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Association of inflorescence architecture traits with synchronous pod maturity in mungbean

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ABSTRACT

Mungbean (*Vigna radiata*) is a legume crop with a short life-cycle and the ability to self-pollinate, which make it easy to breed and to cultivate. Mungbean is adapted to tropical environment condition and it is susceptible to be affected by the flexible environment. So the cultivation area tends to be concentrated in developing countries that are more inflexible than other countries. Mungbean also has the characteristic of non-synchronous maturity caused by indeterminate flowers, which requires several times of harvest.

The objective of this study was to find the association of inflorescence architecture traits with synchrony by observing the inflorescence architecture in the mungbean. Mungbean has a compound raceme inflorescence architecture that has both a main (primary) branch and secondary branches that can produce flowers. On the other hand, there was a unique genotype named 'Binh khe D.X.' that has only a single main branch that produces flowers in a simple raceme inflorescence architecture. Generally, we observed non-synchronous lines made new peduncles and branches during multiple harvesting period. These changes were shown to influence the synchronous pod maturity and this discovery could be used to aid the development in future mungbean breeding.

Keywords: Mungbean (*Vigna radiate*), Inflorescence architecture, Synchronous maturity

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INTRODUCTION

Mungbean (*Vigna radiata* (L.) R. Wilczek) is one of legume species cultivated mostly in South, East and Southeast Asia, and it belongs to the subgenus Ceratotropis of genus *Vigna* in the family *Fabaceae* (Kang et al., 2014). The consumption of mungbean for food is increasing steadily due to its nutritional value, which is higher than most other legumes especially in folate and iron (Shanmugasundaram et al., 2009). In addition, it has advantages for the cultivation because of its growing with a short life-cycle as well as self-pollinating ability (Kim et al., 2015). However, mungbean has flexible growing patterns depending on the environment, so the cultivation area is intensive in developing countries (Anonymous, 2010). Besides, non-synchronous pod maturity in mungbean cause high labor costs for its production because it makes several harvests (Bushby and Lawn, 1992; Mondal et al., 2011).

Although there have been a lot of interests in mungbean, the inflorescence architecture of mungbean is still not well-studied, as to how flowers are generated and how branches are composed. The inflorescence is the region of the plant that contains the flowers and seeds that impact on the production. Inflorescence architecture is classified according to a formation of branching patterns as simple inflorescence architecture and compound inflorescence architecture (Benlloch R et al., 2015). Legumes usually have the compound inflorescence architecture that consisted of a main (primary) branch with several secondary branches forming flowers. In contrast, the simple inflorescence architecture forms flowers directly from the main axis, for example, in the model plant species *Arabidopsis thaliana* (Weberling, 1992; Benlloch et al., 2007; Hofer and Noel, 2014).

Along with identifying the inflorescence architecture of mungbean, the objective of this study is to find the association between inflorescence architecture traits and synchrony in pod maturity, by investigating the changes of inflorescence architecture traits during growth and development. Furthermore, this finding can suggest not only a desirable standard for inflorescence architecture traits for future breeding strategies, as well as for genetic research in mungbean flowering synchrony.

LITERATURE REVIEW

Mungbean

Mungbean (*Vigna radiata* (L.) R. Wilczek) is one of the major legumes cultivated in South and Southeast Asia with more than 6 million hectares annual cultivation around the world (Nair et al., 2012). There has been an increase of 22-66% consumption of mungbean from 1984 to 2006 (Shanmaugasundaram et al., 2009) and the production also is steadily increasing because of their cost-effectiveness for the cultivation (Kim et al., 2015). Recently, the reference genome consisting 421Mb (80% of total estimated genome of mungbean) was published (Kang et al., 2014). According to that, Mungbean has a diploid chromosome number of 2n = 2x =22 and it belongs to the subgenus Ceratotropis of genus *Vigna* in the family *Fabaceae*. Besides, Mungbean could be a guide plant for other genera *Vigna* including black gram (*V.mungo*), rice bean (*V.umbellata*) and adzuki bean (*V.angularis*) due to its short life-cycle and small genome size in comparison with other legumes.

Inflorescence Architecture

The inflorescence is the part where flowers are produced and the architecture of inflorescence is the concept that involves the patterns of branching and flowering (Weberling, 1992; Benlloch et al., 2007; Hofer and Noel, 2014). The classification is mostly based on how or where to form flowers (Benlloch et al., 2015). In the former case, there are two types; determinate and indeterminate inflorescence. This classification focuses on only whether the main inflorescence axis terminal makes flowers constantly or not. Following these criteria, three typical groups named the raceme, the cyme and the panicle usually have been used for more specific classification (Weberling, 1992; Han et al., 2014).

