International Journal of Plant Breeding ©2013 Global Science Books

Framework for Selecting Suitable Indicators to Improve Yield Potential in Fine Rice (*Oryza sativa* L.)

Bhabendra K. Biswas[1*] • Nazmul Alam[2] • Jaime A. Teixeira da Silva[3] • Mohammad M. Haque[1] • Mohammad A. K. Azad[1] • Mohammed K. Hossain[2]

[1] Department of Genetics and Plant Breeding, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh
[2] Department of Botany, Jahangirnagar University, Savar, Dhaka, Bangladesh
[3] Faculty of Agriculture and Graduate School of Agriculture, Kagawa University, Ikenobe, Miki-cho, 761-0795, Japan

Corresponding author: ***professorbiswas@gmail.com**

ABSTRACT

An experiment was conducted in the Genetics and Plant Breeding Field of Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh on 28 primitive, one modern ('BR 34') and one exotic ('Philippine katari') fine rice cultivars during the rainy season (July-December) to construct selection indices based on correlation coefficients and path analysis of 12 characters. The yield potential of these cultivars was generally poor and ranged from 2.03-5.04 t/ha. Several characters including effective tillers/hill, panicle length, spikelets/panicle, 1000-grain weight, days to 50% flowering and days to maturity showed positive and significant associations with yield (t/ha) at genotypic and phenotypic levels. In contrast, the percentage of sterility and lodging showed negative and significant associations with yield (t/ha) at both levels. Genotypic correlation coefficients were higher than corresponding phenotypic coefficients. Therefore, the former were separated into direct and indirect effects. Effective tillers/hill, spikelets/panicle, 1000-grain weight and days to 50% flowering showed positive and strong associations with yield. The negative direct effects of sterility percentage, flag leaf angle and lodging percentage were not encountered by sum total indirect effects caused by other characters, ultimately revealing significant and negative correlation coefficients with yield. A total of 31 selection indices, together with genetic worth and relative efficiencies of selection against yield (t/ha) alone were estimated. Except for yield (t/ha), days to 50% flowering singly exaggerated maximum relative efficiency (89.49%). The relative efficiency over straight was selection increased by integrating more yield-contributing characters into mathematical functions. Although a tedious approach, I_{12345} scored the highest relative efficiency value (246.48%). Thus, this selection function might be a suitable method to adopt for improving the yield potential of fine rice cultivars by by-passing genetic recombination or modification.

Keywords: association, path analysis, selection index
Abbreviations: 2AP, 2-acetyl-1-pyrroline; **GDP**, gross domestic product; **SI**, selection index

INTRODUCTION

Rice (*Oryza sativa* L.) is the main staple food and dominant crop in Bangladesh and is grown on more than 75% of the total cultivable land, dominating the cropping pattern throughout the country. Almost all of the 13 million Bangladeshi farm families grow rice. Rice is grown on about 10.5 million ha which has remained almost stable over the past three decades (BRKB). About 75% of the total cropped area and over 80% of the total irrigated area is planted to rice. Thus, rice plays a vital role in the livelihood of the people of Bangladesh (BBS 2009). Food self sufficiency in Bangladesh mostly depends on rice production (Barmon and Chaudhury 2012). The Government of Bangladesh (GOB) is intent on achieving self-sufficiency in food grain production based on rice (Gain Report 2011). The total contribution of rice production is about 70% of the total agricultural contribution to gross domestic product (GDP) (BBS 2009). Bangladesh's rice production is estimated to reach 33.83 million tons in the current fiscal year 2011-2012, up from about 33.54 million tons in 2010-11, and up from about 32.3 million tons in 2009-2010 (Oryza 2012). Rice is considered as the model cereal crop due to its small genome size (2n=24), vast germplasm collection, enormous repositories of genetic resources at gene and molecular levels with efficient genetic transformation systems (Paterson *et al.* 2005). The Himalayan foothills of South and Southeast Asia, including some parts of Bangladesh, are considered to be the center of diversity of the genus *Oryza* (Morishima 1984). Rice is grown in tropical and temperate countries over a wide range of soil and climatic conditions and more than 90% of the world's rice is produced and consumed in Asia (Virmani 1996). World food prices dramatically increased in 2007-2008 and brought an acute food crisis to the poorest people in the world. The World Bank reported that global food prices rose 83% over the last three years and the FAO cited a 45% increase in their world food price index during September, 2007 - April, 2008 (Shah 2008). Prices of food and agricultural commodities remained high, but had nevertheless declined from the peaks of 2008, and the world economy was emerging from recession. However, there are growing concerns about high market volatility. These were reinforced from June through October 2010 (FAO 2011). Primitive cultivars which have been cultivated for successive generations in farmers' fields without interference by breeders are termed land races. Land races have more genetic diversity, wider adaptability and a high degree of resistance to biotic and abiotic stresses. On the Indian subcontinent, thousands of locally adapted rice genotypes have evolved by natural and human selection (Kaul *et al.* 1982; Singh *et al.* 2000), many of which are either fine grain or aromatic types (Ullah *et al.* 2011). However, the area under local rice cultivars in Bangladesh is not likely to change, covering approximately one-third of the cropping area during the rainy season (July-December). The yield potential of local rice varies from 2.5 to 3.5 t/ha (Anon 1997). However, the yield potential of local rice cultivars has

Received: 20 September, 2012. Accepted: 14 November, 2012.

Original Research Paper

Table 1 List of correlation and path analysis on different characters for improving rice yield.

Reference	Studied characters	Type of correlation	Type of path analysis	Important characters	Characters name
Mustafa and Elsheikh 2007	11	Phenotypic	Phenotypic	2	Grains/panicle and panicles/m^2
Kole *et al*. 2008	12	Genotypic and phenotypic	Genotypic	4	Panicles/plant, test weight, straw weight and plant height
Akinwale *et al.* 2011	10	Phenotypic	------------	3	Panicles/plant, panicle weight and grains/panicle
Sadeghi 2011	13	Phenotypic	Phenotypic	4	Productive tillers/plant, days to maturity, grains/panicle and 1000-grain weight
Seyoum *et al*. 2012	10	Genotypic and phenotypic	Genotypic	5	Grains/panicle, tillers/plant, panicles/plant, spikelet fertility and panicle size.

deteriorated and reached only 2.44 t/ha during 2010-2011 (BBS 2012a). It is well known that local rice is mostly non-responsive to nitrogenous fertilizer and yield reduction is caused by lodging in most cultivars. Although the nutritional quality, palatability, delectableness, taste, cooking quality and consumer demand are higher for local rice than for high-yielding varieties, some architectural defects cause significant problems with assimilation and translocation during grain-filling stages of the cultivars. Nevertheless, higher prices, export quality and a vital role in the global market warrant their higher production, hence the need to increase the yield potential of fine rice cultivars (Golam *et al.* 2003).

