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The Use of Multiple Seed Vigor Indices to Predict Field Emergence and Grain Yield of Naked and Malting Barley**

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複合種子勢指數를 이용한 보리 圃場出芽率과 收量豫測**

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ABSTRACT

In order to estimate field seedling emergence and grain yield by the information collected from various laboratory seed vigor tests, each two malting and naked barley cultivar seeds were artificially aged according to the standard aging treatment suggested by the Association of Official Seed Analysts. The seed vigor tests adopted were warm- and cold-germination test, tetrazolium vigor test and electroconductivity test. Field emergence of malting barley (Y) was estimated by $Y=-2.962+0.229X_1$ (% warm germination) $-0.001X_2$ (vigor of warm germination test : WGT) $+0.354X_3$ (vigor of cold germination test : CT) $-0.558X_4$ (% cold germination).

The multiple correlation coefficient indicated that % warm germination was contributed 64% of the variation in seedling emergence rate of malting barley. The vigor of warm and cold germination tests, and % cold germination contributed additional 4, 7, and 9%, respectively, upon addition of the variables into regression. For naked barley, the regression equation of emergence rate was less efficient ($R^2=54\%$) than that of malting barley ($R^2=84\%$).

A model to predict grain yield by the results of various seed vigor tests was not evaluated for both malting and naked barley.

INTRODUCTION

The development, evaluation and use of vigor tests are of great interest to both farmers and seed producers for assessing seed quality in a wide range of crops. The standard warm germination test is showing a tendency to overestimate field performance[11,12,33,34]. Although many tests can be used to measure seed quality, most researchers believe that no single test can possibly measure seed vigor relating to field performance. Thus, it is important to understand the relationship between the various laboratory expression of seed vigor and field performance in a wide range of crops. Such relationships are reasonably well established for crops such as corn, soybeans, and certain vegetables. However, relatively little work has been done for the small grains, particularly barley

Many types of tests have been proposed to measure seed and seedling vigor[1,2,7,16,17,20,22,23,30,31,32]. Scientists have suggested combining physiological and biochemical test indices for improving the accuracy of predicting field performance of a given seed lot[8,14,15,18,21]. DasGupta and Austenson[9,10]

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concluded that the warm germination test could be supplemented with tests such as early seedling growth rate or root and shoot measurements to assess barley field performance more reliably. Bishnoi and Delouche[5] reported that the cold test and accelerated aging test which simulated adverse field conditions were adequate for predicting deterioration levels and field performance of cotton. Using six soybean varieties that had been naturally and artificially aged, Burris et al.[6] found that 4-day germination count and seedling growth rate gave the best estimates of soybean vigor, while Tekrony[28] proposed a combination of the standard germination test with one or more vigor tests to provide a broad evaluation of soybean vigor. Don et al.[13] concluded that several methods were needed for a full evaluation of wheat seed quality and that no single test was in itself adequate in estimating seed vigor.

In explaining the inadequacy of the germination test as a complete quality test, Yaklich and Kulik[34] showed that high germination percentage was not necessarily correlated with vigorous seedling growth. Scott[26] regarded vigor testing as an extension of the standard germination test and observed that vigor tests detect subtle abnormalities or weaknesses which are able to affect field performance.

Stand establishment, as influenced by the rate and vigor of germination and emergence, is one of the most critical factors in obtaining maximum grain yield in cereals. In barley, rapid and uniform germination has an additional value to the malting barley. To date, plant breeders have been restricted by rapid emergence in selection due to lack of an effective selection criteria.

Field emergence and subsequent stands are affected by seed weight[8], seed maturity[3], seed vigor[14,21,29], seedling elongation rate[24,25], soil temperature[24] and soil moisture[24] and their interactions. In addition to the interaction between those factors, there is also genotype-environment interaction that further impedes the progress in developing rapidly emerging cultivars. Because field conditions are difficult to predict and control, the intrinsic potential of seed vigor is to be highly appreciated.

