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Evaluation of Agronomic Stability of North Korean Rice Varieties using Statistical Models

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ABSTRACT This experiment was carried out to evaluate the agronomic stability of North Korean rice varieties using the statistical model developed by Grafius, Finlay, and Everhart. The lowest yearly variation based on coefficients of variation was found in Hannam 29 for number of panicles per hill, in Sijoong 9 for number of grains per panicle, in Pyeongyang 3 for ripened grain ratio, in Sijoong 16 for 1,000 grain weight, and in Yeomju 1 for grain yield. By Grafius's model, Pyeongbook 3, Weonsan 66 in early maturing groups and Seohaechalbyeo in medium maturing groups show stable for 3 years. Weonsan 66 in early maturing groups and Seohaechalbyeo in medium maturing groups were found to be highly stable as analyzed by both Finlay and Wilkinson's model and Everhart & Russell's model. With reference to three models, Weonsan 66 was highly stable for 3 years with showing more yield than Odaebyeo in early maturing groups while Seohaechalbyeo was highly stable for 3 years with showing high yield than Hwaseongbyeo in medium maturing groups above 5 t ha^{-1} of milled rice respectively.

Keywords : North Korean rice variety, yield components, agronomic stability

Genotype × environment (G×E) interactions are of major concerns to crop breeders, because they reduce the correlation between phenotype and genotype, and make it difficult to estimate the genetic potential of a genotype. Crop breeders determine the magnitude of G×E interactions by testing agronomic performances of genotypes at different sites in different years. Stable variety shows consistent performance across the range of environments. In the presence of significant G×E interactions, stability parameters could be used to determine the superiorities of each genotypes across the range of environments.

Methods available for estimating the G×E interactions were based on a traditional analysis of variance (ANOVA) at first (Sprague & Federe, 1951). then, further partitioning the G×E interaction from a traditional analysis of variance into linear trends and a departure from linear (residual) is to arrive at estimates of genetic effects. It is then possible to examine the genetic structure underlying yield stability in terms of heterosis, general combining ability (GCA), and specific combining ability (SCA). This method was first proposed by Yates & Cochran (1938) and later modified by Finlay & Wilkinson (1963), Eberhart & Russell (1966), and Perkins & Jinks (1968). It includes the regression of each genotype on an environmental index that is determined by the mean performance of all genotypes grown in each environment. In local adaptability tests, the coefficient of variance (CV), F value has been adopted dominantly in measuring stability of tested genotypes, and some papers on stability of newly bred varieties were reported by Lee *et al* (2001), and Yang *et al.* (2003).

North Korea is divided into eight agro-geological regions according to their climate and altitude, and most of them are located in the mountainous area (Moon & Song 1998). The weather varies markedly according to elevation, and uneven precipitation, along with low soil fertility, which have resulted in serious food shortages in North Korea. Stable rice production is one of ways to solve this food shortages in North Korea, which can be achieved with use of elite germplasms adaptable to various environments. However, the reports on yield stabilities about North Korean varieties are rare. The objectives of this study were i) to determine the range of variability of yield and yield components of North Korea varieties, ii) to estimate the stability related

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parameters of yield and yield components of North Korea varieties, iii) to identify elite rice germplasms which show more stable in yields.

MATERIALS AND METHODS

This experiment was conducted at the National Institute of Crop Science, Suwon, Korea. The accessions consisted of 20 varieties, including 18 from North Korea and 2 from South Korea. The tested varieties were cultivated according to the experimental Guidelines of the Rural Development Administration. These North Korea cultivars are divided into two groups based on the maturity; early and medium maturity. Both groups were sown on April 25, and transplanted on May 25 by 3 plants per hill spaced at 30×15 cm. The cultivation experiments were conducted with same practices for 3 years of 2000, 2001 and 2002. The fertilization rates of NPK were 110 kg, 70 kg and 80 kg per ha respectively. The traits of interest are number of panicles per hill, number of spikelets per panicle, panicle length, ripened grain ratio, 1,000-grain weight of brown rice, and Yield. For measuring number of panicles per hill and panicle length, ten plants per varieties were sampled from each plot. Two representative panicles per plant (a total of 20 panicles per variety) were cut and bagged after panicle emergence to avoid shattering and evaluated for ripened grain ratio. 1,000-grain weight of brown rice was measured on 50 grains per plant (10 plants per line). Yield was calculated as the average weight per plant of bulked grains harvested from the hundred plants per variety. 1,000-grain weight of brown rice and yield were corrected based on the fixed moisture content of 14%.