A plant breeding program can be divided into three stages: building up a gene pool from variable germplasm, selection of individuals from the gene pool and utilization of selected individuals to evolve a superior variety (Kempthorne 1957). Yield is a complex character that is affected by a number of component characters under the environment where the crop is grown. Thus, selection for improving yield becomes futile unless the associations among the yield-contributing characters are known. Correlation studies provide reliable information on the nature and extent of the relationship for bringing about an improvement in yield and other characters and partitioning of the correlation coefficient helps to identify the relative contribution of the component characters to yield (Panse 1957). Path coefficient analysis partitions the correlation among yield and its components into direct and indirect effects and therefore, correlation and path analysis both have effectively been used to identify useful characters in selection criteria to improve rice yield. The importance of correlation and path analysis on yield-contributing characters with respect to yield by selecting desirable characters for improving grain yield in rice is presented in **Table 1**. Path analysis implies the forces governing the correlation and thus provides a tool for selecting better genotypes. The selection index (SI) is the most widely used approach for simultaneous selection of more than a single character to improve the ultimate product, yield. The efficiency of SI relative to selection based on yield alone or tandem selection or independent culling of characters during the entire selection process is well established. The superiority of SI increases as the number of characters under selection increases and decreases with corresponding subtraction or increasing differences in relative importance of the characters. It is invariably common to dignify the genetic merit of the characters in the selection as a linear function of various characters for the improvement of yield. The superiority of SI is maximum when each of the integrated characters has an equal effect on yield. In another sense, selection is carried out for a SI calculated from the relative performance of several characters having different economic weights. In population improvement programs, several characters are considered at the same time because genetic correlations exist among the characters. Therefore, characters could not be selected on an individual basis, moreover, improving of one may bring change the means of other characters in undesirable ways. Such situation, the alternative way is to apply selection indices which evaluate the genotypic worth of an individual character estimated in several genotypes. Hence, the advantage of index selection (SI) is that several characters are improved simultaneously (FAO 2012). The interrelationship of yield-related component characters provides information about the likely consequences of selection for simultaneous improvement of desirable characters (Anbumalarmathi and Nadarajan 2008). It is therefore imperative that the choice of characters be made with great care and clear-cut objectives (Henderson 1963). Selection for grain weight, number of panicles/plant and panicle length by using their phenotypic and/or genotypic direct effects (path coefficient) as economic weights should serve as effective selection criteria for using either the optimum or base index (Sabouri *et al.* 2008). Ten selections have been made by employing a discriminant function technique involving grain yield and other component traits like plant height, number of effective tillers, number of grains/panicle and 100-grain weight (Purohit and Majumder 2009). Pandey *et al.* (2012) reported that harvest index, days to maturity and effective tillers/hill, 1000-grain weight, flag leaf area and panicle length should be given emphasis as selection criteria for the genetic improvement of rice yield. Poor attention has been paid to date in Bangladesh to the improvement of the yield status of fine rice cultivars because primitive cultivars still lay beyond research and development programs and because farmers cultivate land races every year under traditional management. Aromatic fine rice cultivars emit a specific aroma in the field, in storage, and during milling, cooking and eating (Efferson 1985). The biochemical basis of the aroma was identified as 2-acetyl-1-pyroline (2AP) and more than 100 other volatile compounds (Buttery *et al.* 1983). Taking into consideration the cross incompatibility between fine and high-yielding, non-scented rice cultivars and the expression of yield- and quality-attributing characters with a consistent performance under heterogeneous environments, it is essential to implement selection criteria and other approaches to screen out the best genotypes (Yadavendra *et al.* 2011). Therefore, the objective of this study was to identify those characters that are important for yield based on the association and contribution of the characters as assessed by path analysis. Based on these characters, different selection indices were constructed. The genetic worth and relative efficiencies of these indices compared to conventional selection solely on grain yield were estimated. At the end of the analyses, a framework for all interpretations was considered from which judicious functions were identified for improving the yield potential in fine rice.

MATERIALS AND METHODS

The experiment was carried out at the experimental field laboratory of the Department of Genetics and Plant Breeding, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh from July to December, 2009 with 28 indigenous, one modern and one exotic rice cultivars. The experiment was laid out in randomized complete block design with three replications. Each replication contained the hills of 30 cultivars having a 20 cm × 20 cm spacing. Each plot was 3 m in length and 2 m in breadth. Healthy 25-day-old seedlings were transplanted in separate strips of the experimental field. Necessary intercultural operations were performed during the cropping period for proper growth and development of the plants. Crop maturity was determined when

80% of the seeds attained physiological maturity. Data on different yield and yield-contributing characters were recorded on plot and hill based at different dates according to the experimental requirement. Data was recorded for plant height (cm), tillers/hill, effective tillers/hill, panicle length (cm), spikelets/panicle, sterility (%), 1000-grain weight (g), yield (t/ha), days to 50% flowering, days to maturity, flag leaf angle (°) and lodging (%).

The genotypic and phenotypic correlation coefficients of yield and its different contributing characters were estimated by the following formulae given by Johnson *et al.* (1955) and Singh and Chaudhary (1985):

However, the genotypic (r_g) and phenotypic correlations (r_p) between two characters, x_1 and x_2, were estimated according to Kwon and Torrie (1964).

$$r_g = \frac{covg\,(x1\,x2)}{\sqrt{vg\,(x1).vg\,(x2)}}$$

where

$covg(x_1x_2)$ = Genetic covariance between characters x_1 and x_2.
$vg(x_1)$ and $vg(x_2)$ = Genetic variance for characters x_1 and x_2, respectively.

$$r_p = \frac{covp\,(x1\,x2)}{\sqrt{vp\,(x1).vp\,(x2)}}$$

where
ovp (x_1x_2) = Phenotypic covariance between characters x_1 and x_2
$vp(x_1)$ and $vp(x_2)$ = Phenotypic variance for characters x_1 and x_2, respectively.