In this study a particular interest was given to develop a model to predict field seedling emergence by the various laboratory seed vigor tests and to compare the efficiency of the model of malting barley with that of naked barley of which characteristics of plumules are different from those of malting barley.

MATERIALS AND METHODS

Seeds and aging treatment : Seeds of two naked barley(cv. Saesalbori, Yeongsangbori), and two malting barley(cv. Doosan # 12 and Doosan # 22) were harvested at Gyeongsang National University Experiment Station's Farm in 1987. The seeds were artificial-aged for 0(control), 2, 4 and 6 days, incubated at 41±1.0℃ in near 100% relative humidity by the 'Wire-mesh tray' procedure with three hundred seeds per tray. Seeds were then placed in a single-seed layer at room temperature and dried up to 12-14% moisture content. All subsamples were stored at 10℃ in 50% relative humidity until completion of the laboratory tests.

Laboratory tests : Seeds from each of the above treatments(days of aging) were tested by each of the following laboratory tests.

Warm germination tests : According to the "Rules for Testing Seeds" of the Association of Official Seed Analysts(AOSA)[4], three 100-seed replications of seed were germinated by rolled paper towel method at 20℃ for 7 days, then plumule length of normal seedling was measured.

Vigor index : Vigor levels were calculated by multiplying percent normal germination by length of plumule.

Cold germination test(soil germination) : A cold test was conducted by exposing the seeds to 5℃ for 3 days, followed by successive 7 days at 20℃ under warm conditions. The cold test was performed by three 100-seed replications of seeds in soil medium which was composed of equal parts of vermiculite and soil(v/v). A 3 cm thick soil layer was placed on the bottom of each plastic box(9.7cm×8.4cm×9.4cm) on which 100 seeds were placed and covered uniformly with the half amount of soil. Seventy percentage of water holding capacity was maintained. After replacing the lids, the plastic boxes were incubated for 3 day at 5℃ and then removed the boxes from the cold chamber set at 20℃ in 90% relative humidity for 7 days. The lids were removed from the boxes after 4 days to allow seedling to grow. Normal seedlings were evaluated after 7 days with the number of emerged seedling above the germination medium.

Tetrazolium vigor test : The AOSA standard procedures[2] were adopted to categorize the vigor into high, medium, and low. A cumulative index of vigor was calculated by the indices.

Conductivity test (electroconductivity) : A conductivity test was performed by using the Suntax SC-17 Conductivity Tester. The sample seeds were soaked in tube with 30ml deionized water at 20℃ for 20 hours. The average microamp. per seed was calculated by dividing the sum of all 100 seeds and the values were shown in microsiemens cm/g/seed 30ml. The details were published in previous paper[19].

Field test : Field plot were established at the Gyeongsang National University Experiment Station's Farm at Chinju, Gyeongnam. The seeds were sown at the rate of 12 ℓ/10 a, with plot size 3.3m². Fertilizer 12-9-7 kg/10a was applied. The sowing date was October 27, 1987.

Field emergence counts were made on 20th day from sowing. The rate of compensation(C) was estimated from the number of seedlings before wintering per 3.3 m²(E), the number of tillers at heading per 3.3m²(T).

The formular used was

$$C=\frac{T}{E}\times 100$$

Grain yield was calculated from the dry weight harvested from 3.3m². The samples were used for measuring of one ℓ weight by using the Brauer's Grain Balance(Kiya 127). The number of grains per spike and the number of spikes per m² were estimated. The harvest index values were calculated from the dry weight of grain and straw.

