Genetic and Environmental Variation of First Pod Height in Soybean [*Glycine max* (L.) Merr.]

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ABSTRACT First pod height (FPH) is an agronomic trait for the mechanical harvesting of soybeans with combines. The seed loss could be minimized, if the FPH is higher than the height of the cutter bar in combines. Hence, developing soybeans with high FPH has become one of important breeding goals in current crop improvement programs. The objective of this study was to evaluate genetic and environmental variation of FPH in soybean and to analyze the effect of ratio of FPH to plant height (PH) on seed yield. Four genotypes were evaluated across six different environments to analyze environmental variation of agronomic traits including FPH. Three F₂ populations were evaluated to analyze genetic variation and relationship between the ratio of FPH to PH and seed yield. The main effects of planting distance, genotype and seeding date were significant for FPH, but FPH is affected more by genetic factors than by environmental factors. The mean heritability value of FPH was 66% across three F₂ populations. Seed yield was found to reduce with increase in the FPH/PH ratio. In conclusion, genetic factors have effect more than environments to the variation of FPH. While FPH is higher than cutting height, the smaller ratio can minimize seed yield decrease.

Keywords Soybean, First pod height, Yield, Mechanical harvest

INTRODUCTION

Harvesting is one of the most laborious operations in crop production (Ramteke *et al.* 2012). Mechanized harvesting offers a reliable and cost effective option to the farmers thereby help agriculture to remain competitive (Thompson and Blank 2000). The combine harvesters are widely used to harvest the field crops including soybean [*Glycine max* (L.) Merr.]. Although harvesting soybeans with combine has an advantage of reducing the labor and production cost, but it induces seed losses. Charles *et al.* (1993) described six major reasons for losses during harvesting; those were pre-harvest loss (naturally lodging and shattering before harvest), shatter loss (pods are shattered by machinery shock at combine header), stubble

loss (stems are cut above the lower pods and those remain on stubble), non-cutting loss (lodged plants remain on the ground below the combine cutter), cylinder loss (pods are not threshed in combine due to the high moisture and incorrect cylinder-concave settings) and separation loss (seeds pass out of the combine without storage). While the cylinder loss and separation loss could be minimized by controlling concave-setting. The development of shattering and lodging resistant soybean cultivars may help to reduce pre-harvest losses, shatter losses and non-cutting losses. Very often, the pods that are missed by the cutter bars are left on the stubble and hence not gathered into the combine. Such losses are mostly reduced by using a flexible cutter bar. Previous studies have showed that 2.5 and 2.6 cm increase of cutter bar caused yield loss of 94.1 kg/ha and 27

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kg/ha, respectively (Martin and Wilcox 1973; Kowalczyk 1999). However, lowering the cutter bar may induce mechanical damage by influx with soil substances such as stones in the field. These studies imply that adjusting the cutter bar height is important and developing the soybean cultivar with higher first pod height (FPH) is also important.

Compared to the other agronomic traits, FPH have received little attention of the breeders. Nevertheless, several researchers have analyzed the genetic and environmental variation among soybean genotypes and studied the correlation of FPH with other important traits. The genetic effects of FPH are estimated by determining the broad sense heritability. Martin and Wilcox (1973) evaluated three F_2 populations for FPH variation to estimate the genetic effects of F_2 plants and observed heritability estimates of 0.62. Similarly, Costa *et al.* (2008) evaluated 57 F_2 plants and F_3 lines derived from six populations and estimated heritability value, which was found to be 0.63. Since the heritability is an indicator for genetic effects of the trait in a population or among family means (Holland and Nyquist 2003), such heritability estimates may help in early-stage phenotypic selection (Costa *et al.* 2008).