The genotypic correlation coefficients were partitioned into direct and indirect effects with the help of path coefficient analysis. One of the variables under study was taken as the dependent variable (effect), which was assumed to be influenced by the other characters called independent characters or variables (causes). The path coefficient was estimated by solving the following sets of simultaneous equations indicating the basic relationship between correlation and path coefficients (Cyprien and Kumar 2011):

$$r_{iy} = p_{iy} + r_{i1}\, p_{1y} + r_{i2}\, p_{2y} + \ldots.. + r_{i(i-1)}\, p_{iy}\, ;\ i = 1, 2, 3\ldots.., n$$

where *n* was the number of independent characters (causes); r_{1y} to r_{iy} denoted coefficients of correlation between causal factors 1 to *i* and dependent character y, $r_{1.2}$ to $r_{(i-1)i}$ the coefficients of correlation among all possible combinations of causal factors and p_{1y} to p_{iy} denote the direct effects of character *1* to *i* on character y. The indirect effect of the i^{th} variable through to the j^{th} variable on y (the dependent variable) was computed as $p_{iy} \times r_{ji}$.

The application of selection indices used simultaneous selection of several characters and aimed at discriminating desirable from undesirable cultivars on the basis of their phenotypic performance (Smith 1936). The genetic worth (H) of an individual was:

$$H = a_1G_1 + a_2\,G_2 + \ldots.. + a_n\,G_n$$

where
$G_1, G_2, \ldots., G_n$ were the genotypic values of individual characters and
$a_1, a_2, \ldots..., a_n$ signify their relative economic importance.

Another function (I), based on the phenotypic performance of various selected characters was defined as:

$$I = b_1p_1 + b_2p_2 + \ldots. + b_np_n$$

where

$b_1, b_2, \ldots, b_n$ were estimated such that the correlation between H and I, i.e., r(H,I), became maximum.

Once such a function (I) was obtained, discrimination of desirable genotypes from undesirable ones is possible on the basis of phenotypic performance, i.e., $p_1, p_2, \ldots, p_n$ directly. After calculating the SI, the expected genetic gain through selection was predicted by the following formula:

$$\Delta G = (Z/v)\sum\sum a_ib_jG_{ij} / \left(\sum\sum b_ib_jp_{ij}\right)^{1/2}$$

where:
Z/v = intensity of selection (i)
a_i = economic weightage
b_i = regression coefficient
G_{ij} = genotypic variance-covariance matrix
P_{ij} = phenotypic variance-covariance matrix

In population improvement programs, selection is based on the phenotypic evaluation of several characters that are frequently obtained from the means of several replications. This is carried out to minimize the influence of experimental error and thus increase the precision of those means.

When considering several traits at the same time, the genotypic worth (G_j) of each genotype for the various characters should be obtained (Baker 1986), that is:

$$G_j = a_1G_{1j} + a_2G_{2j} + \ldots + a_mG_{mj} = \sum_i^m a_iG_{ij}$$

where:
a_i corresponds to the relative weights attributed to the various characters according to their economic importance (FAO 2012).

If the characters have different economic weights, different scales and are correlated, the index can be calculated as the sum of the characters times their heritability (h^2), their economical weight (w) and the factor transforming the characters to the same scale (f). Hence, the mathematical type of the equation for SI is given as:

$$I_i = f_1w_1h_1^2x_{1i} + f_2w_2h_2^2x_{2i}$$

The aim of the index is to select for a genotypic value. However, this is not possible thus phenotypic values are used. It has to be determined how a weight vector has to be chosen to maximize the correlation between genotypic and phenotypic values (Cropscience.ch 2011).

The collected data were compiled and tabulated in proper forms for statistical analysis. Analysis of variance was performed following a randomized complete block (RCB) design with the help of a MSTAT-C program (Freed 1986).

RESULTS AND DISCUSSION

A set of 30 genetically diverged cultivars including a high-yielding variety, 'BR 34' and an exotic variety, 'Philippine katari' were collected from different parts of Bangladesh (**Table 3**). All the cultivars were photosensitive and were suitable for growing in the rainy season (July -December). The mean yields of the cultivars ranged from 2.03-5.04 t/ha and the yield of most cultivars was poorer than high-yielding varieties of rice whose yield ranged from 3.90-5.70 t/ha (BBS 2012b). Bangladeshi plant breeders are always interested to improve the yield status of modern varieties with maximal effort. Therefore, the yield potential of the collected cultivars needs to be increased through appropriate breeding strategies. In this situation SI would be highly effective to estimate the genetic worth as well as the relative efficiency of yield-contributing characters, with the purpose of increasing yield. However, construction of an SI would be futile without an assessment of the associations between yield and yield-contributing characters. Hence, genotypic and phenotypic correlation coefficients of yield and 11 yield-contributing characters were estimated (**Table 4**). Genotypic and phenotypic correlation coefficients indicated a similar trend but genotypic correlation coefficients were higher in magnitude than the corresponding phenotypic correlation coefficients which might be due to the masking or modifying effects of the environment on character associations at the genetic level (Zahid *et al.* 2006; Agahi *et al.* 2007). Out of 132 associations, 63 showed positive and significant associations among themselves while only 7 associations showed negative and significant associations among themselves. Effective tillers/hill, panicle length, spikelets/panicle, 1000-grain weight, days to 50% flowering and days to maturity showed positive and significant associations with yield (t/ha) both at genotypic and phenotypic levels. The significance of correlation and path analysis for selecting the best yield-contributing characters are presented in **Table 2**. Those characters having significant genotypic and

Table 2 Identification of yield influencing characters based on genotypic and phenotypic relationship with yield.

Studied characters	Characters showed ± r_g*	Characters showed ± r_p*	Yield enhancing characters	Characters name	Reported authors
8	2	5	1	Grains/panicle	Zahid *et al.* 2006
16	10	9	4	Panicle length, total tillers/plant, productive tillers/plant and flag leaf width	Agahi *et al.* 2007
7	6	4	3	Panicle/plant, panicle length and effective grains/panicle	Chakraborty *et al.* 2010
13	7	4	4	Productive tillers/plant, spikelet/panicle, spikelet fertility and amylase percentage	Basavaraja *et al.* 2011
10	7	7	3	Spikelet fertility, grains/panicle and 1000-grain weight	Haider *et al.* 2012

r_g* and r_p* indicate significant genotypic and phenotypic correlation coefficients respectively

Table 3 List of different fine rice cultivars with their yield potential.

