Interrelationship and cause effect analysis among panicle yield attributing traits in lowland Traditional Rice

Ashim CHAKRAVORTY[1]* and Parthadeb GHOSH[2]
[1]Department of Botany, Sripat Singh College, Jiaganj, Murshidabad, West Bengal, India.Telephone : +91 9433814800, [2]Department of Botany, University of Kalyani, West Bengal, India
Email: ashimbot@gmail.com
*Correspondence

ABSTRACT

Yield component analysis provides a framework for identifying potentially useful traits for yield improvement. A field experiment was conducted for two consecutive years to evaluate the forty four low land traditional rice cultivars for twenty three panicle yield and its attributing traits during kharif season at the Zonal Adaptive Research Station, Krishnagar, Nadia, West Bengal, India. Significant varietal differences were observed for all the characters. Among the panicle yield attributing traits, number of primary branches per panicle, number of grains on primary branches panicle^{-1}, number of spikelets on primary branches panicle^{-1}, grain length, grain breadth, grain thickness, kernel breadth, kernel thickness, 100 grain weight, 100 kernel weight correlated significantly and positively with panicle yield both at the genotypic and phenotypic levels. Results of path analysis showed that the direct positive effect on panicle yield was greatest for number of spikelets on secondary branches panicle^{-1} (0.998) which is followed by number of grains on secondary branches panicle^{-1} (0.948), grain length (0.755), and number of spikelets on primary branches panicle^{-1} (0.625), grain thickness (0.392) and fertility % of spikelets on primary branches panicle^{-1} (0.378). Few characters like number of primary branches panicle^{-1}, number of spikelets panicle^{-1}, by number of grains on primary branches panicle^{-1} and grain breadth showed negative direct effect on panicle yield even though the genotypic correlation coefficients on panicle yield were positive. The study revealed that the direct selection of the above said traits might be rewarding for panicle yield improvement since they revealed a true relationship with the panicle yield.

Key words: cultivar, direct effect, genotypic and phenotypic correlation, indirect effect, path analysis

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food crop of more than half of the world's population (Anonymous, 2009). Ninety percent of this crop is grown and consumed in South and South East Asia, the major centers of the world's population (Nanda, 2002). Most of the consumers, who depend on rice as their primary food, live in less developed countries. In sub continent, thousands of locally adapted cultivars of rice have evolved by nature and human (Singh *et al*., 2000), many of which are either fine grain or aromatic types.In order to feed the growing population, ventures are being made in all the rice growing areas to augment the yield per hectare but the success of hybridization and thereafter selection of desirable segregants depends largely on the selection of parents with high variability for different characters. The diversity in crop varieties is considered as a significant parameter for increasing food production, mitigating poverty and promoting economic growth overall contributing to the development of Agriculture. It serves as an insurance against unknown future needs and conditions thereby contributing to the stability of forming systems at local, national and global levels (Singh *et al*. 2000).

The collection of adequate information about the nature and magnitude of variability present in the available breeding materials is essential for successful selection procedure on higher grain yield, as yield components are of quantitative nature (St. Martin, 1984). Hence, the information about the traits' variability and heritability is collected from the assessment of different selection parameters, such as, coefficient of variation and heritability. A greater proportion of genetic components in connection with the environmental and genotype x environment interaction components in the total phenotypic variance of a trait is indicated by the lower values of coefficient of variation and higher heritability estimations of trait. In other words, the expression of trait is less variable with the environment and the trait is more stable allowing for its use as an efficient selection criterion in the breeding process (Burton, 1987; Bos and Caligari, 1995; Hill et al., 1998). Johnson et al. (1955) suggested that heritability estimates along with GA would be more useful in predicting gain under phenotypic selection than heritability estimates alone.

For a rational approach to the improvement of yield, it is essential to have some information on the nature of inheritance and association between different yield components and their relative contributions to yield. The correlation analysis measures the existence of relationship between various plant characters and determines the components on which selection can be based for improvement in seed yield.The progress in breeding for yield and its contributing characters of any crop is polygenic controlled, environmentally influenced and determined by the magnitude and nature of their genetic variability in which they grow (Falconer and Mackay, 1996; Singh *et al*., 2000). Variability, interrelationship and cause effect analysis are pre-requisites for improvement of any crop including rice for selection of superior genotypes and improvement of any trait (Krishnaveni *et al*., 2006). In agriculture, path analysis has been used by plant breeders to assist in identifying traits that are useful as selection criteria to improve crop yield (Surek and Beser, 2003).

