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Effect of nodal position on rachis morphology and yield attributes in raceme of mungbean [*Vigna radiata* (L.) *Wilczek*]

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Abstract

In mungbean, pod set probability differs among nodal positions within racemes, with proximal flowers set more pod than distal flowers. Experiments were conducted in 2009 and 2010 under sub-tropical condition to investigate the effect of nodal position on morphological and anatomical features of rachis and pod yield in mungbean. Results revealed that pod setting capacity, number of seeds pod^{-1}, pod size and seed yield were decreased from proximal to distal end of rachis in normal raceme irrespective of season and genotype. Further, early- and later-set pods had different pod growth rate and duration with the early setting pods had higher pod filling rate and increased filling duration compared to latter ones. The rachis diameter, radial length of xylem and phloem gradually and markedly decreased from proximal end to the distal end of the raceme irrespective of season and genotype due to the vascular tissues were fewer and poorly developed in the distal part compared to that of the proximal part in the rachis. The implication of inadequate phloem tissue in relation to flower shedding in the distal part of raceme is also discussed.

Keywords: mungbean, raceme, nodal position effect, pod retention, xylem and phloem.
Abbreviations: DAA-days after anthesis; DAS-days after sowing; PGR-pod growth rate.

Introduction

Most of the leguminous pulse including mungbean possesses raceme type of inflorescence. Mungbean plant generally bears 6-15 racemes and each raceme consists of 16-30 nodes and each node bears two buds i.e. each raceme bears 32-60 buds (Fakir et al., 2011). In the other word, each plant may have a capacity to produce as many as 140-350 pods, but interestingly only 10-35 matured pods are borne in a plant with the majority of buds and flowers abscise (Kumari and Verma, 1983; Mondal et al., 2011a). The flowering pattern in mungbean is indeterminate. The indeterminate and acropetal habit of flowering in the raceme results in a consecutive development of flowering and poding structures. The plant thus attends poding at the proximal (basal) nodes followed by the distal (top) nodes of the raceme. This characteristic feature allows considerably higher contribution to yield by the first few reproductive nodes of the raceme whilst distal nodes contribute lesser to yield (Munier-Jolain et al., 1993). Even, within individual raceme, the distal flowers abscise more than proximals in soybean (Wiebold, 1990; Kuroda et al., 1998; Kokubun et al., 2001), in pigeonpea (Sheldrake and Narayanan, 1979; Begum et al., 2007) and in lignosus bean (Bari and Prodhan, 2001). The later event could be due to insufficient photosynthate supply to the distal part of rachis. This might happen either by source limitation or translocation barrier in the rachis itself (Wiebold and Panciera, 1990). Further, the pods and seeds that set earlier in the proximal end of racemes produce larger and heavier pods than those form from later ones (Board et al., 1995; Saito et al., 1998; Bari and Prodhan, 2001). Furthermore, studies have also suggested that early- and later-set soybean pods have different pod growth rate and duration. The early setting pods have higher rate of pod filling and also increased filling duration compared to latter ones (Spollen et al., 1986a).

It is reported that inadequate phloem development may be responsible for increased flower abscission in the distal portion of the raceme in soybean (Wiebold and Panciera, 1990), in lignosus bean (Bari and Prodhan, 2001) and in pigeonpea (Begum et al., 2007). No such details investigation was carried out in mungbean both in Bangladesh and abroad. So, it is necessary to investigate the anatomical structures of xylem and phloem at the proximal and distal part of the raceme in mungbean which may cause increased floral abscission in the distal end of raceme. Therefore, the objectives of the study were: 1. to investigate the morphological and anatomical features of rachis at different nodal positions in a raceme; 2. to assess growth rate of early- and later-formed pods of rachis; and 3. to study pod production and seed yield at different nodal position of rachis in mungbean.