FPH is positively correlated with plant height, but negatively correlated with number of pods, number of seeds per plant, number of seeds per pod and seed weight (Oz *et al.* 2009). In an another study, Ramteke *et al.* (2012) reported that plant height, number of nodes and stem diameter are positively correlated with each other. However, Ghodrati *et al.* (2013) noted that FPH was found to be negatively correlated with the seed yield, which may

have been due to the high ratio of FPH to plant height (FPH/PH) and may have decreased the number of pods. Hence, more studies are needed to estimate the effects of variation in FPH/PH on the actual seed yield, in order to develop an ideal soybean plant type. The objective of this study was to assess the genetic and environmental variation for the FPH and to understand the effect of FPH/PH ratio on seed yield per plant in three F_2 populations. Additionally, broad-sense heritability was determined to understand the extent of FPH variation due to the genetic effects in the populations used. Environmental variation of FPH and correlation between FPH and agronomic traits in different seeding date and planting distance were also evaluated among the four genotypes.

MATERIALS AND METHODS

Plant materials and evaluation of FPH

Four genotypes, 'Uram' (Ko *et al.* 2016), 'Seonpung' (Lee *et al.* 2015), 'Tawon' (Lee *et al.* 2015), and 'Milyang 255' (Somyeong/Hannam) were selected to evaluate variation of FPH in different seeding date and planting distance. Uram, Seonpung, and Tawon are commercial cultivars whereas Milyang 255 was a breeding line. FPH of Uram and Seonpung was 19 and 18 cm, respectively, whereas that of Tawon and Milyang 255 was found to be 7 cm (Table 1).

The experiment was conducted in Daegu experiment station, Rural Development Administration (RDA) (Dalseong, 35°54'18"N, 128°26'42"E, Republic of Korea) in 2014. The experiments were designed in a split plot

Table 1. Agronomic traits of four genotypes, Uram, Seonpung, Tawon and Milyang 255 evaluated in regional yield trials conducted across eight regions in Korea for 3 years (2011-2013).

Genotypes	Agronomic traits							
	Flowering date (month day)	Maturity date (month day)	Plant height (cm)	First pod height (cm)	Number of nodes	Number of branches	Number of pods	100-seed weight (g)
Uram	Aug. 1	Oct. 9	79a ²⁾	19a	14b	3.1a	47b	25.8a
Seonpung	Aug. 5	Oct. 19	67b	18a	16a	3.0a	43b	25.9a
Tawon	July 21	Sep. 29	51c	7b	13c	2.7a	69a	9.7b
Milyang 255	July 27	Oct. 9	44c	7b	13bc	3.1a	71a	9.4b

²⁾Means followed by the same letter within columns are not significantly different according to DMRT at 0.05 level.

design with two replications in each seeding date. Main plots had three planting distances (7.5, 15, and 30 cm) and sub plots had four soybean genotypes. The plantings were made in 29th May and 27th June 2014. Plots of each genotype were planted in four-row plots 2 m long with spacing of 60 cm between rows, and hills within rows were spaced at 15 cm intervals with two seedlings per hill. The plants were phenotyped at R6 stage (Fehr *et al.* 1971) for agronomic traits such as plant height (cm), FPH (cm), number of nodes, number of branches, number of pods and stem diameter (mm). Plant height was measured as the length of the stem from the ground up to the top node. FPH was measured as the length of the stem from the ground up to the bottom of the first pod over cotyledon node. All the nodes on main stem, the branches including more than two nodes and all the pods on a plant except the empty ones were counted. Also, most thin parts of the stem between cotyledon node and unifoliate node were measured by calipers.

Estimating the genetic variation of FPH

Four soybean genotypes, a cultivar Uram and ‘Chamol’ (Lee *et al.* 2015), a breeding line ‘Milyang 257’ (Holl/Shingi) and a land race ‘IT143195’, were used to develop the segregating populations. The FPH of Uram, Chamol, Milyang 257, and IT143195 was 19, 10, 25, and 30 cm, respectively. Four soybean genotypes were crossed in 2012 in the following combinations to develop three different segregating populations: Uram × Chamol (Pop I; $n = 704$), Uram × Milyang 257 (Pop II; $n = 679$) and IT143195 × Uram (Pop III; $n = 538$). The parents and F_2 populations were grown at Daegu experiment station, RDA (Dalseong, 35°54′18″N, 128°26′42″E, Republic of Korea). Planting was made with two seeds per hill on 19th June 2014 and thinning was carried out at V4 stage (Fehr *et al.* 1971) to keep one plant per hill. The plot was 4 m long with row spacing of 60 cm and hill spacing of 15 cm, and every plot was mulched with black vinyl. All the individuals from three F_2 populations were phenotyped for plant height and FPH at R6 stage (Fehr *et al.* 1971). To evaluate yield components by the ratio of FPH to plant height (FPH/PH), Pop I and Pop II populations were categorized seven levels, with 5% difference in FPH/PH. Fifteen to twenty plants

were sampled randomly. The selected plants were phenotyped for number of pods, 100-seed weight, and seed yield.