Cause-effect analysis provides an effective means of partitioning the correlation coefficients into direct and indirect effects of the component characters on yield on the basis of which crop improvement programmes can be logically devised (Kozak *et al*.,2007). Any successful hybridization program for varietals improvement depends mainly on the selection of parents having high variability so that desired character (s) combinations may be selected to improve grain quality and higher grain yield. The information on relative direct and indirect contribution of each component character towards panicle yield will help breeders to formulate the effective criteria in selecting desirable cultivars in segregating populations. In view of this, the present study was planned to determine the correlation and path coefficients of panicle yield and yield contributing characters in the traditional lowland rice cultivars that all contributed to the yield.

It has been observed that yield of rice per unit area is primarily determined by the mean panicle yield and the number of effective tillers (i.e. number of panicles).

But beyond a certain limit, accommodating more tillers per unit area through choice of cultivar and for agronomic management cannot be expected to enhance yield; further, increase in yield per unit area would necessarily come from increase in mean panicle yield. Thus, information on panicle yield determination should be of considerable value in the development of heavy panicle type rice cultivars having high yield potential and productivity.

MATERIALS AND METHODS

The present investigation was carried out using forty four traditional lowland rice cultivars, collected from the gene bank of rice Research Station, Chinsurah, Hoogly during kharif season of 2009 and 2010 at the Instructional Farm of Zonal Adaptive Research Station, Krishnagar, Nadia, West Bengal (23˚24´N latitude and 88˚31´E longitude with an altitude of 9.75 meters above mean sea level). The soil reaction gives a slightly acidic pH of 6.0, with low soluble salts (EC of 0.15 dS m^{-1}), medium organic carbon content (0.57%), Total N (0.056%), medium in available P (25.28 kg ha^{-1}) and K (148.77 kg ha^{-1}). The materials were grown using completely randomized block design with three replications. Each entry was transplanted (45 days old seedling) in a plot of $6m^2$ with a spacing of 20cm. between rows and 15cm. between plants in a row. A random sample of five competitive plants was used for observations on different traits under study. Nutrients ($N:P_2O_5:K_2O$) @ 40:20:20 kg ha^{-1} were applied. During the crop period, the water depth of the field was 40-50cm. Among the forty four lowland rice cultivars, out of West Bengal, nine cultivars were collected from 24 Parganas (N), eight from Midnapore (W), two from Midnapore(N) , Midnapore(E), West Dinajpur and Jalpaiguri each, four cultivars from Assam, three cultivars from Uttar Pradesh and Orissa each and one from Bangladesh.

The panicle characters, with their respective codes (only codes of the characters are cited in table 2,3 and 4), observed in undergoing the experiment were panicle length (Ch1), number of nodes $panicle^{-1}$(Ch2), number of primary branches $panicle^{-1}$(Ch3),number of secondary branches $panicle^{-1}$(Ch4),number of spikelets on primary branches $panicle^{-1}$(Ch5),number of spikelets on secondary branches $panicle^{-1}$(Ch6),number of spikelets $panicle^{-1}$(Ch7),number of grains on primary branches $panicle^{-1}$(Ch8),number of grains on secondary branches $panicle^{-1}$(Ch9), fertility% of spikelets on primary branches $panicle^{-1}$(Ch10), fertility% of spikelets on secondary branches $panicle^{-1}$(Ch11), fertility% of spikelets $panicle^{-1}$(Ch12), grain length (Ch13), grain breadth (Ch14), grain length/breadth ratio (Ch15), grain thickness (Ch16), kernel length (Ch17), kernel breadth (Ch18), kernel length/breadth ratio (Ch19), kernel thickness (Ch20), 100 grain weight (Ch21), 100 kernel weight (Ch22) and panicle yield (Ch23). Various statistical calculation procedures were undertaken for evaluation of the characters. Variance and covariance analysis was in the usual way suggested by Singh and Chaudhury (1985). The replication-wise mean values of cultivars were subjected to statistical analysis using AGRISTAT software. Mean values of the cultivars were subjected to genotypic correlation co-efficients as per the method suggested by Falconer and Mackay (1996). Path coefficient analysis as applied by Dewey and Lu (1959), was utilized for the partition of the genotypic correlation coefficients into measures of direct and indirect effects.

RESULTS AND DISCUSSION

The rice cultivars differed significantly for all the traits indicating the presence of sufficient variability for effective selection to identify the superior cultivars (Table

1).The considerable range of variation expressed for the traits indicated good scope for crop improvement programe.

Table 1: Estimation of statistical parameters of agro-morphological traits for different lowland rice cultivars.

