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Quantitative Trait Analysis and Path Coefficient Modeling for Yield Optimization in Rice (Oryza sativa L.) Restorer Lines

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ABSTRACT

This research focuses on the correlation and path coefficient analysis of 90 rice restorer lines *(Oryza sativa L.)* evaluated for 29 quantitative and qualitative traits to elucidate the key contributors to grain yield. The analysis revealed that traits such as panicle length, panicle index, productive tillers per plant, and harvest index exhibited a strong positive correlation with grain yield and exerted significant direct effects, making them reliable selection criteria for genetic improvement and hybrid breeding programs. In contrast, stem length displayed a significant negative correlation with grain yield at the genotypic level, while plant height showed negative direct effects, underscoring their limited relevance as indicators for yield enhancement. Furthermore, a negative association was observed between plant height, stem length, and several economic traits, including total tillers per plant, productive tillers per plant, 1000-grain weight, panicle index, and harvest index, at both genotypic and phenotypic levels. This association underscores the yield advantage of short-statured or dwarf genotypes, which are better suited for achieving higher grain yield. Notably, restorer lines with favourable traits, including total spikelets per panicle, fertile spikelets per panicle, and spikelet density percentage, were positively correlated with late maturity, indicating that late-maturing lines hold greater promise as superior restorers compared to early-maturing lines. Key traits identified for yield improvement include stem length, panicle length, panicle index, spikelet density percentage, productive tillers per plant, length-to-breadth ratio, harvest index, biological yield per plant, and decorticated grain width. These findings provide critical insights into the development of robust hybridization and breeding programs aimed at optimizing grain yield in rice.

Introduction

Rice (*Oryza sativa L.*) is a cornerstone of global food systems, particularly in Asia, where it has been a staple crop for millennia. As the primary caloric source for approximately half of the world's population, especially in Asian regions where it constitutes around 90% of dietary intake (Tiwari et al., 2021), rice plays a central role in ensuring food security. However, with the accelerating increase in global population and the mounting challenges posed by climate change, the need to enhance rice productivity has never been more urgent.

Compounding these challenges is the looming threat of water scarcity. Projections indicate that by 2025, nearly 20% of irrigated rice-growing areas could experience "physical

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water scarcity" (Surendran et al., 2021), significantly impacting rice yields. As such, the focus of rice improvement must extend beyond mere yield enhancement to encompass traits that influence crop resilience, water-use efficiency, and environmental adaptability. These efforts require a nuanced understanding of the genetic and phenotypic interrelationships among traits that contribute to rice yield.
Understanding the genetic correlations between agronomic traits is essential for efficient selection in breeding programs. Positive correlations between traits allow for concurrent improvement of multiple yield-contributing factors, while negative correlations highlight the trade-offs inherent in optimizing one trait at the expense of another. The ability to navigate these complex relationships is pivotal for selecting traits that maximize grain yield and overall productivity.

To achieve a deeper understanding of trait interactions, **path coefficient analysis** offers a sophisticated statistical approach for partitioning the correlation between traits into direct and indirect effects. This method allows for a clear delineation between the immediate influence of a trait on yield (direct effects) and its impact mediated through other traits (indirect effects). Path analysis is conducted at three distinct levels:

1. **Phenotypic Path Coefficients**: These represent the observable relationships between traits as influenced by both genetic factors and environmental conditions.
2. **Genotypic Path Coefficients**: These coefficients reflect the genetic associations between traits, isolating the influence of environmental factors.
3. **Environmental Path Coefficients**: These coefficients quantify the effects of environmental variables on trait relationships, independent of genetic influences.

By partitioning the total correlation into these components, path coefficient analysis provides a granular view of the direct and mediated effects of various traits on yield. This approach facilitates the identification of key traits that can be targeted for genetic enhancement. Genotypic effects, which tend to be more robust and stable than phenotypic effects, are particularly valuable in guiding selection strategies aimed at long-term yield improvement.

In this study, we employ correlation and path coefficient analyses to evaluate 90 rice restorer lines, focusing on 29 quantitative and qualitative traits. The objective is to elucidate the genetic and phenotypic relationships among these traits and to identify those most significantly associated with grain yield. By leveraging these insights, this research aims to inform the development of more effective hybridization strategies for rice breeding, thereby contributing to the optimization of rice productivity and its sustainability under changing global conditions.

Materials and Methods

The study was carried out at the Seed Breeding Farm, JNKVV, Jabalpur, as part of the Rice Improvement Project-2019, with lines seeded in Randomized Block Design (RBD). In terms of geography and fertility, the experimental region was relatively homogeneous. Crop protection methods were used during the crop growing phase, together with approved agronomic techniques, to ensure a satisfactory crop. The 90 restorer lines were planted in three replications, each with four rows, and five random plants from each replication were selected for twenty-nine quantitative features, namely, Days to panicle initiation (days), Days to 50% flowering (days), Flag leaf length (cm), Flag leaf width (cm), Stem length (cm), Stem thickness (mm), Plant height (cm), Number of tillers/plant, Number of productive tillers/plant, Panicle length (cm), Days to maturity (days), Total spikelets/panicle, Fertile spikelets/panicle, Grain length (mm), Grain breadth (mm), Thousand-grain weight (g), Decorticated grain length (mm), Decorticated grain breadth (mm), Length to breadth ratio of decorticated grain, Spikelet fertility (%), Spikelet density (%), Biological yield/plant (g), Panicle weight/plant (g), Panicle index (%), Harvest index (%), Hulling (%), Milling (%), Head rice recovery (%) and Grain yield/plant (g). Correlation coefficients were calculated for all quantitative characters' mean data exposed to combinations at the phenotypic, genotypic and environmental levels by the formula given by Miller et al. (1958).

