Trait Associations and Path Coefficient Analysis for Yield Improvement in Advanced Breeding Lines of Rice (*Oryza sativa* L.)

Abstract

Rice (*Oryza sativa* L.) is a staple crop critical for global food security. Enhancing grain yield requires an in-depth understanding of trait associations and their direct and indirect effects. This study evaluates 46 advanced breeding lines including five check varieties of rice to assess correlation and path coefficient analysis for key yield components. The biological yield (1.148) and harvest index (1.08) were identified as the most influential traits with strong direct positive effects on grain yield at both phenotypic and genotypic level. Whereas,100 seed weight (0.287), days to 50% flowering (0.245), panicle length (0.130), and spikelet fertility (0.054) also contributed significantly for grain yield per plant. Therefore, in the process of selecting rice genotypes for further breeding programs of yield improvement characters like biological yield and harvest index that had the highest positive association and high direct influence could be primarily used as selection criteria, since improvement of these traits leads to grain yield enhancement.

Keywords: Rice breeding, correlation, path analysis, yield traits, trait association, selection.

1.Introduction

Rice (*Oryza sativa* L., 2n=24) is a self-pollinated, short-day, monocotyledonous angiosperm belonging to the genus *Oryza* of the family Poaceae (formerly Gramineae). Rice is a crucial staple crop in India, occupying a significant portion of cultivated land and supporting millions of farmers (Gupta, 2024). Globally, rice production reached 495.78 million tons in recent years, with projections of 525 million tons by 2050. (Salihi *et al*., 2024). In alignment with a nutritional profile assessment, rice provides 715 calories per individual daily or 27 % of the energy in the diet, 20 % of its protein, and 3 % of its fat in developing countries. In certain regions of South Asia, rice constitutes more than 50% of the energy and protein supply per person in the diet, while accounting for 17–27 % of the fat. (Khamari *et al.,* 2020). Beyond energy, rice is also a good source of essential nutrients like fiber, and minerals such as iron, zinc, potassium, and manganese. Chhattisgarh, known as the "Rice Bowl of India," is a major contributor to the country's rice production, cultivating diverse rice varieties across its 38.93 lakh hectares with a dry tropical sub-humid climate and annual rainfall of 1200-1400 mm, the state produces 150.44 lakh tons of rice with a productivity of 3864 kg/ha (Anonymous, 2024). The enhancement of genetic gain in rice is one of the most important target in recent times. (Sao *et al.,* 2024).

Understanding the relationships among yield-related traits is crucial for designing effective breeding strategies. Correlation analysis helps to estimate the impact of individual traits on yield improvement, aiding breeders in selecting desirable traits. However, correlation alone only evaluates the relationship between two variables, while path coefficient analysis further dissects both direct and indirect effects, providing deeper insight into trait associations for enhanced yield selection (Wright, 1921). This approach enables breeders to make informed decisions when selecting traits that significantly impact grain yield (Ali *et al*., 2020). Given these considerations, the present study aims to determine the relationship between the traits and their interrelationship through path coefficient analysis for grain yield.

2.Material and Method:

The experiment was carried out at Research cum Instructional Farm, Department of Genetics and Plant Breeding, College of Agriculture, IGKV, Raipur with 46 advanced breeding lines of rice along with 5 checks namely, CG Dhan1919, CG Devbhog, BPT 5204, Dubraj Sel.1 and Badshahbhog Sel.1 during *kharif,* 2023 in a randomized block design with two replications. Observations were recorded for different traits *viz*., days to 50% flowering, plant height (cm), panicle length (cm), number of effective tillers per plant, spikelet fertility (%), grain yield per plant (g), biological yield per plant (g), 100 seed weight (g) and harvest index (%). The statistical studies for the above characters were conducted in accordance with Miller (1958) formula to measure correlation coefficients analysis and Dewey and Lu (1959) for path analysis.