Another classification is to categorize the inflorescence architecture according to where flowers are formed (Weberling, 1992). For example, Arabidopsis is a representative model of simple inflorescence architecture because flowers are directly produced in the main (primary) inflorescence axis. On the other hand, legumes classified as compound inflorescence architecture have lateral (secondary) inflorescences extended from the main stem and thus flowers are formed in lateral (secondary) inflorescence. To sum up, the classification of inflorescence depends on the formation of meristems to branches or to flowers (Coen and Nugent, 1994).

Synchronous and Non-synchronous Pod Maturity in Mungbean

In most legume crops, it is a natural for flowers to be generated indeterminately (Tickoo et al., 1996). This growth habit was considered to produce the higher yield in comparison to determinate growth type (Podleoeny, 2001). Mungbean also has indeterminate flowers from a peduncle with the raceme type, and thus the overall period between the flowering and the pod maturity takes a long time. That means non-synchronous pod maturity occurs, that can be inefficient for the farmers because of extra harvests (Iqbal et al., 2015). For the future breeding strategies in mungbean, the characteristic of synchronous pod maturity is considered as an ideal type.

MATERIALS AND METHODS

Plant Materials

Six accessions, Binh khe D.X., Tam Chi Lang Lang Son, Mo Quang Ngai, Tam Nghia Dan, Ma thua khieu and Sunhwa Nokdu were used in this study. Among them, five are landraces and one (Sunhwa Nokdu) is a cultivar (Table 1). Five accessions have a country and origin, while the origin of Binh khe D.X. is unknown (Table 1). The accessions were planted on 22 June 2016 and arranged in a randomized block design with three replicates. Each genotype was planted in a row and their space was 15cm. The distance between rows was spaced at 70cm regularly. The experiment was conducted in the experimental field of Seoul National University (37.27°N, 126.99°E), Suwon, and Korea in 2016.

Table 1. List of six accessions number, name, country and origin

Accession number	Accession name	Country	Origin
IT208075	Binh khe D.X.(local var.)		
IT304355	Tam Chi Lang Lang Son	Vietnam	Lang Son
IT304358	Mo Quang Ngai	Vietnam	Quang Ngai
IT304378	Tam Nghia Dan	Vietnam	Nghe An
IT304396	Ma thua khieu	Vietnam	Son La
IT144011	Sunhwa Nokdu (선화녹두)	Taiwan	

Harvest Methods

Harvests were conducted in two ways for 42 days starting from days of first mature pods. One of the methods is that plants are harvested six times with one-week interval after maturity time. It is like a traditional way that pods are harvested whenever they ripened into maturity because of the non-synchronous pod maturation in mungbean.

The other way is that plants were harvested only once at six weeks after maturity time. The period for harvesting was same between two methods, but the number of harvests is different in six times and once, respectively, which is for comparing growing patterns and responses to the different harvesting method.

Phenotypic Data Collection

The phenotypic data were recorded as the average value of 2 randomly selected plants per replication and measured following the descriptors for *Vigna mungo* and *V. radiata* (IBPGR, 1985). The phenotypes are selected a total of 10 traits related to phenology and inflorescence (Table 2).

First, days to flowering and days to first mature pods means the number of days from sowing to a stage when 50% of plants have flowers and mature (color changed green to black or brown) pods respectively.