$$r(XiXj) = \frac{Cov.(XiXj)}{\sqrt{Var(Xi)Var(Xj)}}$$

Where,

$r(X_iX_j)$ = Coefficient of correlation between characters X_i and X_j

$Cov\ (X_iX_j)$ = Covariance between characters X_i and X_j

$Var\ (X_i)$ = Variance of character X_i

$Var\ (X_j)$ = Variance of character X_j

The above formula was used to calculate genotypic, phenotypic, and environmental correlations by substituting corresponding variance and covariance. The estimation of covariance between two characteristics was obtained in the same way as the estimation of corresponding variance components was. Statistical analyses for the above characters were done following Singh and Chaudhary (1995) for correlation coefficient and Dewey and Lu (1959) for path analysis.aPath coefficients were rated based on the scales given below

Value of direct or indirect effect	Rate or Scale
>1.00	Very high
0.3-0.99	High
0.2-0.29	Moderate
0.1-0.19	Low
0.0-0.09	Negligible

Results and Discussion

Effective selection in breeding programs requires a comprehensive understanding of the relationships between yield and its associated traits, particularly their genetic basis.

Correlation Analysis

Phenotypic and genotypic correlations were analyzed with grain yield per plant as the dependent variable. The genotypic correlation coefficients were consistently higher than the phenotypic values, indicating that genetic factors primarily drive the observed relationships. Grain yield showed significant positive correlations with panicle index, harvest index, fertile spikelets per panicle, 1000-grain weight, productive tillers, panicle weight, panicle length, and total spikelets per panicle. These findings align with previous studies (Ashfaq et al., 2012; Guru et al., 2016; Kumar et al., 2018), highlighting the importance of these traits for improving yield in rice restorer lines.

At the phenotypic level, no traits exhibited negative correlations with yield. However, at the genotypic level, traits such as days to 50% flowering, days to maturity, flag leaf length, and stem length showed significant negative associations, suggesting they are not ideal for direct selection for yield improvement.

Panicle index (PI) and harvest index (HI) were positively associated with head rice recovery, though HI negatively correlated with grain width, indicating that larger grain size could reduce yield-contributing traits. Days to 50% flowering and maturity were positively correlated with yield-related traits, reinforcing the potential benefits of late-maturing lines as superior restorers.

The total number of tillers per plant showed a strong positive correlation with productive tillers and other yield-contributing traits, such as panicle length and panicle weight. Negative associations with plant height and stem length support the advantage of dwarf plants, which contribute to higher grain yield, consistent with Bhutta et al. (2019).

Additionally, a significant positive relationship was observed between panicle length and panicle weight per plant. The negative correlation between plant height and yield, linked to excess vegetative growth and increased lodging susceptibility, underscores the benefit of selecting shorter-statured varieties for improved yield stability (Roy et al., 2015).

Path Coefficient Analysis

To further elucidate the contribution of traits to grain yield, genotypic correlations were decomposed into direct and indirect effects using path coefficient analysis (Wright, 1921). This analysis allows for a clearer understanding of cause-effect relationships between traits (Tables 3 and 4).

The traits exhibiting the highest direct positive effects on grain yield per plant were stem length, followed by panicle length, panicle index, spikelet density percentage, productive tillers per plant, length-to-breadth ratio, harvest index, biological yield per plant, and decorticated grain width. However, stem length was not identified as a reliable selection criterion for high-yielding genotypes, which aligns with Dongre et al. (2014) for stem length and Selvaraj et al. (2011) for panicle length. Contradictory results were reported by Sohgaura et al. (2014) and others for panicle index and by Govindraj et al. (2018) and Bhuj et al. (2018) for thousand-seed weight.

Negative direct effects were observed for plant height, panicle weight per plant, total spikelets per plant, number of panicles per plant, total tillers per plant, and decorticated grain length, suggesting these traits are not optimal for yield improvement. The negative direct effect of plant height corroborates the findings of Akhter et al. (2011).

Panicle length had a strong positive indirect effect on grain yield via panicle weight per plant and the number of panicles per plant. Similarly, panicle index positively influenced grain yield through harvest index. Traits like fertile spikelets per plant and total productive tillers showed substantial positive indirect effects via total tillers per plant and panicle number. These findings highlight key traits to focus on for improving yield through indirect pathways.

Conclusion

The partitioning of correlation values in this study revealed that certain traits failed to establish a significant correlation with single-plant yield, likely due to substantial negative direct effects or minimal positive direct impacts. However, a thorough analysis of trait associations and path coefficients identified panicle length, panicle index, productive tillers per plant, and harvest index as key traits with both strong positive correlations and significant direct effects on yield. These traits emerge as critical determinants for yield improvement and provide a robust foundation for the development of high-yielding hybridization strategies. By focusing on these promising traits, breeding programs can be more effectively tailored to enhance grain yield in rice, optimizing productivity in both conventional and advanced breeding systems.

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APPENDIX

Table 1: Estimation of Genotypic and Phenotypic correlation of various yield attributing traits on grain yield