Statistical analysis

The trait data were used for the analysis of variance (ANOVA) of seeding date, planting distance and interactions, and for the analysis of correlation coefficient. The ANOVA was performed using PROC GLM of SAS (SAS 9.2). The data were analyzed in a split plot design with two seeding dates. The differences among mean values were determined using Least Significant Difference at $P \leq 0.05$ or Duncan’s multiple range test at $P \leq 0.05$. R version 3.0.2 was used to draw or calculate distribution, skewness, kurtosis in F_2 population and the correlation coefficient of the traits. Coefficient of variation (CV) was used as a parameter to compare the stability of genotypes within treatments. Broad-sense heritability for FPH in the F_2 populations was calculated as per the equation given by Mahmud and Kramer (1951).

$$H = \frac{V_G}{V_P}$$

$$V_P = V_G + V_E$$

$$H = \frac{\sigma_{F_2}^2 - \sqrt{\sigma_{P_1}^2 \times \sigma_{P_2}^2}}{\sigma_{F_2}^2}$$

Where H is broad-sense heritability, V_G is a genetic variance, V_P is a phenotypic variance, V_E is an environmental variance, $\sigma_{F_2}^2$ is a variance of F_2 population, $\sigma_{P_1}^2$ is a variance of maternal parent, $\sigma_{P_2}^2$ is a variance of paternal parent.

RESULTS

Analysis of variance of four soybean genotypes for the agronomic traits

The combined ANOVA indicated that planting distance (D), genotype (G) were significant for plant height, FPH, number of nodes, number of branches, number of pods and stem thickness. Seeding date (S) was also significant for all the traits except number of branches. Seeding date an effect

on FPH and interaction between genotype and seeding date was also detected (Table 2 and 3). Early seeding date showed significantly higher FPH than late seeding date, however not all the genotypes showed significant decrease at late seeding date. FPH in Seonpung significantly decreased at late seeding date but the other genotypes were not significantly changed. Genotype was significantly interacted with seeding date and planting distance for plant height, number of nodes, and number of pods, but not for the number of branches (Table 2).

The FPH was decreased by increasing the planting distance. Mean values for FPH in planting distance 15,

17.5, and 30 cm were 16.1, 15.3, and 13.4 cm, respectively (Table 3). Furthermore, the results show that the four genotypes responded differently by planting distance. FPH did not differ significantly in all the 4 genotypes planted in 7.5 and 15 cm distances; however the genotypes except Uram planted in 30 cm distance showed significant reduction in FPH.

The mean value of FPH for Uram, Seonpung, Tawon, and Milyang 255 were 21.1, 19.5, 8.1, and 11.1 cm, respectively (Table 3). CV of four genotypes in planting distance and seeding date was different. CV for planting distance of Uram, Seonpung, Tawon and Milyang 255 was

Table 2. Mean square value and degree of freedom for analysis of environmental variation for plant height, first pod height, number of nodes, number of branches, number of pods and stem thickness for four soybean genotypes grown in three planting distances and two seeding date in Daegu experiment station at 2014.

Source	df ^(x)	Plant height	First pod height	Number of nodes	Number of branches	Number of pods	Stem thickness
Seeding date (S)	1	23,166.3***	280.1***	406.1***	4.3	27,592.9***	390.3***
Block (B)	1	547.3***	7.3	15.1***	5.3*	1462.5*	0.4
Block (in seeding)	1	3894.0***	130.7*	2.0	3.3	1188.3	25.2***
Distance (D)	2	2553.3***	181.9***	3.9*	107.0***	73,923.2***	105.6***
D × S	2	113.6*	123.2***	2.3	3.6	571.2	1.7
Genotype (G)	3	18,647.8***	2,880.4***	174.8***	21.8***	46,918.1***	32.6***
G × S	3	479.8***	73.3*	7.9***	0.5	2,394.3***	0.6
D × G	6	163.2***	14.9	4.9***	2.3	3,664.2***	2.5*
D × G × S	6	169.7***	34.3	1.9	1.7	614.2	1.3

*, **, and *** stand for significantly different at 0.5, 0.01, and 0.001 level, respectively.