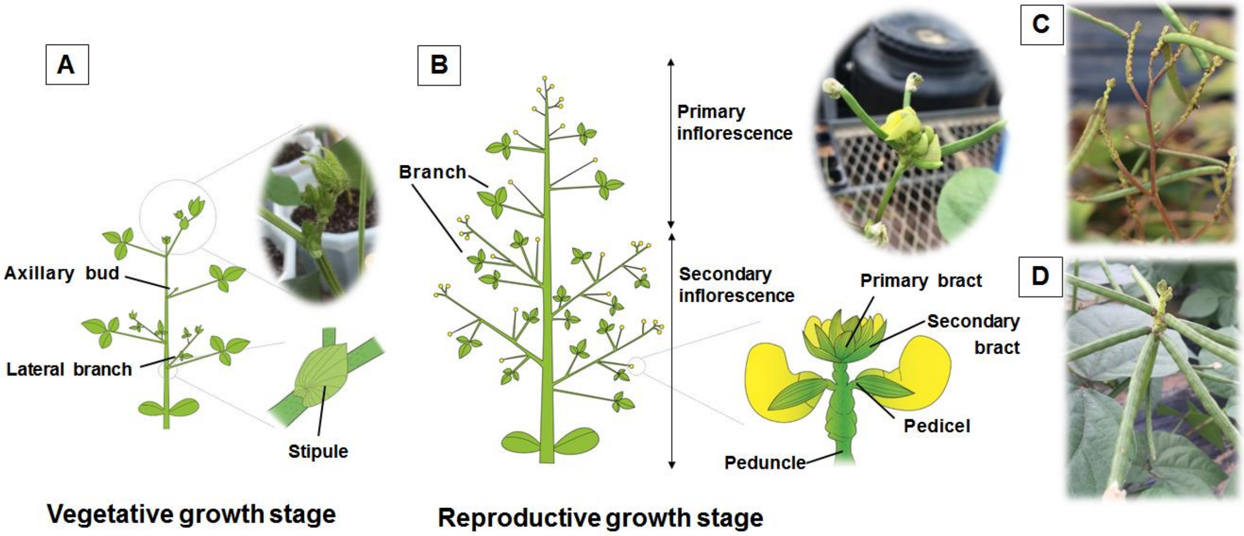
Five traits related to the plant inflorescence architecture such as plant height, the number of nodes on the main stem, number of branches, number of peduncles and number of secondary inflorescence were measured at the final harvest time, which is 42 days after days to first mature pods. Plant height was measured from the unifoliate to the top peduncle on the main stem and number of nodes on the main stem was also counted from the unifoliate (Figure 1). The number of branches was counted only on pod-bearing branches shot out from the leaf axils, but branches that had pods without a leaf were excluded. The number of peduncles was counted only on peduncles that had fully grown pods. Mungbean has the compound raceme inflorescence architecture that consists of primary and secondary inflorescence (Figure 1). The number of secondary inflorescence means the number of lateral branches that make branches that can produce pods and leaves similar to the primary inflorescence.

The number of pods, pods per peduncle and total yield are counted after all harvests. The number of pods means the sum of each harvest pods. Based on above measurements, pods per peduncle was calculated as (number of pods/ number of peduncles). Total yield was measured until the second decimal place after threshing was completed.

Table 2. List of phenotype traits and definition

Phenotype	Definition
Days to flowering	From sowing to stage when 50% of plants have begun to flower
Days to first mature pods	From sowing to stage when 50% of plants have mature pods
Plant height	Plant height from the unifoliate(primary leaf) to the top peduncle on the main stem
Number of nodes on main stem	The node number starting from the unifoliate(primary leaf) node
Number of branches	Count of pod-bearing branches whose origin is in the leaf axils
Number of peduncles	Count of peduncles having at least one fully grown pod at harvest
Number of secondary Inflorescence	Number of lateral(axillary) branches that produce pod-bearing branches as main stem
Number of pods	Number of harvested mature pods
Pods/Peduncle	Number of flowers that set mature pods per peducle.
Total yield	Yield per plant (g)

Figure 1. Inflorescence Architecture Development and Morphology in Mungbean



Statistical Analysis

All measured data were analyzed by analyses of variance (ANOVA) and Pearson correlation analysis. The mean differences between measured data were tested for significance after ANOVA using Tukey HSD test ($p<0.5$) (SAS Institute, 2015). ANOVA was used to separate the genotypes depending on the plant height, the number of pods and yield in weekly harvests. ANOVA also was used to compare the changes of traits between two harvest methods. Furthermore, the interaction between genotypes and two harvest methods on height, the number of nodes, the number of branches, the number of peduncles, the number of pods, pods per peduncles and total yield is analyzed using two-way ANOVA. Pearson correlation analysis was used to identify the correlation between total yield and other traits such as days to flowering, days to first mature pods, plant height, the number of nodes, the number of branches, the number of peduncles, the number of pods and pods per peduncle. After analyses, for finding the association of agronomic traits with synchronous pod maturity, the results were used to make groups having synchrony or non-synchrony in pod maturity.

