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Evaluation of Dense Planting Adaptation Characteristics of Small seed Soybeans by Principal Components Analysis

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For a evaluation method and a selection index for the dense planting adaptation of sprout soybeans, field experiments were conducted with two density levels; dense (30×10 cm, 66 plant m^{-2}) and standard (60×10 cm, 33 plants m^{-2}) planting one by using five cultivars of the small seed soybean for sprout, which showing different plant–types for three years. The yield and the number of pods showed a significant positive correlation. Meanwhile, the internode length and the lodging index showed a negative correlation. Characters correlated with the planting density were the internode length, the lodging index, the pods of main stem, and the harvest index as the primary principle components. Other characters like the branch angle, the number of total pods, and the leaf area index were correlated as the secondary principle components. However, the harvest index, the number of pods, and the leaf area were known as influencing factors to both standard and double density.

Thus, the internode length, the branch angle, the lodging, and the pods of main stem can be selected as infecting characters to the planting density adaptation.

INTRODUCTION

Soybean, their origin was known as East Asia, is nutritionally very important plant (Kim *et al.*, 1998). However, growing conditions of the soybean in Korea were very weak compare to foreign countries in yield and production cost (Kim *et al.*, 2000). The yield potential of soybean varies from 3,500 to 6,000 kg per ha and the seed yield is up to 7,000 kg per ha in Japan and USA (Paroda, 1999). The seed yield of soybean in Korea is remaining around a half in unit area compare to USA and Japan, and the price of the soybean in Korea is around eight times higher than the major production country, USA (Ministry of Agri. & Fores., 2007). Because of the low seed yield per unit area and an insufficient propagation of mechanization technology, the cultivation area of soybean decreased rapidly by 297,000 ha in 1970 to 90,248 ha in 2006 (Cho *et al.*, 2005; Ministry of Agri. & Fores., 2007).

Methods to increase the soybean yield per unit area would be breeding a superior cultivar or improving a cultural technique. The breeding of superior cultivar of the soybean, however, could be difficult in a short time. Thus the improving of cultural technique would be better and easy to increase the production of the soybean. A method, which could increase the plant number per unit area, might be selected easily to increase the yield as a cultural technique (Scheiner *et al.*, 2000). However, the dense planting adaptation characters of each cultivar needed to be analyzed prior to the dense planting and the selection of a dense planting cultivar needed to be proceeded during the breeding process (Scott and Kephart, 1997). But in reality, the selection is carried out in a standard planting density by 60×10 cm in Korea (Cho *et al.*, 2005). Thus most of the information on the dense planting was lost. By considering current status of the dense planting, this research carried out to establish an index for selection of high adaptive soybean cultivar against dense planting cultivar under the cultivar selection process.

MATERIALS AND METHODS

As shown Table 1, the five soybean cultivars were selected among different ecotype characteristics of small seed soybeans for this research; Eunhakong (E), Iksannamulkong (I), Pureunkong (P), Camp (C), and HS287 (H).

Field experiments were conducted over a period of three years in Iksan (126.96° E, 36.00° N). Seeds were planted during the first week of June in a randomized complete block design with three replicates. Each plot consisted of four rows space 0.60 m apart, 4 m in length, in which seeds were sown following a harvest of winter barley.

The planting densities for this research were selected as 33 individuals as the standard planting (row distance 60 cm×plant distance 10 cm) and as 66 individuals as double dense planting (row distance 30 cm×plant distance 10 cm) per unit area (m^2). The seedlings were thinned to achieve a designated plant population at V3 stage. The amount of applied fertilizer was N; 0.1 kg, P; 0.17 kg, and K; 0.15 kg per m^2 as basal fertilizations. Border rows were planted to eliminate edge effects.

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Table 1. General characteristics of sampled soybean cultviars

Cultivars	Type	FD	RD	PL	NB	SW	Characteristics
Eunhakong	DT	31 Jul.	9 Oct.	63	3.2	11.6	Medium type
Iksannamulkong	DT	4 Aug.	9 Oct.	76	4.2	12.6	Long stem, Many blanch
Pureunkong	IDT	13 Jul.	27 Sep.	101	1.2	13.5	Long stem, Few blanch
Camp	DT	2 Aug.	10 Oct.	50	4.1	8.0	Shot stem, Many blanch
HS 287	DT	26 Jul.	29 Sep.	45	2.3	15.4	Shot stem, Few blanch

DT: determinated type, IDT: indeterminated type, FD: Flowering date, RD: Ripening date, PL: Plant length (cm), N: Number of blanches, SW: 100 seed weight (g).

