direct effect was the highest positive (0.9610) and its total effects were also positive due to the positive indirect effects of the traits, viz., plant height, flag leaf area, number of tillers, grains panicle^{-1}, and 1000-grain weight (0.0569, 0.0509, 2.8827, 0.1917, and 0.6139), respectively.

The panicle branches showed the highest negative values for direct and total effects due to the negative indirect effects of the number of panicles and the percentage of unfilled grains (-4.5844 and -1.3341, respectively). The said traits have indirect positive effects due to the characteristics of the plant height, flag leaf area, number of tillers, panicle length, grains panicle^{-1}, and 1000-grain weight (0.0069, 0.0590, 3.9791, 0.6669, 0.2805, and 0.6327, respectively). The grains panicle^{-1} achieved a direct positive effect (0.3417), but, its total effects were the highest negative (-0.5400) due to indirect negative effects of the traits, viz., number of panicles, panicle branches, and percentage of unfilled grains (-6.0863, -0.0253, and -1.2705, respectively), and the indirect positive effects of the plant height, flag leaf area, number of tillers, panicle length, and 1000-grain weight (0.0923, 0.0226, 5.2565, 0.5391, and 0.5898, sequentially).

The trait 1000-grain weight showed the highest direct positive effect, yet, its total effects were the highest negative (-0.6240) due to the indirect negative effects of the traits, i.e., plant height, number of panicles, panicle branches, and percentage of unfilled grains (-0.0979, -5.1049, -0.0187, and -1.3794). The positive effect did not affect it except the direct positive effects of flag leaf area, number of tillers, panicle length, and grains panicle^{-1} (0.0233, 4.1509, 0.5639, and 0.1926, respectively). The trait percentage of unfilled grains achieved a negative direct (-1.4661) and total effects (-0.4775) because of the negative indirect effects of the traits, i.e., plant height, number of panicles, and panicle branches (-0.0193, -6.1452, and -0.0281, respectively). The presented results also agree with the past findings as they reported similar results in rice (Nadali *et al*., 2011; Alogaidi *et al*., 2019) and maize crops (Hassan *et al*., 2018; Hadi *et al*., 2019a). The influence of unstudied factors amounted to 0.045; however, the studied traits contributed the largest part to managing the variance in grain yield, which amounted to 0.955 with plant spacing of 20 cm× 20 cm (Table 2).

Path coefficient analysis with a plant spacing of 25 cm × 25 cm

The direct and indirect effects of the genetic correlation coefficient between the grain yield and other variables in rice cultivars with a plant spacing of 25 cm × 25 cm occur in Table 3. The plant height achieved a direct positive effect (0.2305), as well as, its total effects were negative (-0.2601) due to the indirect negative effects of the traits, i.e., number of tillers, number of panicles, panicle branches, and percentage of unfilled grains (-0.0145, -1.2780, -0.0651, and -0.0568, respectively), with its positive and indirect effects unaffected by the traits, viz., flag leaf area, panicle length, grains panicle^{-1}, and 1000-grain weight (0.1833, 0.0355, 0.6382, and 0.0669, respectively). The flag leaf area showed a direct positive effect (0.1704), while its total effects were negative (-1.0442) due to indirect negative effects of the traits, viz., number of tillers, number of panicles, panicle length, panicle branches, 1000-grain weight, and the percentage of unfilled grains (-0.0122, -1.1174, -0.3285, -0.1136, -0.2122, and -0.0236, respectively). Contrarily, the indirect positive effects did not affect them through the traits, i.e., plant height and grains panicle^{-1} (0.2479 and 0.3450, respectively).

Table 3. Direct and indirect effects of some traits on rice grain yield with a plant spacing of 25 cm × 25 cm.

Studied traits	Plant height	Flag leaf area	Number oftillers	Panicle number	Panicle length	Panicle branches	Grains panicle^{-1}	1000-grain weight	Unfilled grains %	Total effects
Plant height	0.2305	0.1833	-0.0145	-1.2780	0.0355	-0.0651	0.6382	0.0669	-0.0568	-0.2601
Flag leaf area	0.2479	0.1704	-0.0122	-1.1174	-0.3285	-0.1136	0.3450	-0.2122	-0.0236	-1.0442
Number of tillers	-0.0977	-0.0609	0.0341	2.7969	-0.3794	-0.2490	-2.2518	-0.6710	0.1809	-0.6979
Panicle number	-0.1072	-0.0693	0.0347	2.7495	-0.4025	-0.2429	-2.3459	-0.6746	0.1812	-0.8769
Panicle length	0.0100	-0.0687	-0.0159	-1.3585	0.8146	0.2291	1.7104	0.4739	-0.1396	1.6553
Panicle branches	-0.0488	-0.0630	-0.0277	-2.1730	0.6072	0.3074	1.9766	0.7359	-0.1653	1.1492
Grains per panicle	0.0690	0.0276	-0.0361	-3.0247	0.6534	0.2849	2.1324	0.7088	-0.1930	0.6223
1000-grain weight	0.0168	-0.0393	-0.0249	-2.0173	0.4199	0.2460	1.6438	0.9194	-0.2011	0.9632
Unfilled grains %	0.0651	0.0200	-0.0307	-2.4752	0.6552	0.2525	2.0440	0.9190	-0.2012	1.1593
Residual	0.067									