^xDegree of freedom.

Table 3. Evaluation of first pod height and coefficient of variation in different planting distance and seeding date.

Treatments		First pod height (cm)			
		Uram	Seonpung	Tawon	Milyang 255
Planting distance (cm)	7.5	21.0	21.2	9.1	13.0
	15	22.3	19.2	8.6	11.1
	30	19.8	18.0	6.4	9.3
	CV(%)	6	8	18	16
	LSD _{0.05}	3.2	2.9	1.3	2.7
Seeding date	May 29 2014	21.7	21.9	8.1	11.9
	June 27 2014	20.4	17.1	8.0	10.4
	CV(%)	4	18	1	10
	LSD _{0.05}	2.6	2.4	1.1	2.2
CV(%) ²⁾		27	29	39	45
Mean ^{y)}		21.1	19.5	8.1	11.1

²⁾CV(%) was calculated across planting distance and seeding date.

^{y)}Mean FPH calculated across planting distance and seeding date.

6, 8, 18, and 16%, respectively. Uram was less affected by planting distance compared to other three genotypes. CV for seeding date of Uram, Seonpung, Tawon, and Milyang 255 were 4, 18, 1, and 10%, respectively and Tawon was found to be less affected by seeding date. The CVs in all six environments by three planting distances and two seeding dates for Uram, Seonpung, Tawon, and Milyang 255 were 27, 29, 39, and 45%, respectively. This result suggests that Uram is the most stable genotype across the seeding date and planting distance.

Phenotypic distribution, heritability and correlation coefficient analysis for FPH in F₂ populations

Phenotypic values, standard deviation (SD), CV, skewness, and kurtosis of FPH in three F₂ populations for FPH are given in Table 4, and the frequency distribution are

shown in Fig. 1. FPH of all the three populations showed transgressive segregation, suggesting the quantitative behavior of the trait. The range of FPH for Pop I, Pop II, and Pop III was 1-37, 4-50, and 4-67 cm, respectively. Mean values with SD were 14.7 ± 6.2 , 24.0 ± 6.1 , and 25.6 ± 9.1 cm, and CV values were 42.1, 25.5, and 35.6% for Pop I, Pop II, and Pop III, respectively. The skewness of Pop I, Pop II, and Pop III was 0.41, 0.58, and 0.92, respectively and distributions were right-skewed. The kurtosis of Pop I, II, and III was 0.01, 1.44, and 1.88 and those distributions were all positive and had sharper peak with fatter tails than a normal distribution.

The range of plant height for Pop I, Pop II, and Pop III was 19-105, 30-150, and 25-200 cm, respectively. Mean values with SD of plant height for Pop I, Pop II, and Pop III were 62.9 ± 17.6 , 92.6 ± 13.4 , and 108.0 ± 23.9 cm,

Table 4. Mean with standard deviation (SD), range, coefficient variance (CV), skewness, kurtosis, and heritability of plant height and first pod height of three cross combinations in three F₂ populations.

