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ACCOUNTING FOR MULTI TRAITS IN RECOMMENDING RICE VARIETIES FOR DIVERSE ENVIRONMENTS

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SUMMARY

Recommendations of crop varieties are usually done on the basis of grain yield. However, there are other important traits related to quality and agronomy that need to be considered. This study has clearly shown that grain yield is often not related to some important traits of the crop. Under such circumstances, selection based on yield can lead to the loss of these important characters. Recent research has also indicated the need for a multi-trait approach to recommending crop varieties. However, such approaches, as suggested in the literature, are subjective and do not have a sufficient statistical basis. This study proposes a methodology for varietal recommendations by taking account of all important traits. It is a multivariate approach considered to be an improvement on the univariate method previously proposed. Data from rice varieties of 3, $3^1/_2$ and $4^1/_2$ month maturity groups, cultivated across diverse environments, over two seasons in Sri Lanka were used to illustrate the proposed methodology. The results suggest that the new method will be appropriate for taking in to account all important traits along with yield.

INTRODUCTION

A promising crop variety (genotype) for cultivation is one that gives a high economic return to farmers with low production costs and good consumer preference. In addition, performance of a promising crop variety should be consistent across locations over different seasons over a long period of time. The economic merit of a crop depends on many individual traits (characters). However, varietal selection is often based primarily on grain yield (single trait). Studies on rice (Khush, 1990; Niu *et al.*, 2001) have shown that other than yield, traits such as resistance to adverse environments, shortening crop maturity duration (vegetative phase and reproductive phase) and improving grain quality should also be considered. Some of these traits are not correlated to the primary trait, yield. Under such situations, selection based on yield can lead to loss of these important characters. Selection based on multiple traits can provide a solution to this problem. If varieties need to be selected based on several traits, they need to be compared or tested with respect to all these characters simultaneously. Multivariate statistical techniques provide a basis for handling several variables simultaneously so that they can be adopted as an alternative to univariate techniques.

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Sometimes when data on several traits are available, analysis (usually ANOVA) is carried out for each trait separately and conclusions drawn. This approach is error bound (Type II error) and should be avoided. In the past, attempts have been made to select varieties based on multi responses (Johnson *et al.*,1988; Bernado, 1991; Dolan *et al.*, 1996; Abeyasekera, 2002; Gold *et al.*, 2002). Although some of these techniques are fairly simple most of them are subjective. The objective of the present study is to propose and illustrate a simple method of taking account of multi traits in varietal selection on a proper statistical basis.

MATERIALS AND METHODS

Univariate techniques

A large number of techniques (Yates and Cochran, 1938; Eberhart and Russel, 1966; Abeysiriwardena *et al.*, 1991) are currently used on a univariate basis for varietal selection. Most of these consist of fairly complicated analysis which cannot be performed using currently available standard statistical software. However, Kamidi (2001) proposed a simple technique for varietal selection. The biggest advantage of this technique is that the methodology can be adopted easily using standard statistical software. It is based on a regression model of the form:

$$y_{ij} = \mu_i + \beta_i x_{ij} + d_{ij} \tag{1}$$

where

y_{ij} = yield of the i^{th} genotype in the j^{th} environment,
$\mu = i^{\text{th}}$ genotype mean,
β_i = regression coefficient,
d_{ij} = deviation from regression, and
x_{ij} = environmental index for the i^{th} genotype at the j^{th} environment
given by:

$$x_{ij} = \frac{g\bar{y}_{\cdot j} - y_{ij}}{g-1} \tag{2}$$

where

$\bar{y}_{\cdot j}$ = marginal mean of the j^{th} environment,
g = number of genotypes.
Note that it is assumed y_{ij} are distributed normally and $d_{ij} \sim N(0, \sigma_\varepsilon^2)$.

The three measures used for varietal recommendation are specific stability, relative performance and relative superiority.