Sl. No.	Code	Traits	Mean±S.E.	Range	h^2	G.A.(%)	CV%
1	Ch1	Panicle length	26.86±0.99	23.20-30.8#	70.53	12.11	4.52
2	Ch2	No. of nodes panicle^{-1}	8.51±0.69	6.33-11	49.21	14.19	9.97
3	Ch3	No. of pri. branches panicle^{-1}	12.09±0.82	8.66-14.88	69.91	22.04	8.39
4	Ch4	No. of sec. branches panicle^{-1}	39.42±5.27	20.22-65.4	69.95	43.09	16.39
5	Ch5	No. of spikelets on pri. br. panicle^{-1}	72.03±6.03	51.44-98.3	63.98	22.55	10.26
6	Ch6	No. of spikelets on sec br. panicle^{-1}	136.24±20.	47.55-282.3	78.77	64.93	18.43
7	Ch7	No. of spikelets panicle^{-1}	208.07±22.	108.22-346.8	76.17	43.21	13.44
8	Ch8	No. of grains on pri. br. panicle^{-1}	64.61±6.22	42-85.66	57.90	21.70	11.8
9	Ch9	No. of grains on sec. br. panicle^{-1}	104.54±16.	39.99-223.11	80.31	70.59	18.92
10	Ch10	Fertility % of spikelets on pri. br. panicle^{-1}	89.76±4.28	79.30-95.82	14.68	2.16	6.58
11	Ch11	Fertility % of spikelets on sec. br. panicle^{-1}	77.22±6.24	41.55-95.05	65.63	22.82	9.89
12	Ch12	Fertility % of spikelets panicle^{-1}	81.98±4.15	55.70-93.80	70.98	16.87	6.21
13	Ch13	Grain length	8.15±0.28	6.04-11.05@	92.41	29.52	4.27
14	Ch14	Grain breadth	2.83±0.06	1.89-3.72@	97.77	36.37	2.69
15	Ch15	Grain length/breadth	2.93±0.11	2.18-4.16@	93.22	36.80	4.98
16	Ch16	Grain thickness	2.00±0.05	1.6-2.43	92.70	22.31	3.15
17	Ch17	Kernel length	5.71±0.14	4.08-7.97@	96.24	31.46	3.07
18	Ch18	Kernel breadth	2.41±0.05	1.7-3.24@	97.48	36.06	2.85
19	Ch19	Kernel length/breadth	2.41±0.08	1.77-3.42@	95.14	39.45	4.43
20	Ch20	Kernel thickness	1.78±0.04	1.46-2.27	92.96	22.94	3.17
21	Ch21	100 grain weight	2.37±0.007	1.08-3.65$	99.99	67.32	0.37
22	Ch22	100 kernel weight	1.84±0.02	0.84-2.84$	99.80	68.17	1.5
23	Ch23	Panicle yield	3.915±0.36	1.81-7.16	88.80	62.27	11.39

Note: # - cm, @ - mm, $ - g, h^2-Heritability, G.A.-Genetic advance in percent of mean

Regarding correlation study, interrelationships of major yield contributing characters on yield are essential to the plant breeder in order to ensure effective selection. In rice, number of findings based on common yield contributing traits has been reported (Rajagopalan, 1967; Shivani and Sree Rama Reddy, 2000), but this lacking for panicle components has also been reported (Jauoria *et al*., 1991). Of the two types of correlations, the genotypic correlation is chiefly accounted for linkage, pleiotropic action of genes and effect of selection. The phenotypic correlation is genotypic and environmental in origin and provides information about association between two observable characters.

In this study, genotypic correlation coefficients were in general higher than corresponding phenotypic ones demonstrating that the observed relationships among various characters were due to genetic causes. Panicle yield was significantly and positively correlated with number of primary branches panicle^{-1}, number of spikelets on secondary branches panicle^{-1}, number of grains on primary branches panicle^{-1}, grain length, grain breadth, grain thickness, kernel length, kernel breadth, kernel thickness, 100 grain weight and 100 kernel weight at both genotypic and phenotypic level (Table 2). This was in agreement with the earlier reports of Sinha *et al* (1999). Similar findings were made by Ekka *et al*. (2011) for grain length, grain breadth, kernel length and kernel breadth. Reddy (1991), Acharya *et al*. (1995), Prashanth *et al*. (1999), Sawarkar and Senapati (2014), Chakravorty and Ghosh (2013) also observed significant positive correlation at both genotypic and phenotypic levels for 100 grain weight. With regard to component characters, panicle length exhibited significant positive association only with number of nodes panicle^{-1}at phenotypic level. Number of primary branches panicle^{-1} showed highest significant positive association with number of spikelets on primary branches panicle^{-1}, number of grains on primary branches panicle^{-1}, and number of spikelets panicle^{-1} at both phenotypic and genotypic level (Table 2).