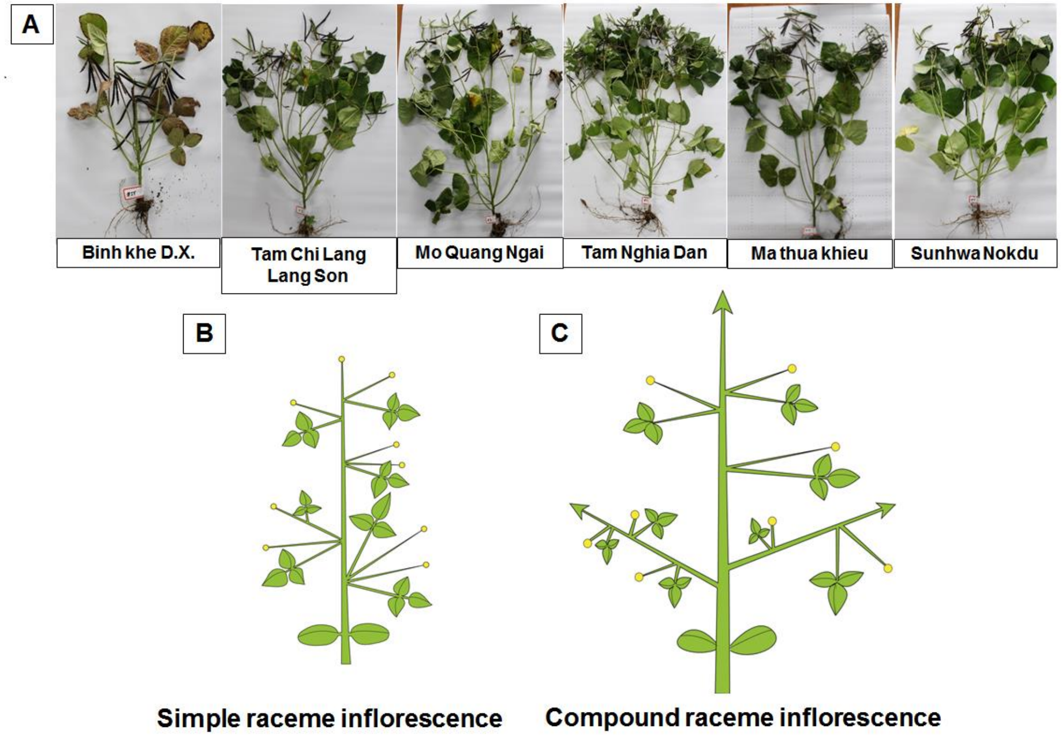
RESULTS

Inflorescence Architecture Development in Mungbean

The development of the inflorescence architecture in mungbean is divided into two stage; the vegetative growth stage and the reproductive growth stage. Only leaves were generated by the shoot apical meristem (SAM) with elongation of height during the vegetative growth stage, and then flowers were produced at the apical meristems of each stems after the transition to floral meristem during the reproductive growth stage.

In vegetative phase, axillary buds and lateral branches were generated from stipules (Figure 1 A). Lateral branches later produce secondary inflorescences, and they have branches bearing flowers with trifoliolate leaf like the primary inflorescence. An indeterminate number of flowers and pods were produced by lateral branches, and peduncles producing pedicels form bracts in reproductive phase (Figure 1 B, D). The inflorescence type of mungbean could be defined as the compound raceme inflorescence architecture by its branching and flowering patterns depending on how and where flowers are generated (Figure 2 A, C).

Figure 2. Overall inflorescence architecture and schematic diagram of six accessions



Unique Characteristics of Binh khe D.X.

As mentioned above, lateral branches that become secondary inflorescence were found in five accessions: Tam Chi Lang Lang son, Mo Quang Ngai, Tam Nghia Dan, Ma thua khieu and Sunhwa Nokdu, which have the compound raceme inflorescence architecture (Figure 2 A, C).

However, Binh khe D.X. has a different type. There is not secondary inflorescence in Binh khe D.X., and its flowers are directly generated from the main stem like the simple raceme inflorescence (Figure 2 B). Instead of secondary inflorescence, there are nodes that produced two or three branches bearing pods at the same site.

Interestingly, Binh khe D.X. has not only the different inflorescence type, but it has a different characteristic of peduncles. In other accessions, the end of each inflorescence contained several peduncles (Figure 1 C). That means the SAM of each inflorescence has kept active in reproductive phase and produced several peduncles. But Binh khe D.X. has only one peduncle at the end of inflorescence without formation of other peduncles.

Phenology

In this study, six accessions were selected based on their variations in the vegetative and reproductive stages. The duration, from sowing to flowering time (days to flowering) and to maturity time (days to maturity), ranged between 29 to 45 days and 42 to 58 days, respectively (Table 3). In contrast, days to maturity from flowering ranging between 12 to 17 days did not differ broadly compared to days to flowering and maturity (Table 3). For all accessions, total planting duration ranging between 84 to 100 days included 42days of harvests after maturity time. Five accessions except Binh khe D.X. showed similar planting duration at around 97 days, while total planting duration of Binh khe D.X. at 84 days was noticeably shorter than the others.