Statistical analysis was conducted for each character attained based on a randomized, complete-block design with three years as replications for analyzing yearly variation and stability of yield and yield components. GRAFIUS (1956) has studied a theoretical model and presented experimental data for selecting a universal variety. Grain yield was represented geometrically as a rectangular parallelepiped of volume W and with edges X (number of panicles per unit area), Y (number of spikelets per panicle × ripened grain ratio), and Z (1,000-grain weight of brown rice). A universal variety was defined as a variety which equals or exceeds the mean yield at all locations in a region, then If W of genotypes are within $X+Y+Z \geq 3$, $X \times Y \times Z \geq 1$, they can be selected as universal varieties.

The second statistical model of Finlay & Wilkinson (1973) was obtained from the regression coefficient (b coefficient) of genotype yield in individual environments as a function of the environment mean yield (m_j), The modelled genotype response:

$$R_{ij} = a_i + b_i m_j$$

where a_i = intercept value, is analogous to equation reported for joint regression analysis of adaptation, then greatest stability in response to environments is $b = 0$.

The third statistical method is Everhart & Russell's model, the behavior of the cultivars was assessed by the model $Y_{ij} = m + b_i I_j + d_{ij} + \bar{\varepsilon}_{ij}$, where Y_{ij} = observation of the i-th (i = 1, 2, ..., g) cultivar in the j-th (j = 1, 2, ...n) environment, m = general mean, b_i = regression coefficient, I_j = environmental index obtained by the difference among the mean of each environment and the general mean ($\sum_{j=l}^{n} I_j = 0$), δ_{ij} = the regression deviation of the i-th cultivar in the j-th environment and e_{ij} = effect of the mean experimental error, which interprets the variance of the regression deviations (s_{di}^2) as a measure of cultivar stability and the linear regression coefficient (b_i) as a measure of the cultivar adaptability

RESULT AND DISCUSSION

Yearly variation of yield and yield components

Rice yield components and yield were determined from eighteen North Korea varieties including two South Korea varieties over three years. Table 1 showed range, mean, coefficient of variance of each yield components and yields over years. In the number of panicles per hill, Hannam 29 showed the lowest coefficient of variance (0%), then Haebang 1 (4.2%), Weonsan 66 (4.2%) showed also lower coefficient in early maturing groups. Pyeongyang 12 was the variety that showed the lowest coefficient of variance (8.3%) in medium maturing groups. However, Ryongseong 7 showed the largest coefficient of variance (22.4%), which is much greater than that of Odaebyeo (13.3%), Hwaseongbyeo (14.5%). In the number of spikelets per panicle, Sijoong 10 showed

Table 1. Yearly variation of yield components of 18 North Korea rice varieties.

Variety	Panicles/hill (no.)			Spikelets/panicle (no.)			Ripened grain ratio (%)			1,000-grain wt of brown rice (g)		
	Range	Mean	C.V[†]	Range	Mean	C.V	Range	Mean	C.V	Range	Mean	C.V
Early maturing group												
Donghaechal	12-15	13	11.5	97-124	112	12.2	58-81	67	18.0	17.9-20.6	18.9	7.7
Haebang 1	13-14	14	4.2	103-121	111	8.2	53-70	64	14.6	19.6-20.4	20.1	2.2
Hamnam 29	13-13	13	0.0	59-98	80	24.6	48-80	69	26.4	18.7-22.2	20.5	8.6
Hwanghae 60	13-16	14	10.7	91-99	96	4.4	43-80	67	31.1	20.0-21.1	20.5	2.8
Onpo 6	12-15	14	11.2	84-110	100	14.2	49-83	61	31.3	19.7-20.8	20.3	2.8
Pyeongbook 3	12-16	14	14.5	72-99	89	16.8	76-80	79	2.9	18.7-24.0	21.8	12.7
Ryongcheon	14-17	15	11.5	70-94	83	14.6	56-83	71	19.3	19.6-20.9	20.4	3.3
Weonsan 66	13-14	14	4.2	103-112	109	4.5	46-78	62	25.8	17.6-20.3	19.3	7.6
Yeomju 1	12-14	13	7.7	87-118	104	15.1	66-93	79	17.0	20.8-22.0	21.6	3.2
Odaebyeo (ck)	13-17	15	13.3	75-96	87	12.4	70-85	75	11.1	21.5-22.3	21.8	2.1
Medium maturing group												
Pyeongyang 3	12-14	13	8.7	70-101	90	19.5	83-87	85	2.5	19.5-24.1	22.0	10.6
Pyeongyang 4	11-14	13	12.1	60-98	82	24.0	78-88	84	6.5	22.8-24.3	23.4	3.4
Pyeongyang 10	10-14	12	16.7	68-110	86	24.9	80-88	84	4.8	18.9-22.5	21.2	9.4
Pyeongyang 12	11-13	12	8.3	70-119	90	28.6	76-90	82	8.8	20.4-23.3	21.4	7.7
Ryongseong 7	12-18	14	22.4	65-106	99	31.1	82-88	85	3.5	19.8-22.5	21.1	6.4
Ryongseong 25	14-17	15	10.0	67-130	99	31.8	81-86	83	3.5	19.5-20.8	20.1	3.2
Seohaechal	12-14	13	9.1	79-125	104	22.4	70-90	78	13.9	18.5-22.3	20.4	9.3
Sijoong 10	15-17	15	10.0	79-104	90	14.4	66-86	78	13.4	17.5-21.1	19.4	9.3
Sijoong 16	15-20	17	15.6	72-77	74	3.9	75-85	80	6.3	18.8-19.5	19.2	1.8
Hwaseongbyeo (ck)	12-16	14	14.5	79-105	93	14.1	88-93	91	2.8	20.3-20.8	20.5	1.2