Accession no.	Name	Place of collection	Yield (t/ha)
FR 1	Zirashail	Sadar, Dinajpur	2.28 jk
FR 2	Nazirshail	Sadar, Kurigram	2.54 hk
FR 3	Philippine katari	Birol, Dinajpur	3.57 c-g
FR 4	Kaloshoru	Sadar, Dinajpur	2.48 i-k
FR 5	Sanla	Naogaon	3.48 d-g
FR 6	Ranjit	Fulbari, Dinajpur	5.04 a
FR 7	Chicon sorna	Naogaon	3.05 f-j
FR 8	Shadakatari	Chirirbondar, Dinajpur	2.32 jk
FR 9	Shilkumul	Fulbari, Dinajpur	4.16 b-d
FR 10	Binnipakri	Chirirbondar, Dinajpur	2.03 k
FR 11	Paijam	Fulbari, Dinajpur	4.35 a-c
FR 12	Shitabhog	Barisal	3.55 c-g
FR 13	Zira	Birol, Dinajpur	3.50 d-g
FR 14	Kalozira	Narail	4.63 ab
FR 15	Lalfota	Khulna	2.37 i-k
FR 16	Darkashail	Natore	4.27 b-d
FR 17	Badshabhog	Chirirbandar, Dinajpur	3.33 e-h
FR 18	BR 34	BRRI, Joydebpur	3.83 b-f
FR 19	Dudshar	Rajshahi	4.44 ab
FR 20	Begunbichi	Patuakhali	2.47 i-k
FR 21	Sumon sorna	Naogaon	4.03 b-e
FR 22	Moulata	Panchagarh	2.50 i-k
FR 23	Zaitha katari	Birol, Dinajpur	2.66 h-k
FR 24	Lalchicon	Jessore	3.16 f-i
FR 25	Malshira	Fulbari, Dinajpur	4.23 b-d
FR 26	Chinigura	Kurigram	2.82 g-k
FR 27	Rajshahi sorna	Rajshahi	2.63 h-k
FR 28	Uknimodhu	Kurigram	2.64 h-k
FR 29	Radhunipagal	Birol, Dinajpur	4.10 b-e
FR 30	Katari	Sadar, Dinajpur	2.79 g-k

Means with the same letters do not differ significantly at the 5% level of probability (DMRT)

phenotypic correlation coefficients revealed the most important yield-enhancing characters. Chaudey and Singh (1994), Ajmer *et al.* (1979), and Haque *et al.* (1991) observed that the environment influenced the development of associations of yield with yield-contributing characters in rice. Steel and Torrie (1984) stated that correlation is an indicator of the intensity of the association between characters. The selection for one character resulted in progress for all characters that were positively correlated and retrogressed for the characters that were negatively correlated. Therefore, selection for any one of the positively correlated characters viz. effective tillers/hill would accelerate the improvement of other positively correlated characters like panicle length, spikelets/panicle, 1000-grain weight, days to 50% flowering and days to maturity. On the contrary, selection from any of the negatively correlated characters like sterility percentage, flag leaf angle and lodging percentage would reduce yield potential in fine rice (**Table 4**). Mathure *et al.* (2011) proposed that, for the improvement of scented rice, a special strategy needs to be designed by taking into consideration the correlation between those factors that contribute to total yield.

Furthermore, path coefficient analysis permitted a thorough understanding about the contribution of various characters by partitioning the correlation coefficients into components of direct and indirect effects (Laxuman *et al.* 2011). Therefore, the contribution of correlated characters was partitioned into direct and indirect effects by path analysis (**Table 5**). Since genotypic correlation coefficients were higher than phenotypic correlation coefficients, only the genotypic correlation coefficients were partitioned by path analysis to determine the direct and indirect effects of contributing characters towards grain yield. From the path analysis (**Table 5**), it was revealed that effective tillers/hill exhibited the highest positive direct effect (0.756) followed by spikelets/panicle (0.520), days to 50% flowering (0.432) and 1000-grain weight (0.410) to develop a strong genotypic correlation with grain yield. On the contrary, the highest negative direct effect on the development of a genotypic correlation with yield was caused by sterility percentage (-0.696) followed by flag leaf angle (-0.478) and lodging percentage (-0.456). Panicle length exerted maximum positive indirect effect (0.564) through spikelets/panicle while spikelets/panicle again had a considerable indirect effect (0.512) via 1000-grain weight. On the other hand, lodging percentage alone showed the highest negative indirect effect (-0.654) via 1000-grain weight which was compensated by the positive direct effect (0.410) of 1000-grain weight and indirect effects of other characters except for flag leaf angle. The residual effect, 0.136 was converted to a percentage and then the contribution of 11 component characters on grain yield was estimated by subtracting the residual effect from 100%, as 86.4% (Singh and Chaudhary 1985). Therefore, those characters having 13.6% effect were not studied. However, the direct effects along with correlations of the characters and residual effect were diagrammatically presented for visual confirmation (**Fig. 1**). Akhond *et al.* (1998) suggested that selection could be made mainly on panicles/hill and grains/panicle but a joint venture of correlation coefficients for spikelets/panicle, days to 1st flowering and effective tillers/hill must be considered to develop a discriminant function to improve the yield potential of rice. Moreover, Rao (1973) stated that the relative gain and efficiency of selection depend greatly upon the choice of character combinations for the construction of selection functions. Thus, negative influencing characters such as sterility percentage, flag leaf angle and lodging percentage were not included in the function analysis. Hence, breeders should discard these three characters to develop SIs for the improvement of yield potential in fine rice. Besides, variation for any character within a pure line has no genetic basis, and any operation depending upon the variation for a particular character within a pure line such as fine rice would not be effective for improving yield (Singh 2005). Although six characters showed a positive and significant correlation with yield (except for panicle length and days to maturity), showing an association at the 5% level, the associations of the other four characters such as effective tillers/hill (r_g= 0.93), spikelets/panicle (r_g = 0.91), 1000-grain weight (r_g = 0.96) and days to 50% flowering (r_g = 0.79) were significant at the 1% level of probability following the application of the *t*-test (Fisher and Yates 1938). Therefore, panicle length and days to maturity were not finally integrated into the function. The SIs were constructed according to the method proposed by Hazel (1943). Purohit and Majumder (2009) constructed 10 SIs by employing a discriminant function technique involving grain

Table 4 Genotypic and phenotypic correlation coefficients on twelve characters in fine rice cultivars.