Table 3. Number of days to flowering, flowering to maturity and to maturity, and total planting duration

Accession name	Days to flowering	Days to maturity from flowering	Days to maturity	Total planting date
Binh khe D.X.(local var.)	29	13	42	84
Tam Chi Lang Lang Son	39	16	55	97
Mo Quang Ngai	45	14	58	100
Tam Nghia Dan	43	12	55	97
Ma thua khieu	38	14	52	94
Sunhwa Nokdu (선화녹두)	36	17	54	96

General Trend in Plant Height

Heights were measured at the flowering time, maturity time and every harvesting times. There had been an extension and growing until maturity time, and plant height increased mainly before maturity time (Table 4). Binh khe D.X. (31.30cm) was the shortest and Tam Chi Lang Lang Son (97.57cm) was the tallest of all at the last harvest time (Table 4). After maturity, growth was not noticeable because they make only a longer apex peduncle, producing an indeterminate number of flowers without increasing nodes numbers.

Table 4. Heights measured from flowering time, maturity time and every harvest times

	Height (cm)							
	Flowering Time	Maturity Time	Harvest					
Accession name			1st	2nd	3rd	4th	5th	6th
Binh khe D.X.	21.28	25.97	26.68	29.43	29.73	31.03	31.17	31.30
Tam Chi Lang Lang Son	35.10	93.30	94.17	95.07	96.33	96.90	97.20	97.57
Mo Quang Ngai	46.33	83.53	84.00	86.13	86.97	87.17	87.30	87.60
Tam Nghia Dan	44.87	78.93	79.58	81.17	82.57	83.07	83.47	83.47
Ma thua khieu	31.23	76.67	84.90	86.53	87.40	87.60	88.00	88.17
Sunhwa Nokdu	24.03	71.17	75.10	75.23	76.33	76.67	76.90	77.07

General Trend in Number of Pods and Yield per Harvest

The number of pods and yield had a similar pattern in all accessions. Half of the total amount was obtained in first and second harvests, but the harvests from each accession started to differ the third harvest (Table 5). They can be divided into three groups based on the trend.

First, the amount of harvest in Binh khe D.X. decreased at the third harvest and then increased again at the fourth harvest. The amount of harvest tends to concentrate in the early stage. After that, the amount of harvested pods decreased again. There are two peak harvests during the six harvest.

Four accessions such as Tam Chi Lang Lang Son, Mo Quang Ngai, Tam Nghia Dan and Ma thua khieu have a common point at the final harvest. They produced a lot of pods and yield at the final harvest time, as much as the amount obtained in the first peak curve. It is expected that they required a long time to produce the second peak, after about 2-3 harvest times.

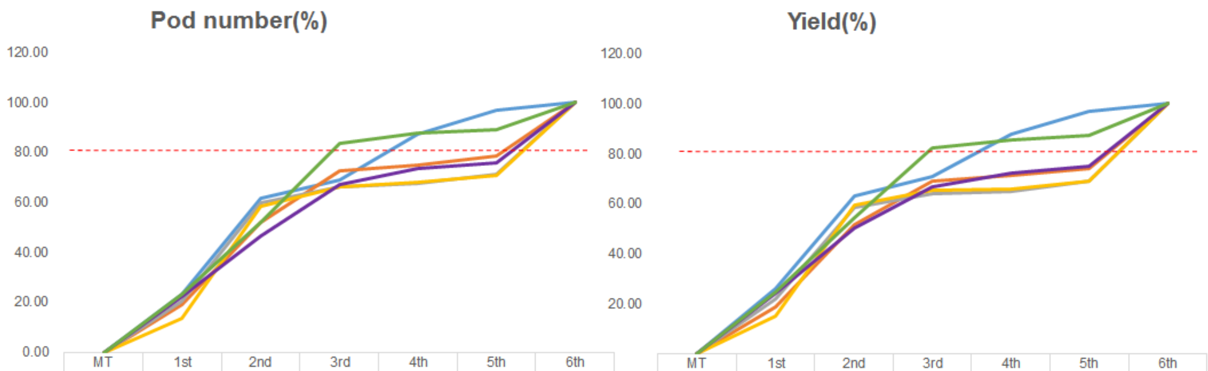
Sunhwa Nokdu had an obvious first peak and a weak second peak. The most amount of harvested pods and yield were concentrated in the first peak and there was less yield at the next peak. Especially, only Sunhwa Nokdu had increased pod number and yield at third harvest, while other accessions had decreased. This pattern is in contrast with the others.