Specific stability. The specific stability (henceforth referred to as stability) is defined as the correlation between genotype and the environmental index. This correlation has to be sufficiently strong for a stable genotype. A variety that gives the correlation coefficient $(\rho) = 1$ is regarded as stable. Thus, in testing the stability, it is necessary to determine whether the estimate of the correlation (r_{ge}) actually represents $\rho = 1$. The test is then H_o: $\rho = 1$ versus H_A: $\rho < 1$. Varieties are classified, depending on the outcome. If ρ is not significantly different from unity at $\alpha = 0.05$ (i.e. $P > 0.05$)

the genotype is regarded as very stable. Similarly, if $0.01 < p < 0.05$, the variety is considered as sufficiently stable, if $0.001 < p < 0.01$ the variety is considered as fairly stable and if $p < 0.001$, the variety is considered as unstable.

Testing ρ with H_o: $\rho = 1$ versus H_A: $\rho < 1$ is usually done using the test proposed by Gayen (1951). However, one can use the critical values published by Kamidi (2001) and make inferences without actually performing the test.

Relative performance. The relative performance (henceforth referred to as performance) of the i^{th} variety (p_i) is defined as $b_i - 1$, where b_i is the estimated regression coefficient from model (1); i.e. by how much its response lies above or below the average ($b = 1$).

Relative superiority. The relative superiority (henceforth referred to as superiority) of the i^{th} variety (s_i) is measured as a product of performance and stability i.e. ($s_i = p_i \times r_{ge}$).

Based on the three measures, stable varieties with high superiority are recommended.

Kamidi's method (2001) can be considered to be an improvement on those of Yates and Cochran (1938) and Eberhart and Russel (1966). Yates and Cochran's method is based only on the regression coefficient of model (1). Eberhart and Russel's method includes a stability parameter in addition to the regression coefficient. However, a simpler approach is followed in computing the stability parameter in Kamidi's method compared to Eberhart and Russel's method.

Multivariate approach

Our method is mostly based on principal component analysis (PCA) (Chatfield and Collins, 1980) of multivariate statistical methods. In PCA, the l^{th} principal component (Q_l) in general is of the form:

$$Q_l = a_{1l}y_1 + a_{2l}y_2 + \cdots + a_{pl}y_p; \quad l = 1, 2 \ldots, p \tag{3}$$

where y_1 to y_p are the p response variables and a_{1l} to a_{pl} are the eigenvector coefficients corresponding to p response variables respectively.

If only m ($m < p$) principal components (PCs) are sufficient to explain the variability of the variables y_1 to y_p, the aggregated index score for the i^{th} variety from j^{th} environment, z_{ij} can be computed based on a linear combination of selected m principal components as:

$$z_{ij} = w_1 Q_{1ij} + w_2 Q_{2ij} + \cdots + w_m Q_{mij}; \quad i = 1, 2, \ldots \quad j = 1, 2 \ldots \tag{4}$$

where w_1 to w_m are the weights corresponding to m PCs and Q_{1ij} to Q_{mij} are scores of m PCs for the i^{th} variety from the j^{th} environment. If λ_l ($l = 1, 2, \ldots m$) are the eigenvalues corresponding to m PCs, the weight for each of the m PCs can be defined on the basis of a proportion of the variability explained by each principal component. Thus $w_l = \lambda_l / \sum_{l=1}^{p} \lambda_l$ and hence $\sum_{l=1}^{m} w_l \approx 1$. Note that if PCA is based on standardized variables $\sum_{l=1}^{p} \lambda_l = p$.

Table 1. The varieties used under different maturity groups in two seasons and their respective locations.

Season	Maturity group	Varieties tested	Test locations
Maha (2001/02)	3 month	Bg2845, Ld98-3, Bg300, Bg305, Bg2834 and At303	Ambalantota, Ampara, Arulaganwila, Batalagoda, Bombuwela, Eastern-University
	$3^1/_2$ month	Bg2879, Bg2780, Bw328-1, Bg359, Bg300, Bg2835, Bw99-1058, Bg99-1046 and Bg357	Ambalantota, Ampara, Arulaganwila, Batalagoda, Bombuwela, Eastern-University
	$4^1/_2$ month	Bg2949-1, Bg379-2, Bg2937-2, Bg403, Bg2893 and Bg450	Ambalantota, Arulaganwila, Batalagoda and Bombuwela
Yala (2002)	3 month	Bg2845, Ld98-3, Bg300, Bg2834, At303 and Bg305	Ambalantota, Batalagoda, Bombuwela, Eastern-University Labuduwa and Maha–Illupallama
	$3^1/_2$ month	Bg2880, Bw1059, Bw328-2, Bg2836, Bg2781, Bg358, Bg301, Bw1047 and Bg360	Ambalantota, Ampara, Arulaganwila, Batalagoda, Bombuwela, Eastern-University Labuduwa and Maha–Illupallama
	$4^1/_2$ month	Bg2949-2, Bg379-2, Bg2937-2, Bg2893, Bg403 and Bg450	Ambalantota, Arulaganwila, Batalagoda and Labuduwa