Cross combination		Plant height (cm)						First pod height (cm)					
		Mean $\pm$ SD	Range	CV (%)	Skewness	Kurtosis	Heritability (%) ²⁾	Mean $\pm$ SD	Range	CV (%)	Skewness	Kurtosis	Heritability (%) ²⁾
Pop I (Uram $\times$ Chamol)	P1 (n = 22)	83.4 $\pm$ 9.0	72-120	10.8	-0.81	1.24	90	17.5 $\pm$ 4.8	12-35	27.6	2.11	6.66	51
	P2 (n = 24)	43.7 $\pm$ 3.6	37-52	8.2	0.35	0.02		10.6 $\pm$ 3.9	3-18	15.1	0.29	-0.43	
	F ₂ (n = 704)	62.9 $\pm$ 17.6	19-105	27.9	-0.28	-0.54		14.7 $\pm$ 6.2	1-37	42.1	0.41	0.01	
Pop II (Uram $\times$ Milyang 257)	P1 (n = 25)	91.7 $\pm$ 4.2	81-98	4.6	-0.63	-0.08	82	21.6 $\pm$ 2.2	16-25	10.3	-0.49	0.17	79
	P2 (n = 23)	88.0 $\pm$ 7.9	71-100	9.0	-0.87	-0.03		24.6 $\pm$ 4.2	15-33	17.1	-0.12	0.32	
	F ₂ (n = 679)	92.6 $\pm$ 13.4	30-150	14.5	-0.22	1.65		24.1 $\pm$ 6.1	4-50	25.5	0.58	1.44	
Pop III (IT143195 $\times$ Uram)	P1 (n = 11)	126.8 $\pm$ 18.6	81-162	14.7	-0.79	3.42	73	30.9 $\pm$ 5.4	20-38	17.4	-0.48	-0.30	67
	P2 (n = 25)	86.4 $\pm$ 8.4	63-101	9.7	-0.78	0.88		20.2 $\pm$ 5.1	10-31	25.2	-0.17	-0.06	
	F ₂ (n = 538)	108.0 $\pm$ 23.9	25-200	22.1	0.39	1.44		25.6 $\pm$ 9.1	4-67	35.6	0.92	1.88	
Mean							81						66

²⁾Broad sense heritability.

Fig. 1. Frequency distribution for first pod height in three F₂ populations evaluated in Daegu experiment station 2014. P1, maternal parent; P2, paternal parent.

respectively. CV values for Pop I, Pop II, and Pop III were 27.9, 14.5, and 22.1%, respectively. The skewness of Pop I, Pop II, and Pop III for plant height was -0.28 , -0.22 , and 0.39 , respectively. The kurtosis of Pop I, Pop II, and Pop III for plant height was -0.54 , 1.65 , and 1.44 ,

respectively. The skewness and kurtosis of plant height were tended to left skewed and wider peak compared with FPH.

Broad-sense heritability estimates for FPH and plant height in three populations are shown in Table 4.

Table 5. Correlation coefficient among agronomic traits of four genotypes evaluated in two seeding date and three planting distance.

Agronomic traits	Plant height	First pod height	Number of nodes	Number of branches	Number of pods	Stem thickness
Plant height	1					
FPH	0.61***	1				
No. of nodes	0.66***	0.49***	1			
No. of branches	-0.06^{NS}	-0.18^{***}	0.25***	1		
No. of pods	-0.29^{***}	-0.47^{***}	0.06 ^{NS}	0.58***	1	
Stem thickness	0.45***	0.17***	0.67***	0.47***	0.43***	1

NS and *** stands for none significant at 0.05 level and significant different at 0.001 level, respectively.

Table 6. Mean value of seed yield per plant, number of pods, one hundred weight, first pod height and plant height by the ratio of FPH to plant height which calculated from randomly sampled plants in two F₂ populations in Daegu experiment station in 2014.