3. Result and Discussion

3.1 Correlation studies

Table 1 enlists the genotypic and phenotypic connection between yield and eight metric traits. Figs. 1 and 2 showed the genotypic and phenotypic correlation matrix, respectively. The correlation analysis revealed both positive and negative relationships among various traits, with significant associations that could be utilized for indirect selection in rice breeding programs.

Table 1: Genotypic and phenotypic correlation coefficients of yield and yield contributing characters

		1	2	3	4	5	6	7	8	9	10	11
1	G		0.889**	0.719**	0.522**	0.663**	-0.1601	0.571**	-0.870**	0.694**	-0.737**	-0.1159
	P		0.821**	0.584**	0.431**	0.615**	-0.1541	0.426**	-0.804**	0.626**	-0.663**	-0.0954
2	G			0.778**	0.291*	0.582**	-0.228*	0.566**	-0.831**	0.561**	-0.760**	-0.342**
	P			0.691**	0.276*	0.559**	-0.220*	0.419**	-0.783**	0.532**	-0.699**	-0.279*
3	G				0.162	0.657**	-0.0987	0.505**	-0.738**	0.417**	-0.603**	-0.241*
	P				0.213*	0.551**	-0.0687	0.239*	-0.620**	0.392**	-0.478**	-0.1044
4	G					0.395**	-0.0929	0.356**	-0.616**	0.441**	-0.252*	0.1399
	P					0.349**	-0.0569	0.1389	-0.521**	0.450**	-0.232*	0.1945
5	G						-0.1163	0.660**	-0.816**	0.513**	-0.343**	0.1547
	P						-0.1068	0.540**	-0.758**	0.475**	-0.317*	0.1472
6	G							-0.952**	0.1465	-0.330*	0.349**	0.1117
	P							-0.779**	0.1534	-0.300*	0.327*	0.1127
7	G								-0.595**	0.630**	-0.547**	-0.0094
	P								-0.463**	0.417**	-0.382**	-0.0486
8	G									-0.630**	0.569**	0.0448
	P									-0.568**	0.524**	0.0401
9	G										-0.666**	0.335*
	P										-0.644**	0.366**
10	G											0.431**
	P											0.422**
11	G											
	P											

Note: Name of traits

1. Days to 50% flowering	2. Plant height (cm)	3. Panicle length (cm)	4. Number of effective tillers	5. Number of filled grains per panicle	6. Number of unfilled grains per panicle
7. Spikelet fertility %	8. 100 seed weight (g)	9. Biological yield per plant (g)	10. Harvest index %	11. Grain yield per plant	

The character days to 50% flowering showed positive and highly significant genotypic and phenotypic correlation with plant height (0.889; 0.821), panicle length (0.719; 0.584), biological yield per plant (0.694; 0.626), number of filled grains per panicle (0.663; 0.615), spikelet fertility (0.571;0.426) and number of effective tillers (0.522; 0.431). In contrast, the trait exhibits significant and negative genotypic and phenotypic correlation with 100 seed weight (-0.87; -0.80) and harvest index (-0.73; -0.66). Similar results were found by Mahalakshmi *et al.* (2024) for plant height and panicle length, Faysal *et al*. (2022) for number of effective tillers and spikelet fertility.

The plant height had a highly significant positive correlation with panicle length (0.778; 0.691), number of filled grains per panicle (0.582; 0.559), spikelet fertility (0.566; 0.419), and biological yield (0.561; 0.532). The positive association between plant height and yield components suggests that taller plants tend to produce longer panicles and more spikelets. However, excessive plant height (semi dwarf type) can lead to lodging problems, so an optimal plant height should be maintained in breeding programs.

The traits number of filled grains per panicle (0.657; 0.551) and biological yield (0.417; 0.392), showed a positive and highly significant genotypic and phenotypic association with panicle length. In contrast, the trait exhibits highly significant and negative genotypic and phenotypic correlation with 100 seed weight (-0.783; -0.738), and harvest index (-0.603; -0.478). Demeke (2023) reported similar observations for harvest index and Sadimantara (2021) for number of filled grains per panicle.