High significant and positive genotypic and phenotypic association was revealed between number of secondary branches panicle^{-1}, number of spikelets panicle^{-1}, number of spikelets on secondary branches panicle^{-1}and number of grains on secondary branches panicle^{-1}.This is in agreement with earlier works of Sinha *et al*. (1999) for number of grains on secondary branches panicle^{-1}. For number of spikelets on secondary branches panicle^{-1}, results revealed a significant and negative relationship with most of the traits except number of grains on secondary branches panicle^{-1}. Importance of secondary branches for improvement of grain number was also reported by Prasad and Sharma (1973).

Traits	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10	Ch11	Ch12	Ch13	Ch14	Ch15	Ch16	Ch17	Ch18	Ch19	Ch20	Ch21	Ch22	Ch23
Ch1		0.400**	-0.350**	-0.155	-0.12	-0.041	-0.119	-0.022	-0.009	0.260*	0.149	0.287**	-0.539**	-0.218*	-0.224*	-0.205	-0.573**	-0.19	-0.283**	-0.156	-0.442**	-0.415**	-0.510**
Ch2	0.287**		0.355**	0.554**	0.630**	0.396**	0.571**	0.405**	0.662**	0.224*	0.819**	0.284**	-0.458**	-0.412**	0.021	-0.426**	-0.413**	-0.380**	0.003	-0.338**	-0.492**	-0.461**	-0.058
Ch3	-0.166*	0.251*		0.298**	0.379**	0.857**	0.219*	0.853**	0.183	-0.072	0.049	-0.131	0.221*	0.158	0.001	0.107	0.256*	0.149	0.05	0.143	0.251*	0.237*	0.588**
Ch4	0.007	0.405**	0.397**		0.965**	0.102	0.980**	0.011	0.926**	-0.195	-0.447**	-0.106	-0.381**	-0.526**	0.157	-0.630**	-0.244*	-0.482**	0.189	-0.613**	-0.495**	-0.485**	0.097
Ch5	0.018	0.430**	0.446**	0.947**		0.266*	0.980**	0.161	0.905**	-0.226*	-0.501**	-0.122	-0.406**	-0.414**	0.031	-0.534**	-0.293**	-0.367**	0.059	-0.503**	-0.421**	-0.444**	0.172
Ch6	0.062	0.248*	0.809**	0.192	0.325**		0.074	0.984**	0.033	-0.029	0.016	-0.086	0.082	0.246*	-0.17	0.222*	0.114	0.253*	-0.127	0.275**	0.285**	0.208*	0.539**
Ch7	0.001	0.392**	0.287**	0.953**	0.977**	0.118		-0.031	0.930**	-0.224*	-0.519**	-0.109	-0.440**	-0.479**	0.073	-0.594**	-0.318**	-0.432**	0.093	-0.575**	-0.490**	-0.497**	0.076
Ch8	0.086	0.233*	0.736**	0.123	0.239*	0.908**	0.046		-0.001	0.152	0.193	0.082	0.104	0.313**	-0.208*	0.276**	0.137	0.323**	-0.169	0.327**	0.291**	0.253**	0.539**
Ch9	0.069	0.433**	0.243*	0.880**	0.887**	0.061	0.918**	0.049		0.139	-0.155	0.253*	-0.495**	-0.522**	0.071	-0.620**	-0.397**	-0.470**	0.061	-0.605**	-0.584**	-0.519**	0.019