[†]Coefficient of variation (%).

the lowest coefficient of variance (3.9%) in all varieties, Hanghae 60 (4.4%), Weonsan 66 (4.5%), Haebang 1 (8.2%) were also showed lower value in early maturing group. However, Ryongseong 25 showed the largest coefficient of variance (31.8%), which was greater than that of Odaebyeo (12.4%), Hwaseongbyeo (14.1%). In ripened grain ratio, the lowest coefficient of variance (2.5%) in all varieties was observed in Pyeongyang 3 (2.5%), then Pyeongbook 3 (2.9%), Haebang 1 (14.6%) were also higher in early maturing varieties, while Ryongseong 7 (3.5%), Ryongseong 25 (3.5%) in medium maturing group. However, Hwanghae 60 showed the largest coefficient of variance (31.1%), that was larger than that of Korean varieties, Odaebyeo (11.1%), Hwaseongbyeo (2.8%). In 1,000 grain weight of brown rice, all North Korea varieties showed higher coefficient of variance comparing to Odaebyeo (2.1%), Hwaseongbyeo (1.2%).

Stability of yield and yield components

Grafius's model for selecting universal variety

Yield can be presumed by the yield components such as the number of panicles per hill, number of spikelets per panicle, ripened grain ratio, and 1,000-grain weight of brown rice. In Grafius's model, yield may be represented geometrically as a volume with edges such as the number of panicles per hill (X), multiplication number of spikelets per panicle by ripened grain ratio (Y), and 1,000-grain weight of brown rice (Z) for selecting the universal variety which has high yield in response to environments. The universal variety should meet a requirements of a mean $X+Y+Z \geq 3$ with $XYZ \geq 1$ in Grafius's model. Table 2 showed that Donghaechalbyeo, Haebang 1, etc. were satisfied on this condition in early maturing groups, and moreover Pyeong-

Table 2. Yield component-based parameter expressed as Grafius's model.

Variety	X[†]	Y	Z	X+Y+Z	X×Y×Z
Early maturing group					
Donghaechal	0.97	1.19	0.92	3.09	1.07
Haebang 1	1.00	1.18	0.98	3.16	1.16
Hamnam 29	1.29	0.77	1.07	3.14	1.07
Hwanghae 60	1.05	1.02	1.00	3.06	1.06
Onpo 6	1.00	1.07	0.99	3.06	1.06
Pyeongbook 3	1.05	0.95	1.06	3.06	1.06
Ryongcheon	1.10	0.88	0.99	2.97	0.96
Weonsan 66	1.00	1.15	0.94	3.09	1.08
Yeomju 1	0.95	1.10	1.05	3.11	1.10
Odaebyeo (ck)	1.10	0.92	1.06	3.08	1.08
Medium maturing group					
Pyeongyang 3	0.97	0.96	1.07	3.01	1.00
Pyeongyang 4	0.93	0.87	0.82	2.61	0.66
Pyeongyang 10	0.88	0.92	1.03	2.83	0.83
Pyeongyang 12	0.88	0.96	1.04	2.88	0.88
Ryongseong 7	1.05	1.05	1.03	3.13	1.13
Ryongseong 25	1.12	1.05	0.98	3.16	1.16
Seohaechal	0.93	1.11	1.00	3.03	1.02
Sijoong 10	1.12	0.95	0.95	3.02	1.01
Sijoong 16	1.24	0.78	0.94	2.96	0.91
Hwaseongbyeo (ck)	1.05	0.98	1.00	3.03	1.03