	T/H		ET/H		PL		SK/P		SP		TGW	
	r_g	r_p	r_g	r_p	r_g	r_p	r_g	r_p	r_g	r_p	r_g	r_p
PH	-0.34	-0.32	-0.38	-0.35	0.82**	0.80**	0.44	0.40	0.45	0.49	0.32	0.30
T/H			0.29	0.23	0.32	0.29	0.27	0.23	0.63*	0.68*	0.49	0.45
ET/H					0.89**	0.86**	0.78**	0.76**	0.79**	0.76**	0.75**	0.72**
PL							-0.30	-0.28	-0.33	-0.33	0.57*	0.63*
SK/P									-0.87**	0.83**	0.48	0.45
SP											0.69*	0.66*
TGW												
DF												
DM												
FLA												
LP												

	DF		DM		FLA		LP		Y/H	
	r_g	r_p	r_g	r_p	r_g	r_p	r_g	r_p	r_g	r_p
PH	0.30	0.27	0.40	0.35	0.32	0.30	0.81**	0.89**	0.48	0.43
T/H	0.43	0.40	0.29	0.27	0.49	0.45	0.59*	0.59*	0.50	0.46
ET/H	0.50	0.49	0.61*	0.59*	0.75**	0.72**	0.67*	0.69*	0.93**	0.90**
PL	0.69*	0.64*	0.26	0.22	0.57*	0.63*	0.66*	0.70*	0.70*	0.64*
SK/P	0.61*	0.60*	0.91**	0.87**	0.48	0.45	0.61*	0.63*	0.91**	0.90**
SP	0.33	0.30	0.26	0.24	0.69*	0.66*	0.92**	0.93**	-0.89**	-0.82**
TGW	0.61*	0.58*	0.40	0.36			0.68*	0.69*	0.96**	0.93**
DF			0.90**	0.84**			0.22	0.21	0.79**	0.76**
DM							0.80**	0.80**	0.66*	0.64*
FLA							0.72*	0.74*	-0.80*	-0.79*
LP									-0.92**	-0.94**

PH = plant height, TH = tillers/hill, ETH = effective tillers/hill, PL = panicle length, SKP = spikelets/panicle, SP = sterility (%), TGW = 1000-grain weight, DF = days to 50% flowering, DM = days to maturity, FLA = flag leaf angle, LP = lodging percentage, YH = yield/ha

* and ** indicate significant at 5% and 1% levels of probability respectively

Table 5 Path coefficient analysis of eleven characters on yield in fine rice.

Characters	PH	T/H	ET/H	PL	SK/P	SP	TGW	DF	DM	FLA	LP	r_g with yield
PH	**0.145**	-0.307	-0.429	0.156	-0.329	0.107	-0.133	0.423	0.316	0.012	0.519	0.480
T/H	-0.401	**0.112**	0.204	-0.221	0.303	0.417	0.197	-0.199	-0.203	0.087	0.202	0.498
ET/H	-0.318	0.442	**0.756**	0.366	-0.332	-0.218	0.024	-0.008	-0.029	0.010	0.232	0.925**
PL	0.152	-0.117	-0.209	**0.228**	0.318	-0.344	0.220	0.161	0.217	0.102	0.069	0.697*
SK/P	0.115	0.264	0.308	0.564	**0.520**	-0.578	0.080	-0.139	-0.202	0.237	-0.257	0.912**
SP	-0.382	-0.520	0.354	0.216	-0.490	**-0.696**	-0.104	0.077	0.096	0.223	0.339	-0.887**
TGW	0.076	0.214	0.091	0.248	0.512	0.053	**0.410**	0.103	0.354	-0.450	-0.654	0.957**
DF	0.230	-0.472	-0.276	0.099	0.087	-0.308	0.105	**0.432**	0.487	0.198	0.204	0.786**
DM	0.186	0.098	0.074	0.038	0.146	0.022	0.319	-0.118	**0.305**	-0.142	-0.171	0.658*
FLA	-0.365	-0.093	-0.045	0.108	-0.089	0.107	0.222	-0.188	-0.124	**-0.478**	0.150	-0.795*
LP	0.239	-0.224	-0.376	0.187	0.165	0.428	-0.473	-0.364	-0.421	0.374	**-0.456**	-0.921**

Residual effect = 0.136

The bold figures along the diagonal indicate direct effects.

yield and other components such as plant height, number of effective tillers, number of grains/panicle and 1000-grain weight where the efficiency of selection based on yield alone was assumed to be 100 to measure the relative efficiencies of other indices. Therefore, yield was considered as 100 and the values of expected genetic worth scored by other indices were finally transferred accordingly to judge the relative efficiencies of simultaneous selection. Selection for yield would not be effective unless other yield components influencing yield directly or indirectly are taken into consideration. Again, when selection pressure is exercised for the improvement of any yield-related character, it may concurrently affect yield and other correlated characters. Thus, measurement of correlation coefficients helped to identify the relative contribution of component characters towards yield of fine rice. Results of selection indices showed that selection for grain weight, number of panicles/hill and panicle length by using their phenotypic and/or genotypic direct effects (path coefficient) as economic weights should serve as an effective selection criterion for using either the optimum or base index (Sabouri *et al.* 2008).

A total of 31 selection indices together with genetic worth and relative efficiencies over straight selection are presented in **Table 6**. It is apparent that the greater the number of characters included in the discriminant function, the higher was the efficiency over straight selection for yield (t/ha). The maximum relative efficiency over straight selection (246.48%) was realized when grain yield (t/ha) (x_1), days to 50% flowering (x_2), effective tillers/hill (x_3), spikelets/panicle (x_4) and 1000-grain weight (x_5) comprised the selection index (I_{12345}). The relative efficiency of selection on the basis of SI score was expected to increase up to 114.37% relative to direct selection of grain yield in rice (Bastia *et al.* 2008). Besides, Ferdous *et al.* (2010) developed SIs based on plant height, grains/spike, 1000-grain weight, days to maturity, harvest index and grain yield/plant in which the highest relative efficiency was estimated by incorporating three characters viz. plant height, grains/spike and grain yield/plant in wheat. A plant breeder is always interested in maximizing genetic gain by incorporating the minimum number of characters into the selection function. Rabiei *et al.* (2004) developed SIs by selecting minimum number of characters based on path analysis results and reported that plant height and grain size would be effective selection criteria in rice. A well planned breeding program would rank the single character SI, days to 50% flowering (x_2) as the key component to construct a discriminant function. Usually, late flowering cultivars pass a prolonged vegetative phase which results in higher yield but with disease incidence, which reduces yield. In Bangladesh, out of 32 diseases of rice 10 are considered as major diseases among which bacterial leaf blight caused by *Xanthomonas oryzae* pv. oryzae may cause substantial losses (20-30%) in yield depending upon the severity of infection (Begum *et al.*