		DFF	DTM	FLL	FLW	TT/P	PT/P	ST	SL	PH	Pa/Pl	PL	BY/Pl	PaWt/Pl	Fsp/pa	TSp/pa
DFF	P	1.00	0.25**	0.05	-0.11	0.01	0.00	-0.04	0.1758**	0.1858**	0.01	0.09	0.15**	0.09	0.21**	0.218**
	G	1.00	0.27	0.07	-0.13	0.03	0.02	-0.05	0.19	0.20	0.02	0.11	0.19	0.11	0.22	0.23
DTM	P		1.00	-0.02	0.03	-0.1833**	-0.1930**	0.02	0.08	0.08	-0.2043**	0.05	0.08	0.05	0.1452*	0.1926**
	G		1.00	-0.01	0.03	-0.22	-0.25	0.03	0.08	0.09	-0.25	0.06	0.09	0.06	0.15	0.20
FLL	P			1.00	0.44**	-0.10	-0.08	-0.05	0.46**	0.4658**	-0.08	0.12	0.08	0.12	-0.09	-0.05
	G			1.00	0.63	-0.15	-0.13	-0.05	0.67	0.69	-0.11	0.24	0.16	0.24	-0.12	-0.07
FLW	P				1.00	-0.264	-0.2180**	0.1655**	0.2660**	0.2558**	-0.2385**	-0.02	0.12	-0.02	-0.1265*	-0.1313*
	G				1.00	-0.32	-0.29	0.23	0.35	0.35	-0.32	0.02	0.20	0.02	-0.14	-0.15
TT/P	P					1.00	0.9508**	-0.11	-0.1742**	-0.1438*	0.9277**	0.1578**	0.10	0.1576**	-0.1194*	-0.11
	G					1.00	0.98	-0.17	-0.20	-0.16	0.95	0.27	-0.09	0.27	-0.14	-0.12
PT/P	P						1.00	-0.12	-0.1707**	-0.1435*	0.9578**	0.1388*	0.1391*	0.1390*	-0.11	-0.10
	G						1.00	-0.17	-0.20	-0.16	0.98	0.27	-0.07	0.27	-0.13	-0.12
ST	P							1.00	-0.1483*	-0.1404*	-0.1495*	0.02	0.240**	0.02	0.2036**	0.1718**
	G							1.00	-0.21	-0.21	-0.17	0.03	0.39	0.03	0.25	0.21
SL	P								1.00	0.9872**	-0.1707**	0.10	0.10	0.10	-0.04	-0.04
	G								1.00	0.99	-0.19	0.08	0.11	0.08	-0.04	-0.04
PH	P									1.00	-0.1392*	0.2564**	0.10	0.2569**	-0.04	-0.06
	G									1.00	-0.15	0.22	0.12	0.22	-0.04	-0.06
Pa/Pl	P										1.00	0.1656**	0.11	0.1656**	-0.1305*	-0.1210*
	G										1.00	0.28	-0.12	0.28	-0.16	-0.14
PL	P											1.00	0.04	0.9998**	0.03	-0.12
	G											1.00	0.05	1.00	-0.03	-0.14
BY/Pl	P												1.00	0.04	0.1875**	0.1393*
	G												1.00	0.05	0.24	0.18
PaWt/Pl	P													1.00	-0.03	-0.12
	G													1.00	-0.04	-0.14

Fsp/pa	P														1.00	0.9226**
	G														1.00	0.92
TSp/pa	P															1.00
	G															1.00
Gy/Pl	P	0.02	-0.09	-0.06	-0.10	0.34	0.34	0.04	-0.06	-0.01	0.34	0.33	0.18	0.33	0.35	0.28
	G	0.03	-0.12	-0.11	-0.14	0.37	0.36	0.10	-0.10	-0.04	0.34	0.40	0.19	0.40	0.44	0.34

Table 2: Estimation of Genotypic and Phenotypic correlation of various yield attributing traits on grain yield (Cont…)

		SF%	SD%	ThSWt.	PI	HI	GL	GW	DGL	DGW	L/B	H%	M%	HRR %
DFF	P	-0.03	0.1990**	-0.2258***	0.00	-0.1381*	0.00	-0.07	-0.09	-0.137*	0.03	-0.07	0.06	0.03
	G	-0.03	0.21	-0.24	0.01	-0.14	-0.01	-0.08	-0.09	-0.16	0.04	-0.07	0.07	0.03
DTM	P	-0.1472*	0.1891**	-0.2760***	-0.11	-0.1343*	-0.1520*	0.04	-0.2823***	-0.1402*	-0.09	0.1436*	0.1506*	0.07
	G	-0.15	0.19	-0.29	-0.14	-0.14	-0.16	0.05	-0.29	-0.17	-0.09	0.17	0.18	0.07
FLL	P	-0.04	-0.06	-0.08	-0.09	-0.1522*	-0.1499*	0.04	-0.04	0.06	-0.07	-0.09	-0.10	0.01
	G	-0.07	-0.10	-0.10	-0.19	-0.25	-0.22	0.09	-0.05	0.15	-0.14	-0.16	-0.16	0.02
FLW	P	0.02	-0.1240*	0.08	-0.09	-0.1826**	-0.08	0.06	-0.07	0.2541***	-0.2004***	0.02	-0.01	0.02
	G	0.02	-0.15	0.10	-0.15	-0.23	-0.09	0.08	-0.09	0.31	-0.24	0.05	0.00	0.02
TT/P	P	0.01	-0.1331*	-0.08	0.2988***	0.1438*	0.2050***	-0.04	0.07	-0.12	0.1282*	0.02	0.08	0.10
	G	0.00	-0.16	-0.08	0.31	0.21	0.26	-0.08	0.08	-0.15	0.15	0.04	0.12	0.18
PT/P	P	0.02	-0.1263*	-0.07	0.3125***	0.1253*	0.1852**	-0.01	0.07	-0.11	0.1271*	-0.02	0.05	0.09
	G	0.01	-0.17	-0.07	0.29	0.20	0.25	-0.04	0.09	-0.13	0.14	-0.02	0.07	0.18
ST	P	-0.01	0.1558*	0.07	0.02	-0.1346*	0.00	0.04	0.00	0.2675***	-0.1924**	0.11	0.08	0.1443*
	G	-0.01	0.19	0.09	0.08	-0.17	0.02	0.06	0.00	0.29	-0.20	0.17	0.09	0.19
SL	P	0.1437*	-0.06	-0.04	-0.07	-0.1870**	-0.12	0.03	-0.02	0.09	-0.07	-0.04	-0.09	-0.03
	G	0.15	-0.05	-0.04	-0.10	-0.20	-0.12	0.04	-0.02	0.09	-0.07	-0.06	-0.12	-0.05
PH	P	0.1772**	-0.11	-0.01	-0.07	-0.1430*	-0.09	0.02	0.02	0.08	-0.04	-0.03	-0.08	-0.02
	G	0.19	-0.10	-0.01	-0.09	-0.16	-0.09	0.03	0.03	0.09	-0.03	-0.05	-0.11	-0.03
Pa/Pl	P	0.01	-0.1483*	-0.07	0.3026***	0.1576**	0.1206*	-0.04	0.09	-0.10	0.1291*	-0.04	0.05	0.08
	G	0.00	-0.18	-0.07	0.26	0.23	0.16	-0.09	0.11	-0.11	0.14	-0.03	0.06	0.15