Ch10	0.184	0.072	-0.087	-0.199	-0.230*	-0.07	-0.224*	0.153	0.152		0.968**	0.978**	-0.105	-0.047	-0.029	0.009	-0.17	-0.02	-0.117	0.007	-0.172	-0.023	-0.06
Ch11	0.09	0.003	-0.043	-0.14	-0.166	-0.053	-0.166	0.363**	-0.027	0.547**		0.892**	0.106	0.303**	-0.157	0.261*	0.101	0.319**	-0.181	0.266*	0.042	0.213*	0.044
Ch12	0.215*	0.127	-0.08	-0.088	-0.108	-0.075	-0.098	0.052	0.279**	0.934**	0.317**		0.236*	-0.152	-0.038	-0.1	-0.300**	-0.113	-0.14	-0.096	-0.290**	-0.148	-0.138
Ch13	-0.422**	-0.316**	0.211*	-0.299**	-0.341**	0.088	-0.372**	0.091	-0.423**	-0.084	0.03	-0.17		0.369**	0.472**	0.490**	0.981**	0.313**	0.528**	0.445**	0.741**	0.749**	0.554**
Ch14	-0.189	-0.298**	0.132	-0.425**	-0.354**	0.196	-0.411**	0.209*	-0.454**	-0.038	0.109	-0.116	0.358**		-0.633**	0.948**	0.352**	0.994**	-0.576**	0.931**	0.821**	0.794**	0.583**
Ch15	-0.162	0.014	0.022	0.122	0.031	-0.086	0.056	-0.112	0.053	-0.024	-0.056	-0.023	0.496**	-0.619**		-0.484**	0.479**	-0.668**	0.992**	-0.497**	-0.16	-0.132	-0.095
Ch16	-0.177	-0.259*	0.082	-0.514**	-0.459**	0.153	-0.516**	0.195	-0.541**	0.019	0.123	-0.064	0.460**	0.903**	-0.442**		0.468**	0.947**	-0.432**	0.998**	0.895**	0.861**	0.584**
Ch17	-0.476**	-0.298**	0.216*	-0.214*	-0.259*	0.098	-0.288**	0.111	-0.367**	-0.149	0.042	-0.252*	0.934**	0.340**	0.464**	0.445**		0.304**	0.555**	0.429**	0.736**	0.751**	0.620**
Ch18	-0.171	-0.245*	0.118	-0.407**	0.326**	-0.191	-0.387**	0.223*	-0.423**	-0.023	0.093	-0.092	0.292**	0.974**	-0.643**	0.9	0.294**		-0.612**	0.934**	0.803**	0.764**	0.587**
Ch19	-0.221*	-0.031	0.047	0.15	0.049	-0.091	0.078	-0.1	0.048	-0.085	-0.024	-0.112	0.505**	-0.559**	0.946**	-0.404**	0.559**	-0.614**		-0.447**	-0.093	-0.053	-0.016
Ch20	-0.124	-0.230*	0.137	-0.479**	-0.409**	0.219*	-0.479**	0.254*	-0.515	-0.005	0.106	-0.09	0.413**	0.884**	-0.459**	0.921**	0.416**	0.894**	-0.417**		0.857**	0.832**	0.551**
Ch21	-0.370**	-0.346**	0.230*	-0.415**	-0.368**	0.228*	-0.434**	0.221*	-0.523**	-0.145	0.159	-0.234*	0.712**	0.811**	-0.154	0.862**	0.727**	0.793**	-0.091	0.826**		0.923**	0.751**
Ch22	-0.344**	-0.318**	0.201	-0.402**	-0.383**	0.168	-0.437**	-0.193	0.461**	-0.021	0.077	-0.12	-0.720**	0.784**	-0.128	0.826**	0.735**	-0.755**	0.053	0.804**	0.922**		0.715**
Ch23	-0.346**	-0.315**	0.540**	0.193	0.257*	0.468**	0.168	0.475**	0.129	-0.019	0.086	-0.066	0.511**	0.543**	-0.08	0.519**	0.561**	0.536**	-0.012	0.501**	0.708**	0.676**	