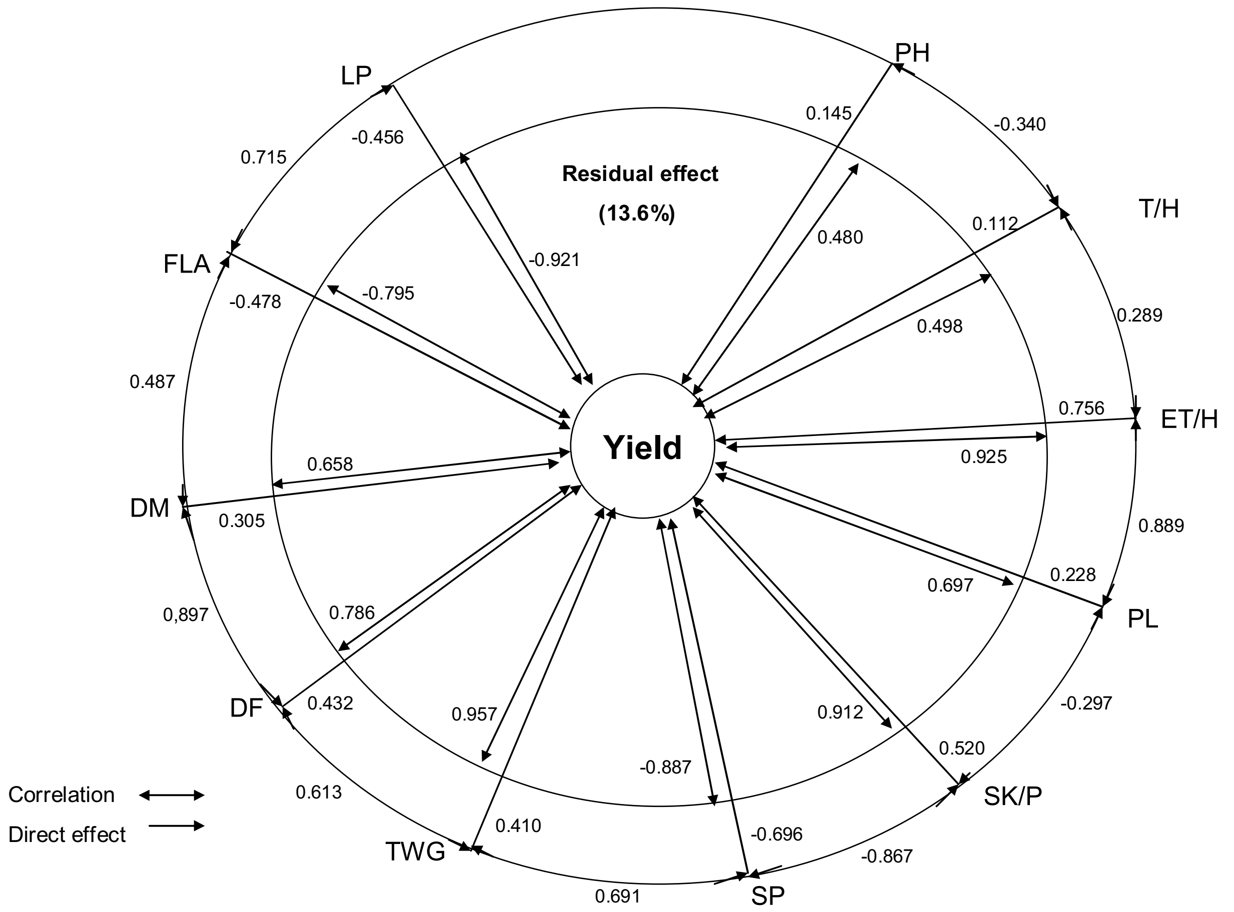

Fig. 1 Genotypic correlation coefficients and direct effects of different characters on yield in fine rice. PH = plant height, TH = tillers/hill, ETH = effective tillers/hill, PL = panicle length, SKP = spikelets/panicle, SP = sterility (%), TGW = 1000-grain weight, DF = days to 50% flowering, DM = days to maturity, FLA = flag leaf angle, LP = lodging percentage, YH = yield/ha

2011). However, among the two character combination functions a substantial gain of 183.49% was estimated when spikelets/panicle was selected together with 1000-grain weight. It was obvious that index I_{345}, developed by inclusion of effective tillers/hill, spikelets/panicle and 1000-grain weight, accounted for a profitable efficiency (228.58%) relative to the other three characters' integrated functions. The four-character indexes, I_{1245} with a relative efficiency of 234.01% appeared to be more beneficial than direct selection only for yield (t/ ha) in fine rice (**Table 6**). These results indicate that there was an increase in efficiency of selection with corresponding integration of more characters in the function but the approach would be more laborious and cumbersome for breeders. The five-character index (I_{12345}) scored the highest relative efficiency value (246.48%) over the conventional selection, but based only on grain yield. In this situation, a tedious approach, I_{12345} might be constructed and exploited as a reliable SI for grain yield improvement but this index would be troublesome for breeders due to the need to concurrently consider several characters during a breeding programs. With respect to the achieved results, effective tillers/hill, spikelets/panicle, 1000-grain weight, days to 50% flowering as well as grain yield (t/ha) could be considered as suitable selection criteria for improving yield potential in fine rice.

CONCLUSION

In general, the yield potential of the cultivars was poor and improvement of yield status is very difficult by hybridization due to lack of high-yielding genotypes among the cultivars examined. Genetic recombination may bring about modification in the expression of a target character which would not entail an improvement in yield. Considering these shortcomings in breeding fine rice, SIs could be applied by breeders. Several characters, i.e., effective tillers/hill, panicle length, spikelets/panicle, 1000-grain weight, days to 50% flowering and days to maturity, had positive and significant correlation coefficients with yield both at genotypic and phenotypic levels. On the other hand, sterility and lodging percentage along with flag leaf angle showed a negative and significant association with yield. The genotypic correlation coefficients of 11 characters with yield were segmented into direct and indirect effects. Effective tillers/hill had a maximum direct effect (0.756) and the highest negative indirect effect (-0.654) of lodging percentage was counter-balanced through 1000-grain weight. A total of 31 SIs along with genetic worth and relative efficiencies over straight selection for yield were estimated. Supporting yield (t/ha), days to 50% flowering singly exaggerated maximum relative efficiency (89.49%). The index I_{345} accounted for a profitable efficiency (228.68%) more than the other three character functions and the relative efficiency over straight selection increased by increasing the number of yield-contributing characters in the function. I_{12345} scored the highest relative efficiency value (246.48%). Thus, this integration might be adopted by breeders for improving the yield potential of fine rice by by-passing hybridization or genetic modification programs.

REFERENCES

Agahi K, Fotokian MH, Farshadfar E (2007) Correlation and path coefficient analysis for some yield-related traits in rice genotypes (*Oryza sativa* L.). *Asian Journal of Plant Science* **6**, 513-517

Ajmer S, Jatasra DS, Ram C, Battan S, Panwar DVS (1979) Components of grain yield in rice. *Cereal Research Communications* **7 (3)**, 241-247

Akhond MAY, Amiruzzaman M, Bhuiyan MSA, Uddin MN, Hoque MM (1998) Genetic parameters and character association in grain sorghum. *Ban-*

Table 6 Construction of selection indices in fine rice cultivars.