Then this research analyzed the samples according to the dense planting, evaluated relationships in each characteristic, and found out important selection characteristics related to the dense planting adaptation. The three individuals were randomly taken from each of two central rows in each plot for collection of growth characteristics, including yield, yield components and dry matter. Leaf area was measured on an electronic area meter (LI–3100, USA). Dry matter was determined after mature plants dried in an oven for 3 days at 80 °C. Lodging index was based on a 1 (no lodging) to 9 (completely lodged) scale (Bertram and Pedersen, 2004). Harvest index, the ratio of seed weight to total plant biomass, was calculated as total dry seed weight divided by total above ground dry biomass per plant (Denier van der Gon *et al.*, 2002). Correlation analysis for soybean traits against dense planting as well as principal component analysis (PCA) was analyzed by SAS Program (SAS institude, Inc., 1990).

RESULTS AND DISCUSSION

Correlations among principal characters

Table 2 shows the correlations among principal characters according to the planting density. The harvesting index showed the positive correlation with the number of leaves and the pods number of main stem. Meanwhile, the harvesting index showed the negative correlation with the internode length and the lodging index. This result showed the same trend as the report (Lee *et al.*, 1991) stated that there was a highly correlation between the seed yield and number of pod.

The lodging index showed the positive correlation with the internode length, the plant height, the number of branch, and the branch angle and the negative correlation with the pod number of main stem and harvest index. This result also showed the same trend as the report (Park, 1974) stated that there were highly correlations among lodging index, plant height, and internode length.

The branch number showed the positive correlation with the petiole length and the lodging index, and showed the negative correlation with the harvest index. The pod number of main stem showed the significant negative correlation with the internode length, the lodging, and the seed yield. This kind of a trend was the similar to the report by Kwon *et al.* (1973). As stated above, the results from the correlation analysis in each major character according to the planting density about five different ecotypes of the soybean sprouts, the branch length, the branch angle, the internode length, the lodging index, the number of pod, the pod number of main stem, the harvest index, and the LAI were considered to be major dense planting adaptation characters.

Evaluation of characters related to the dense planting adaptation

Table 3 shows the results of the analysis of the principal components of the dense planting adaptation related characters, which were highly correlated principal components. From Table 3, it was possible to explain the dense planting adaptation related characters by 73% based on the 1st and 2nd principal components. For the 1st principal component, the internode length, the lodg-

Table 2. Correlation coefficient between principal characters at different dense planting

Characters	PH	NB	BL	BA	IL	PL	LAI	NP	MP	HI	LI
NB	0.68*										
BL	0.33	0.48									
BA	0.64*	0.54	0.29								
IL	0.46	0.27	0.20	0.62*							
PL	0.69*	0.63*	0.26	0.24	0.24						
LAI	0.26	0.49	–0.08	0.35	–0.21	0.37					
NP	0.23	0.46	–0.05	0.08	–0.51	0.44	0.75**				
M P	–0.44	–0.28	–0.28	–0.57*	–0.82**	0.17	0.20	–0.27			
H I	–0.85**	–0.59*	–0.21	–0.47	–0.59*	–0.67*	–0.05	0.06	–0.60*		
L I	0.70*	0.59*	0.53	0.58*	0.72**	0.41	–0.18	–0.20	–0.71**	–0.67*	
Yield	–0.30	0.02	–0.37	0.01	–0.61*	–0.24	0.51	0.66*	0.62*	0.55	–0.59*

PH: Plant height, NB: Number of branch, BL: Branch length, BA: Branch angle, IL: Internnode length, PL: Petiole length, LAI: Leaf area index, NP: Number of pod, MD: Maturation date, HI: Harvest index, LI: Lodging index.

Table 3. Principal component score between the main characters at different density of planting

Characters	Principal component			
	1st	2nd	3rd	4th
Yield	– 0.38	0.28	0.18	0.38
Branch length	0.22	0.12	– 0.82	0.33
Branch angle	0.26	0.48	0.21	0.43
Internode length	0.42	0.06	0.30	0.11
Lodging	0.41	0.17	– 0.21	– 0.04
No. of pod	– 0.27	0.50	– 0.22	– 0.26
Main–stem pod	– 0.43	– 0.02	– 0.24	– 0.16
Leaf area index	– 0.16	0.58	0.11	– 0.11
Harvest index	– 0.34	– 0.24	– 0.02	0.67
Eigenvalue	4.43	2.12	0.98	0.68
Contribution (%)	49.2	23.5	10.9	7.5
Cumulative contribution (%)	49.2	72.7	83.6	91.2

ing index, and the pod number of main stem contributed as major roles. And for the 2nd principal component, the branch angle, the number of pod, and the LAI contributed as major roles.

Results of the correlation analysis between major dense adaptation character and the 1st and 2nd principal components of characters were shown in Table 4. The important characters related to the dense planting adaptation were found out eight characters at the 1st and 2nd principal components. Those characters showed highly correlated, over 0.7 of correlation coefficient, were the internode length (positive), the lodging (positive), the pod number of main stem (negative), and the harvest index (negative) in the 1st principal component and the branch angle (positive), the number of pod (positive), and the LAI (positive) in the 2nd principal component.