Results

Morphology and anatomy of rachis in raceme

Results showed that rachis diameter of mungbean genotypes gradually and markedly decreased from proximal towards the

Table 1. Rachis diameter at two nodal positions in raceme of four mungbean genotypes in Kharif-I season of 2009 and 2010

Genotype	Rachis diameter (cm) Year: 2009		Year: 2010	
	Proximal	Distal	Proximal	Distal
BMX 942-8	0.31	0.21 **	0.30	0.17 **
VC 6173	0.35	0.22 **	0.33	0.18 **
MB 300	0.35	0.21 **	0.41	0.27 **
VC 3960	0.37	0.23 **	0.36	0.24 **
LSD (0.05)	0.035		0.05	

** indicate significant at 1% level of probability between proximal and distal positions in a raceme

Table 2. Radial length of vascular tissue, xylem and phloem both at proximal and distal end of pod bearing rachis in two mungbean genotypes in 2009 and 2010

	Xylem (mm)		Phloem (mm)		Vascular tissue (mm)	
Genotype	Proximal end	Distal end	Proximal end	Distal end	Proximal end	Distal end
Year: 2009						
BMX 942-8	0.111	0.024**	0.086	0.056**	0.197	0.080 **
MB 300	0.112	0.041**	0.090	0.055**	0.203	0.096 **
LSD (0.05)	0.006		0.0045		0.008	
Year: 2010						
BMX 942-8	0.109	0.022 **	0.085	0.054**	0.194	0.076 **
MB 300	0.111	0.038 **	0.090	0.050**	0.205	0.090 **
LSD (0.05)	0.006		0.005		0.075	

** indicate significant at 1% level of probability between proximal and distal xylem, phloem and vascular tissue in a raceme

distal end of the raceme irrespective of season and genotype (Table 1). Similar result was also observed in case of radial length of vascular tissue (Table 2). The radial length of phloem and xylem decreased from proximal to distal end of the raceme. Similarly, the vascular tissues in the upper part of rachis were poorly developed compared to that of the basal part in raceme (Fig. 1).

Pod growth rate in the raceme

Changes in pod growth rate (PGR) at two positions of the raceme at different days after anthesis (DAA) in four mungbean genotypes are presented in the Fig. 2. The pattern of PGR followed more or less a normal curve (Fig. 2). The duration of pod growth was shorter in 2010 (range 16-20 days) than that in 2009 (20 days). In 2010, PGR increased linearly reaching peak at 12 DAA followed by a decline in both proximal and distal pods. In 2009, the peak PGR was observed at 16 DAA for proximal while 12 DAA for distal pods in all the genotypes (Fig. 2). Furthermore, PGR was greater at proximal positions than distal positions of the racemes over all growth stages.

Yield and yield attributes in raceme

The effect of nodal position on seed yield and yield attributes was significant (Tables 3-6). Results showed that there was a decreasing trend in number of pod node^{-1}, seeds pod^{-1}, single pod weight and seed weight node^{-1} from proximal to distal nodes within the raceme among the genotypes (Tables 3-6). Results further revealed that 2nd flush contributes little to total yield compared to 1st flush (Table 6). In 2010, node-2, in general, produced maximum number of pods node^{-1} that was not significantly different from node-1 (Table 3). Similar result was also observed in case of seeds pod^{-1} (Table 4). The number of seeds pod^{-1} was the highest at node-2, which was not significantly different from node-1 and node-3 (except VC 3960) in both the seasons and beyond node-3, the number of seeds pod^{-1} decreased significantly (Table 4). Single pod weight, generally, decreased with increased nodal position within the raceme (Table 5). In both seasons, the variation in decrement of single pod weight was not significant between node-1 and node-2 followed by a significant decrease with increasing nodal position in the raceme. Node wise seed weight up to node-3 showed small difference and after node-3 seed weight decreased rapidly in 2010 where as in 2009, seed weight rapidly decreased after node-2. In 1st flush, podset was observed up to node-5 in high yielding genotypes and up to node-4 in low yielding genotypes. In 2nd flush, podset was noted generally 2 nodes within 10-16 nodes from the proximal position.