In PCA, the PCs are derived in a way such that the eigenvalue of the first PC is the largest followed by the second PC and so on. Thus according to equation (4) the weights will be in the order $w_1 > w_2 > w_3 > \ldots . > w_m$. Then the variables contributing to the first PC will receive higher weights than those contributing to the second PC and so on. If the eigenvalues are more or less the same, all the variables will receive more or less equal weights.

Once the combined index scores are computed using equation (4), the analysis is performed according to the model (equation 1) using combined index scores. Thus results can be interpreted as in the univariate case. Note that similar assumptions are taken for z_{ij} as with y_{ij} in equation (1). It is important to note that even if variables do not distribute normally, a multivariate index based on those variables tend to distribute normally.

Secondary data used

Data from the rice varietal testing programme for Maha[1] (2001/02) and Yala (2002) seasons of the Rice Research and Development Institute of Sri Lanka were used for the analysis. The test sites were located in different parts of the country and they represented different climatic conditions. For both seasons, varieties used in the analysis belonged to three maturity groups (3, $3^1/_2$ and $4^1/_2$ month). The varieties used under each season and maturity group, and their respective locations are presented in Table 1. Each variety was replicated four times at the respective locations. With the availability of data and the usefulness of the variables, other than the yield (YLD), the traits considered were: days taken for flowering (DTF), days taken for maturity

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[1] Rainfall in Sri Lanka is distributed bimodally. The period October to March during which the northeast monsoon brings the rain is known as the Maha season. The period April to September during which the southwest monsoon brings the rain is called Yala.

Table 2. The correlation coefficients of five traits to yield for three maturity groups in two seasons.†

	Maha			Yala		
Trait	3 month	3½ month	4½ month	3 month	3½ month	4½ month
DTF	0.16	0.08	− 0.34	0.40	0.26	− 0.23
	(0.35)*	(0.55)	(0.10)	(0.02)	(0.03)	(0.29)
DTM	− 0.24	− 0.22	− 0.76	0.36	0.24	− 0.23
	(0.16)	(0.11)	(< 0.001)	(0.03)	(0.05)	(0.27)
BRP	0.48	0.27	0.68	0.42	0.10	0.30
	(< 0.01)	(0.05)	(< 0.001)	(0.01)	(0.40)	(0.15)
TRP	0.31	0.38	0.70	− 0.16	0.30	0.25
	(0.07)	(< 0.01)	(< 0.001)	(0.34)	(0.01)	(0.24)
HGP	− 0.05	0.07	0.41	− 0.16	0.03	0.04
	(0.76)	(0.61)	(0.05)	(0.35)	(0.79)	(0.87)

† See text for definition of traits.

* The values in parentheses are the corresponding significant levels.

(DTM), brown rice percentage (BRP), total milled rice percentage (TRP) and head grain percentage (HGP). The analysis was carried out using SAS Version 8.2.

RESULTS

The correlation coefficients of yield versus the five traits used in the study are presented in Table 2. The correlation structure is not at all consistent across the seasons and the maturity groups. Thus, selection based on yield alone can lead to loss of other good characteristics.

Out of the six PCs resulting from the PCA using six traits, the eigenvalues of the first three were relatively large, even though sometimes that of the third PC was smaller than unity. Three PCs were necessary to explain the substantial amount of observed variability of each maturity group and season. Moreover, at least two variables contributed to the third PC in all the maturity groups and seasons. Therefore, the first three PCs were used for follow-up analysis. In fact, requiring three PCs confirmed the results of correlation analysis and indicated the fact that traits were not particularly interrelated. For these three PCs, the eigenvalues, eigenvectors and the percentage variability explained are presented in Tables 3.1 and 3.2. As the traits had been measured in different units, the PCA was performed based on a correlation matrix instead of a covariance matrix.