Cumulative graph of six harvests in all accessions was calculated for comparing the characteristic of synchronous and non-synchronous pod maturity in munbean (Figure 3). Pod number and yield of Sunhwa Nokdu and Binh khe D.X. reached 80% of the total yield earlier than other accessions, which regards them as a synchronous pod maturity group. On the other hand, Tam Chi Lang Lang Son, Mo Quang Ngai, Tam Nghia Dan and Ma thua khieu stayed productive and reached on 80% of the total yield relatively late, between fifth and sixth harvest. Based on this cumulative result, they can be regarded as non-synchronous pod maturity group.

Table 5. Pod number and yield per harvest (%)

Accession name	Pod number (%)						Yield (%)					
	1st	2nd	3rd	4th	5th	6th	1st	2nd	3rd	4th	5th	6th
Binh khe D.X.	23.32	38.31	7.29 b	18.13 a	9.97 a	2.99 b	26.00	37.09	7.80 b	16.87 a	9.10 a	3.13 b
Tam Chi Lang Lang Son	18.99	33.22	20.22 ab	2.61 b	3.44 ab	21.52 ab	18.59	32.84	17.56 ab	2.14 b	3.17 ab	25.70 ab
Mo Quang Ngai	20.38	39.29	6.69 b	1.11 b	3.69 ab	28.83 a	21.65	37.00	5.34 b	1.00 b	4.27 ab	30.75 a
Tam Nghia Dan	13.44	44.85	7.96 b	1.53 b	2.96 ab	29.25 a	15.21	44.36	5.64 b	0.85 b	2.95 ab	30.98 a
Ma thua khieu	22.39	24.32	20.30 ab	6.27 b	2.56 ab	24.15 ab	23.98	26.50	16.38 ab	5.48 b	2.67 ab	24.98 ab
Sunhwa Nokdu	23.17	28.75	31.72 a	4.06 b	1.49 b	10.81 ab	24.55	29.90	27.98 a	3.28 b	1.50 b	12.78 ab
significant	0.5473	0.1594	0.0028	0.0007	0.0333	0.01	0.5374	0.3556	0.0031	0.0005	0.0622	0.0181

Figure 3. Cumulative graph for pod numbers and yield (%)



Pod number(%)

	MT	1st	2nd	3rd	4th	5th	6th
Binh khe D.X.	0.00	23.32	61.62	68.91	87.04	97.01	100.00
Tam Chi Lang Lang Son	0.00	18.99	52.21	72.43	75.04	78.48	100.00
Mo Quang Ngai	0.00	20.38	59.67	66.37	67.48	71.17	100.00
Tam Nghia Dan	0.00	13.44	58.29	66.25	67.79	70.75	100.00
Ma thua khieu	0.00	22.39	46.72	67.02	73.29	75.86	100.00
Sunhwa Nokdu	0.00	23.17	51.92	83.64	87.70	89.19	100.00

Yield(%)

MT	1st	2nd	3rd	4th	5th	6th
0.00	26.00	63.10	70.90	87.77	96.87	100.00
0.00	18.59	51.43	68.99	71.13	74.30	100.00
0.00	21.65	58.65	63.99	64.99	69.26	100.00
0.00	15.21	59.57	65.21	66.06	69.02	100.00
0.00	23.98	50.49	66.87	72.35	75.02	100.00
0.00	24.55	54.46	82.44	85.72	87.22	100.00

Differences between Single and Multiple Harvests

The six mungbean accessions were compared by ANOVA analysis to observe the effects of single and multiple harvests on agronomic traits. There was a significant harvest method x accession interaction on three inflorescence architecture traits; number of branches, number of peduncles and number of pods (Table 6). The accessions could be divided into two groups; synchronous and non-synchronous, based on how soon they reached 80% total yield in the cumulative yield graph (Figure 3).

Two accessions, Binh khe D.X. and Sunhwa Nokdu, which were grouped as synchronous accessions, had not significantly different total yield when harvested six times instead of just once because their yield was concentrated in the early. Binh khe D.X. had a significant difference in the number of branches and the number of peduncles, when harvested more than once, while other traits had no significant difference in either harvesting methods. Sunhwa Nokdu had a significant difference in the height when harvested once more than six times. Except for the height, there was no significant difference in the other traits between harvest methods in Sunhwa Nokdu.