Discussion

Number of pod, number of seeds pod^{-1} and seed size are the prime yield attributes in mungbean (Mondal et al., 2011b). Pod number, seeds pod^{-1} and pod size decreased with increasing nodal position in the rachis. It means the latter-formed pods were smaller than the earlier-formed ones indicating either inadequate assimilate supply (source limitation) to the later formed pods or presence of translocation barrier of assimilates may have existed in the rachis. Within the raceme, podset probability varied with nodal position and generally it decreased with increasing

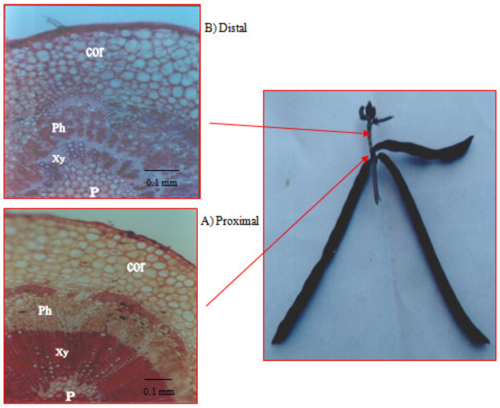

Fig 1. Showing anatomy of (A) proximl and (B) distal part of a normal rachis in mungbean raceme. Legend shows cortex (cor), pholem (Ph), xylem (Xy) and pith (P). The arrows indicate areas of transverse section of the proximal (pod setting area) and distal (non-pod setting area) part of the rachis

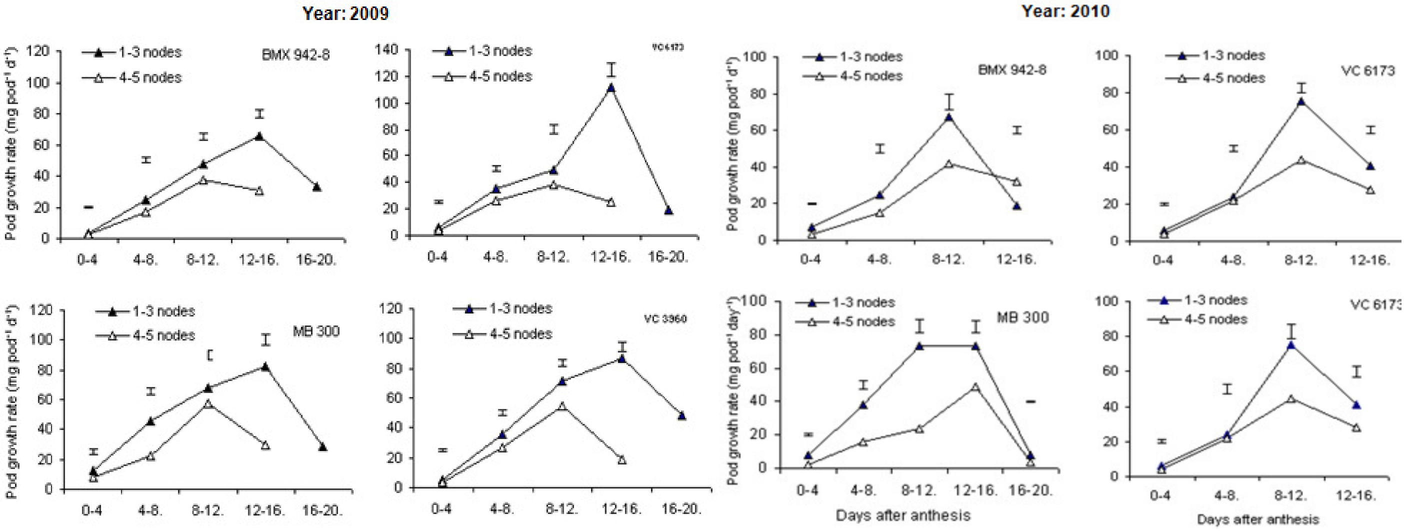

Fig 2. Effect of nodal position on pod growth rate within raceme in four mungbean genotypes.BMX 942-8 and VC 6173: high yielding and MB 300 and VC 3960: low yielding genotypes. Vertical bars represent LSD (0.05).

