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Original Article

Heritability and association for agronomic traits, sesamin and sesamolin of sesame in parental lines and their hybrids

Ittipon Khuimphukhieo*, and Parinda Khaengkhan

Division of Plant Production Technology, Faculty of Agricultural Technology,
Kalasin University, Mueang, Kalasin, 46000 Thailand

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Abstract

Heritability and association between agronomic traits with sesamin and sesamolin are very important. The aims of this study were to estimate broad-sense heritability and to investigate association of agronomic traits with sesamin and sesamolin in sesame. Seven parental lines and twenty-one hybrid genotypes were evaluated in RCBD with three replications. Agronomic traits were recorded. Sesamin and sesamolin were determined using HPLC. Parent and hybrid populations had large genetic coefficient of variation for both sesamin and sesamolin. Broad-sense heritability of sesamin and sesamolin was high for both parent and hybrid populations. Therefore, selection for those traits based on phenotype in the early generation should be effective. Plant height had significant negative correlation and the largest negative direct effect on both target traits in parental population. Day to harvest was the most influential trait on the target traits in hybrids. These results may facilitate sesame breeding programs to improve lignan content in sesame.

Keywords: lignan, antioxidant, genetic variance, correlation, indirect selection

1. Introduction

Sesame is an ancient oil crop, and it has been long used as a traditional food. Sesamin and sesamolin are lignans isolated from sesame seeds, and they have been reported to have many medical benefits. Sesamin, which is the main major lignan in sesame seeds, has been recognized for its antioxidant, blood pressure lowing, anticarcinogenic, and serum lipid lowering effects (Jeong *et al.*, 2004). Similarly, sesamolin induces apoptosis of human lymphoid leukemia Molt 4B cells, inhibits the growth of those cells, prevents mutagenic activity of H_2O_2, and provides protection against neuronal hypoxia (Michailidis, Angelis, Aligiannis, Mitakou, & Skaltsounis, 2019).

Breeding sesame for higher content levels of sesamin and sesamolin is beneficial for both consumers and several medical applications. The coefficient of variation is used to determine the variability that exists in the population (Taneva, Bozhanova, & Petrova, 2019). It has been used to determine the genetic variability of several nutritive characters such as protein (Taneva *et al.*, 2019), oil (Smita & Kishori, 2018) and anthocyanin contents (Konyak, Kanaujia, Jha, Chaturvedi, & Ananda, 2020). However, it has not been reported for sesamin and sesamolin in sesame. Broad-sense heritability is the ratio of genotypic variance to the phenotypic variance (Singh & Chaudhary, 1979). An estimate of heritability assists plant breeders to allocate necessary resources to effectively select for desired traits. Heritability of sesamin and sesamolin contents has been reported by Ogata & Kato (2016) and by Khuimphukhieo, Khaengkhan, & Sarepoua (2020). However, heritability estimates of these traits by the formula explained by Singh & Chaudhary (1979) has never been reported. Correlation coefficients generally indicate the degrees of association among traits, and path analysis can separate direct and indirect effect on studied traits. These have been widely used to assess the association of agronomic traits with antioxidant contents across various crops including the vegetables amaranth (Sarker, Islam, Rabbani, & Oba, 2016) and eggplant (Koundinya, Das, Layek, Chowdhury, & Pandit, 2017).

Although heritability and association to agronomic traits for sesamin and sesamolin in sesame have been reported

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*Corresponding author
Email address: ittipon49@hotmail.com

previously, these have never been compared between F_1 hybrids and their parents. They need to be determined in each specific case (parent or hybrid) because a hybrid has vigorous and accurate interaction of heterotic effects, while a parent does not have those effects (Sari, Nualsri, Junsawang, & Soonsuwon, 2019). Therefore, the aims of this study were to estimate broad-sense heritability of agronomic traits, and sesamin and sesamolin contents, and to determine the correlation coefficients and assess path analysis of agronomic traits in relation to sesamin and sesamolin contents of sesame, in both parent and hybrid populations.