The number of effective tillers per plant had a significant positive correlation with biological yield (0.441; 0.450) and number of filled grains per panicle (0.395; 0.349). This indicates that higher tillering capacity contributes to greater biomass production and grain yield, this is in accordance with the findings of Sadimantara *et al.* (2021). Spikelet fertility exhibited positive correlations with biological yield (0.630; 0.417), indicating that higher spikelet fertility enhances total grain production, this observation was in conformity with the findings of Yadav *et al.* (2024).

The grain trait like, 100-seed weight had a strong negative correlation with biological yield (-0.630; -0.568) and harvest index (-0.595; -0.463). This suggests that higher seed weight is associated with lower biomass production and harvest index this is accordance with the findings of Naik *et al.,* (2005) and Perween *et al.* (2020).

Biological yield had the strongest positive correlation with grain yield (0.335;0.366), confirming that plants with higher biomass tend to produce more grains, this aligns with the findings of Fentie *et al.* (2021). This suggests that selection for high biomass-producing genotypes would directly enhance grain yield. Whereas, harvest index showed a negative correlation with number of filled grains per panicle (-0.666; -0.644). This was in conformity with the findings of Singh *et al.* (2022).

Based on the magnitude of correlation coefficient values, harvest index and biological yield showed significant and positive correlation with grain yield per plant. Hence higher yield could be obtained by exerting selection pressure on any of these traits. A positive correlation between desirable traits is advantageous to the plant breeder since it facilitates the simultaneous improvement of both characters; conversely, a negative correlation will prevent both high-value characters from expressing themselves simultaneously. Similar results were recorded by Ramchander *et al.* (2014), Fentie *et al*. (2021), Faysal *et al*. (2022), Mandal *et al*. (2023) and Prasad *et al.* (2024), Dubey *et al*. (2018), Singh *et al.* (2022), Perween *et al.* (2020), Yadav *et al.* (2024), Roy *et al.* (2024) and Bandhe *et al*. (2023) in their respective study in rice breeding programmes. The path coefficient analysis is further done to ascertain the relative contribution of traits to grain through their direct and indirect contribution.