nodal position except node-2 (Table 3). Podset probability was 61% (range 50-73%), 67% (range 58-82%), 48% (range 38-65%), 22% (range 9-30%) and 8% (range 3-14%) at node-1, 2, 3, 4 and 5, respectively (Data not shown but calculated from Table 3). After node-5, no pod was set until 2nd flush started. It indicates abscission probability changes with the nodal position; some control may have existed along the raceme axis. Biochemical agents like cytokinin and abscissic acid (Kokubun and Honda, 2000) and photosynthate supply (Heitholt et al., 1986) have been implicated. The trend of decreasing pod setting probability with increasing nodal position within the raceme is consistent with the results of other studies (Spollen et al., 1986a; Wiebold and Panciera, 1990; Saitoh et al., 1998; Kokubun et al., 2001). Brun and Betts (1984) have shown that podset is determined at or near anthesis, as detected by a decrease in relative accumulation capacity for photosynthates of flowers destined to abscise. Proximal flowers and fruits thus influence distal podset as early as anthesis. In most instances, weight pod^{-1} and seed weight node^{-1} was significantly decreased from node-3 to distal position in the raceme (Tables 5 and 6). These data suggest that there may be an inadequate supply of assimilates to fill the distal pods. PGR are used to indicate the availability of assimilate transport to the fruit. Hence, PGR was studied between early- and later-formed pods within the raceme of mungbean and results revealed that PGR was greater at proximal positions than distal positions of the racemes over all growth stages indicating inadequate assimilate supply might have occurred to the later-formed pods from the source. The higher growth rate of proximal pods could be due to more assimilate received by the basal pods than in the distal ones. This might have resulted smaller pod size in the distal end. These results are agreed with the reports of Saitoh et al. (1998) and Egli and Bruening (2001) in soybean who reported that earlier-setting pods were heavier than the later-setting ones. Spollen et al. (1986b) studied assimilate translocation pattern within the raceme in soybean and reported that proximal and distal pods accounted for 70 and 30% of the translocated ^{14}C, respectively. These data indicated that most of the carbohydrate produced by leaf is used in filling the pods that occur at proximal position of the raceme. Similar phenomenon may have occurred in the present experiment. Source limitation during seed filling seem to be relatively common as indicated by starch and

Table 3. Effect of nodal position on pod number within a raceme in four mungbean genotypes in Kharif-I season of 2009 and 2010

Nodal position of raceme	Year: 2009				Year: 2010			
	Pods node^{-1} (no.)				Pods node^{-1} (no.)			
	BMX 942-8	VC 6173	MB 300	VC 3960	BMX 942-8	VC 6173	MB 300	VC 3960
1	1.44 a	1.25 a	1.18 a	1.58 a	1.24 a	1.10 b	1.25 a	1.16 a
2	1.44 a	1.25 a	1.12 a	1.25 b	1.30 a	1.20 a	1.34 a	1.20 a
3	0.83 b	0.75 b	0.50 c	0.46 c	1.25 a	0.93 b	1.01 b	1.13 a
4	0.39 d	0.38 c	0.25 d	0.02 e	0.76 b	0.60 c	0.20 d	0.43 b
5	0.11 e	0.07 d	---	---	0.26 d	0.30 d	---	---
6	---	---	---	---	---	0.03 f	---	---
7	---	---	---	---	---	---	---	---
8	---	---	---	---	---	---	---	---
9	---	---	---	---	---	---	---	---
10	---	---	0.78 b	---	---	---	---	---
11	0.62 c	---	0.53 c	---	---	---	---	---
12	0.31 d	0.74 b	---	---	---	---	0.76 c	---
13	---	0.37 c	---	---	0.55 c	0.36 d	0.18 d	---
14	---	---	---	0.20 d	0.29 d	0.11 e	---	---
15	---	---	---	0.03 e	0.06 e	0.02 f	---	0.39 b
16	---	---	---	---	---	---	---	0.14 c
17	---	---	---	---	---	---	---	---
18	---	---	---	---	---	---	---	---
19	---	---	---	---	---	---	---	---
20	---	---		---	---	---	---	---
21	---	---	---	---	---	---	---	---
22	---	---	---	---	---	---	---	---