The trait number of tillers had a direct positive effect (0.0341), while its total effects were negative (-0.6979) due to indirect negative effects of the traits. i.e., plant height, flag leaf area, panicle length, panicle branches, grains panicle^{-1}, and 1000-grain weight (-0.0977, -0.0609, -0.3794, -0.2490, -2.2518, and -0.6710, respectively). The trait number of panicles showed a direct positive effect (2.7495) and its total effects were negative (-0.8769) due to indirect negative effects of plant height, flag leaf area, panicle length, panicle branches, grains panicle^{-1}, and 1000-grain weight (-0.1072, -0.0693,-0.4025, -0.2429, -2.3459, and -0.6746, respectively). However, the indirect positive effects did not affect the two traits, i.e., number of tillers and percentage of unfilled grains (0.0347 and 0.1812, respectively).

The trait panicle length behaved like the number of tillers as its direct and total effects were positive (0.8146 and 1.6553), with the indirect negative effects unaffecting it through the traits, i.e., flag leaf area, number of tillers, number of panicles, and percentage of unfilled grains (-0.0687, -0.0159, -1.3585, and -0.1396, respectively). The trait panicle branches also showed positive values for direct and total effects due to positive indirect effects of the traits, viz., panicle length, panicle number, and 1000-grain weight (0.6072, 1.9766, and 0.7359, respectively). The said trait had indirect negative effects from the traits, i.e., plant height, flag leaf area, number of tillers, number of panicles, and percentage of unfilled grains (-0.0488, -0.0630, -0.0277 -2.1730, and -0.1653, respectively). The grains panicle^{-1} showed positive values for direct and indirect effects through the traits, i.e., plant height, flag leaf area, panicle length, panicle branches, and 1000-grain weight (0.0690, 0.0276, 0.6534, 0.2849, and 0.7088, respectively), and negative indirect effects with the traits, viz., number of tillers, number of panicles, and percentage of unfilled grains (-0.0361, -3.0247, and -0.1930, respectively).

The trait 1000-grain weight showed positive values for direct and total effects (0.9194 and 0.9632, respectively) due to the indirect positive effects of the traits, i.e., plant height, panicle length, panicle branches, and grains panicle^{-1} (0.0168, 0.4199, 0.2460, and 1.6438, respectively). The percentage of the unfilled grains had a negative direct effect (-0.2012), while its total effects were the highest positive (1.1593) due to indirect effects of the traits, i.e., plant height, flag leaf area, panicle length, panicle branches, grains panicle^{-1}, and 1000-grain weight (0.0651, 0.0200, 0.6552, 0.2525, 2.0440, and 0.9190, respectively). Alhassan and Musa (2021) also reported similar results for the traits, panicle length, grains panicle^{-1}, and the 1000-grain weight, with direct positive effects on grain yield. Table 3 also revealed that the percentage of influence of other unstudied factors amounted to 0.067, while the studied traits contributed the largest part of the variance (0.933) with plant spacing of 25 cm × 25 cm.

In light of all the results, evidence proved the direct effects of the studied traits on rice grain yield at different plant spacing. The recorded highest direct positive effects were for the number of panicles with a plant spacing of 20 cm × 20 cm (6.2182), followed by plant spacing of 15 cm × 15 cm with the highest direct positive effects (5.8918) (Tables 1, 2, and 3). Based on the results of Tables 1, 2, and 3, the number of panicles with a plant spacing of 20 cm × 20 cm showed the highest direct effects (5.8918), followed by plant spacing of 25 cm × 25 cm with a value of 2.7495 for the said trait. The trait number of tillers with a plant spacing of 20 cm × 20 cm showed the highest direct negative effect (-5.2858), followed by plant spacing of 15 cm × 15 cm with a value of -4.4590. The said results were consistent with the past findings as earlier reports on direct positive and negative effects for the traits like plant height, number of tillers, number of panicles, and grains per panicle in rice have come out (Nandan and Singh, 2010; Mervat *et al*., 2019; Dutt *et al*., 2020; Singh and Singh, 2020).

CONCLUSIONS

The values of the direct and indirect effects of the various traits differed according to the plant spacing, with the best values obtained for the plant spacing of 25 cm × 25 cm. In conclusion, the traits, viz., panicle length, number of tillers, grains panicle, and 1000-grain weight emerged as essential selection criteria for improvement in rice grain yield, especially with a plant spacing of 25 cm × 25 cm.

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