The contribution of variables to each PC can be identified by the eigenvector coefficients. Tables 3.1 and 3.2 show that this contribution was not consistent and varied across maturity groups as well as seasons.

According to Table 3.1, for instance, scores for the first PC, Q_1 (equation 3) for the i^{th} variety from j^{th} environment for the 3 month maturity group of Maha season can be computed as follows:

$$\begin{aligned} Q_{1ij} &= 0.20 \times YLD_{ij} - 0.45 \times DTF_{ij} - 0.48 \times DTM_{ij} + 0.23 \times BRP_{ij} \\ &\quad + 0.49 \times TRP_{ij} + 0.49 \times HGP_{ij} \end{aligned}$$

Table 3.1. Eigenvectors, eigenvalues and cumulative variability of the first three principal components (PC) for different maturity groups in the Maha season.

	3 month			3½ month			4½ month		
Trait	PC_1	PC_2	PC_3	PC_1	PC_2	PC_3	PC_1	PC_2	PC_3
YLD	0.20	0.61	− 0.05	− 0.04	0.61	0.08	0.46	− 0.04	0.46
DTF	− 0.45	0.43	0.23	0.63	0.00	− 0.05	− 0.25	0.70	0.27
DTM	− 0.48	− 0.03	0.69	0.61	− 0.15	− 0.29	− 0.44	0.43	− 0.02
BRP	0.23	0.58	− 0.04	0.24	0.48	− 0.46	0.42	0.42	0.24
TRP	0.49	0.13	0.58	− 0.11	0.59	− 0.02	0.47	0.19	0.05
HGP	0.49	− 0.27	0.35	0.39	0.17	0.83	0.35	0.33	− 0.81
λ	2.38	1.67	0.74	1.80	1.65	0.85	3.55	1.45	0.56
CVE %	40	67	80	30	57	72	59	83	93

λ – Eigenvalue, CVE % – Percentage cumulative variability explained.

Table 3.2. Eigenvectors, eigenvalues and cumulative variability of the first three principal components (PC) for different maturity groups in the Yala season.

	3 month			3½ month			4½ month		
Trait	PC_1	PC_2	PC_3	PC_1	PC_2	PC_3	PC_1	PC_2	PC_3
YLD	0.51	0.03	− 0.32	0.56	0.17	0.21	0.32	− 0.18	0.71
DTF	0.52	0.22	0.45	0.53	− 0.29	0.12	− 0.55	0.17	0.35
DTM	0.55	0.01	0.36	0.22	0.45	0.67	− 0.41	0.41	0.46
BRP	0.30	0.32	− 0.70	0.22	0.47	− 0.55	0.38	− 0.30	0.34
TRP	− 0.23	0.61	0.27	0.51	0.01	− 0.43	0.42	0.51	0.16
HGP	− 0.14	0.69	− 0.04	0.22	− 0.68	0.07	0.33	0.65	− 0.15
λ	2.16	1.57	1.06	1.67	1.32	1.03	2.41	1.38	0.93
CVE %	36	62	80	28	50	67	40	63	79

λ – Eigenvalue, CVE % – Percentage cumulative variability explained.

where, YLD_{ij}, DTF_{ij}, DTM_{ij}, BRP_{ij}, TRP_{ij} and HGP_{ij} are the corresponding standardized (zero mean and unit variance) variable values for the i^{th} variety from the j^{th} environment. Similarly scores for the other two PCs, Q_{2ij} and Q_{3ij} (since only three PCs were selected) can be computed for the same maturity group and season. Note that PCA using standard statistical software usually produces PC scores as a standard output. The weights in equation (4) can be computed as, for instance, $w_1 = \lambda_1/\sum_{l=1}^{6}\lambda_l = (2.38/6) = 0.40$. Similarly, w_2 and w_3 were 0.28 and 0.12 respectively. Accordingly, z_{ij} of equation (4) for the 3 month maturity group in the Maha season is of the form,

$$z_{ij} = 0.40Q_{1ij} + 0.28Q_{2ij} + 0.12Q_{3ij}$$

Using z_{ij} as the response variable, the regression analysis was computed for the model specified in equation (1), i.e. simple linear regression was computed for each variety separately using an aggregated index for the i^{th} variety (z_{ij}) as the response variable and the environmental index for the i^{th} variety (x_{ij}) as the explanatory variable.