---: Empty node, no pod was set

Table 4. Effect of nodal position on number of seeds pod^{-1} within a raceme in four mungbean genotypes in Kharif-I season of 2009 and 2010.

Nodal position of raceme	Year: 2009				Year: 2010			
	Seeds pod^{-1} (no.)				Seeds pod^{-1} (no.)			
	BMX 942-8	VC 6173	MB 300	VC 3960	BMX 942-8	VC 6173	MB 300	VC 3960
1	10.97 a	12.00 a	10.45 ab	11.30 a	10.65 a	11.40 a	9.60 a	10.90 a
2	11.30 a	12.00 a	10.83 a	11.00 a	10.56 a	11.80 a	9.90 a	11.50 a
3	10.30 b	10.80 b	10.00 b	8.38 b	9.72 b	10.80 b	9.20 b	9.40 b
4	6.00 c	9.40 c	7.64 c	5.00 d	4.46 f	9.50 c	6.52 c	6.33 c
5	1.33 f	3.40 f	---	---	---	7.50 e	---	---
6	---	---	---	---	---	---	---	---
7	---	---	---	---	---	---	---	---
8	---	---	---	---	---	---	---	---
9	---	---	---	---	---	---	---	---
10	---	---	5.60 d	---	---	---	---	---
11	5.40 d	---	2.33 e	---	---	---	---	---
12	2.33 e	8.73 d	---	---	---	---	6.90 c	---
13	---	4.35 e	---	---	9.15 c	8.53 d	5.36 d	---
14	---	---	---	7.13 c	7.46 d	7.00 e	---	---
15	---	---	---	4.61 d	5.67 e	5.55 f	---	6.73 c
16	---	---	---	---	---	---	---	4.50 d
17	---	---	---	---	---	---	---	---
18	---	---	---	---	---	---	---	---
20	---	---	---	---	---	---	---	---
21	---	---	---	---	---	---	---	---
22	---	---	---	---	---	---	---	---

--: Empty node, no pod was set.

nitrogen levels in soybean leaves during seed filling (Egli, 1999). Moreover, several workers (Shibles et al., 1987; Egli and Crafts-Brandner, 1996; Saitoh et al., 1998) opinioned that soybean yield under most field conditions is thought to be source restricted during the late reproductive period. Further, rachis diameter and radial length of xylem and phloem and vascular tissues decreased at the distal end compared to proximal one (Tables 1, 2 and Fig. 1). These results suggested that phloem was poorly developed in the distal part of the raceme and thus providing possibly inadequate amount of photosynthate to the later-formed flowers/pods which may have caused more flower shedding at the distal end of the raceme. This further indicates that irrespective of yield capacity, the mungbean genotype possibly confer a vascular tissue limitation in the distal part of the rachis. Similar results were also found in soybean (Wiebold and Panciera, 1990), in lignosus bean (Bari and Prodhan, 2001) and in pigeonpea (Begum et al., 2007).In conclusion, the yield attributes decreased with increased nodal position in rachis of mungbean due to vascular tissue limitation in the distal part of rachis.

Materials and methods

Site description

Two experiments were carried out at the Field Laboratory of Bangladesh Agricultural University (BAU), Mymensingh (24.8^0 N 90.5^0 E), Bangladesh, during Kharif-I season (February-May) of 2009 and 2010. The soil of the experimental area of BAU is silty loam having a total nitrogen 0.06%, organic matter 1.15%, available phosphorus 18.5 ppm, exchangeable potassium 0.28 meq%, sulphur 18 ppm and pH 6.8.