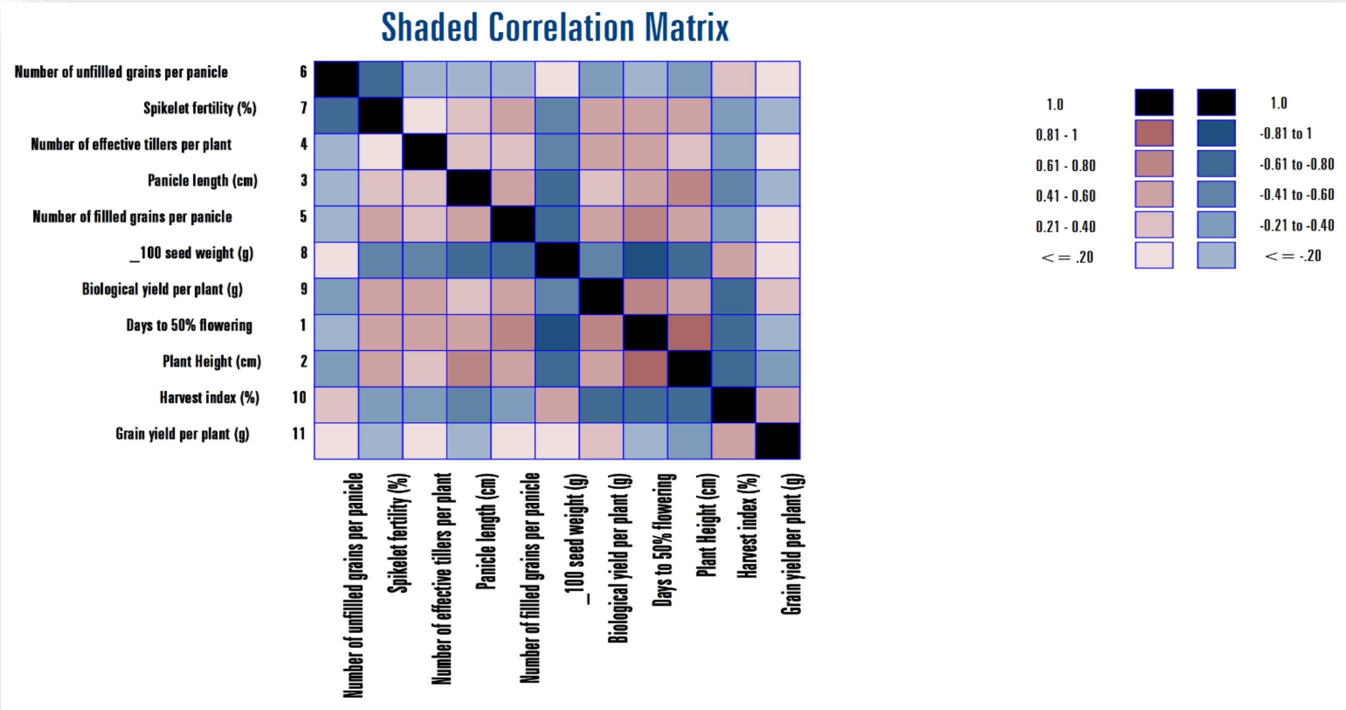

Fig 1: Phenotypic correlation shaded matrix for grain yield per plant.

