Genetic and Environmental Variation of First Pod Height in Soybean \textit{[Glycine max (L.) Merr.]} \\

Beom-Kyu Kang$^1$, Hyun-Tae Kim$^1$, Man-Soo Choi$^1$, Seong-Chul Koo$^1$, Jeong-Hyun Seo$^1$, Hong-Sik Kim$^1$, Sang-Ouk Shin$^1$, Hong-Tae Yun$^1$, In-Seok Oh$^1$, Krishnanand P. Kulkarni$^2$, Jeong-Dong Lee$^2$* \\

$^1$National Institute of Crop Science, RDA, Miryang 50424, Korea  \\
$^2$School of Applied Biosciences, Kyungpook National University, Daegu 41566, Korea \\

**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 \textit{F$_2$} 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 \textit{F$_2$} 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 \textit{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 \textit{[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 \textit{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 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...
kg/ha, respectively (Martin and Wilcox 1973; Kowaleczuk 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 F2 populations for FPH variation to estimate the genetic effects of F2 plants and observed heritability estimates of 0.62. Similarly, Costa et al. (2008) evaluated 57 F2 plants and F3 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 another study, Ramteke et al. (2012) reported that plant height, number of nods 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 F2 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’ (Somjeong/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

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**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     | 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†               | 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              |

†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 F2 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 F2 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 inter-
actions, 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 F2 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 F2
populations was calculated as per the equation given by
Mahmud and Kramer (1951).

$$H = \frac{V_G}{V_P}$$
$$V_P = V_G + V_E$$
$$H = \frac{\sigma^2_{F_2}}{\sigma^2_{F_2} + \sigma^2_P \times \sigma^2_P}$$

Where $H$ is broad-sense heritability, $V_G$ is a genetic
variance, $V_P$ is a phenotypic variance, $V_E$ is an environ-
mental variance, $\sigma^2_{F_2}$ is a variance of F2 population, $\sigma^2_P$ is
a variance of maternal parent, $\sigma^2_P$ 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 (z) | 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.

1)Degree of freedom.

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

| Treatments                | 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<sub>.05</sub>         | 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<sub>.05</sub>         | 2.6  | 2.4      | 1.1   | 2.2         |
| CV(%)<sup>2</sup>         | 27   | 29       | 39    | 45          |
| Mean<sup>3</sup>          | 21.1 | 19.5     | 8.1   | 11.1        |

<sup>2</sup>CV(%) was calculated across planting distance and seeding date.
<sup>3</sup>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,

| Cross combination | Plant height (cm) | First pod height (cm) |
|-------------------|-------------------|-----------------------|
|                   | Mean ± SD | Range | CV (%) | Skewness | Kurtosis | Heritability (%) | Mean ± SD | Range | CV (%) | Skewness | Kurtosis | Heritability (%) |
| Pop I (Uram × Chamol) |          |       |        |         |          |                |          |       |        |         |          |                |
| P1 (n = 22)       | 83.4 ± 9.0 | 72-120 | 10.8   | −0.81   | 1.24     |                | 17.5 ± 4.8 | 12-35 | 27.6   | 0.29    | 0.43      | 6.66            |
| P2 (n = 24)       | 43.7 ± 3.6 | 37-52  | 8.2    | 0.35    | 0.02     | 90             | 10.6 ± 3.9 | 3-18  | 15.1   | 0.29    | 0.43      | 10.6 ± 4.8     |
| F2 (n = 704)      | 62.9 ± 17.6 | 19-105 | 27.9   | −0.28   | −0.54    |                | 14.7 ± 6.2 | 1-37  | 42.1   | 0.41    | 0.01      | 14.7 ± 6.2     |
| Pop II (Uram × Milyang 257) |          |       |        |         |          |                |          |       |        |         |          |                |
| P1 (n = 25)       | 91.7 ± 4.2 | 81-98  | 4.6    | −0.63   | −0.08    |                | 21.6 ± 2.2 | 16-25 | 10.3   | −0.49   | 0.17      | 21.6 ± 2.2     |
| P2 (n = 23)       | 88.0 ± 7.9 | 71-100 | 9.0    | −0.87   | −0.03    | 82             | 24.6 ± 4.2 | 15-33 | 17.1   | −0.12   | 0.32      | 24.6 ± 4.2     |
| F2 (n = 679)      | 92.6 ± 13.4 | 30-150 | 14.5   | −0.22   | 1.65     |                | 24.1 ± 6.1 | 4-50  | 25.5   | 0.58    | 1.44      | 24.1 ± 6.1     |
| Pop III (IT143195 × Uram) |          |       |        |         |          |                |          |       |        |         |          |                |
| P1 (n = 11)       | 126.8 ± 18.6 | 81-162 | 14.7   | −0.79   | 3.42     |                | 30.9 ± 5.4 | 20-38 | 17.4   | −0.48   | −0.30     | 30.9 ± 5.4     |
| P2 (n = 25)       | 86.4 ± 8.4 | 63-101 | 9.7    | −0.78   | 0.88     | 73             | 20.2 ± 5.1 | 10-31 | 25.2   | −0.17   | −0.06     | 20.2 ± 5.1     |
| F2 (n = 538)      | 108.0 ± 23.9 | 25-200 | 22.1   | 0.39    | 1.44     |                | 25.6 ± 9.1 | 4-67  | 35.6   | 0.92    | 1.88      | 25.6 ± 9.1     |
| Mean              | 81        |        |        |         |          |                |          |       |        |         |          |                |