Planting materials and experimental design

Four genotypes (Two high and two low yielding) were considered in the study. Two high yielding genotypes were BMX 942-8 and VC 6173, and two low yielding genotypes were MB 300 and VC 3960. Seeds were sown on 22 and 18 February for the year 2009 and 2010, respectively. Seeds were sown in line having row to row distance was 30 cm and plant to plant distance was 10 cm. A randomized complete block design with 3 replications was followed and unit plot size was 1.5 m × 1.5 m.

Management practices

Seeds were sown continuously in line and two weeks after germination, the plants were thinned to a density of 30 plants/m^2. Cultural practices were the same in both the seasons. Uniform plant stands (30 plants m^{-2}) were maintained in both the seasons. Urea, triple superphosphate, muriate of potash and gypsum were used as a source of nitrogen, phosphorus, potassium and sulphur at the rate of 40, 120, 80 and 30 kg ha^{-1}, respectively at the time of final land preparation. First weeding was done followed by thinning at about 21 days after sowing (DAS) and second weeding was done at 40 DAS. A single irrigation was given at 25 DAS at both the seasons. Insecticide (Ripcord 50 EC at 0.025%) was sprayed twice (50 and 60 DAS) at flowering and fruiting stage to control shoot and fruit borer.

Parameters measured

For investigation of the pattern of podset within raceme, 50 undamaged racemes plot^{-1} were collected from each genotype. Racemes were collected from the upper three nodes of the mainstem and were considered for studying yield components and pod growth within raceme. Pods were harvested node wise in the raceme and pooled, and finally, the number of pod set node^{-1}, number of seeds pod^{-1} and pod size were recorded on individual node. For growth study of earlier- and later-formed pods in the raceme, all opened flowers were tagged at the two nodal positions, proximal 1-3 nodes and distal 4-6 nodes separately during flower opening so that the age of pods can be determined. Pods were harvested at 2 days interval from opening up to maturity. Each sample consisted of three replicates and a replicate had 10 pods. Samples were oven dried to a constant weight at 80 ± 2 ^{0}C for 48 hours and the dry weights of seeds and pericarps were recorded. Finally, pod growth rate (PGR) at 4 days interval until maturity was calculated separately for two positions in the raceme. For anatomical investigation of rachis of the raceme, two genotypes were considered in the experiment *viz*., BMX 942-8 (high yielding) and MB 300 (low yielding). The raceme samples were collected from upper part of the mainstem. Normally individual raceme consists of 16-30 nodes and flowering begins from the basal node and proceeds acropetally i.e. flowering proceeds from base towards top in the rachis, and each raceme takes about a week for flower opening is called first flush (1-5 nodes). Following first flushes, further flowering do not occur until pod growth of first flush completes within 14-16 days after flowering begins. After physiological maturity of pods from first flush, flower opening begins again at the distal end (11-15 nodes) of the same raceme, which is termed as second flush (11-15 nodes) and the duration of flowering in the second flush is only about 2-4 days. In the present investigation, free hand sectioning of rachis in the two positions, 1-5 nodes where pods were set and from 6-14 nodes where no pod was set in the first flush of the raceme was considered. Before sectioning, the length and diameter of pod bearing rachis was recorded using a ruler and slide calipers, respectively. Hand sectioning of fresh material was done by sharp stainless razor blades within four hours after sample collection. Following cutting, the sections were stained with Safranin dye and were examined under the compound microscope immediately after slide preparation. The radial length of vascular tissue, xylem and phloem, was measured separately using a micrometer set at the eyepiece. The radial length of vascular tissue, xylem and phloem, was measured at the proximal (1-5 nodes) and distal part (6-15 nodes) of the rachis.