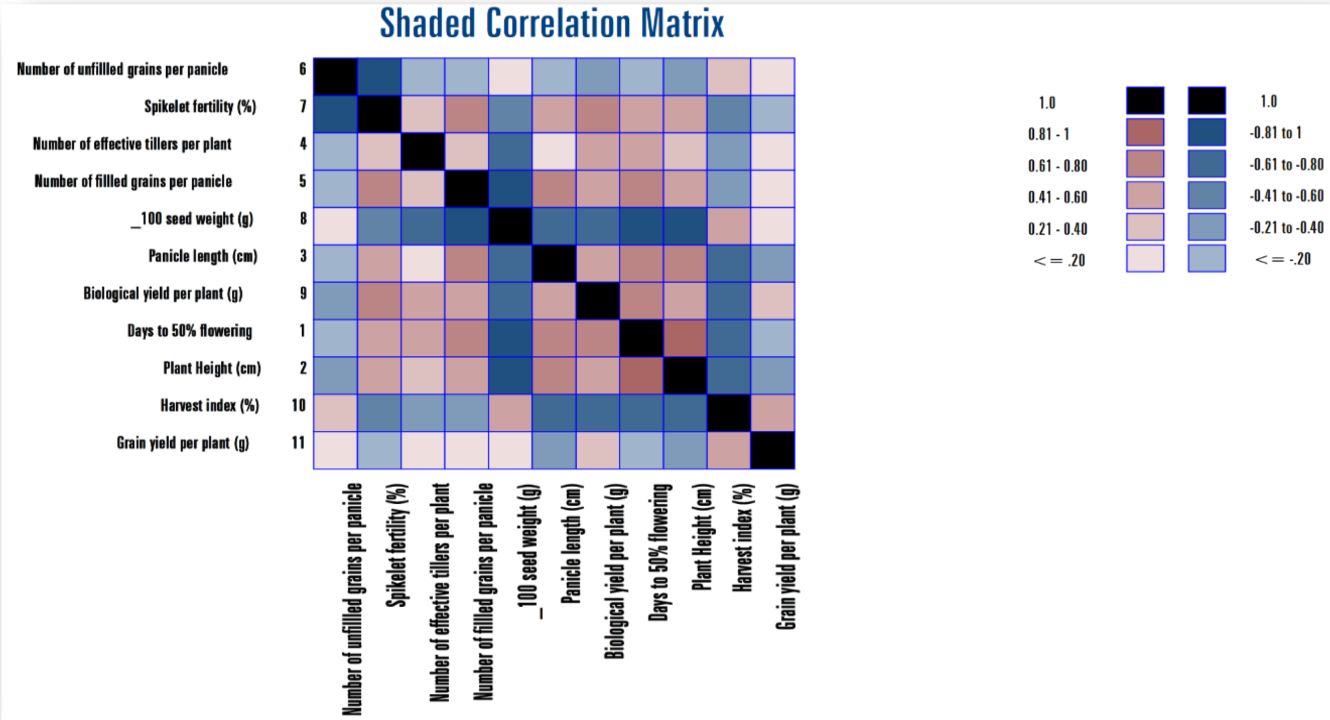

Fig 2: Genotypic correlation shaded matrix for grain yield per plant.

Path Analysis

The results of path analysis revealed significant direct and indirect effects of various traits on grain yield, providing valuable insights for selecting key yield-contributing traits in breeding programs. The direct and indirect values for path analysis are mentioned in Table 2.

Importance of Direct Effects on Grain Yield

The study identified biological yield per plant (1.148) and harvest index (1.08) as the two most influential traits with strong direct positive effects on grain yield. These results align with previous findings by Fentie *et al.* (2021) and Abd Rahman *et al*. (2011), who reported that biological yield significantly contributes to final grain production. The harvest index, which represents the efficiency of resource partitioning, was also observed to play a critical role, as supported by Sudeepthi *et al.* (2020). These two traits can be used as primary selection criteria in breeding programs aiming for higher grain yield.

In addition to biological yield and harvest index, 100 seed weight (0.287) and days to 50% flowering (0.245) exhibited significant direct positive effects on grain yield. A high 100 seed weight indicates enhanced productivity, which was similarly observed by Manivelan *et al.* (2022). Early flowering traits, as seen in Patil and Sahu (2009) and Saketh *et al.* (2023), have been linked to improved yield potential by ensuring better environmental adaptation. These traits should be prioritized in developing early-maturing, high-yielding rice varieties.

Role of Indirect Effects in Yield Determination

Several traits exhibited indirect effects on grain yield through their influence on other yield components. Days to 50% flowering had strong positive indirect effects on grain yield through plant height (0.219), panicle length (0.177), and number of filled grains per panicle (0.163). This suggests that early flowering plants might indirectly enhance yield by promoting better plant architecture and grain filling. Similar indirect contributions were reported by Saketh *et al.* (2023). Conversely, plant height (-0.284) had a negative direct effect on grain yield, although it positively influenced yield indirectly through 100 seed weight (0.236) and harvest index (0.215). This suggests that taller plants might not always be advantageous for grain yield, as they could lead to lodging, but their positive influence on certain other yield components helps compensate for the negative direct effect. Similar findings were reported by Bagheri *et al.* (2011).

Table 2: Direct and indirect effects of different yield contributing characters on grain yield