*and**indicate significance at 5% and 1% levels, respectively. Upper diagonal correlations are genotypic correlations and lower diagonal correlations are phenotypic correlation. Correlation coefficient r=0.206-0.266 and r>0.266 are significant at at 5% and 1% level respectively.

The estimates of correlation coefficients revealed only the relationship between panicle yield and yield associated characters but did not show the direct and indirect effects of different traits on yield per se. This is, because the attributes that are in association do not exist by themselves, but are linked to other components. The coefficient analysis suggested by Dewey and Lu (1959) specified the effective measure of direct and indirect causes of association and also depicted the relative importance of each factor involved in contributing to the final product, *i.e*., panicle yield. Table 3 and 4 revealed the results of direct and indirect effects of various panicle yield components on panicle yield per plant. The highest positive direct effect of number of spikelets on secondary branches panicle^{-1} on panicle yield was observed (0.998) followed by number of grains on secondary branches panicle^{-1} (0.948), grain length (0.755), Number of spikelets on primary branches panicle^{-1}(0.625), grain thickness (0.392) and fertility % of spikelets on primary branches panicle^{-1} (0.378). Sawarkar and Senapati (2014) also found the direct positive effect of number of grains on secondary branches panicle^{-1} and grain length on grain yield. Chakravorty and Ghosh (2014) recently found the direct positive effect of grain length on panicle yield. Hasan *et al*.,(2013) found the direct positive effect of fertility % of spikelets on primary branches panicle^{-1} on grain yield. Negative direct effects on panicle yield were exhibited by grain breadth (-0.924) and grain length/breadth ratio (-0.753). Similar findings were also made by Sawarkar and Senapati (2014). The corresponding correlation coefficients of these two traits on plant yield were also with negative direction. Few characters like number of primary branches panicle^{-1}, number of spikelets panicle^{-1}, by number of grains on primary branches panicle^{-1} and grain breadth showed negative direct effect on panicle yield even though the genotypic correlation coefficients on panicle yield were positive. The residual effect was 0.25 indicating that about 99.74 percent of the variability in panicle yield was contributed by twenty two characters studied in path analysis. Thus, from the analysis of path coefficient both at genotypic and phenotypic levels, it is clear that the causal variables are efficient to explain the variation in response variable, i.e., panicle yield, more at genotypic levels than at phenotypic levels. The environment has probably masked a portion of the genotypic effects of the panicle yield and this yield attributing traits. The values and the differences in path coefficient values at genotypic and phenotypic levels should be taken into consideration while framing the selection criteria for breeding program based on the characters under study.