Cross combination	Traits ²⁾	Ratio of first pod height to plant height						
		0.05-0.10	0.11-0.15	0.16-0.20	0.21-0.25	0.26-0.30	0.31-0.35	0.36-0.40
Pop I (Uram × Chamol)	YP (g/plant)	32.0a ^{y)} (8-50) ^{x)}	26.3ab	21.7bc	21.0bc	23.3abc	15.5c	15.2c
	NP	79a (25-148)	59abc (10-130)	49bc (21-111)	50bc (19-124)	64ab (8-160)	45bc (6-128)	40c (12-94)
	HSW (g)	29.5ab (16.0-38.9)	30.9a (24.0-37.0)	30.1a (17.1-36.0)	30.9a (22.0-37.8)	25.5b (16.0-33.9)	25.9b (12.1-40.0)	29.6ab (14.3-40.0)
	FPH (cm)	4d (2-7)	7d (4-11)	11c (8-17)	16b (7-25)	21a (8-31)	21a (9-31)	22a (9-37)
	PH (cm)	52cd (26-89)	49d (27-73)	62abcd (46-96)	66ab (29-101)	74a (26-105)	64abc (29-95)	56bcd (22-92)
	No. of samples	11	16	18	21	26	22	12
	YP (g/plant)	48.3a (46-51)	38.3ab (4-96)	26.1bc (10-50)	25.2bc (2-72)	15.2c (2-28)	18.3c (6-38)	15.1c (2-30)
	NP	109a (103-114)	110a (17-227)	78ab (34-138)	81ab (18-157)	58b (10-89)	61b (27-96)	46b (11-81)
	HSW (g)	23.8a (22.0-25.5)	20.1ab (10.0-30.0)	21.0ab (12.0-26.0)	18.7ab (8.7-28.6)	16.9b (9.6-26.5)	18.7ab (11.7-24.7)	18.8ab (9.5-28.0)
	FPH (cm)	5f (4-5)	13e (9-17)	17d (11-24)	22c (17-28)	28b (22-35)	30b (24-38)	35a (29-45)
	PH (cm)	70b (65-75)	95a (77-126)	92a (60-122)	93a (78-113)	98a (80-117)	88a (70-113)	92a (76-111)
	No. of samples	2	15	15	15	15	16	10

²⁾YP: seed yield per plant, NP: number of pods, HSW: 100-seed weight, FPH: first pod height, PH: plant height.

^{y)}Within rows, means followed by the same letter are not significantly different according to DMRT at 0.05 level.

^{x)}Value in parenthesis indicate the range of evaluated traits in each ratio of first pod height to plant height.

Heritability for FPH of Pop I, Pop II, and Pop III was 51, 79, and 67%, respectively. Mean heritability for FPH was 66%. Heritability for plant height of Pop I, Pop II, and Pop III was 90, 82, and 73%, respectively. Mean heritability for plant height was 81% and comparably higher than that of FPH. In correlation analysis, FPH showed positive and significant correlation with plant height ($r = 0.61$, $P < 0.001$), number of nodes ($r = 0.49$, $P < 0.001$) and stem thickness ($r = 0.17$, $P < 0.001$) but showed negative correlation with the number of pods ($r = -0.47$, $P < 0.001$) (Table 5).

The effect of ratio of FPH to PH on seed yield, number of pods and 100-seed weight in F₂ populations

Mean and range data obtained from the samples in Pop I and Pop II are given in Table 6. The data suggests that the increased FPH/PH affects number of pods per plant and yield negatively. When FPH/PH was more, the yield decreased significantly. In Pop I, the seed yield was significantly decreased from 32.0 g in 0.05-0.10 ratio to 5.5 g in 0.31-0.35. The number of pod that is a trait highly related to seed yield was also significantly decreased from 79 in 0.05-0.10 ratio to 45 in 0.31-0.35. In Pop II, similar variation of evaluated traits was recognized. The seed yield was significantly decreased from 48.3 g in 0.05-0.10 ratio to 0.26-0.30 and the number of pods was also significantly decreased from 109 in 0.05-0.10 ratio to 58 in 0.26-0.30. The variation of one-hundred seed weight in Pop I and Pop II was not shown meaningful tendency relating to FPH/PH. FPH in Pop I and Pop II was increased, but variation of plant height was not relating to variation of FPH/PH.

DISCUSSION

Phenotypic variation for a quantitative trait is influenced by the genetic and environmental factors. FPH is a quantitative trait (Fig. 1) and affected by the environments, such as seeding date and planting distance. In this study, decrease in the FPH was observed with increased planting distance and delayed the seeding date. These results were similar with the studies reported by Ibrahim (2012a, 2012b). Furthermore, significant $D \times S$ and $G \times S$ interactions, like those reported by Ibrahim (2012a, 2012b) and

Karaaslan *et al.* (2012) were observed. However, in one of the study, Naglamu (2013) showed that $G \times S$ interactions were not significant in the genotypes they evaluated. It is evident from these results that genotypes may respond differently to the environments such as planting distance and seeding date. Thus, the genotypes, showing stable variation for FPH need to be identified and used as a breeding resource for different cultivation environments.