Table 4. Mean aggregated index for six varieties at six locations (3 month maturity group, Maha season).

Location	Bg2845	Bg2834	At303	Bg305	Ld98–3	Bg300	mean ($\bar{z}_{\cdot j}$)
Ambalantota	− 0.15	− 0.94	− 0.51	0.33	− 0.06	0.00	− 0.22
Ampara	0.27	0.06	0.45	0.50	0.79	0.81	0.48
Arulaganwila	− 1.89	− 0.68	− 1.36	− 0.46	− 1.62	− 0.90	− 1.15
Batalagoda	0.42	1.16	− 0.43	0.79	0.27	0.55	0.46
Bombuwela	− 0.13	− 0.49	− 0.63	0.25	0.09	0.34	− 0.09
Eastern University	0.40	0.63	0.06	0.94	0.58	0.58	0.53

Table 5.1. Mean aggregated index and corresponding measures for varieties of three maturity groups in Maha.

Variety	Yield (t ha^{-1})	Aggregated index (z_{ij})	Specific stability (r_{ge})	Relative performance ($p_i = b_i - 1$)	Relative superiority ($s_i = r_{ge} * p_i$)
3 month					
Bg2845	5.09	− 0.18	0.95***	0.36	0.34
Ld98-3	5.26	0.10	0.94**	0.31	0.29
Bg300	5.14	0.23	0.96***	− 0.10	− 0.10
Bg2834	5.95	− 0.04	0.61^{a}	− 0.26	− 0.16
At303	5.21	− 0.40	0.85*	− 0.22	− 0.19
Bg305	5.87	0.39	0.94**	− 0.32	− 0.30
3½ month					
Bg2879	5.08	− 0.62	0.70^{a}	0.31	0.22
Bg2780	5.09	− 0.09	0.94**	0.22	0.21
Bw328-1	5.85	0.08	0.86*	0.19	0.16
Bg2835	4.65	0.04	0.78*	0.12	0.09
Bg300	4.65	0.10	0.87*	0.09	0.08
Bg359	4.94	0.07	0.67^{a}	− 0.11	− 0.07
Bg99-1046	5.32	− 0.21	0.88*	− 0.19	− 0.17
Bg357	5.65	0.30	0.39^{a}	− 0.64	− 0.25
Bw99-1058	5.19	0.31	0.70^{a}	− 0.52	− 0.36
4½ month					
Bg2949-1	4.55	0.02	0.98***	0.21	0.21
Bg379-2	4.95	− 0.42	0.99***	0.14	0.14
Bg2937-2	4.27	− 0.04	0.95***	0.10	0.10
Bg403	4.44	− 0.08	0.96***	0.00	0.00
Bg2893	4.41	0.13	0.99***	− 0.07	− 0.07
Bg450	4.56	0.39	0.87**	− 0.42	− 0.37

*,**,*** – r_{ge} not significantly different from one ($P > 0.001$, $P > 0.01$, $P > 0.05$ respectively), a – r_{ge} significantly different from one.

The x_{ij} were computed as described in equation (2). The $\bar{z}_j$, required to compute x_{ij}, can be computed as shown in Table 4. According to Table 4, for instance, the environmental index for Bg2845 at Ambalantota, x_{11}, of the 3 month maturity group in Maha is computed as $x_{11} = [(6)X(-0.22) - (-0.15)]/5 = -0.23$. Similarly all these computations can be extended to other maturity groups and seasons.

The estimated performance, stability and superiority from these regressions are presented in Tables 5.1 and 5.2.

None of the varieties in the 4½ month maturity group was found to be unstable in Maha. In Yala, only the variety Bg2937-2 in the 4½ month maturity group became

Table 5.2. Mean aggregated index and corresponding measures for varieties of three maturity groups in Yala.