CONCLUSIONS

To sum up, correlation studies showed that panicle yield has positive association with all the characters except for panicle length, number of nodes panicle^{-1}, fertility % of spikelets on primary branches panicle^{-1}, fertility % of spikelets panicle-^{1}, grain length/breadth ratio and kernel length/breadth ratio, as they were negatively correlated. Path analysis revealed the direct selection for number of spikelets on secondary branches panicle^{-1}, number of grains on secondary branches panicle^{-1}, grain length, number of spikelet on primary branches panicle^{-1}, grain thickness and fertility % of spikelets on primary branches panicle^{-1} that might be rewarding for panicle yield improvement since they revealed true relationship with panicle yield. The direct effect for panicle length and fertility % of spikelets on primary branches panicle^{-1} was positive but the correlation was negative; in such a situation, the direct selection for these traits should be practised to reduce the undesirable indirect effect.

Table 3 : Path analysis (genotypic) showing the direct and indirect effects of 22 traits on panicle yield(Ch23) in traditional lowland rice cultivars.

Traits	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10	Ch11	Ch12	Ch13	Ch14	Ch15	Ch16	Ch17	Ch18	Ch19	Ch20	Ch21	Ch22
Ch1	**0.013**	-0.135	0.029	0.000	0.011	0.062	-0.001	-0.057	0.065	0.070	0.021	-0.093	-0.319	0.175	0.122	-0.069	-0.153	0.00004	0.042	-0.005	-0.124	-0.00003
Ch2	0.004	**-0.471**	-0.043	0.014	0.269	0.248	-0.276	-0.153	0.411	0.027	0.001	-0.055	-0.239	0.275	-0.011	-0.101	-0.096	0.00006	0.006	-0.009	-0.116	-0.00003
Ch3	-0.002	-0.118	**-0.172**	0.014	0.279	0.808	-0.202	-0.484	0.230	-0.033	-0.010	0.035	0.159	-0.122	-0.017	0.032	0.069	-0.00003	-0.009	0.005	0.077	0.00002
Ch4	0.000	-0.191	-0.068	**0.035**	0.592	0.192	-0.670	-0.081	0.834	-0.075	-0.032	0.038	-0.226	0.393	-0.092	-0.201	-0.069	0.00010	-0.028	-0.018	-0.139	-0.00004
Ch5	0.000	-0.202	-0.077	0.033	**0.625**	0.324	-0.687	-0.157	0.841	-0.087	-0.038	0.047	-0.258	0.327	-0.023	-0.180	-0.083	-0.00008	-0.009	-0.016	-0.123	-0.00004
Ch6	0.001	-0.117	-0.139	0.007	0.203	**0.998**	-0.083	-0.597	0.058	-0.026	-0.012	0.032	0.066	-0.181	0.065	0.060	0.032	0.00005	0.017	0.008	0.077	0.00002
Ch7	0.000	-0.185	-0.049	0.033	0.611	0.118	**-0.703**	-0.030	0.870	-0.085	-0.038	0.042	-0.281	0.380	-0.042	-0.202	-0.093	0.00009	-0.015	-0.018	-0.146	-0.00004
Ch8	0.001	-0.110	-0.127	0.004	0.149	0.907	-0.032	**-0.658**	0.046	0.058	0.084	-0.022	0.069	-0.193	0.084	0.076	0.036	-0.00005	0.019	0.010	0.074	-0.00002
Ch9	0.001	-0.204	-0.042	0.031	0.555	0.061	-0.645	-0.032	**0.948**	0.058	-0.006	-0.121	-0.319	0.419	-0.040	-0.212	-0.118	0.00010	-0.009	-0.020	-0.176	0.00004
Ch10	0.002	-0.034	0.015	-0.007	-0.144	-0.070	0.157	-0.101	0.144	**0.378**	0.126	-0.404	-0.063	0.035	0.018	0.007	-0.048	0.00001	0.016	0.000	-0.049	0.00000
Ch11	0.001	-0.001	0.007	-0.005	-0.104	-0.053	0.117	-0.239	-0.026	0.207	**0.230**	-0.137	0.023	-0.101	0.042	0.048	0.014	-0.00002	0.005	0.004	0.053	0.00001
Ch12	0.003	-0.060	0.014	-0.003	-0.068	-0.075	0.069	-0.034	0.265	0.353	0.073	**-0.432**	-0.128	0.107	0.017	-0.025	-0.081	0.00002	0.021	-0.003	-0.079	-0.00001
Ch13	-0.006	0.149	-0.036	-0.010	-0.213	0.088	0.261	-0.060	-0.401	-0.032	0.007	0.073	**0.755**	-0.331	-0.373	0.180	0.300	-0.00007	-0.095	0.016	0.239	-0.00007
Ch14	-0.003	0.140	-0.023	-0.015	-0.221	0.196	0.289	-0.137	-0.431	-0.014	0.025	0.050	0.270	**-0.924**	0.466	0.354	0.109	-0.00023	0.106	0.034	0.272	0.00007
Ch15	-0.002	-0.007	-0.004	0.004	0.019	-0.086	-0.039	0.074	0.050	-0.009	-0.013	0.010	0.375	0.572	**-0.753**	-0.173	0.149	0.00015	-0.179	-0.017	-0.052	-0.00001
Ch16	-0.002	0.122	-0.014	-0.018	-0.287	0.153	0.363	-0.128	-0.513	0.007	0.028	0.028	0.347	-0.834	0.333	**0.392**	0.143	-0.00021	0.076	0.035	0.289	0.00008
Ch17	-0.006	0.140	-0.037	-0.007	-0.162	0.098	0.202	-0.073	-0.348	-0.056	0.010	0.109	0.705	-0.314	-0.349	0.174	**0.322**	-0.00007	-0.106	0.016	0.244	0.00007
Ch18	-0.002	0.115	-0.020	-0.014	0.204	-0.191	0.272	-0.147	-0.401	-0.009	0.021	0.040	0.221	-0.900	0.484	0.352	0.095	**-0.00024**	0.116	0.034	0.266	-0.00007
Ch19	-0.003	0.015	-0.008	0.005	0.031	-0.091	-0.055	0.066	0.046	-0.032	-0.006	0.048	0.381	0.516	-0.712	-0.158	0.180	0.00014	**-0.189**	-0.016	-0.031	0.00000
Ch20	-0.002	0.108	-0.024	-0.017	-0.256	0.219	0.337	-0.167	-0.488	-0.002	0.024	0.039	0.312	-0.817	0.346	0.361	0.134	-0.00021	0.079	**0.038**	0.277	0.00007
Ch21	-0.005	0.163	-0.040	-0.014	-0.230	0.228	0.305	-0.145	-0.496	-0.055	0.037	0.101	0.538	-0.749	0.116	0.338	0.234	-0.00019	0.017	0.031	**0.336**	0.00009
Ch22	-0.005	0.150	-0.035	-0.014	-0.240	0.168	0.307	0.127	0.437	-0.008	0.018	0.052	-0.544	-0.724	0.096	0.323	0.236	0.00018	-0.010	0.031	0.309	**0.00009**