PL	P	0.2340**	-0.3215***	0.1220*	-0.02	0.2408***	0.1650**	-0.06	0.2687***	-0.01	0.1713**	0.03	0.04	0.07
	G	0.28	-0.32	0.15	0.03	0.28	0.19	-0.06	0.33	-0.01	0.21	0.04	0.04	0.12
BY/Pl	P	0.10	0.12	-0.06	0.1753**	-0.5674***	-0.04	0.2309***	-0.07	0.07	-0.08	-0.10	-0.01	-0.11
	G	0.11	0.16	-0.06	0.19	-0.61	-0.03	0.27	-0.09	0.11	-0.13	-0.16	-0.02	-0.12
PaWt/Pl	P	0.2356**	-0.3230***	0.1236*	-0.02	0.2409***	0.1648**	-0.06	0.269***	-0.01	0.1717**	0.03	0.04	0.07
	G	0.29	-0.32	0.15	0.03	0.28	0.19	-0.06	0.33	0.00	0.21	0.04	0.04	0.12
Fsp/pa	P	-0.03	0.8735***	-0.2323***	0.3837***	0.1509*	-0.1938**	-0.1297*	-0.1773**	-0.05	-0.10	0.04	0.1261*	0.08
	G	-0.03	0.88	-0.24	0.50	0.16	-0.20	-0.14	-0.18	-0.05	-0.11	0.04	0.14	0.09
TSp/pa	P	-0.3877**	0.9736***	-0.3290***	0.3331***	0.11	-0.2347***	-0.1373*	-0.2352***	-0.03	-0.1474*	0.01	0.08	0.02
	G	-0.39	0.98	-0.34	0.44	0.12	-0.24	-0.15	-0.24	-0.03	-0.16	0.01	0.09	0.03
SF%	P	1.00	-0.4273***	0.2958***	0.10	0.08	0.1396*	0.06	0.1543*	-0.01	0.09	0.05	0.03	0.11
	G	1.00	-0.43	0.31	0.14	0.09	0.14	0.06	0.16	-0.01	0.09	0.06	0.04	0.13
SD%	P		1.00	-0.3452***	0.3222***	0.06	-0.2519***	-0.12	-0.2798***	-0.02	-0.1761**	0.01	0.07	0.01
	G		1.00	-0.36	0.41	0.06	-0.26	-0.13	-0.29	-0.02	-0.19	0.00	0.08	0.00
ThSWt.	P			1.00	0.3145***	0.3384***	0.2901***	0.2077***	0.3507***	0.3764***	-0.02	-0.12	-0.1525*	-0.04
	G			1.00	0.42	0.35	0.30	0.23	0.36	0.42	-0.02	-0.14	-0.18	-0.05
PI	P				1.00	0.4016***	0.03	0.03	0.03	0.1597**	-0.09	-0.04	0.01	0.1664**
	G				1.00	0.51	0.05	0.07	0.06	0.22	-0.11	-0.06	0.04	0.21
HI	P					1.00	0.12	-0.1687**	0.2294***	0.03	0.12	0.02	-0.02	0.1371*
	G					1.00	0.12	-0.19	0.24	0.03	0.13	0.03	-0.02	0.15
GL	P						1.00	-0.06	0.5011***	-0.1739**	0.4910***	-0.03	-0.08	-0.05
	G						1.00	-0.05	0.52	-0.18	0.52	-0.04	-0.09	-0.05
GW	P							1.00	-0.05	0.2792***	-0.2308***	-0.03	-0.07	0.00
	G							1.00	-0.07	0.33	-0.27	-0.07	-0.09	0.02
DGL	P								1.00	-0.03	0.7223***	-0.1244*	-0.1388*	-0.07
	G								1.00	-0.03	0.75	-0.14	-0.15	-0.07
DGW	P									1.00	-0.6985***	-0.01	-0.02	0.11
	G									1.00	-0.67	-0.03	-0.02	0.14

L/B	P										1.00	-0.10	-0.10	-0.1527*
	G										1.00	-0.10	-0.11	-0.17
H%	P											1.00	0.7531***	0.5182***
	G											1.00	0.76	0.58
M%	P												1.00	0.5101***
	G												1.00	0.57
HRR %	P													1.00
	G													1.00
Gy/Pl	P	0.17	0.19	0.35	0.93	0.48	0.09	0.02	0.12	0.15	-0.03	-0.02	0.02	0.18
	G	0.22	0.25	0.45	0.93	0.59	0.11	0.05	0.18	0.20	-0.02	-0.04	0.04	0.23

Table 3: Estimation of Genotypic and Phenotypic Path coefficient showing direct and indirect effect of various component on grain yeild