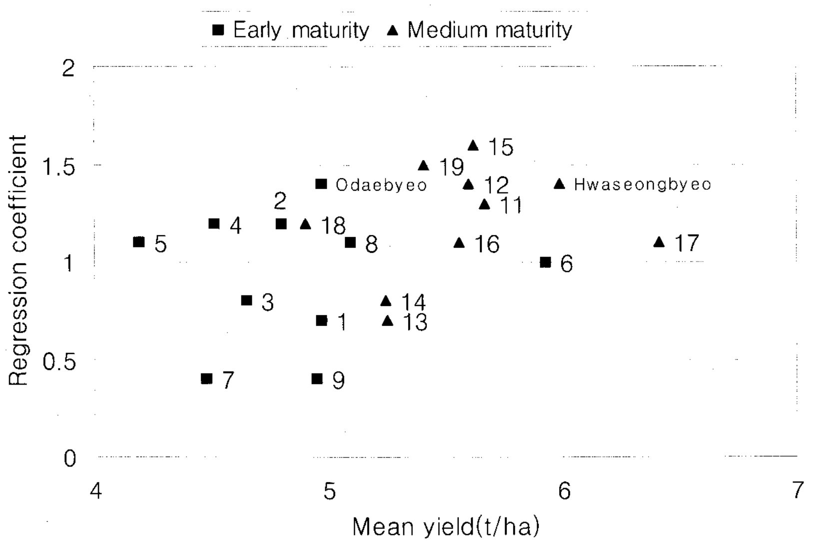
[†]X = Number of panicles/hill, Y = Number of grains/panicle, Z = 1,000 grain weight.

book 3, Weonsan 66 were selected as universal varieties with having more yields than Odaebyeo. Pyeongyang 3, Ryongseong 7, etc. were satisfied on this condition, and in addition, Seohaechalbyeo was chosen as a universal variety with having more yield than Hwaseongbyeo in medium maturing groups. With this statistical method, yield of some genotypes may remain relatively invariant over a range of environments even as the components of yield vary. The changes of yield components which are compensating their product (X. Y. Z) is relatively invariable in universal variety. With this statistical model, Elite germplasms could be selected in response to various environments with showing high and stable yield performances yearly, which is important one of qualifications in newly bred varieties.

Test of stability with Finlay & Wilkinson's model.

This model was proposed by Finlay & Wilkinson (1973), which was a slope of the regressions of individual genotype's yields against environmental mean yields. If the regression coefficient of a variety is equal to 1 or less than 1, it is considered that the variety has the yield stability for year.

This model was used by several scientists, Choi *et al.* (1976) used this model for evaluating stability of Tongil-type elite lines in 1970's. and Lee *et al.* (2000) also studied the yield stability of newly bred Korean rice varieties using this model. The result of linear regression analysis for varietal yield stability in Fig. 1 showed that Hamnam 29, Pyeongbook 3, etc. were stable over years, and moreover, Weonsan 66 showed yield stability with having more yield than Odaebyeo in early maturing group. Pyeongbook 3, Yeomju 1, and Pyeongyang 10, Pyeongyang 12, etc. were stable, and in addition, Seohaechalbyeo showed a little high yield stability with having more yield than Hwaseongbyeo in medium maturing groups. With Finlay & Wilkinson's model, Yield performance of germplasms could be compared over years and sites, which enable the breeder not only to compare cul-



1	Donghaechal	6	Pyeongbook 3	11	Pyeongyang 3	16	Ryongseong 25
2	Haebang 1	7	Ryongcheon	12	Pyeongyang 4	17	Seohaechal
3	Hamnam 29	8	Weonsan 66	13	Pyeongyang 10	18	Sijoong 10
4	Hwanghae 60	9	Yeomju 1	14	Pyeongyang 12	19	Sijoong 16
5	Onpo 6	10	Odaebyeo	15	Ryongseong 7	20	Hwaseongbyeo

Fig. 1. Test of stability with Finlay and Wilkinson's model.

tivars, but also provides a grading measure to characterize environments, sites, and seasons.