Heritability analyses in the segregating populations are conducted to estimate the genetic effects of FPH. Martin and Wilcox (1973) evaluated three F₂ populations for FPH and estimates of heritability were 63% (Beeson $\times$ L66-1085-1-270), 74% (Amsoy71 $\times$ L66-1085-1-239) and 50% (Wayne $\times$ L66-1085-1-251). Costa *et al.* (2008) also evaluated 57 F₂ and F₃ families derived from six populations, in which the estimates of broad sense heritability were 82% (BRSMG Renasença $\times$ BR-16), 48% (MGBR95-20937 $\times$ IAC Foscarin31), 45% (MGBR95-20937 $\times$ BR-16), 66% (BRSMG Liderança $\times$ Embrapa-48), 43% (BRSMG Liderança $\times$ IAC Foscarin31), and 95% (BRSMG Renasença $\times$ Embrapa-48) for the respective crosses. When heritability is higher than 50%, it means that phenotypic variation is more affected by genetic factors than environmental factors (Stansfield 2005). High heritability for FPH was observed in this study. This result show that 66% of the overall variation could be explained by genotypic differences among individuals in F₂ population. Therefore, selection for FPH in early generation like as F₂ population is possible and efficient for maintaining phenotype to the following generation (Costa *et al.* 2008).

The frequency distribution of FPH in three F₂ populations (Pop I: Uram $\times$ Chamol, Pop II: Uram $\times$ Milyang 257 and Pop III: IT143195 $\times$ Uram) showed normal distribution in the F₂ populations, indicating that FPH behave as a quantitative trait in these populations.

FPH was found to show positive correlation with plant height, number of nodes and stem thickness, but negative correlation with the number of pods. Similar correlations were observed by Oz *et al.* (2009), Ramteke *et al.* (2012), Ghodrati *et al.* (2013) and Pirdashti *et al.* (2010). Especially, the number of pods was negatively correlated with FPH. This result suggests that higher FPH may cause

decrease in the number of pods and seed yield.

The number of pods is one of the most important traits determining seed yield (Oz *et al.* 2009). Previous studies indicated the positive correlation between seed yield and number of pods (Malik *et al.* 2006; Ramgiry *et al.* 1998). For this reason, it should be avoided to develop only a higher FPH cultivar without considering relationship between FPH and seed yield. Our results indicated that not only FPH but also the FPH/PH ratio is a significant factor that affect the seed yield (Table 6). It is important to understand that while the FPH should be higher than the height of the cutter in combine harvester, the FPH/PH ratio should be kept minimum. Ramteke *et al.* (2012) referred that FPH should be at least 12 cm for minimum yield loss with combine harvest. Stubble height was about 15 cm therefore, lower pods than this height should make yield loss (Son and Heo 2002).

Although the highest yield was achieved in the two populations when the FPH/PH ratio was between 0.05-0.10, the FPH for the Pop I and Pop II was in the range 2-7 and 4-5, respectively. Therefore, it is difficult to select FPH around 15cm for combine harvest in this ratio. However, when the FPH/PH ratio range was 0.16-0.25, the seed yield per plant was 8-58 g with FPH ranged 4-17 cm in Pop I. In case of Pop II, when the FPH/PH ratio range was 0.11-0.20, the seed yield per plant was 4-96 g with FPH ranged 9-24 cm. These results indicated that soybean yield and FPH were different by cross combination and FPH/PH ratio range 0.16-0.25 had proper range for FPH and seed yield in both population.

In conclusion, high FPH prevents harvesting losses, but seed yield in a plant could be decreased. Seed yield was found to reduce with increase in the FPH/PH ratio. The adequate FPH/PH ratio for a plant was found to be 0.16-0.25 in the present study. FPH is a trait which can be selected by phenotype in the field because genetic variation of FPH is higher than environmental variation. However, genetic information (e.g., QTLs and related genes) of FPH is not analyzed at this time. Knowledge of genetic background of agricultural trait is important for breeders. Therefore, further research for identifying detailed genetic information should be conducted in the future.

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