		DFF	DTM	FLL	FLW	TT/P	PT/P	ST	SL	PH	Pa/Pl	PL	BY/Pl	PaWt/Pl	Fsp/pa	TSp/pa
DFF	G	-0.0049	-0.0013	-0.0004	0.0007	-0.0001	-0.0001	0.0002	-0.0009	-0.001	-0.0001	-0.0005	-0.0009	-0.0005	-0.0011	-0.0011
	P	0.0032	0.0008	0.0002	-0.0003	0	0	-0.0001	0.0006	0.0006	0	0.0003	0.0005	0.0003	0.0007	0.0007
DTM	G	-0.0034	-0.0128	0.0001	-0.0003	0.0028	0.0032	-0.0003	-0.001	-0.0011	0.0032	-0.0007	-0.0012	-0.0007	-0.0019	-0.0025
	P	-0.0027	-0.0106	0.0002	-0.0003	0.0019	0.0021	-0.0002	-0.0008	-0.0009	0.0022	-0.0005	-0.0009	-0.0005	-0.0015	-0.002
FLL	G	0.0014	-0.0001	0.0182	0.0115	-0.0027	-0.0023	-0.0009	0.0122	0.0126	-0.0021	0.0043	0.0029	0.0043	-0.0022	-0.0012
	P	-0.0003	0.0001	-0.0055	-0.0024	0.0006	0.0005	0.0003	-0.0025	-0.0026	0.0004	-0.0006	-0.0004	-0.0006	0.0005	0.0003
FLW	G	0.0036	-0.0007	-0.0167	-0.0265	0.0085	0.0078	-0.0062	-0.0093	-0.0092	0.0085	-0.0006	-0.0052	-0.0006	0.0038	0.0039
	P	0	0	0.0001	0.0002	-0.0001	0	0	0.0001	0.0001	0	0	0	0	0	0
TT/P	G	-0.0048	0.036	0.0241	0.0527	-0.1647	-0.1619	0.0277	0.0327	0.0257	-0.1565	-0.0442	0.0152	-0.0442	0.023	0.0202
	P	0	0.0003	0.0002	0.0004	-0.0016	-0.0015	0.0002	0.0003	0.0002	-0.0015	-0.0003	-0.0002	-0.0003	0.0002	0.0002
PT/P	G	0.0087	-0.0964	-0.049	-0.1141	0.3822	0.3888	-0.0662	-0.0771	-0.0604	0.3815	0.1056	-0.0277	0.1054	-0.0513	-0.0481
	P	0	-0.0016	-0.0007	-0.0018	0.0078	0.0082	-0.001	-0.0014	-0.0012	0.0078	0.0011	0.0011	0.0011	-0.0009	-0.0008
ST	G	0.0003	-0.0002	0.0003	-0.0014	0.001	0.0011	-0.0062	0.0013	0.0013	0.0011	-0.0002	-0.0024	-0.0002	-0.0015	-0.0013
	P	-0.0003	0.0002	-0.0004	0.0013	-0.0009	-0.0009	0.0079	-0.0012	-0.0011	-0.0012	0.0002	0.0019	0.0002	0.0016	0.0014

SL	G	17.9225	7.5129	63.571	33.3952	-18.8032	-18.7888	-20.3474	94.6921	93.7271	-18.2328	7.47	10.7995	7.5167	-3.4131	-4.1
	P	-6.2732	-2.6871	-16.417	-9.4884	6.2142	6.0884	5.2918	-35.6737	-35.2156	6.0913	-3.5223	-3.4014	-3.5414	1.2907	1.5489
PH	G	-19.4226	-8.2878	-66.8945	-33.7399	15.0949	15.0355	19.916	-95.8126	-96.799	14.3503	-21.2992	-11.4709	-21.346	3.8968	6.0557
	P	6.8179	2.9627	17.0963	9.3884	-5.2793	-5.2653	-5.1517	36.2312	36.7025	-5.1102	9.4116	3.661	9.4296	-1.4462	-2.2315
Pa/Pl	G	-0.0046	0.0465	0.0215	0.0604	-0.1779	-0.1838	0.0327	0.0361	0.0278	-0.1873	-0.0526	0.0226	-0.0525	0.0296	0.027
	P	-0.0001	0.002	0.0008	0.0023	-0.0091	-0.0094	0.0015	0.0017	0.0014	-0.0098	-0.0016	-0.001	-0.0016	0.0013	0.0012
PL	G	1.6231	0.8369	3.5869	0.3613	4.0324	4.0796	0.4747	1.1847	3.3044	4.2205	15.0175	0.7233	15.0176	-0.5231	-2.1205
	P	-0.5422	-0.2734	-0.6818	0.093	-0.9183	-0.8078	-0.1343	-0.5745	-1.492	-0.9636	-5.8183	-0.2579	-5.8172	0.1541	0.6744
BY/Pl	G	0.0276	0.0133	0.0234	0.0282	-0.0134	-0.0103	0.0562	0.0165	0.0171	-0.0175	0.007	0.1446	0.0071	0.0344	0.0264
	P	0.0053	0.0028	0.0026	0.004	0.0035	0.0047	0.0082	0.0032	0.0034	0.0036	0.0015	0.0339	0.0015	0.0064	0.0047
PaWt/Pl	G	-0.0824	-0.0426	-0.1829	-0.0179	-0.2066	-0.2086	-0.0238	-0.0611	-0.1696	-0.2157	-0.7693	-0.0375	-0.7693	0.0279	0.11
	P	0.0211	0.0106	0.0266	-0.0036	0.0361	0.0318	0.0053	0.0227	0.0588	0.0379	0.2289	0.0102	0.229	-0.0063	-0.0269
Fsp/pa	G	-0.0016	-0.0011	0.0009	0.001	0.001	0.0009	-0.0018	0.0003	0.0003	0.0011	0.0002	-0.0017	0.0003	-0.0071	-0.0066
	P	-0.0024	-0.0016	0.001	0.0014	0.0013	0.0012	-0.0023	0.0004	0.0004	0.0014	0.0003	-0.0021	0.0003	-0.0111	-0.0102
TSp/pa	G	-0.1134	-0.0986	0.0338	0.0741	0.0613	0.0621	-0.1039	0.0217	0.0314	0.0721	0.0708	-0.0914	0.0717	-0.4623	-0.5011
	P	0.0415	0.0366	-0.0095	-0.0249	-0.0204	-0.0192	0.0326	-0.0082	-0.0115	-0.023	-0.022	0.0265	-0.0223	0.1752	0.1899
SF%	G	0	0.0002	0.0001	0	0	0	0	-0.0002	-0.0003	0	-0.0004	-0.0002	-0.0004	0	0.0006
	P	0.0003	0.0018	0.0005	-0.0003	-0.0001	-0.0002	0.0001	-0.0017	-0.0021	-0.0002	-0.0028	-0.0012	-0.0028	0.0004	0.0047
SD%	G	0.1167	0.1085	-0.0544	-0.0849	-0.0888	-0.0921	0.1075	-0.0302	-0.0546	-0.1024	-0.1758	0.0869	-0.1768	0.49	0.5463
	P	-0.0381	-0.0362	0.0123	0.0237	0.0255	0.0242	-0.0298	0.0114	0.0209	0.0284	0.0615	-0.0221	0.0618	-0.1671	-0.1863
ThSWt.	G	-0.0223	-0.0269	-0.0099	0.0095	-0.0072	-0.0066	0.0084	-0.0034	-0.0013	-0.0068	0.0141	-0.006	0.0143	-0.0222	-0.0316
	P	-0.0035	-0.0042	-0.0012	0.0012	-0.0012	-0.0011	0.0011	-0.0005	-0.0002	-0.0011	0.0019	-0.001	0.0019	-0.0036	-0.0051
PI	G	0.0091	-0.1093	-0.146	-0.1148	0.2332	0.2213	0.059	-0.073	-0.0682	0.1989	0.0227	0.1445	0.0228	0.3828	0.3313
	P	-0.001	-0.0966	-0.0825	-0.085	0.2736	0.2861	0.0216	-0.0652	-0.0664	0.2771	-0.0189	0.1606	-0.0184	0.3514	0.305