2. Materials and Methods

2.1 Plant materials and experimental management

The twenty-eight genotypes used in this study consisted of seven parental lines, *i.e.*, MKS-I-84001, White UB 2, Kanchanaburi, C-plus 2, KKU1, MK60, CM-07 and twenty-one hybrids, which were generated according to diallel crosses design without reciprocal crossing. The twenty-eight genotypes of sesame were evaluated in a randomized complete block design with three replications in the early rainy season in 2017 at Faculty of Agricultural Technology, Kalasin University, Kalasin, Thailand. The experimental unit consisted of three rows with three meters in length, and spacing of 50 x 10 cm. Agronomic procedures were done uniformly. NPK fertilizers (15-15-15) were applied at 30 days after planting at the rate of 25 kg/1,600m^2. The nine agronomic traits observed were day to flower, day to harvest, height of first capsule (cm), plant height (cm), branch per plant, length of capsule (cm), capsule per plant, thousand grain weight (g), and grain yield (kg/1,600m^2). The twenty-eight genotypes were harvested and randomly 10 g of grain were sampled from each experimental unit for analysis of sesamin and sesamolin levels.

2.2 Sample extraction for sesamin and sesamolin determination

Grain samples were extracted according to the method previously explained by Rangkadilok *et al.* (2010) with slight modifications**.** Briefly, each 10 g grain sample was ground into fine powder. It was accurately weighed for 0.4 g subsamples placed into 15 ml plastic tubes. Then 5 ml of 80% methanol was added and allowed to extract for 30 min. The samples were centrifuged at 2000g for 3 min at 25ºC. The supernatant was transferred into a 10 ml volumetric flask. The residue was re-extracted with the 4.0 ml of 80% methanol. All extracted solutions were combined, and volume was adjusted with 80% methanol to 10 ml. The solutions were filtered through a 0.45 µm Nylon membrane before analysis using an HPLC.

2.3 HPLC analysis for sesamin and sesamolin levels

The HPLC analysis of sesamin and sesamolin was done using a Shimadzu SPD-M20A with diode array detector, using the reversed-phase column Inertsil ODS-3 C_{18} 5 µm, 4.6 x 250 mm (GL Sciences Inc, Japan). The composition of solvent and the gradient elution conditions used in this study were those that have been described by Rangkadilok *et al.* (2010) with slight modifications. The mobile phase consisted of water (solvent A) and methanol (Merck, KGaA, Germany) (solvent B) at a flow rate of 1 ml/min. Gradient elution was performed as follows: 0-5 min, 5-18% solvent B; 5-10 min, 18-35% solvent B; 10-15 min, 35-62% solvent B; 15-20 min, 80% solvent B; 20-25 min, 80% solvent B; 25-30 min, 80-5% solvent B. The operating conditions were as follows: column temperature at 25ºC, injection volume 20 µl, and detection at 280 nm. The standards of sesamin and sesamolin were purchased from Sigma-Aldrich. Sesamin and sesamolin in the samples were identified by comparing their relative retention times with those of the standard compounds.

2.4 Statistical and genetic analysis

Genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), and broad-sense heritability (H^2_b) based on mean were calculated according to Singh & Chaudhary (1979) as:

$$\mathrm{GCV} = \frac{\sqrt{\sigma^2 g}}{\bar{x}} \times 100$$

$$\mathrm{PCV} = \frac{\sqrt{\sigma^2 p}}{\bar{x}} \times 100$$

$$H^2_b = \frac{\sigma^2 g}{\sigma^2 p}$$

Here $\sigma^2_g = \frac{MS_g - MS_e}{r}$, $\sigma^2_p = \sigma^2_g + \sigma^2_e$, MS_g = mean square of genotypes, MS_e = mean square of error, r = number of replications, and $\vec{x}$ = mean of the trait. The Pearson correlation coefficients were calculated, and path analysis was computed according to Dewey & Lu (1959).

3. Results and Discussion

3.1 Coefficient of variation and broad-sense heritability

Genetic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) of parents were higher than those of hybrids for most studied traits. Large GCV was found for sesamin and sesamolin in both parents and hybrids (Table 1). This shows that parents with high GCV of sesamin and sesamolin will offer high GCV of those in their hybrids. Coefficient of variation, which is higher than 20%, is an indicator of great diversity (Taneva *et al.*, 2019). This result reveals the existence of sufficient variability in lignan among genotypes. Small differences between PCV and GCA were observed for day to flower, day to harvest, length of capsule, 1,000 grain weight, and sesamolin, in both populations. This is an indicator for comparatively lesser influence of the environment on phenotypic expression (Taneva *et al.*, 2019).