Variety	Yield (t ha^{-1})	Aggregated index (z_{ij})	Specific stability (r_{ge})	Relative performance ($p_i = b_i - 1$)	Relative superiority ($s_i = r_{ge}*p_i$)
3 month					
Ld98-3	4.52	0.19	0.95***	0.38	0.36
Bg2834	4.52	0.21	0.89**	0.22	0.19
Bg2845	4.31	−0.40	0.97***	0.03	0.03
At303	4.24	−0.29	0.76^{a}	−0.15	−0.11
Bg305	4.64	0.38	0.80*	−0.20	−0.16
Bg300	4.48	−0.09	0.95***	−0.46	−0.44
3½ month					
Bg2880	4.84	−0.29	0.98***	0.47	0.46
Bw1059	4.65	−0.24	0.95**	0.43	0.41
Bg358	5.57	0.13	0.95**	0.16	0.15
Bg2781	5.42	0.23	0.93**	0.09	0.08
Bw328-2	5.47	0.22	0.89*	0.09	0.08
Bg2836	5.36	0.01	0.81^{a}	−0.13	−0.11
Bg301	5.05	0.07	0.83^{a}	−0.28	−0.23
Bw1047	4.74	−0.32	0.73^{a}	−0.40	−0.29
Bg360	5.28	0.19	0.76^{a}	−0.53	−0.40
4½ month					
Bg379-2	5.59	−0.05	0.93***	0.78	0.73
Bg2949-2	5.51	−0.29	0.94***	0.39	0.37
Bg2893	5.82	−0.10	0.98***	0.18	0.17
Bg450	5.11	−0.13	0.87**	−0.13	−0.12
Bg403	5.66	0.28	0.90**	−0.25	−0.22
Bg2937-2	5.20	0.29	0.36^{a}	−0.88	−0.32

*,**,*** – r_{ge} not significantly different from one ($P > 0.001$, $P > 0.01$, $P > 0.05$ respectively), a – r_{ge} significantly different from one.

unstable. However, in each of the other maturity groups, several varieties became unstable, regardless of the season.

DISCUSSION

Simple correlation analysis showed that some characters are not correlated to yield in certain age groups in certain seasons. Eigenvectors from the PCA also confirmed this fact by having traits invariably contributing to principal components. This emphasizes the fact that if only yield is considered in varietal recommendation, other favourable traits will be lost.

At present, varietal recommendations are based only on yield. In other words, stability, performance and superiority are computed based only on yield. Thus, in any method for varietal recommendation, one might expect yield to be given a prominent place. In the method proposed in this study, we also noticed that yield contributes to one of the first few principal components and thus yield is taken in to consideration (Tables 3.1 and 3.2).

Table 6.1. Mean values of each trait for the varieties of three maturity groups in Maha and overall mean for the season.

Variety	Days taken for flowering (Df)	Days taken for maturity (Dm)	Dm-Df	Brown rice %	Total milled rice %	Head grain %
3 month						
Bg2845	68.4	98.0	29.6	79.5	71.6	40.9
Ld98-3	65.3	94.5	29.2	78.9	70.8	44.1
Bg300	65.3	94.8	29.5	79.4	72.3	48.4
Bg2834	67.7	98.5	30.8	79.5	71.4	42.2
At303	64.6	95.2	30.6	78.8	72.1	47.8
Bg305	65.5	95.2	29.7	79.7	72.4	44.3
Overall Mean	66.1	96.0	29.9	79.3	71.8	44.6
3½ month						
Bg2879	62.8	95.6	32.8	79.0	71.3	40.1
Bg2780	70.9	99.6	28.7	79.0	71.8	42.4
Bw328-1	72.4	102.8	30.4	78.9	70.3	47.9
Bg 2835	67.7	99.6	31.9	79.5	72.2	47.3
Bg300	71.0	102.0	31.0	80.0	71.1	41.2
Bg359	71.0	104.1	33.1	79.8	71.9	39.1
Bg99-1046	64.8	96.7	31.9	79.6	72.2	44.9
Bg357	74.4	102.8	28.4	79.1	71.9	47.7
Bw99-1058	71.7	102.1	30.4	79.3	73.1	48.0
Overall mean	69.6	100.6	31.0	79.4	71.7	44.3
4½ month						
Bg2949-1	79.1	111.3	32.2	79.0	72.5	47.3
Bg379-2	77.6	110.3	32.7	78.3	72.0	45.7
Bg2937-2	79.0	110.0	31.0	78.6	72.7	50.1
Bg403	80.0	113.2	33.2	78.7	72.7	49.0
Bg2893	77.4	108.1	30.7	78.8	72.5	56.4
Bg450	77.6	109.7	32.1	79.6	73.3	50.7
Overall mean	78.5	110.4	31.9	78.8	72.6	49.9