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.

**Fig. 1.** Frequency distribution for first pod height in three F2 populations evaluated in Daegu experiment station 2014. P1, maternal parent; P2, paternal parent.
The Variation of First Pod Height in Soybean

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***      | 0.49***          | 1               |                   |                |               |
| No. of nodes     | 0.66***      | 0.49***          | 1               |                   |                |               |
| No. of branches  | −0.06NS      | −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 | Traits5) | 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) | 32.0a5) | 26.3ab | 21.7bc | 21.0bc | 23.3abc | 15.5c | 15.2c |
|                    | (8-50)5) | (2-62) | (8-54) | (6-58) | (4-56) | (4-32) | (4-28) |
|                    | NP       | 79a | 59abc | 49bc | 50bc | 64ab | 45bc | 40c |
|                    | (25-148) | (10-130) | (21-111) | (19-124) | (8-160) | (6-128) | (12-94) |
|                    | HSW (g)  | 29.5ab | 30.9a | 30.1a | 30.9a | 25.5b | 25.9b | 29.6ab |
|                    | (16.0-38.9) | (24.0-37.0) | (17.1-36.0) | (22.0-37.8) | (16.0-33.9) | (12.1-40.0) | (14.3-40.0) |
|                   | FPH (cm) | 4d | 7d | 11c | 16b | 21a | 21a | 22a |
|                    | (2-7) | (4-11) | (8-17) | (7-25) | (8-31) | (9-31) | (9-37) |
|                   | PH (cm)  | 52c | 49d | 62abc | 66ab | 74a | 64abc | 56bcd |
|                    | (26-89) | (27-73) | (46-96) | (29-101) | (26-105) | (29-95) | (22-92) |
| No. of samples   | 11 | 16 | 18 | 21 | 26 | 22 | 12 |

| Pop II (Uram × Milyang 257) | YP (g/plant) | 48.3a | 38.3ab | 26.1bc | 25.2bc | 15.2c | 18.3c | 15.1c |
|                            | (46-51) | (4-96) | (10-50) | (2-72) | (2-28) | (6-38) | (2-30) |
|                            | NP       | 109a | 110a | 78ab | 81ab | 58b | 61b | 46b |
|                            | (103-114) | (17-227) | (34-138) | (18-157) | (10-89) | (27-96) | (11-81) |
|                            | HSW (g)  | 23.8a | 20.1ab | 21.0ab | 18.7ab | 16.9b | 18.7ab | 18.8ab |
|                            | (22-0.25.5) | (10-30.0) | (12.0-26.0) | (8.7-28.6) | (9.6-26.5) | (11.7-24.7) | (9.5-28.0) |
|                            | FPH (cm) | 5f | 13e | 17d | 22c | 28b | 30b | 35a |
|                            | (4.5) | (9-17) | (11-24) | (17-28) | (22-35) | (24-38) | (29-45) |
|                            | PH (cm)  | 70b | 95a | 92a | 93a | 98a | 88a | 92a |
|                            | (65-75) | (77-126) | (60-122) | (78-113) | (80-117) | (70-113) | (76-111) |
| No. of samples            | 2 | 15 | 15 | 15 | 15 | 16 | 10 |

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

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

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 2.6-0.30 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 × S and G × 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 × 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 × L66-1085-1-270), 74% (Amsoy71 × L66-1085-1-239) and 50% (Wayne × 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 Renascença × BR-16), 48% (MGBR95-20937 × IAC Foscarin31), 45% (MGBR95-20937 × BR-16), 66% (BRSMG Liderança × Embrapa-48), 43% (BRSMG Liderança × IAC Foscarin31), and 95% (BRSMG Renascença × 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 × Chamol, Pop II: Uram × Milyang 257 and Pop III: IT143195 × 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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