There was the other group as non-synchronous accessions, Tam Chi

Lang Lang Son, Mo Quang Ngai, Tam Nghia Dan and Ma thua khieu, which reached 80% total yield lately. Among them, three accessions, Mo Quang Ngai, Tam Nghia Dan, and Ma thua khieu, had significantly different total yield when harvested six times than just once. Also, there is significant difference in the number of branches, number of peduncles, and number of pods, and these traits scored higher under multiple harvests than in single harvest, except for the number of peduncles in Mo Quang Ngai.

Tam chi Lang Lang Son didn’t show any significant difference in all compared traits. Even though there was no significant difference in all traits, it classified as the non-synchronous group because multiple harvests produced almost twice as much yield than single harvest.

Table 6. Effect of harvest method and genotype interaction on agronomic traits

	Method	Height	Number of nodes	Number of branches	Number of peduncles	Number of pods	Pods/ peduncle	Total yield
	Six times_H	31.30	6.17	12.83	13.83	60.00	4.36	23.77
Binh khe D.X.	One_H	35.00	6.33	10.00	11.00	42.50	3.86	17.70
		ns	ns	*	*	ns	ns	ns
	Six times_H	97.57	9.00	10.50	36.00	91.00	2.51	52.19
Tam Chi Lang Lang Son	One_H	95.40	9.50	12.17	32.33	59.67	1.86	31.03
		ns	ns	ns	ns	ns	ns	ns
	Six times_H	87.60	11.33	22.67	58.33	112.33	1.91	66.32
Mo Quang Ngai	One_H	92.33	9.67	10.67	35.00	36.67	1.05	24.57
		ns	*	*	ns	*	*	*
	Six times_H	83.47	10.17	19.67	44.17	150.67	3.41	50.56
Tam Nghia Dan	One_H	78.67	8.00	7.33	28.33	62.83	2.29	19.29
		ns	ns	*	**	**	ns	*
	Six times_H	88.17	10.17	19.33	50.67	157.33	3.13	60.90
Ma thua khieu	One_H	89.83	9.67	9.17	30.00	55.17	1.91	25.63
		ns	ns	**	**	***	*	*
	Six times_H	77.07	9.33	12.50	28.33	80.83	2.84	57.95
Sunhwa Nokdu	One_H	86.50	9.50	8.67	29.00	63.67	2.17	41.74
		**	ns	ns	ns	ns	ns	ns
ANOVA results								
Method		0.3022	0.0536	<.0001	<.0001	<.0001	<.0001	<.0001
Acc		<.0001	<.0001	0.0116	<.0001	0.0001	<.0001	0.0082
Method*Acc		0.3902	0.0656	0.0011	0.0104	0.0006	0.7856	0.1813

Relationship between Total Yield and Inflorescence Traits

Table 7 shows the phenotypic correlations between total yield and other agronomic traits. There is no significant correlation between total yield and flowering time, and pods per peduncle. The total yield has weak but significant positive correlations to maturity time and height, but has a very strong correlation with the number of pods. Also, there were strong correlations between total yield and traits related to inflorescence architecture such as the number of nodes, number of branches and number of peduncles.

Table 7. Phenotypic correlations between total yield and flowering time, maturity time and inflorescence architecture traits

		Flowering Time	Maturity Time	Height	Number of nodes	Number of branches	Number of peduncles	Number of pods	Pods/ peduncle
Total yield	Correlation coefficient (r)	0.29	0.39	0.41	0.56	0.70	0.72	0.79	0.09
	Sinificant (p)	ns	*	*	***	***	***	***	ns

DISCUSSION

Inflorescence architecture is an important agronomic characteristic because it has an impact on plant productivity and efficient cultivation management (Benlloch et al., 2015). Nevertheless, there are few studies that investigate the inflorescence architecture of mungbean. By definition, a simple inflorescence forms flowers directly from the main(primary) inflorescence, while compound inflorescence should have secondary inflorescence and then flowers are formed in the secondary inflorescence (Weberling, 1992). Most researches how to form inflorescence by a genetic network in legumes were studied in pea, as a result, the inflorescence architecture of legumes typically belongs to the compound inflorescence (Weberling, 1992; Benlloch et al., 2007; Hofer and Noel, 2014). In this study, most accessions were identified to have the compound raceme inflorescence architecture, except for Binh khe D.X. that has the simple raceme inflorescence architecture (Figure 2).