HI	G	-0.0212	-0.0213	-0.0369	-0.0344	0.0309	0.0299	-0.0259	-0.0305	-0.0238	0.0339	0.0427	-0.091	0.0427	0.0234	0.0173
	P	-0.0062	-0.0061	-0.0069	-0.0082	0.0065	0.0057	-0.0061	-0.0084	-0.0064	0.0071	0.0109	-0.0256	0.0109	0.0068	0.0051
GL	G	0.0003	0.0096	0.0135	0.0055	-0.0158	-0.0151	-0.001	0.0075	0.0057	-0.0097	-0.0117	0.0018	-0.0117	0.0121	0.0146
	P	0	0.0023	0.0023	0.0013	-0.0031	-0.0028	0	0.0018	0.0013	-0.0019	-0.0025	0.0006	-0.0025	0.003	0.0036
GW	G	0.0013	-0.0008	-0.0015	-0.0014	0.0014	0.0007	-0.0009	-0.0006	-0.0004	0.0015	0.001	-0.0045	0.0009	0.0023	0.0024
	P	-0.0006	0.0003	0.0004	0.0005	-0.0003	-0.0001	0.0003	0.0003	0.0002	-0.0003	-0.0005	0.0018	-0.0005	-0.001	-0.0011
DGL	G	0.0127	0.0414	0.0068	0.0124	-0.0116	-0.013	-0.0002	0.0023	-0.0045	-0.0159	-0.0467	0.0121	-0.0468	0.0254	0.0337
	P	0.0006	0.0018	0.0002	0.0004	-0.0004	-0.0005	0	0.0001	-0.0002	-0.0006	-0.0017	0.0004	-0.0017	0.0011	0.0015
DGW	G	-0.0159	-0.0168	0.0154	0.0313	-0.0151	-0.0129	0.0296	0.0094	0.0091	-0.0115	-0.0005	0.0112	-0.0005	-0.0051	-0.0029
	P	0.001	0.001	-0.0005	-0.0019	0.0009	0.0008	-0.002	-0.0006	-0.0006	0.0008	0.0001	-0.0005	0.0001	0.0003	0.0002
L/B	G	0.0068	-0.0176	-0.027	-0.0476	0.0292	0.0279	-0.0399	-0.0129	-0.0068	0.0276	0.0404	-0.0248	0.0403	-0.0209	-0.0304
	P	0.0002	-0.0005	-0.0004	-0.001	0.0007	0.0006	-0.001	-0.0003	-0.0002	0.0007	0.0009	-0.004	0.0009	-0.0005	-0.0008
H%	G	-0.0031	0.0077	-0.0072	0.0022	0.0017	-0.0009	0.0076	-0.0027	-0.0023	-0.0016	0.0019	-0.007	0.0019	0.0018	0.0004
	P	-0.0012	0.0026	-0.0016	0.0003	0.0004	-0.0004	0.0021	-0.0007	-0.0006	-0.0007	0.0005	-0.0018	0.0005	0.0007	0.0003
M%	G	-0.0006	-0.0015	0.0013	0	-0.001	-0.0006	-0.0008	0.001	0.0009	-0.0005	-0.0003	0.0001	-0.0003	-0.0012	-0.0007
	P	-0.001	-0.0026	0.0018	0.0003	-0.0014	-0.0008	-0.0014	0.0015	0.0013	-0.0008	-0.0006	0.0002	-0.0006	-0.0022	-0.0014
HRR %	G	0.0002	0.0004	0.0001	0.0001	0.0012	0.0011	0.0012	-0.0003	-0.0002	0.0009	0.0008	-0.0008	0.0008	0.0006	0.0002
	P	0.0001	0.0001	0	0	0.0002	0.0002	0.0003	-0.0001	0	0.0002	0.0001	-0.0002	0.0001	0.0002	0.0001
GY/Pl	G	0.0334	-0.1223	-0.1089	-0.1372	0.3734	0.3626	0.0956	-0.0982	-0.0396	0.3408	0.3958	0.1916	0.396	0.4408	0.342
	P	0.0184	-0.0942	-0.0625	-0.0995	0.3367	0.3442	0.0434	-0.0648	-0.0104	0.3439	0.3271	0.1821	0.3277	0.3541	0.2761

Table 4: Estimation of Genotypic and Phenotypic Path coefficient showing direct and indirect effect of various component on grain yield (Cont…)