The broad-sense heritability (H^2_b) of parents ranged from 0.21 to 0.87, while those of hybrids ranged from 0.30 to 0.80 (Table 1). There was great difference of heritability between parents with hybrids for some traits because this depends on the population (Khuimphukhieo *et al.*, 2020). Broad-sense heritability of capsule per plant and grain yield was extremely low for both populations. Similar results were

Table 1. Genetic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) and broad-sense heritability (H^2_b) for agronomic traits, sesamin and sesamolin of parent and hybrid

Trait	GCV (%)		PCV (%)		H^2_b	
	parent	hybrid	parent	hybrid	parent	hybrid
Day to flower	4.73	2.01	5.85	3.66	0.65	0.30
Day to harvest	8.09	4.03	8.97	6.31	0.81	0.41
Height of first capsule	20.48	13.65	26.65	15.65	0.59	0.76
Plant height	15.60	8.05	17.46	11.17	0.80	0.52
Branch per plant	44.54	38.79	47.81	43.44	0.87	0.80
Length of capsule	7.04	3.59	7.79	5.44	0.82	0.43
Capsule per plant	9.32	13.65	20.28	21.50	0.21	0.40
Thousand grain weight	13.30	5.32	15.07	8.00	0.78	0.44
Grain yield	23.94	16.27	36.18	27.75	0.44	0.34
Sesamin	24.54	28.65	29.49	34.75	0.69	0.68
Sesamolin	30.30	21.66	32.82	25.23	0.85	0.74

found by Yol & Uzun (2019). According to this result, the direct selection for grain yield should be delayed to late generation. The indirect selection for yield via its components, which are strongly related to it and have higher heritability, is recommended. Branch per plant, sesamin and sesamolin levels had high heritability for both populations. This shows that the genetic variations of these traits are comparatively large in relation to their environmental variations (Chuchert, Nualsri, Junsawang, & Soonsuwon, 2018). The environmental influence on expression of those traits is smaller than the genetic influence. Similar result for sesamin and sesamolin was found by Ogata & Kato (2016), but a different result was reported by Khuimphukhieo *et al.* (2020). Sesamin had higher heritability than sesamolin for both populations. This agrees with prior results of Khuimphukhieo *et al.* (2020).

3.2 Association in parental lines

3.2.1 Correlation

Grain yield of sesame parental lines had a significant positive correlation with day to harvest (0.65**), plant height (0.81**) and capsule per plant (0.51*) (Table 2). Similar results were found by Gnanasekaran, Jebaraj, & Muthuramu (2008) and by Yol, Karaman, Furat, & Uzun (2010). Sesamin and sesamolin had significant negative correlation with day to harvest (-0.49* and -0.50*, respectively), plant height (-0.63** and -0.52*, respectively) and grain yield (-0.59** and -0.53*, respectively). This agrees with the results of Khuimphukhieo *et al.* (2020), who found that capsule per plant, thousand grain weight and grain yield had significant negative correlations with both target traits. In contrast, branch per plant exhibited significant positive correlation with sesamolin (0.51*). Significant positive association between sesamin with sesamolin (0.57**) was found. Similar results were found by Khuimphukhieo *et al.* (2020), Ogata and Kato (2016), Pathak *et al.* (2014), Wang *et al.* (2013), Yasumoto and Katsuta (2006). Consequently, breeding for higher sesamin content will likely result in a simultaneous improvement of sesamolin (Khuimphukhieo & Khaengkhan, 2018).

3.2.2 Path analysis

Direct and indirect effects of agronomic traits on sesamin in parental lines are presented in Table 3. Plant height of sesame parents had the highest negative direct effect on sesamin (-1.34), followed by thousand grain weight (-0.79). There is prior research reporting that thousand grain weight had the highest negative direct effect on sesamin (Khuimphukhieo, Khaengkhan, Sarepoua, & Raksong, 2018). Capsule per plant had the highest positive direct effect on sesamin (0.41), followed by length of capsule (0.28). Different results were found by Khuimphukhieo *et al.* (2020), who found that capsule per plant had negative direct effect on sesamin. Day to harvest had significant negative correlation with sesamin, but its direct effect on sesamin was positive. In the results of the present study, plant height had the most potential among the traits to improve the sesamin of sesame parental lines, because it had the highest negative direct effect along with significant negative correlation on sesamin. The residual effect in the path analysis of sesamin of parental line was quite low (0.1077). This indicates that almost all variability of sesamin of parental lines was described by the 9 agronomic traits observed in the present study.