Index selection	Expected genetic worth	Relative efficiency over straight selection (%)
I1=0.782 x1	11.23	100
I2=0.958 x2	10.05	89.49
I3=0.824 x3	9.87	87.88
I4=0.904 x4	9.27	82.54
I5=0.999 x5	8.78	78.18
I12=0.431 x1+0.736 x2	14.63	130.27
I13=0.628 x1+0.722 x3	12.28	109.26
I14=0.525 x1+1.021 x4	15.30	136.24
I15=0.434 x1+0.971 x5	15.65	139.36
I23=1.994 x2+0.978 x3	18.46	164.38
I24=0.828x2+0.817 x4	19.85	176.75
I25=0.672 x2+0.723 x5	20.21	179.96
I34=0.523 x3+0.827 x4	18.36	163.49
I35=0.982 x3+0.923 x5	19.91	177.29
I45=1.233 x4+1.07 x5	20.66	183.97
I123=0.729 x1+ 0.93 x2 +1.248 x3	21.28	189.49
I124=0.343 x1+1.204 x2+1.063 x4	21.38	190.38
I125=0.307 x1+1.012 x2+0.838 x5	17.23	153.43
I134=0.671 x1+1.003 x3+1.001 x4	20.38	181.47
I135=0.523 x1+1.023 x3+0.886 x5	20.87	185.84
I145=0.523 x1+0.823 x4+0.986 x5	21.06	187.53
I234=1.003 x2+0.983 x3+1.03 x4	22.08	196.61
I235=1.002 x2+0.978 x3+ 1.07 x5	22.01	195.99
I245=1.004 x2+0.898 x4+0.923 x5	23.03	205.07
I345=0.899 x3+1.003 x4+0.838 x5	25.67	228.58
I1234=0.631 x1+0.823 x2+0.947 x3+1.006 x4	23.09	205.60
I1235=0.492 x1+1.027 x2+1.007 x3+0.885 x5	25.60	227.96
I1245=0.434 x1+0.787 x2+1.003x4+0.787 x5	26.28	234.01
I2345=1.001 x2+0.875 x3+0.787 x4+0.997 x5	24.03	213.98
I12345=0.32 x1+1.003 x2+1.004 x3+1.032 x4+1.007 x5	27.68	246.48

x1 = grain yield/ha, x2 = days to 50% flowering, x3 = effective tillers/hill, x4 = spikelets/panicle, x5 = 1000-grain weight

gladesh Journal of Agricultural Research **23**, 247-254

Akinwale AG, Gregorio G, Nwilene F, Akinyele BO, Ogunbayo SA, Odiyi AC (2011) Heritability and correlation coefficient analysis for yield and its components in rice (*Oryza sativa* L.). *African Journal of Plant Science* **5**, 207-212

Anbumalarmathi J, Nadarajan N (2008) Association analysis of yield and drought tolerant characters in rice (*Oryza sativa* L.) under drought stress. *Agriculture Science Digest* **28 (2)**, 89-92

Anon (1997) *Statistical Yearbook of Bangladesh*. BBS (Bangladesh Bureau of Statistics). Dhaka, Ministry of Planning, Government of the People's Republic of Bangladesh

Baker RJ (1986) *Selection Indices in Plant Breeding*, CRC Press, Boca Raton, FL, 218 pp

Barmon BK, Chaudhury M (2012) Impact of price and price variability on acreage allocation in rice and wheat production in Bangladesh. *The Agriculturists* **10 (1)**, 23-30

Basavaraja T, Gangaprasad S, Dhusyantha KBM, Hittlamani S (2011) Correlation and path analysis of yield and yield attributes in local rice cultivars (*Oryza sativa* L.). *Electronic Journal of Plant Breeding* **2 (4)**, 523-526

Bastia D, Mishra TK, Das SR (2008) Genetic variability and selection indices for grain yield in upland rice. *Oryza* **45 (1)**, 72-75

BBS (Bangladesh Bureau of Statistics) (2009) *Statistical Yearbook of Bangladesh*, Planning Division, Ministry of Planning, Government of the People's of Bangladesh, pp 421-423

BBS (2012a) Bangladesh Bureau of Statistics, Agriculture Wing, Government of the People's Republic of Bangladesh, Estimates of Aman Rice, 2011-2012, pp 1-2

BBS (2012b) Bangladesh Bureau of Statistics, Agriculture Wing, Government of the People's Republic of Bangladesh, Estimates of Boro Rice, 2011-2012, pp 1-2

Begum N, Rahman MM, Bashar MA, Hossain MA, Uddin MN (2011) Effect of potassium fertilizer on development of bacterial blight of rice. *Bangladesh Journal of Scientific and Industrial Research* **46 (1)**, 69-76

BRKB (Bangladesh Rice Knowledge Bank) (2011) Training Division, Bangladesh Rice Research Institute (BRRI) Gazipur, Bangladesh. Available online: http://www.knowledgebank-brri.org/riceinban.php

Buttery RG, Ling LC, Juliano BO, Turnbaugh JG (1983) Cooked rice aroma and 2-acetyl-1-pyroline. *Journal of Agricultural and Food Chemistry* **31 (4)**, 823-826

Chakraborty S, Das PK, Guha B, Sarmah KK, Barman B (2010) Quantitative genetic analysis for yield and yield components in boro rice (*Oryza sativa* L.). *Notulae Scientia Biologicae* **2 (1)**, 117-120

Chaubey PK, Singh RP (1994) Genetic variability, correlation and path analysis of yield components of rice. *Madras Agricultural Journal* **81 (9)**, 468-470

Cropscience.ch (2011) Selection index. Available online: http://cropscience.ch/?p=506

Cyprien M, Kumar V (2011) Correlation and path coefficient analysis of rice cultivars data. *Journal of Reliability and Statistical Studies* **4 (2)**, 119-131

Efferson JN (1985) Rice quality in world markets. In: *Rice Grain Quality and Marketing*, IRRI, Los Baños, Philippines, pp 1-13

FAO (Food and Agriculture Organization) (2011) The State of Food and Agriculture 2011, Part II - World food and agriculture in review, p 65

FAO (2012) FAO Corporate Document Repository, Chapter 3, Selection Indices for Population Improvement Programs, Available online: http://www.fao.org/docrep/008/y5843e/y5843e08.htm#TopOfPage

Ferdous MF, Shamsuddin AKM, Hasna D, Bhuiyan MMR (2010) Study on relationship and selection index for yield and yield contributing characters in spring wheat. *Journal of the Bangladesh Agricultural University* **8 (2)**, 191-19