Statistical analyses : A stepwise multiple regression analysis described by Steel and Torrie[27]. was made

RESULTS AND DISCUSSION

As shown in Fig. 1, the warm and cold

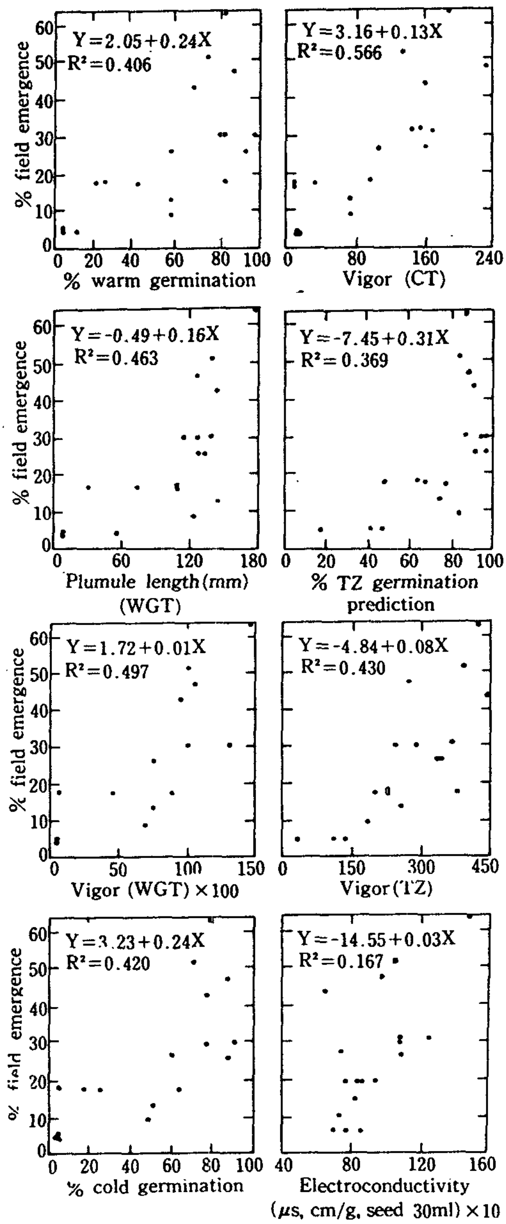

Fig. 1. Relationships between field emergence and several vigor tests in two malting and naked barley cultivars.

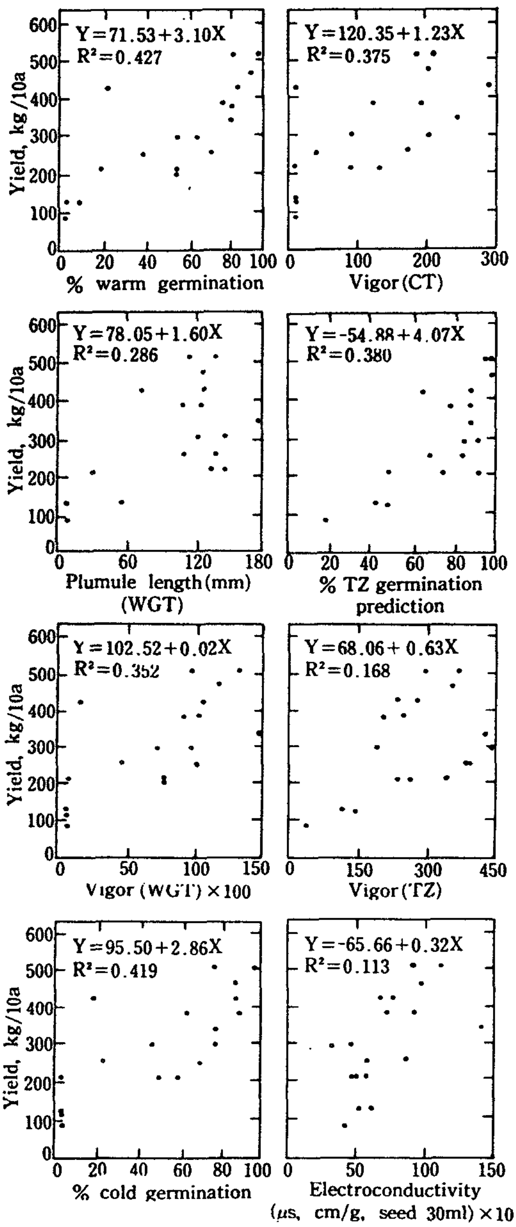

Fig. 2. Relationships between yield and several vigor tests in two malting and naked barley cultivars.