RESIDUAL 0.073

Diagonal values indicate the direct effect

Table 4: Path analysis (phenotypic) showing the direct and indirect effects of 22 traits on panicle yield (Ch23) in traditional lowland rice cultivars

Traits	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10	Ch11	Ch12	Ch13	Ch14	Ch15	Ch16	Ch17	Ch18	Ch19	Ch20	Ch21	Ch22
Ch1	**0.011**	0.006	-0.029	0.135	0.159	0.009	-0.284	-0.015	0.000	0.018	-0.001	0.005	0.009	0.430	0.079	0.127	-0.629	-0.255	0.202	0.028	-0.404	-0.108
Ch2	0.004	**0.016**	0.030	-0.482	-0.832	-0.087	1.361	0.283	0.031	0.015	-0.003	0.005	0.008	0.813	-0.007	0.264	-0.454	-0.511	-0.002	0.060	-0.450	-0.120
Ch3	-0.004	0.006	**0.084**	-0.259	-0.501	-0.187	0.522	0.597	0.009	-0.005	0.000	-0.002	-0.004	-0.312	0.000	-0.066	0.281	0.200	-0.036	-0.025	0.230	0.062
Ch4	-0.002	0.009	0.025	**-0.869**	-1.275	-0.022	2.335	0.008	0.044	-0.013	0.002	-0.002	0.006	1.038	-0.055	0.390	-0.268	-0.648	-0.135	0.109	-0.453	-0.127
Ch5	-0.001	0.010	0.032	-0.839	**-1.321**	-0.058	2.335	0.113	0.043	-0.016	0.002	-0.002	0.007	0.817	-0.011	0.331	-0.322	-0.493	-0.042	0.089	-0.385	-0.116
Ch6	0.000	0.006	0.072	-0.089	-0.351	**-0.219**	0.176	0.688	0.002	-0.002	0.000	-0.001	-0.001	-0.485	0.060	-0.138	0.125	0.340	0.090	-0.049	0.261	0.054
Ch7	-0.001	0.009	0.018	-0.852	-1.295	-0.016	**2.383**	-0.022	0.044	-0.015	0.002	-0.002	0.007	0.945	-0.026	0.368	-0.349	-0.581	-0.066	0.102	-0.448	-0.130
Ch8	0.000	0.006	0.072	-0.010	-0.213	-0.215	-0.074	**0.699**	0.000	0.010	-0.001	0.001	-0.002	-0.618	0.073	-0.171	0.150	0.434	0.120	-0.058	0.266	0.066
Ch9	0.000	0.010	0.015	-0.805	-1.196	-0.007	2.216	-0.001	**0.048**	0.010	0.001	0.004	0.008	1.030	-0.025	0.384	-0.436	-0.632	-0.043	0.107	-0.534	-0.136
Ch10	0.003	0.004	-0.006	0.170	0.299	0.006	-0.534	0.106	0.007	**0.069**	-0.004	0.017	0.002	0.093	0.010	-0.006	-0.187	-0.027	0.083	-0.001	-0.157	-0.006
Ch11	0.002	0.013	0.004	0.389	0.662	-0.004	-1.237	0.135	-0.007	0.066	**-0.004**	0.015	-0.002	-0.598	0.055	-0.162	0.111	0.429	0.129	-0.047	0.038	0.056
Ch12	0.003	0.004	-0.011	0.092	0.161	0.019	-0.260	0.057	0.012	0.067	-0.003	**0.017**	-0.004	0.300	0.013	0.062	-0.329	-0.152	0.100	0.017	-0.265	-0.039
Ch13	-0.006	-0.007	0.019	0.331	0.536	-0.018	-1.048	0.073	-0.024	-0.007	0.000	0.004	**-0.017**	-0.728	-0.166	-0.304	1.077	0.421	-0.376	-0.079	0.678	0.196
Ch14	-0.002	-0.007	0.013	0.457	0.547	-0.054	-1.141	0.219	-0.025	-0.003	-0.001	-0.003	-0.006	**-1.973**	0.223	-0.587	0.387	1.336	0.410	-0.165	0.751	0.207
Ch15	-0.002	0.000	0.000	-0.136	-0.041	0.037	0.174	-0.145	0.003	-0.002	0.001	-0.001	-0.008	1.249	**-0.352**	0.300	0.526	-0.898	-0.706	0.088	-0.146	-0.034
Ch16	-0.002	-0.007	0.009	0.548	0.706	-0.049	-1.415	0.193	-0.029	0.001	-0.001	-0.002	-0.008	-1.871	0.171	**-0.619**	0.514	1.273	0.308	-0.177	0.819	0.225
Ch17	-0.006	-0.007	0.021	0.212	0.387	-0.025	-0.758	0.096	-0.019	-0.012	0.000	-0.005	-0.017	-0.695	-0.169	-0.290	**1.098**	0.409	-0.395	-0.076	0.673	0.196
Ch18	-0.002	-0.006	0.013	0.419	0.485	-0.055	-1.029	0.226	-0.022	-0.001	-0.001	-0.002	-0.005	-1.962	0.235	-0.587	0.334	**1.345**	0.436	-0.166	0.735	0.200
Ch19	-0.003	0.000	0.004	-0.164	-0.078	0.028	0.222	-0.118	0.003	-0.008	0.001	-0.002	-0.009	1.137	-0.350	0.268	0.609	-0.823	**-0.712**	0.079	-0.085	-0.014
Ch20	-0.002	-0.005	0.012	0.533	0.665	-0.060	-1.370	0.229	-0.029	0.000	-0.001	-0.002	-0.008	-1.837	0.175	-0.618	0.471	1.256	0.318	**-0.177**	0.784	0.217
Ch21	-0.005	-0.008	0.021	0.430	0.556	-0.062	-1.168	0.204	-0.028	-0.012	0.000	-0.005	-0.013	-1.620	0.056	-0.554	0.808	1.080	0.066	-0.152	**0.915**	0.241
Ch22	-0.005	-0.007	0.020	0.422	0.587	-0.045	-1.184	0.177	-0.025	-0.002	-0.001	-0.003	-0.013	-1.567	0.047	-0.533	0.825	1.027	0.038	-0.148	0.844	**0.261**
RESIDUAL		0.255																				

Diagonal values indicate the direct effect

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