Direct and indirect effects of agronomic traits on sesamolin in parental lines are shown in Table 4. Plant height had the highest negative direct effect on sesamolin (-1.03), followed by thousand grain weight (-0.97). On the other hand, the highest positive direct effect of length of capsule (0.78) on sesamolin was found, followed by branch per plant (0.37). Negative effects of some agronomic traits on lignans such as those of plant height and day to harvest are advantageous because breeding to increase sesamolin will result in a decrease of those. Therefore, both negative direct effect of plant height, and positive direct effect of length of capsule on sesamolin are useful. Similar results were found by Khuimphukhieo *et al.* (2020), in that the length of capsule and the branch per plant had positive direct effects on sesamolin. Consequently, the two traits that can be used to improve sesamolin of sesame parental lines were the plant height, because it had a large negative direct effect on sesamolin along with significant negative correlation, and the length of

Table 2. Correlation coefficients among studied traits of parent

Trait	DH	HFC	PH	BPP	LC	CPP	TGW	GY	SM	SN
DF	0.32	0.63**	0.24	0.37	0.28	-0.17	-0.06	-0.10	0.07	0.20
DH		0.40	0.81**	-0.21	0.23	0.39	0.07	0.65**	-0.49*	-0.50*
HFC			0.59**	0.49*	0.33	0.18	-0.18	0.40	-0.30	0.03
PH				-0.10	0.11	0.40	-0.27	0.81**	-0.63**	-0.52*
BPP					0.14	-0.12	-0.06	-0.25	-0.15	0.51*
LC						0.30	0.68**	0.12	-0.16	0.12
CPP							0.16	0.51*	-0.12	-0.18
TGW								-0.14	-0.14	-0.11
GY									-0.59**	-0.53*
SM										0.57**

* and ** = significant at 0.05 and 0.01 level, respectively. DF: day to flower, DH: day to harvest, HFC: height of first capsule, PH: plant height, BPP: branch per plant, LC: length of capsule, CPP: capsule per plant, TWG: thousand grain weight, GY: grain yield, SM: sesamin and SN: sesamolin

Table 3. Direct and indirect effects of agronomic traits on sesamin of parent

Trait	DF	DH	HFC	PH	BPP	LC	CPP	TGW	GY	r
DF	**0.22**	0.10	0.20	-0.33	-0.21	0.08	-0.07	0.05	0.03	0.07
DH	0.07	**0.31**	0.12	-1.09	0.12	0.07	0.16	-0.08	-0.20	-0.49*
HFC	0.14	0.12	**0.31**	-0.78	-0.28	0.09	0.07	0.14	-0.12	-0.30
PH	0.05	0.25	0.18	**-1.34**	0.05	0.03	0.16	0.22	-0.25	-0.63**
BPP	0.08	-0.06	0.15	0.13	**-0.56**	0.04	-0.05	0.05	0.08	-0.15
LC	0.06	0.07	0.10	-0.15	-0.08	**0.28**	0.12	-0.54	-0.04	-0.16
CPP	-0.04	0.12	0.06	-0.53	0.07	0.08	**0.41**	-0.13	-0.16	-0.12
TGW	-0.01	0.02	-0.06	0.37	0.03	0.19	0.07	**-0.79**	0.04	-0.14
GY	-0.02	0.20	0.12	-1.09	0.14	0.03	0.21	0.11	**-0.30**	-0.59**

* and ** = significant at 0.05 and 0.01 level, respectively. The underlined and bold numbers on diagonal show direct effects and the rest stand for indirect effects. DF: day to flower, DH: day to harvest, HFC: height of first capsule, PH: plant height, BPP: branch per plant, LC: length of capsule, CPP: capsule per plant, TGW: thousand grain weight and GY: grain yield. Residual effect = 0.1077

Table 4. Direct and indirect effects of agronomic traits on sesamolin of parent

Trait	DF	DH	HFC	PH	BPP	LC	CPP	TGW	GY	r
DF	**0.05**	0.10	-0.09	-0.25	0.14	0.22	-0.02	0.06	0.00	0.20
DH	0.02	**0.31**	-0.06	-0.84	-0.08	0.18	0.05	-0.07	-0.03	-0.50*
HFC	0.03	0.12	**-0.15**	-0.61	0.18	0.25	0.03	0.18	-0.02	0.02
PH	0.01	0.25	-0.09	**-1.03**	-0.04	0.08	0.06	0.27	-0.03	-0.52*
BPP	0.02	-0.06	-0.07	0.10	**0.37**	0.10	-0.02	0.06	0.01	0.51*
LC	0.01	0.07	-0.05	-0.11	0.05	**0.78**	0.04	-0.67	-0.01	0.13
CPP	-0.01	0.12	-0.03	-0.41	-0.04	0.23	**0.14**	-0.16	-0.02	-0.18
TGW	0.00	0.02	0.03	0.28	-0.02	0.53	0.02	**-0.97**	0.01	-0.11
GY	-0.01	0.20	-0.06	-0.84	-0.09	0.10	0.07	0.14	**-0.04**	-0.53*