germination test and TZ vigor test were found to be the most effective in predicting seedling emergence of barley. However, the grain yield was not considered to be effectively predicted by those tests, even though TZ vigor test, warm and cold germination tests contributed to the prediction of field emergence to some extent. (Fig. 2)

The results of analysis of variance of various indices, as shown in Table 1, indicate that the difference of plumule length between malting and naked barley was detected and that the coefficients of variance of % field emergence and grain yield were too high to be accurately determined.

The result of electroconductivity test was significantly different between the cultivars, while the significant correlation coefficients of the values among the other vigor test were recognized as shown in Table 2.

Considering the effects of aging treatment on the predicting grain yield, the 4-day aging treatment was shown to be appropriate as shown

Table 1. Significant test of various indices affected by cultivars, aging treatments and their interaction.

Character	Variety (A)	Aging treat. (B)	A×B	CV(%)
% warm germ.	***	***	***	11.4
Plumule length (mm) (WGT)	ns	***	***	13.0
Vigor (WGT)	***	***	***	15.8
% cold germ.	***	***	***	16.5
Vigor (CT)	***	***	***	23.6
% Tz germ. Pred.	***	***	***	11.8
Vigor (TZ)	*	***	*	16.9
Electroconductivity	***	***	***	15.9
% field emergence	*	***	ns	21.1
Yield(kg/10a)	***	***	ns	24.7

NS, not significant ; *, significant at 5% ; **, significant at 1% ; ***, significant at 0.1% level.

Table 2. Simple correlation coefficients of grain yield with several test indices.

Character	Doonsan # 12	Doosan # 22	Saesal-bori	Yeongsan-bori
% warm germ.	.98**	.91**	.85**	.93**
Plumule length (mm) (WGT)	.98**	.87**	.76**	.92**
Vigor (WGT)	.96**	.90**	.88**	.95**
% cold germ.	.95**	.95**	.92**	.93**
Vigor (CT)	.94**	.96**	.96**	.86**
% TZ germ. pred.	.96**	.93**	.63**	.86**
Vigor (TZ)	.91**	.82**	.80**	.88**
Electroconductivity	.90**	-.17ns	.13ns	.82**
% field emergence	.91**	.92**	.85**	.53**

NS : not significant. *, significant at the 5% and 1% level.

Table 3. Relationships between indices of several laboratory tests and field emergence(FE) and grain yield.

Character	Aging levels							
	Control		2nd day		4th day		6th day	
	FE	Yield	FE	Yield	FE	Yield	FE	Yield
% warm germ.	-.18	.43	.17	.55*	.21	.61*	.06	.18
Plumule length (mm) (WGT)	.45	-.10	.23	.09	.06	-.36	.23	.25
Vigor (WGT)	.23	.28	.01	.43	.25	.47	.21	.12
% cold germ.	-.14	.72**	-.43	.40	.27	.61*	.21	.30
Vigor (CT)	.41	.48	.12	.59*	.29	.58*	.12	.20
% TZ germ. pred.	-.14	.44	.16	.24	.41	.52	.01	.36
Vigor (TZ)	.13	-.16	.20	-.35	.26	-.16	.46	.34
Electro conductivity	.31	.23	.06	.40	.19	.48	.19	.18
% field emergence (FE)	-	.27	-	.07	-	.72**	-	.69**

*, significant at p<0.05 and ** <0.01.

Table 4. Relationship between indices of several laboratory tests and field emergence(FE) and grain yield.