			SF%	**SD%**	**ThS Wt.**	**PI**	**HI**	**GL**	**GW**	**DGL**	**DGW**	**L/B**	**H%**	**M%**	**HRR %**
DFF	G	Genotypic	0.0001	-0.001	0.0012	-0.0001	0.0007	0	0.0004	0.0004	0.0008	-0.0002	0.0003	-0.0003	-0.0002
	P	Phenotypic	-0.0001	0.0006	-0.0007	0	-0.0004	0	-0.0002	-0.0003	-0.0004	0.0001	-0.0002	0.0002	0.0001
DTM	G	Genotypic	0.0019	-0.0025	0.0036	0.0018	0.0018	0.002	-0.0006	0.0037	0.0021	0.0011	-0.0022	-0.0023	-0.0009
	P	Phenotypic	0.0016	-0.002	0.0029	0.0011	0.0014	0.0016	-0.0005	0.003	0.0015	0.001	-0.0015	-0.0016	-0.0007
FLL	G	Genotypic	-0.0012	-0.0018	-0.0019	-0.0035	-0.0045	-0.004	0.0017	-0.0009	0.0028	-0.0025	-0.0029	-0.0029	0.0003
	P	Phenotypic	0.0002	0.0004	0.0004	0.0005	0.0008	0.0008	-0.0002	0.0002	-0.0003	0.0004	0.0005	0.0006	-0.0001
FLW	G	Genotypic	-0.0004	0.004	-0.0027	0.004	0.0061	0.0024	-0.0022	0.0023	-0.0082	0.0064	-0.0013	-0.0001	-0.0006
	P	Phenotypic	0	0	0	0	0	0	0	0	0.0001	0	0	0	0
TT/P	G	Genotypic	-0.0002	0.0263	0.0126	-0.0506	-0.0339	-0.0427	0.0139	-0.0136	0.0245	-0.0246	-0.0063	-0.0194	-0.0298
	P	Phenotypic	0	0.0002	0.0001	-0.0005	-0.0002	-0.0003	0.0001	-0.0001	0.0002	-0.0002	0	-0.0001	-0.0002
PT/P	G	Genotypic	0.0024	-0.0643	-0.0271	0.1133	0.0773	0.0965	-0.0168	0.0359	-0.0497	0.0555	-0.0077	0.0253	0.0688
	P	Phenotypic	0.0001	-0.001	-0.0006	0.0025	0.001	0.0015	-0.0001	0.0006	-0.0009	0.001	-0.0002	0.0004	0.0007
ST	G	Genotypic	0.0001	-0.0012	-0.0006	-0.0005	0.0011	-0.0001	-0.0004	0	-0.0018	0.0013	-0.001	-0.0006	-0.0012
	P	Phenotypic	-0.0001	0.0012	0.0005	0.0002	-0.0011	0	0.0003	0	0.0021	-0.0015	0.0009	0.0007	0.0011

SL	G	Genotypic	14.2486	-5.1307	-3.4091	-9.1051	-19.2604	-11.7002	3.3707	-1.5151	8.7529	-6.2246	-5.6079	-11.0539	-4.5241
	P	Phenotypic	-5.1262	2.1224	1.257	2.5399	6.6693	4.1676	-1.2017	0.7067	-3.0391	2.3198	1.4561	3.0449	1.0265
PH	G	Genotypic	-18.1679	9.4993	1.3464	8.6939	15.3329	9.0345	-2.5618	-3.064	-8.6829	3.3682	5.0192	10.5189	2.8301
	P	Phenotypic	6.5022	-4.0158	-0.5376	-2.6598	-5.247	-3.1911	0.8593	0.8774	2.9544	-1.3084	-1.2798	-2.8242	-0.641
Pa/Pl	G	Genotypic	-0.0003	0.0345	0.0136	-0.0491	-0.0424	-0.0298	0.0165	-0.0211	0.0214	-0.0265	0.0065	-0.0121	-0.0276
	P	Phenotypic	-0.0001	0.0015	0.0007	-0.003	-0.0015	-0.0012	0.0004	-0.0009	0.001	-0.0013	0.0004	-0.0004	-0.0008
PL	G	Genotypic	4.2491	-4.7415	2.2418	0.4494	4.2759	2.8944	-0.882	4.9721	-0.0788	3.1024	0.6395	0.5807	1.8389
	P	Phenotypic	-1.3613	1.8708	-0.7097	0.12	-1.4008	-0.9602	0.3382	-1.5634	0.0817	-0.9969	-0.1729	-0.2154	-0.3792
BY /Pl	G	Genotypic	0.0154	0.0226	-0.0092	0.0275	-0.0876	-0.0043	0.0395	-0.0124	0.0159	-0.0184	-0.0225	-0.0023	-0.0175
	P	Phenotypic	0.0033	0.0039	-0.0021	0.006	-0.0193	-0.0014	0.0078	-0.0023	0.0023	-0.0028	-0.0032	-0.0004	-0.0038
PaWt /Pl	G	Genotypic	-0.2192	0.2443	-0.1165	-0.0231	-0.2189	-0.1479	0.0442	-0.2551	0.0036	-0.1588	-0.0331	-0.0288	-0.0932
	P	Phenotypic	0.0539	-0.0739	0.0283	-0.0046	0.0552	0.0377	-0.0132	0.0616	-0.0033	0.0393	0.0066	0.0081	0.0149
Fsp /pa	G	Genotypic	0.0002	-0.0063	0.0017	-0.0036	-0.0011	0.0014	0.001	0.0013	0.0004	0.0008	-0.0003	-0.001	-0.0007
	P	Phenotypic	0.0003	-0.0097	0.0026	-0.0043	-0.0017	0.0021	0.0014	0.002	0.0005	0.0011	-0.0004	-0.0014	-0.0009
TSp /pa	G	Genotypic	0.193	-0.4918	0.1679	-0.2187	-0.0579	0.1205	0.0742	0.1197	0.0143	0.0779	-0.0048	-0.0441	-0.0126
	P	Phenotypic	-0.0736	0.1849	-0.0625	0.0633	0.0217	-0.0446	-0.0261	-0.0447	-0.0051	-0.028	0.0027	0.0156	0.0046