Among the 3 month maturity group varieties in Maha, Bg2845, Ld98-3 and Bg300 became more superior (Table 5.1). Of these three, Ld98-3 was sufficiently stable and the other two were very stable. The variety Bg2834, which gave the highest yield, became unstable based on the aggregated index. It is interesting to note that although this variety gave the highest yield, it gave the second lowest head grain percentage (Table 6.1), which is important for the marketability of rice. On the other hand, the variety Bg300 was the second highest in terms of aggregated index, although it gave a relatively low yield. The low yield of this variety had been compensated for by the satisfactorily levels for all the other characters. This variety gave the highest head grain percentage, the second highest total milled rice percentage, relatively high brown rice percentage and second shortest grain filling period (Dm–Df) (Table 6.1). Thus, Bg300 clearly demonstrates the merits of the multivariate approach in varietal selection. In the case of variety Bg2845, although the aggregated index was negative, it gave the highest superiority because of its performance and stability. The outcome of Bg2845 is debatable since there is not much use in having a high performance if the variety

Table 6.2. Mean values of each trait for the varieties of three maturity groups in Yala and the overall mean of the season.

Variety	Days taken for flowering (Df)	Days taken for maturity (Dm)	Dm–Df	Brown rice %	Total milled rice %	Head grain %
3 month						
Ld98-3	66.9	95.8	28.9	78.5	73.2	48.53
Bg2834	68.3	97.0	28.7	77.7	73.2	43.9
Bg2845	64.3	95.0	30.7	77.8	72.3	35.4
At303	65.8	94.4	28.6	77.4	72.3	41.2
Bg305	68.4	95.3	26.9	78.4	73.6	53.3
Bg300	65.5	94.3	28.8	78.4	73.0	43.9
Overall mean	66.5	95.3	28.8	78.0	73.0	44.4
3½ month						
Bg2880	70.8	94.0	23.2	78.6	73.6	48.1
Bw1059	73.1	97.8	24.7	77.9	73.4	57.5
Bw328-2	71.8	101.1	29.3	79.0	73.9	54.3
Bg2781	68.4	102.1	33.7	79.5	72.9	47.0
Bg358	72.9	103.0	30.1	77.2	72.6	55.5
Bg301	64.6	102.6	38.0	78.6	73.5	49.8
Bg2836	61.3	100.9	39.6	78.2	73.3	40.9
Bw1047	73.3	93.5	20.2	79.1	73.4	53.8
Bg360	72.9	102.6	29.7	78.6	73.4	57.4
Overall mean	69.9	99.7	29.8	78.5	73.4	51.6
4½ month						
Bg379-2	84.8	113.8	29.0	79.0	72.8	51.0
Bg2949-2	87.1	116.9	29.8	78.4	73.1	45.5
Bg2893	83.7	112.9	29.2	78.9	72.7	48.1
Bg450	85.5	117.1	31.6	77.7	73.2	56.1
Bg403	80.5	109.9	29.4	78.9	73.5	52.4
Bg2937-2	87.0	115.6	28.6	78.2	73.8	62.3
Overall mean	84.8	114.4	29.6	78.5	73.2	52.6

is poor with respect to other characters or the aggregated index. However, from a selection point of view, the superiority criteria are considered to be more important compared to values of the response variable. A detailed discussion on the issue can be found in Kamidi (2001).

In the case of 3 month maturity group varieties in Yala, Ld98-3, Bg2834 and Bg2845 occupied the first three places in terms of superiority (Table 5.2). Among them, Bg2834 was sufficiently stable and the rest were very stable. Bg305 was fairly stable with the highest yield, aggregated index and head grain percentage (Table 6.2), but had poor performance ($p_i < 0$) and thus received the lowest superiority. Ld98-3 which gave the second highest yield became the most superior in the case of aggregated index because of its performance and stability.