Character	Aging levels							
	Control		2nd day		4th day		6th day	
	FE	Yield	FE	Yield	FE	Yield	FE	Yield
Malting barley								
% warm germ.	.57	.44	.28	-.06	-.58	-.09	.78*	.13
Plumule length (mm) (WGT)	.80*	-.01	-.14	-.08	.23	-.65	-.34	.09
Vigor (WGT)	.87**	.29	.13	-.14	-.22	-.45	.48	.05
% cold germ.	.14	.15	.22	.54	-.47	-.35	-.68	-.14
Vigor (CT)	.79*	.11	.57	.40	-.46	-.55	-.68	-.14
% TZ germ. pred.	.06	.65	.02	-.10	-.27	-.88**	-.21	-.58
Vigor (TZ)	-.26	-.38	.73	.10	.54	.29	.78*	.15
Electroconductivity	.92**	.26	.34	.20	-.58	.47	-.35	-.76*
% field emergence (FE)	-	.32	-	.29	-	.07	-	.70
Naked barley								
% warm germ.	-.45	.16	-.19	.52	.07	.05	-.33	-.46
Plumule length (mm) (WGT)	-.04	.45	.81*	.94**	.30	.06	-.46	-.61
Vigor (WGT)	-.22	.38	.39	.92**	.37	.08	-.42	-.56
% cold germ.	.17	.82*	-.81*	-.77*	.69	.56	-.41	-.33
Vigor (CT)	.56	.50	-.61	-.33	.31	.31	-.20	-.31
% TZ germ. pred.	-.08	.30	-.21	.33	.30	.51	.01	-.11
Vigor (TZ)	.20	.56	-.64	.05	.59	.41	.28	.31
Electroconductivity	-.13	.33	-.93**	-.73	.04	-.08	-.11	-.02
% field emergence (FE)	-	.51	-	.64	-	.94**	-	.86*

NS, not significant ; *, significant at 5% level ; **, significant at 1% level

in Table 3.

For predicting seedling emergence, the effects of aging treatment of malting barley was different from those of naked barley, that is, malting barley does not need to have aging treatment while naked barley does about 2-day aging treatment. (Table 4)

Multiple regression equations developed by the stepwise multiple regression based on the indices of the various vigor tests seemed to be effective to predict field emergence, but less effective to predict grain yield.

On the whole, the determination coefficient(R^2) estimated was 50% with the vigor of warm germination test. The coefficient was increased by adding such variables as vigor (CT), plumule length (WGT) and vigor (TZ) into the equation.

Comparing the efficiency of the multiple regression equations of malting barley with that of naked barley, it was noted that the determination coefficient of the regression estimated was 65% with % warm germination test and the coefficient was increased with added variables such as vigor (WGT), vigor (CT), % cold germination by 4, 7 and 9%, respectively. Plumule length of naked barley on 7th day (WGT) seemed to be significantly different from that of malting barley which may affect the model less effectively. (Table 5-6)

Similar approach has been made by Ching et al[8] to determine selection criteria for predicting rate of field emergence in 2-row and 6-row barley with some physiological characters of seedlings such as seed weight, 3-day seedling ATP, and hydrated embryo ATP. However, there is not any available literature which deals with a model development to predict field emergence by various vigor tests with aging treatment.

Grain yield prediction was found to be more restricted than seedling emergence prediction, even though % warm germination, vigor (WGT) and vigor (CT) contributed to some extent. It is suggested that the difficulty in predicting grain yield would be caused by the major influence of environmental factors on seedling growth during the wintering period and subsequent grain yield. Field condition and meteorological factors might be the main causes to the discontinuous effect of seed vigor on the late growth and grain yield of barley. (Table 7-8)

Conclusively, the field emergence of malting barley was effectively predicted by a multiple regression equation based on the seed vigor information provided the equation incluedes 4 variables such as % warm germination, vigor (WGT), vigor (CT), and % cold germination with higher value of determination coefficient (84 %).

Table 5. Summary of stepwise multiple regression analysis of emergence rate and seed vigor criteria in barley cultivars.

Entered variable[a]	R^2	Residual mean squares
Vigor (WGT)	.497	84.185
Vigor (CT)	.569	73.489
Plumule length (mm, WGT)	.588	71.517
Vigor (TZ)	.634	64.711
% cold germ.	.680	57.549
% warm germ.	.692	56.385
% TZ germ. pred.	.692	57.469
Electroconductivity	.695	58.096

[a] Order of variables entered in addition to previous variables.