Genotypic Path Matrix											
	Days to 50% flowering	**Plant Height (cm)**	**Panicle length (cm)**	**Number of effective tillers per plant**	**Number of filled grains per panicle**	**Number of unfilled grains per panicle**	**Spikelet fertility (%)**	**100 seed weight (g)**	**Biological yield per plant (g)**	**Harvest index (%)**	**Grain yield per plant (gm)**
Days to 50% flowering	0.2465	0.2191	0.1774	0.1287	0.1635	-0.0395	0.1408	-0.2144	0.171	-0.1818	-0.1159
Plant Height (cm)	-0.2524	-0.284	-0.221	-0.0825	-0.1652	0.0646	-0.1606	0.2361	-0.1594	0.2157	-0.342**
Panicle length (cm)	0.0942	0.1019	0.1309	0.0212	0.0861	-0.0129	0.0661	-0.0967	0.0546	-0.079	-0.241*
Number of effective tillers per plant	-0.0106	-0.0059	-0.0033	-0.0203	-0.008	0.0019	-0.0072	0.0125	-0.0089	0.0051	0.1399
Number of filled grains per panicle	0.048	0.0421	0.0476	0.0286	0.0724	-0.0084	0.0478	-0.0591	0.0372	-0.0248	0.1547
Number of unfilled grains per panicle	-0.0185	-0.0263	-0.0114	-0.0107	-0.0134	0.1154	-0.1099	0.0169	-0.038	0.0403	0.1117
Spikelet fertility (%)	0.0313	0.031	0.0277	0.0195	0.0362	-0.0522	0.0549	-0.0327	0.0346	-0.03	-0.0094
100 seed weight (g)	-0.2499	-0.2389	-0.2122	-0.177	-0.2344	0.0421	-0.171	0.2873	-0.181	0.1635	0.0448
Biological yield per plant (g)	0.7966	0.6447	0.4786	0.5063	0.5897	-0.3785	0.724	-0.7236	1.1487	-0.765	0.335*
Harvest index (%)	-0.8012	-0.8253	-0.6553	-0.2739	-0.3722	0.3792	-0.5942	0.6184	-0.7237	1.0867	0.431**
Grain yield per plant (gm)	-0.1159	-0.342**	-0.241*	0.1399	0.1547	0.1117	-0.0094	0.0448	0.335*	0.431**	

Residual effectt= 0.277

Complex interactions among yield-contributing traits

The number of effective tillers per plant (-0.023) had a negligible negative direct effect on grain yield. However, it contributed positively through 100 seed weight (0.012) and harvest index (0.005). This suggests that an increase in tiller number does not directly boost yield, it may enhance grain weight and efficiency, leading to an overall positive impact. These findings corroborate previous research by Perween *et al.* (2020).

Spikelet fertility (0.054) had a small but positive direct effect on yield, as observed in studies by Kumar *et al.* (2024). This indicates that ensuring high spikelet fertility is crucial for grain set and yield improvement. Similarly, the number of unfilled grains per panicle (0.115) had a positive direct effect but negative indirect effects through spikelet fertility (-0.109) and biological yield (-0.038), suggesting that selecting for filled grains per panicle should be a priority over unfilled grains.

Residual Effect

The residual effect in this study was 0.277, indicating that while the selected traits explain a significant portion of the variation in grain yield, additional unexamined factors also contribute to yield determination. Traits such as root architecture, stress tolerance, and nutrient use efficiency may further explain the remaining variance, as suggested by Sudeepthi *et al.* (2020). Future studies should explore these factors to develop a better selection strategy.

The findings of this study reinforce the need for a multi-trait selection approach in rice breeding. The traits with strong direct effects (biological yield, harvest index, 100 seed weight, and days to 50% flowering) should be prioritized. Additionally, traits with significant indirect effects (plant height, panicle length, and number of filled grains per panicle) should also be considered to maximize yield improvement. Similar breeding strategies have been successfully applied in rice improvement programs by Babu *et al.* (2012), Maneesha *et al.* (2024) and Noatia *et al.* (2021).