Test of stability with Everhart & Russell's model.

This model utilizes the grand means of experiments as production indexes for environments, and it provides regression response index (β value) and mean square for standard deviation from regression (Sd value) as index of production response and stability, respectively. A desirable and stable variety should have β and Sd close to or equal to 0, respectively. This model was used by Shim *et al.* (2000) who studied the stability of yield related characters in sesame varieties. Table 3 showed that Hwanghae 60, Pyeongbook 3 were selected to be stable in early maturing groups, and moreover, Weonsan 66 was stable variety with having more yields than Odaebyeo. Ryongseong 25, Sijoong 10 were selected to be stable and Seohaechalbyeo was stable variety with having more yields compared to Hwaseongbyeo in medium maturing groups.

Three models were used to provide estimates of stability parameters for 18 North Korea varieties including 2 South Korea varieties. With use of Grafius's model, the universal variety can be selected through investigating the balance of yield components such as the number of panicles per hill (X), multiplication number of spikelets per panicle by ripened grain ratio (Y), and 1,000-grain weight of brown rice (Z), which is used to check high yield potentials in various environments. Finlay & Wilkinson developed the technique of linear regression of yield of each variety on the mean yield of all varieties, for each site and each season, and used this to compare performances of genotypes over years and sites. the site mean yield value enables the breeder not only to compare cultivars, but also provides a grading measure to characterize environments, sites, and seasons. Everhart & Russell modified the Finlay and Wilkinson's model in 1966. Finlay and Wilkinson's model basically involved using the mean yield of all entries as an environment indicator and regressing each entry yield on this base, nothing the mean squares of deviation from regression. they ameliorated the genotype × environment interaction problem. their procedures included the stratification and clustering of testing environments having similar characteristics, which reduced the interaction to a practical minimum through extending by specifying that all environments be included, and by adding a

Table 3. Yield and Yield component-based parameter expressed as Everhart & Russell's model.

Variety	β[†]	Sd[‡]	Yield	
			T/ha	Index
Early maturing group				
Donghaechal	0.62	35.9	4.9	98
Haebang 1	1.22	84.7	4.8	96
Hamnam 29	0.71	12.5	5.0	100
Hwanghae 60	1.12	38.6	4.5	90
Onpo 6	0.96	91.7	4.2	84
Pyeongbook 3	0.92	45.7	5.9	118
Ryongcheon	0.42	41.7	4.5	90
Weonsan 66	0.99	5.6	5.1	102
Yeomju 1	0.32	22.8	5.0	100
Odaebyeo (ck)	1.31	70.2	5.0	100
Medium maturing group				
Pyeongyang 3	1.24	27.4	5.7	95
Pyeongyang 4	1.33	32.4	5.6	93
Pyeongyang 10	0.68	40.5	5.3	88
Pyeongyang 12	0.80	42.2	5.3	88
Ryongseong 7	1.46	8.6	5.6	93
Ryongseong 25	1.05	14.2	5.6	93
Seohaechal	1.07	4.0	6.4	107
Sijoong 10	1.10	5.5	4.9	82
Sijoong 16	1.36	24.8	5.4	90
Hwaseongbyeo (ck)	1.34	5.3	6.0	100

[†]regression response indexes (β)
[‡]mean squares due to standard deviations from regression (Sd)

formula that estimates a stability parameter from deviation mean squares from regression. Anyway, with reference to all models, Weonsan 66 was selected highly stable for years with having more yield than Odaebyeo in early maturing groups, and Seohaechalbyeo was highly stable for years with having more yield than Hwaseongbyeo in medium maturing groups above 5 t/ha. Even though Weonsan 66, and Seohaechalbyeo were bred in North Korea which has different environments compared to South Korea, they would be considered to have stable characteristics of yield and yield components for years comparing Odaebyeo, and Hwaseongbyeo. North Korea is divided into eight agro-geological regions according to their climate and altitude, and most of them are located in the mountainous area (Moon & Song 1998). The weather varies markedly according to elevation, and uneven precipitation, along with low soil fertility, which have resulted in serious food shortages in North Korea. Those varieties would be good germplasms for the use of breeding program for North Korea. However they were only evaluated for yields and yield components in this experiment. To analyze the stabilities of varieties exactly, expansion of better understanding of the effect of environmental variables on the physiological processes that determine the yield of genotypes grown in a specific environment is indispensible. The concept of stability and the kind of environments that are included in the experiment are clearly understood, they are of little use and may be misleading.

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