Table 6. Summary of stepwise multiple regression analysis of emergence rate and seed vigor criteria in barley cultivars.

Entered variable[a]	R^2	Residual mean squares
Malting barley		
% warm germ.	.649	69.998
Vigor (WGT)	.685	65.011
Vigor (CT)	.758	51.934
% cold germ.	.843	35.063
Plumule length (mm, WGT)	.844	36.340
% TZ germ. pred.	.845	37.568
Vigor (TZ)	.850	38.016
Electroconductivity	.852	39.403
Naked barley		
% warm germ.	.356	93.747
Vigor (WGT)	.386	92.724
% cold germ.	.409	92.721
Vigor (CT)	.543	74.526
Plumule length (mm, WGT)	.566	73.732
Vigor (TZ)	.585	73.594
% TZ germ. pred.	.586	76.775
Electroconductivity	.586	80.411

[a] Order of variables entered in addition to the previous variables.

Table 7. Summary of stepwise multiple regression analysis of yield and seed vigor criteria in barley cultivars.

Entered variable[a]	R^2	Residual mean squares
% warm germ.	.427	15277
Vigor (WGT)	.446	15034
Vigor (CT)	.462	14864
% cold germ.	.466	15025
% TZ germ. pred.	.475	15031
Plumule length (mm, WGT)	.476	15287
Vigor (TZ)	.477	15555
Electroconductivity	.481	15733

[a] Order of variables entered in addition to the previous variables.

Table 8. Summary of stepwise multiple regression analysis of yield and seed vigor criteria in malting and naked barley cultivars.

Entered variable[a]	R^2	Residual mean squares
Malting barley		
Vigor (CT)	.344	8981
% warm germ.	.408	8395
Vigor (WGT)	.439	8263
% cold germ.	.450	8436
% TZ germ. pred.	.451	8764
Plumule length (mm, WGT)	.468	8854
Vigor (TZ)	.486	8949
Electroconductivity	.495	9209
Naked barley		
Vigor (WGT)	.360	21035
Vigor (CT)	.384	20996
Vigor (TZ)	.458	19182
Plumule length (mm, WGT)	.491	18731
% cold germ.	.491	19510
% warm germ.	.493	20304
% TZ germ. pred.	.498	21014
Electroconductivity	.511	21413

[a] Order of variables entered on addition to the previous variables.

摘 要

보리종실의 생리적 특성을 포장출아력과 비교함으로써 포장유묘출아율과 수량의 예측에 적합한 검정방법을 구명하고자 맥주보리 2품종과 쌀보리 2품종을 인위노화처리시켜 고온발아검정(warm germination test), 저온발아검정(cold germination test), Tetrazolium 유묘세검정(TZ vigor test), 전기전도도검정(electroconductivity test)의 결과를 포장출아율 및 수량과 비교 검토 하였다.

고온발아검정과 저온발아검정이 포장출아율 예측에 효과적인 검정법으로 나타났으며, 이들의 관계는 맥주보리에서는 Y(포장출아율) $= -2.962 + 0.229X_1$(% warm germination) $- 0.001X_2$ (vigor, WGT) $+ 0.354X_3$(vigor, CT) $- 0.558X_4$ (% cold germination)으로 나타났다. 다중회귀방정식의 결정계수는 맥주보리의 경우 고온발아검정에서의 발아율만으로 포장출아율을 64%예측할 수 있었다. 고온발아유묘세, 저온발아유묘세, 저온발아율은 각각 4, 7, 9%씩 결정계수를 높혔다. 네가지 검정치의 누가적 예측효율은 맥주보리에서 84%, 쌀보리 54%였다.

수량에서는 포장출아율에서 보다 맥주보리, 쌀보리 공히 예측효과가 낮게 나타났다.

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