* and ** = significant at 0.05 and 0.01 level, respectively. The underlined and bold numbers on diagonal show direct effects and the rest stand for indirect effects. DF: day to flower, DH: day to harvest, HFC: height of first capsule, PH: plant height, BPP: branch per plant, LC: length of capsule, CPP: capsule per plant, TGW: thousand grain weight and GY: grain yield. Residual effect = 0.2196

capsule because it had a large positive direct effect on sesamolin. The residual effect was 0.2196, which indicates that 21.96% of sesamolin of parental lines may be associated with other traits that were not investigated in the current study.

3.3 Association in F$_1$ hybrids

3.3.1 Correlation

Grain yield of hybrid sesame had significant positive correlations with day to harvest (0.35**), height of first capsule (0.37**), plant height (0.54**), branch per plant (0.38**) and capsule per plant (0.54**) (Table 5). This agrees with the result of Ibrahim & Khidir (2012), but Yol *et al.* (2010) reported no correlation between height of first capsule with yield. Day to harvest (-0.66** and -0.62**, respectively), height of first capsule (-0.56** and -0.41**, respectively), branch per plant (-0.45** and -0.37**, respectively) and capsule per plant (-0.36** and -0.37**, respectively) had significant negative correlations with both sesamin and sesamolin. Plant height had significant negative correlation with sesamin (-0.37**), while significant positive correlation between length of capsule with sesamolin was found (0.36**).

3.3.2 Path analysis

Direct and indirect effects of agronomic traits on sesamin in hybrids are presented in the Table 6. Day to harvest had the highest negative direct effect on sesamin (-0.67), followed by branch per plant (-0.38). These characters might be choice criteria on selection for improving sesamin in hybrid population because they had large direct effects on sesamin along with the significant negative correlations. Capsule per plant had significant negative correlation with sesamin (-0.36**), but its direct effect on sesamin was positive (0.12). Path analysis revealed the most negative indirect effect of capsule per plant on sesamin via day to harvest (-0.34). This seems to be a cause of correlations**.** According to this result, correlation coefficients among traits offer insufficient information in plant breeding programs, while path analysis gives more effective information (Sarutayophat, 2012).

Direct and indirect effects of agronomic traits on sesamolin in hybrids are shown in Table 7. Day to harvest had the highest negative direct effect on sesamolin (-0.61). This reveals that hybrids with short growth duration often have higher lignan contents than those with long growth duration. Ogata & Kato (2017) revealed that sesamin and sesamolin decreased as the harvesting date was delayed. Length of capsule showed positive direct effect on (0.19) and also significant positive correlation with sesamolin (0.36**). Therefore, indirect selection for sesamolin in F$_1$ hybrid generation via day to harvest and length of capsule is suggested. These are plausible secondary targets because a variety with short growth duration and high antioxidant content is desirable. The residual effect of sesamin and sesamolin of hybrids was quite high (0.3822 and 0.4477), which indicated that the nine studied agronomic traits are insufficient to explain the variability of sesamin and sesamolin in the hybrids.

According to the results, correlation and direct effects of agronomic traits on sesamin and sesamolin of parents were different from those of hybrids. Similar result was found for upland rice (Sari *et al.*, 2019). This shows that a relationship between agronomic traits with lignan in parents could not be used for indirect selection in their hybrids.

4. Conclusions

Parent and hybrid populations showed a large genetic coefficient of variation for both sesamin and sesamolin. Broad-sense heritability of sesamin and sesamolin was high for both populations. Therefore, the early generation selection may be effective in breeding to enhance quantity of these traits. Plant height was the most influential trait on both traits in parental population, while day to harvest was the most influential trait on both traits in hybrid population. These traits can be beneficially used in breeding for lignan content.