Table 4. Correlation coefficient between 1st or 2nd principal component and chracter

Characters	Principal component	
	1st component	2nd component
Yield	–0.79**	0.40
Branch length	0.46	0.17
Branch angle	0.54	0.70*
Internode length	0.89**	0.08
Lodging	0.86**	0.25
No. of pod	–0.57	0.73**
Main–stem pod	–0.90**	–0.04
Leaf area index	–0.34	0.84**
Havest index	–0.71**	–0.35

* and ** are significant at the 5% and the 1% level, respectively.

However, among above seven characters, the harvest index, the number of pod, and LAI were would be such characters which affect to the yield directly either in the standard growing and the dense planting growing. Thus, except these three characters, the rest of four characters were could be approved as the dense planting adaptation characters. Table 5 shows the result of the multiple regression analysis using the four major dense planting adaptation characters. From this result, the appropriateness appeared to be 0.858 by the internode length, the branch angle, and the lodging index.

The correlation between the expectation and the observation by using obtained multiple regression equation was shown in Fig. 1. From the result, the correlation between these two was very significant (R^2=0.725, $p<0.01$) Thus, this research confirmed that the major characters related the dense planting adaptation were the internode length, the branch angle, the lodging index, and the pod number of main stem in order. Also, by using above three characters except the pod number of main stem, the coefficient of determination of the multiple regression analysis was very high as 0.858. From this result, this research found out that investigation of these three characters would be enough for the field selection of the new breeding cultivar with high ability for the dense planting adaptation from the small seed soybeans for sprout. This result also lead saving times and labors to investigate many characters for the dense planting adaptation. This research considered to be that Camp and HS 287 would be proper cultivars for the dense planting adaptation and these cultivars were applicable for the parent of crossing when breeding for the dense planting adaptation cultivar, because these cultivars

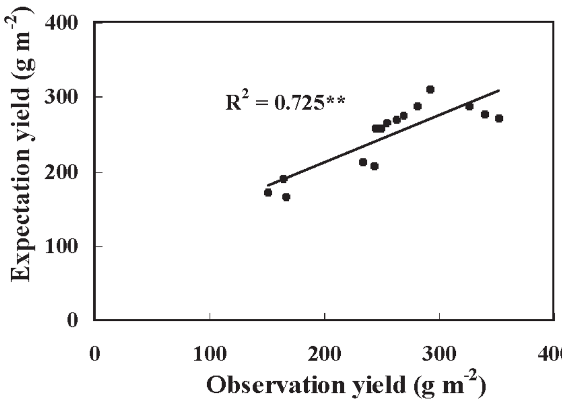

Fig. 1. Correlation coefficient between observation and expectation at different panting density. ** is significant at the 1% level.

Table 5. Multiple regression analysis of principal components at different dense planting

Variable (X)	Multiple regression equation (Y)	R–squares
IL (X_1)	$Y=-13.86\ X_1+347.5$	0.609
BA (X_2), X_1	$Y=-22.72\ X_1+2.77\ X_2+299.8$	0.785
LI (X_3), X_2, X_1	$Y=-15.92X_1+3.26\ X_2-5.53\ X_3+273.2$	0.858
MP (X_4), X_3, X_2, X_1	$Y=-10.90\ X_1+3.33\ X_2-4.63\ X_3+1.36\ X_4+204.5$	0.879

IL: Internode length, BA: Branch angle, LI: Lodging index, MP: Main stem pod.

were strong against the lodging, had high ratio of the pod number of main stem, were short in the internode length, and were narrow in the branch angle.

CONCLUSIONS

The followings are the results obtained from this research on the growing characteristics and the dense planting characters with the standard (33 plants m^{-2}) and the dense planting (66 plants m^{-2}) condition by using five different ecotype cultivars of the small seed soybean to apply as a selection index of the new cultivar breeding for the dense planting adaptation.

At the dense planting condition, the plant height, the petiole length, the internode length, and the LAI increased relative to the standard growing. Meanwhile, the branch number, the branch length and the node number decreased.

The lodging index showed the positive correlation with the plant height, the internode length, and the branch angle, and showed the negative correlation with the pod number of main stem and the harvest index.

From the evaluation of the dense planting adaptation based on the principal characters analysis, the internode length, the lodging index, the pod number of main stem, and the harvest index showed high correlation in the 1st principal components, and the number of pod and the branch angle showed high correlation in the 2nd principal components. Thus, these characters could be related to the dense planting adaptation.

From the multiple regression analysis by using the morphological dense planting adaptation characters, the internode length (X_1), the branch angle (X_2), the lodging (X_3), and pod number of main stem (X_4), $Y=-10.90X_1+3.33X_2-4.63X_3+1.36X_4+204.5$ with the coefficient of determination of 0.879 was obtained.

The correlation coefficient between the observation and the expectation by applying obtained multiple regression equation was very high as R^2=0.725, and these characters were considered to be the most important characters related to the dense planting adaptation.

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