Statistical analysis

All data were analyzed statistically as per the used design following the analysis of variance (ANOVA) technique and the mean differences were adjusted with Duncan's Multiple Range Test (DMRT) using the statistical computer package program, MSTAT-C (Russell, 1986).

Table 5. Effect of nodal position on single pod weight within a raceme in four mungbean , Genotypes in Kharif-I season of 2009 and 2010.

Nodal position of raceme	Year: 2009				Year: 2010			
	Single pod weight (mg)				Single pod weight (mg)			
	BMX 942-8	VC 6173	MB 300	VC 3960	BMX 942-8	VC 6173	MB 300	VC 3960
1	695 a	788 a	985 a	1000 a	475 a	532 a	594 a	707 a
2	669 a	802 a	930 b	980 a	467 a	508 a	603 a	729 a
3	609 b	603 b	827 c	771 b	440 b	482 b	503 b	582 b
4	311 d	450 d	378 e	355 d	404 c	425 c	350 d	386 d
5	264 e	204 e	---	---	241 f	342 e	---	241 f
6	---	---	---	---	---	187 g	---	---
7	---	---	---	---	---	---	---	---
8	---	---	---	---	---	---	---	---
9	---	---	---	---	---	---	---	---
10	---	---	560 d	---	---	---	---	---
11	552 c	---	279 f	---	---	---	---	---
12	124 f	505 c	---	---	---	---	402 c	---
13	---	195 e	---	---	334 d	384 d	314 e	---
14	---	---	---	552 c	291 e	258 f	---	---
15	---	---	---	241 e	135 g	107 h	---	455 c
16	---	---	---	---	---	---	---	325 e
17	---	---	---	---	---	---	---	---
18	---	---	---	---	---	---	---	---
19	---	---	---	---	---	---	---	---
20	---	---	---	---	---	---	---	---
21	---	---	---	---	---	---	---	---
22	---	---	---	---	---	---	---	---

---: Empty node, no pod was set

Table 6. Effect of nodal position on seed weight within a raceme in four mungbean ,Genotypes in Kharif-I season of 2009 and 2010.

Nodal position of raceme	Year: 2009				Year: 2010			
	Seeds weight node^{-1} (mg)				Seeds weight node^{-1} (mg)			
	BMX 942-8	VC 6173	MB 300	VC 3960	BMX 942-8	VC 6173	MB 300	VC 3960
1	697 a	725 a	714 a	994 a	411 a	373 b	650 a	520 b
2	689 a	743 a	704 a	880 b	436 a	402 a	698 a	574 a
3	332 b	328 b	287 b	150 c	400 a	237 c	473 b	535 b
4	128 c	120 c	72 c	26 d	235 b	165 d	178 c	110 c
5	20 d	27 d	---	---	39 d	69 e	---	---
6	---	---	---	---	---	12 f	---	---
7	---	---	---	---	---	---	---	---
8	---	---	---	---	---	---	---	---
9	---	---	---	---	---	---	---	---
10	---	---	267 b	---	---	---	---	---
11	284 b	---	79 c	---	---	---	---	---
12	164 c	342 b	---	---	---	---	212 c	---
13	---	105 c	---	---	133 c	68 e	66 d	---
14	---	---	---	142 c	35 d	37 f	---	---
15	---	---	---	62 d	18 d	30 f	---	118 c
16	---	---	---	---	---	---	---	33 d
17	---	---	---	---	---	---	---	---
18	---	---	---	---	---	---	---	---
19	---	---	---	---	---	---	---	---
20	---	---	---	---	---	---	---	---
21	---	---	---	---	---	---	---	---
22	---	---	---	---	---	---	---	---

---: Empty node, no pod was set

The parameters of rachis diameter, xylem, phloem and vascular tissue were analyzed as design of two factor completely randomized design year wise. Node wise yield attributes and seed yield of rachis were analyzed as one factor randomized complete block design year wise. Microsoft Excel was used for graphical presentation.

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