Fisher RA, Yates F (1938) *Statistical Tables for Biological, Agricultural and Medical Research*, Oliver and Boyd, Edinburgh

Freed R (1986) MSTAT-C program, Plant and Soil Sciences, Michigan State University, East Lansing, MI

Gain Report (2011) Global Agricultural Information Network. Number: BG 1101

Golam F, Mohamad O, Hadjim M, Meisner CA (2003) Kernel ageing: An analysis in four Malaysian rice varieties. *International Journal of Agriculture and Biology* **3**, 230-232

Haider Z, Khan AS, Zia S (2012) Correlation and path coefficient analysis of yield components in rice (*Oryza sativa* L.) under simulated drought stress condition. *American-Eurasian Journal of Agricultural and Environmental Science* **12 (1)**, 100-104

Haque ME, Baset A, Zeenat Z, Miah NM (1991) Path coefficient analysis of seven characters in cold tolerant rice (*Oryza sativa* L.). *Bangladesh Rice Journal* **2 (1-2)**, 1-7

Hazel LN (1943) The genetic basis for constructing selection indices. *Genetics* **28**, 476-490

Henderson CR (1963) Selection index and expected genetic advance. In: Hanson WD, Robinson HF (Eds) *Statistical Genetics and Plant Breeding*, Publication 982, NAS-NRC, Washington DC

Johnson HW, Robinson HF, Comstock RE (1955) Estimates of genetic and environmental variability in soybean. *Agronomy Journal* **47**, 314-318

Kaul AK, Khan MRI, Munir KM (1982) *Rice Quality: A Survey of Bangladesh Germplasm*, Bangladesh Rice Research Institute, Joydebpur, Gazipur, pp 1-3

Kempthorne O (1957) *An Introduction to Genetical Statistics*, John Wiley and Sons. Inc., New York, 545 pp

Kole PC, Chakraborty NR, Bhat JS (2008) Analysis of variability, correlation and path coefficients in induced mutants of aromatic non-basmati rice. *Tropical Agricultural Research and Extension* **113**, 60-64

Kwon SH, Torrie JH (1964) Heritability and inter-relationship among traits of two soybean populations. *Crop Science* **4**, 196-198

Laxuman PM, Salimath HE, Shashidhar HD, Mohankumar SS, Patil HM, Vamadevaiah, Janagoudar BS (2011) Character association and path coefficient analysis among the backcross inbred lines derived from Indica x NERICA cross for productivity traits in rice (*Oryza sativa* L.). *Karnataka Journal* of *Agricultural Sciences* **24 (5)**, 626-628

Mathure S, Shaikh A, Renuka N, Wakte K, Jawali N, Thengane R, Nadaf A (2011) Characterisation of aromatic rice (*Oryza sativa* L.) germplasm and correlation between their agronomic and quality traits. *Euphytica* **179 (2)**, 237-246

Morishima H (1984) Wild plants and domestication. In: Tsunoda S, Takahashi N (Eds) *Biology of Rice*, Japan Scientific Society Press, Tokyo, pp 3-30

Mustafa MA, Elsheikh MAY (2007) Variability, correlation and path coefficient analysis for yield and its components in rice. *African Crop Science Journal* **15**, 183-189

Oryza (2012) Bangladesh record rice output to miss 34.7 million ton target. Oryza News on June 05, 2012. Available online: http://oryza.com/Rice-News/15316.html

Pandey VR, Singh PK, Verma OP, Pandey P (2012) Inter-relationship and path coefficient estimation in rice under salt stress environment. *International Journal of Agricultural Research* **7 (4)**, 169-184

Panse VG (1957) Genetics of quantitative characters in relation to plant breeding. *Indian Journal of Genetics* **17**, 318-328

Paterson AH, Freeling M, Sasaki T (2005) Grains of knowledge: Genomics of model cereals. *Genome Research* **15**, 1643-1650

Purohit S, Majumder MK (2009) Selection of high yielding rice variety from a cold tolerant three-way rice (*Oryza sativa* L.) cross involving *indica*, *japonica* and wide compatible variety. *Middle-East Journal of Scientific Research* **4 (1)**, 28-31

Rabiei B, Valizadeh M, Ghareyazie B, Moghaddam M (2004) Evaluation of selection indices for improving rice grain shape. *Field Crops Research* **89 (2–3)**, 359-367

Rao NGP, House LR (1973) *Sorghum in Seventies*, Oxford & IBH Pub. Co., New Delhi, India

Sabouri H, Rabiei B, Fazlalipour M (2008) Use of selection indices based on multivariate analysis for improving grain yield in rice. *Rice Science* **15 (4)**, 303-310

Sadeghi SM (2011) Heritability, phenotypic correlation and path coefficient studies for some agronomic characters in landraces rice varieties. *World Applied Science Journal* **13**, 1229-1233

Seyoum M, Alamerew S, Bantte K (2012) Genetic variability, heritability, correlation coefficient and path analysis for yield and yield related traits in upland rice (*Oryza sativa* L.). *Journal of Plant Sciences* **7 (1)**, 13-22

Shah A (2008) Global Food Crisis 2008, *Global Issues*. Available online: http://www.globalissues.org/article/758/global-food-crisis-2008

Singh BD (2005) *Plant Breeding: Principles and Methods* (7th revised Edn), Kalyani Publishers, New Delhi, India, 183 pp

Singh RK, Chaudhury BD (1985) *Biometrical Methods in Quantitative Genetic Analysis* (revised Edn), Kalyani Publishers, New Delhi, India

Smith HF (1936) A discriminant function for plant selection. *Annals of Eugenics* **7**, 240-250

Steel RG, Torrie JH (1984) *Principles and Procedure of Statistics*, McGraw-Hill Book Co., New York, USA, pp 137-167

Ullah MZ, Bashar MK, Bhuiyan MSR, Khalequzzaman M, Hasan MJ (2011) Interrelationship and cause-effect analysis among morpho-physiological traits in biroin rice of Bangladesh. *International Journal of Plant Breeding and Genetics* **5**, 246-254

Virmani SS (1996) Hybrid rice. *Advances in Agronomy* **57**, 379

Yadavendra KBN, Singh OP, Verma ST, Dwived DK (2011) Correlation and path coefficient analysis in scented rice (*Oryza sativa* L.) under sodicity. *Environment and Ecology* **29 (3B)**, 1550-1556

Zahid MA, Akter M, Sabar M, Manzoor Z, Awan T (2006) Correlation and path analysis studies of yield and economic traits in basmati rice (*Oryza sativa* L.). *Asian Journal of Plant Science* **5**, 643-645