Table 5. Correlation coefficients among studied traits of hybrid

Trait	DH	HFC	PH	BPP	LC	CPP	TGW	GY	SM	SN
DF	0.23	0.40**	0.20	0.53**	0.114	0.32**	0.09	0.22	-0.14	-0.10
DH		0.42**	0.50**	0.28*	-0.15	0.50**	0.31*	0.35**	-0.66**	-0.62**
HFC			0.50**	0.65**	0.13	0.40**	0.02	0.37**	-0.56**	-0.41**
PH				0.22	0.21	0.51**	-0.05	0.54**	-0.37**	-0.20
BPP					-0.08	0.54**	0.20	0.38**	-0.45**	-0.37**
LC						-0.06	0.28*	0.10	0.13	0.36**
CPP							0.02	0.54**	-0.36**	-0.37**
TGW								0.15	-0.11	-0.06
GY									-0.19	-0.22
SM										0.83**

* and ** = significant at 0.05 and 0.01 level, respectively. DF: day to flower, DH: day to harvest, HFC: height of first capsule, PH: plant height, BPP: branch per plant, LC: length of capsule, CPP: capsule per plant, TGW: thousand grain weight, GY: grain yield, SM: sesamin and SN: sesamolin

Table 6. Direct and indirect effects of agronomic traits on sesamin of hybrid

Trait	DF	DH	HFC	PH	BPP	LC	CPP	TGW	GY	r
DF	**0.22**	-0.15	-0.09	0.00	-0.20	0.00	0.04	0.01	0.03	-0.14
DH	0.05	**-0.67**	-0.09	0.00	-0.11	0.01	0.06	0.05	0.05	-0.66**
HFC	0.09	-0.28	**-0.22**	0.00	-0.25	-0.01	0.05	0.00	0.05	-0.56**
PH	0.04	-0.33	-0.11	**-0.01**	-0.09	-0.01	0.06	-0.01	0.08	-0.37**
BPP	0.12	-0.19	-0.14	0.00	**-0.38**	0.00	0.06	0.03	0.05	-0.45**
LC	0.03	0.10	-0.03	0.00	0.03	**-0.04**	-0.01	0.04	0.01	0.13
CPP	0.07	-0.34	-0.09	0.00	-0.21	0.00	**0.12**	0.00	0.08	-0.36**
TGW	0.02	-0.21	0.00	0.00	-0.08	-0.01	0.00	**0.15**	0.02	-0.11
GY	0.05	-0.23	-0.08	0.00	-0.14	0.00	0.06	0.02	**0.14**	-0.19

** = significant at 0.01 level. The underlined and bold numbers on diagonal show direct effects and the rest stand for indirect effects. DF: day to flower, DH: day to harvest, HFC: height of first capsule, PH: plant height, BPP: branch per plant, LC: length of capsule, CPP: capsule per plant, TGW: thousand grain weight and GY: grain yield. Residual effect = 0.3822.

Table 7. Direct and indirect effects of agronomic traits on sesamolin of hybrid

Trait	DF	DH	HFC	PH	BPP	LC	CPP	TGW	GY	r
DF	**0.16**	-0.14	-0.09	0.04	-0.09	0.02	-0.01	0.01	-0.01	-0.10
DH	0.04	**-0.61**	-0.09	0.11	-0.05	-0.03	-0.01	0.04	-0.01	-0.62**
HFC	0.06	-0.26	**-0.23**	0.11	-0.12	0.02	-0.01	0.00	-0.01	-0.41**
PH	0.03	-0.30	-0.11	**0.23**	-0.04	0.04	-0.01	-0.01	-0.02	-0.20
BPP	0.08	-0.17	-0.15	0.05	**-0.18**	-0.02	-0.01	0.02	-0.01	-0.37**
LC	0.02	0.09	-0.03	0.05	0.01	**0.19**	0.00	0.03	0.00	0.36**
CPP	0.05	-0.30	-0.09	0.11	-0.10	-0.01	**-0.02**	0.00	-0.02	-0.37**
TGW	0.01	-0.19	-0.01	-0.01	-0.04	0.05	0.00	**0.12**	0.00	-0.06
GY	0.03	-0.21	-0.08	0.12	-0.07	0.02	-0.01	0.02	**-0.03**	-0.22

** = significant at 0.01 level. The underlined and bold numbers on diagonal show direct effects and the rest stand for indirect effects. DF: day to flower, DH: day to harvest, HFC: height of first capsule, PH: plant height, BPP: branch per plant, LC: length of capsule, CPP: capsule per plant, TGW: thousand grain weight and GY: grain yield. Residual effect = 0.4477.

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