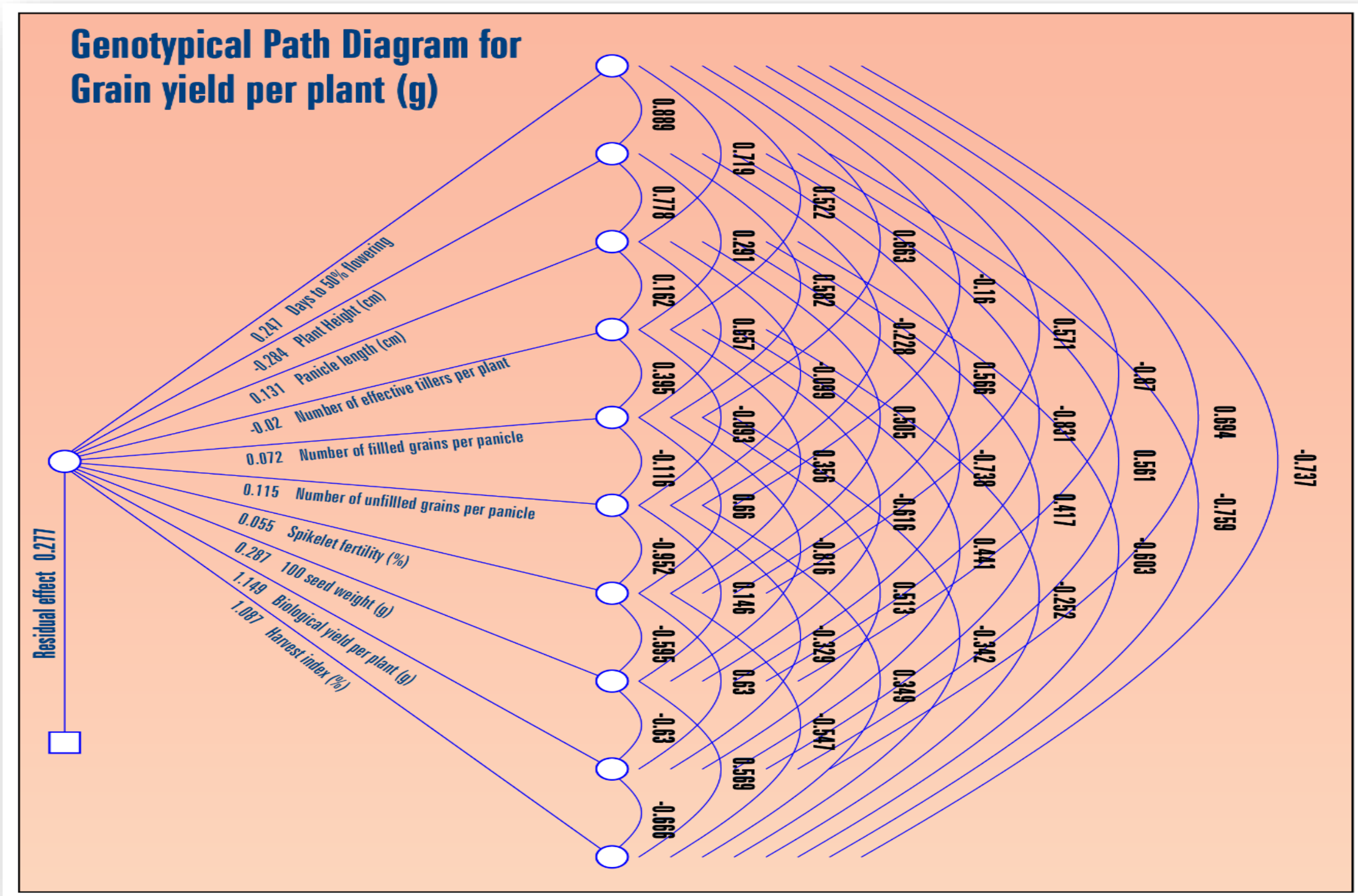

Fig 3: Genotypic path diagram for grain yield per plant

Conclusion

This study highlights the key yield-contributing traits in rice, revealing that biological yield, harvest index, 100 seed weight, days to 50% flowering, panicle length, and spikelet fertility have significant direct and indirect effects on grain yield. Among these, biological yield and harvest index exhibited the strongest direct positive effects, making them crucial selection criteria for breeding high-yielding rice varieties. Correlation analysis further confirmed the positive associations between panicle length, spikelet fertility, and number of filled grains per panicle with grain yield, while 100 seed weight showed a trade-off with biological yield and harvest index. Selection based on the traits such as biomass, harvest index, grain length, days to 50 % flowering, productive tiller, panicle length, and filled grain will therefore, be more beneficial and effective in rice breeding and yield enhancement programs for any activity aiming to increase grain output.

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