Among the 3½ month maturity group varieties in Maha, the varieties Bg2879, Bg359, Bg357 and Bw99-1058 gave high yields (more than 5 t ha^{-1}, except for Bg359) but were found to be unstable based on the aggregated index (Table 5.1). In fact, the varieties that became unstable included the one with the highest superiority. None of the varieties in this maturity group became very stable based on the aggregated index. Bg357, which gave the second highest yield, as well as the variety Bg2879, which gave the lowest aggregated index, became unstable. This demonstrated the fact that stability is a crucial factor in the recommendation of varieties.

Selection of varieties from the 3½ month maturity group in Yala also demonstrates a typical use of the multivariate approach. The highest superiority was given by Bg2880 (Table 5.2). This variety did not give the highest value for any of the traits, but it did produce moderate values for all the traits, and thus the cumulative effect resulted in the highest superiority. The varieties that gave high superiority were stable. Among these, Bg2880 was very stable, the next three were sufficiently stable and the other was fairly stable.

In the case of the 4½ month maturity group in Maha, all the varieties were very stable, except for Bg450 which was sufficiently stable (Table 5.1). Bg2949-1, Bg379-2 and Bg2937-2 occupied the first three places in terms of superiority. Bg2893 which gave second highest index with superior head grain percentage (Table 6.1) became the second lowest because of low performance.

The varieties from the 4½ month maturity group in Yala varied in stability except Bg2937-2 which was unstable (Table 5.2). Bg379-2, Bg2949-2 and Bg2893 occupied the first three places in terms of superiority. Bg2937-2, which obtained the highest aggregated index along with highest head grain percentage (Table 6.2) had the lowest superiority because of low performance.

The most superior varieties with better stability are recommended for each location but these are not necessarily the best in terms of the aggregated index. This emphasizes the fact that the aggregated index is not the main criterion for selection but superiority is. The results obtained based on the aggregated index (multivariate approach) were compared with the results obtained based on yield (data not shown) (univariate approach). By both methods, the varieties that occupied the first three places were the same, except in the case of 3 and 4½ month maturity groups in Maha. This indicated the fact that even under the multi trait approach, yield plays an important role in the recommendation. This emphasizes the fact that the proposed method is an improvement on the existing method because other characters are given due recognition in the presence of yield.

The same varieties were used for 3 and 4½ month maturity groups in both seasons. However, their superiority and stability were different in the two seasons. Therefore, recommendation should be made for each season separately.

In the calculation of the aggregated index, the first principal component is the most important and this often represents yield, days taken to flowering and days taken to maturity. Accordingly, the days taken for flowering and days taken for maturity play an equal role as yield in giving a higher aggregated index. This emphasizes the importance of giving attention to these characters as well. It was noticed from the analysis that if all three traits were found together in one principal component, all three gave positive eigenvector coefficients. This implies that they are interrelated and when one trait is improved the other two are also improved. Thus, these three traits need not be considered separately. The economically important traits were found mostly in the second and third principal components. Not having these traits in the first principal component implies that they are more or less independent from yield and thus should be considered separately in breeding. However, the analysis revealed that the correlation structure is not consistent between seasons as well as between maturity groups. Thus, in general, all the traits need to be considered separately and a multivariate approach needs to be adopted in recommendations. One might argue that farmers are selling their product before processing or they are getting the price for rice regardless of the variety. However, the consumer actually pays for it and variety specific consumer demand is increasingly high at present. Therefore, it is mandatory to give attention to the other traits too.

CONCLUSION

The need for a multivariate approach in varietal recommendation and the proposed method provides an appealing solution to the need. The importance of the proposed method is that it paves the way for taking account of all important traits, in addition to yield, on a proper statistical basis. The methodology proposed here can easily be implemented using standard statistical software. Information on stability, performance and superiority can also be obtained by this method. The additional information resulting from this method is not obtained by sacrificing information obtained using univariate methods. Therefore, this approach is superior compared with existing univariate methods.

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