	G	Genotypic	-0.002	0.0007	-0.0005	-0.0002	-0.0001	-0.0002	-0.0001	-0.0002	0	-0.0001	-0.0001	-0.0001	-0.0002
SF%	P	Phenotypic	-0.012	0.0052	-0.0036	-0.0012	-0.001	-0.0017	-0.0007	-0.0019	0.0001	-0.0011	-0.0006	-0.0003	-0.0014
	G	Genotypic	-0.2393	0.5566	-0.1977	0.2292	0.0326	-0.1442	-0.0712	-0.1594	-0.0132	-0.104	0.0013	0.0425	0.0025
SD%	P	Phenotypic	0.0817	-0.191	0.066	-0.0616	-0.0107	0.0482	0.0227	0.0535	0.0042	0.0337	-0.0024	-0.0137	-0.0028
	G	Genotypic	0.0287	-0.0335	0.0942	0.0398	0.0328	0.028	0.0216	0.0343	0.0397	-0.0019	-0.0132	-0.0174	-0.0046
ThS Wt.	P	Phenotypic	0.0045	-0.0053	0.0154	0.0048	0.0052	0.0045	0.0032	0.0054	0.0058	-0.0002	-0.0018	-0.0023	-0.0006
	G	Genotypic	0.1033	0.3126	0.3206	0.7592	0.3889	0.0379	0.0552	0.0492	0.1686	-0.0818	-0.0484	0.0272	0.1629
PI	P	Phenotypic	0.0905	0.2951	0.288	0.9157	0.3678	0.0308	0.0255	0.0255	0.1463	-0.0828	-0.0368	0.012	0.1524
	G	Genotypic	0.0141	0.0088	0.0523	0.0769	0.1501	0.0179	-0.0291	0.0362	0.0051	0.0188	0.0044	-0.0027	0.023
HI	P	Phenotypic	0.0037	0.0025	0.0153	0.0181	0.0451	0.0053	-0.0076	0.0103	0.0012	0.0053	0.0008	-0.0009	0.0062
	G	Genotypic	-0.0087	0.0157	-0.0181	-0.003	-0.0073	-0.061	0.0032	-0.0317	0.011	-0.0318	0.0026	0.0057	0.0031
GL	P	Phenotypic	-0.0021	0.0039	-0.0045	-0.0005	-0.0018	-0.015	0.0009	-0.0077	0.0027	-0.0075	0.0005	0.0012	0.0007
	G	Genotypic	-0.001	0.0021	-0.0038	-0.0012	0.0032	0.0009	-0.017	0.0011	-0.0054	0.0044	0.0011	0.0015	-0.0003
GW	P	Phenotypic	0.0005	-0.0009	0.0016	0.0002	-0.0013	-0.0005	0.0079	-0.0004	0.0022	-0.0018	-0.0002	-0.0005	0
	G	Genotypic	-0.0222	0.0404	-0.0514	-0.0091	-0.034	-0.0736	0.0093	-0.141	0.0046	-0.1065	0.0193	0.0214	0.0104
DGL	P	Phenotypic	-0.001	0.0018	-0.0023	-0.0002	-0.0015	-0.0032	0.0003	-0.007	0.0002	-0.0047	0.0008	0.0009	0.0005

	G	Genotypic	-0.0 008	-0.0 024	0.0 426	0.0 225	0.0 034	-0.0 183	0.0 329	-0.0 033	0.1 012	-0.0 677	-0.0 026	-0.0 017	0.0 139
DGW	P	Phenotypic	0.0 001	0.0 002	-0.0 028	-0.0 012	-0.0 002	0.0 013	-0.0 021	0.0 002	-0.0 07	0.0 051	0.0 001	0.0 001	-0.0 008
	G	Genotypic	0.0 185	-0.0 365	-0.0 04	-0.0 211	0.02 44	0.1 021	-0.0 521	0.1 476	-0.1 307	0.1 955	-0.0 191	-0.0 207	-0.0 334
L/B	P	Phenotypic	0.0 005	-0.0 009	-0.0 001	-0.0 005	0.0 006	0.0 025	-0.0 012	0.0 037	-0.0 036	0.0 051	-0.0 005	-0.0 005	-0.0 008
	G	Genotypic	0.0 028	0.0 001	-0.0 063	-0.0 029	0.0 013	-0.0 019	-0.0 029	-0.0 062	-0.0 012	-0.0 044	0.0 451	0.0 343	0.0 261
H%	P	Phenotypic	0.0 009	0.0 002	-0.0 021	-0.0 007	0.0 003	-0.0 006	-0.0 006	-0.0 023	-0.0 002	-0.0 018	0.0 184	0.0 138	0.0 095
	G	Genotypic	-0.0 003	-0.0 006	0.0 016	-0.0 003	0.0 002	0.0 008	0.0 008	0.0 013	0.0 001	0.0 009	-0.0 065	-0.0 09	-0.0 049
M%	P	Phenotypic	-0.0 005	-0.0 012	0.0 026	-0.0 002	0.0 004	0.0 014	0.0 011	0.0 024	0.0 003	0.0 017	-0.0 13	-0.0 17	-0.0 088
	G	Genotypic	0.0 008	0	-0.0 003	0.0 014	0.0 01	-0.0 003	0.0 001	-0.0 005	0.0 009	-0.0 011	0.0 037	0.0 037	0.0 064
HRR %	P	Phenotypic	0.0 002	0	-0.0 001	0.0 004	0.0 003	-0.0 001	0	-0.0 002	0.0 002	-0.0 003	0.0 011	0.0 011	0.0 022
	G	Genotypic	0.2 16	0.2 541	0.4 509	0.9 267	0.5 856	0.1 108	0.0 495	0.1 805	0.19 81	-0.0 216	-0.0 367	0.0 423	0.2 349
Gy/Pl	P	Phenotypic	0.1 672	0.1 926	0.3 53	0.9 345	0.4 805	0.0 851	0.0 151	0.1 221	0.1 467	-0.0 258	-0.0 247	0.0 204	0.1 778