Currently, there is no standard on the appropriate criteria for measuring synchronous pod maturity in mungbean. In on study, height was used to estimate the determinate growth type and for defining the synchronous characteristic of pod maturity in mungbean, by comparing height at the flowering time, first pod maturity time and 90% pod maturity time (Iqbal et al., 2015). But in mungbean, the height measured at those times actually only measure the increased length of the apex peduncle. Also, 90% pod maturity was decided before the first harvest, so these height measurements are not enough to explain the growth type because the apex peduncle continues to produce an indeterminate number of pedicels and flowers (Figure 1 B). In addition, there aren't any significant increases in growth after maturity time (Table 4).

In this study, the synchrony in pod maturity was estimated based on the time needed for yield harvested in six weeks after the maturity time to reach 80% of total yield. Two accessions, Binh khe D.X. and Sunhwa Nokdu, reached 87.77% of total yield at the fourth harvest and 82.44% of total yield at the third harvest respectively, so they were classified as having synchronous pod maturity (Figure 3). On the other hand, four accessions were classified as having non-synchronous pod maturity because they can’t get 80% of total yield until fifth harvesting, as well as because their yield at sixth harvest was similar with the first harvest (Figure 3). Importantly, ANOVA showed that there were significant differences in total yield, the number of branches, peduncles, and pods in those non-synchronous accessions (except for Tam Chi Lang Lang Son) under the two different harvesting methods (Table 6). The reason why they produced the higher yield than synchronous accessions after six harvests can be explained based on the strong positive correlation between total yield and other traits such as the number of branches, peduncles, and pods (Table 7). In other words, accessions with non-synchronous maturity had increased the number of branches and peduncles, as well as pods/peduncle ratio when they were harvested multiple times.

These results can be used for future improvements of mungbean. First, genes associated with inflorescence meristem could be linked with synchronous pod maturity. There were trends that non-synchronous group had almost twice total yield and significant difference in the number of branches and number of peduncles when multiple harvested than only once (Table 6). Also, total yield had a strong correlation with the number of branches and number of peduncles (Table 7). So, in sum, increasing branches and peduncles causes more yield during growing and non-synchronous maturity in mungbean. Recently, the genome sequence of the mungbean has been published (Kang et al., 2014), so it can facilitate identification of candidate genes that regulate synchrony as well as inflorescence architecture through comparative studies with homologous genes that are already identified in other legumes.

Second, as described above, the accessions that showed little changes between multiple and single harvests can be useful for the future breeding program for synchronous maturity in mungbean. In this case, Binh khe D.X. and Sunhwa Nokdu are expected to be invaluable genetic resources for synchronous pod maturity for the future.

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ABSTRACT IN KOREAN

초록

녹두(*Vigna radiata*)는 콩과 식물에 속하는 작물로서 짧은 생육 주기와 자가 수정 작물이라는 장점에도 불구하고 재배가 용이하지 않다. 이는 꼬투리의 성숙이 한 번에 이루어지지 않기 때문에 여러 번의 수확과정이 필요하여 높은 노동력을 요구하기 때문이다. 따라서 본 연구에서는 녹두의 꽃이 피는 순서를 밝힘과 동시에 이와 같은 순서가 동시성숙에 어떠한 영향을 미치는지 알아보고자 하였다.

녹두는 일반적으로 주경에서 분지를 만들어 분지로부터 꽃이 생성되는 복총상화서구조(compound raceme inflorescence architecture) 임을 관찰하였다. 그러나 실험에 수행된 녹두 계통 가운데 Binh khe D.X.는 분지를 생성하지 않고 주경에서 꽃을 피우고 있음을 확인하여 기존의 알려진 콩과 식물과 다른 단총상화서구조(simple raceme inflorescence architecture)에 가까운 화서구조를 갖는 것을 확인하였다.

또한 녹두의 동시성숙성(synchronous)을 평가하기 위하여 성숙기 이후 일정 간격을 두어 여러 번 수확하는 경우와 그러지 않은 경우로 두 가지 방법으로 나누어 계통간의 차이를 보고자 하였다. 그 결과 녹두의 비동시성숙성(non-synchronous)을 보이는 계통들에 가지의 수, 꽃차례의 수가 영향을 미친다는 것을 확인 하였으며, 이는 향후 녹두의 연구와 육종방향에 도움이 되는 의미 있는 성과이다.

주요어: 녹두(*Vigna radiata*), 화서구조, 동시등숙성

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