

Pod Dehiscence in Soybean : Assessing Methods and Varietal Difference

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Abstract : The varietal difference of pod dehiscence in 25 soybean cultivars consisting of 16 Japanese and 9 Thai cultivars was examined at 3, 5, 7, 14, 21, 28 and 35 days after placing in a desiccator (desiccator method) and 2, 4 and 7 hrs after placing in an oven at 60°C (oven-dried method). The cultivars examined were divided into susceptible and resistant groups according to the degree of pod dehiscence. Most of the Japanese cultivars (excepting Suzuotome) and NS1 were susceptible while most of the Thai cultivars (excepting NS1) and Suzuotome were resistant to dehiscence. The degrees of pod dehiscence measured by the desiccator and oven-dried methods were nearly the same, and the moisture content of the pods not dehisced was always higher than that of the dehisced pod. The effect of ambient humidity on pod dehiscence was examined in five soybean cultivars SJ5, Shirotae, Tamahomare, CM60 and Fukuyutaka. When the pods were exposed to 15 or 25% relative humidity (RH), the pods of susceptible cultivars, Shirotae, Tamahomare and Fukuyutaka, started to dehisce at 24 hrs after the start of the treatment, but those of resistant cultivars, SJ5 and CM60, did not dehisce for 72 hrs. None of the cultivars dehisced under 50 and 60% RH. These results revealed that placing the pods in the desiccator for 14 days (desiccator method) or exposing the pods to 60°C for 7 hrs in an oven (oven-dried method) were useful methods for checking the degree of dehiscence.

Key words : Desiccator method, Moisture content, Oven-dried method, Pod dehiscence, Relative humidity, Soybean, Strain gauge method, Varietal difference.

Pod dehiscence or pod shattering is one of major factors leading to remarkable yield losses in harvesting. Pod dehiscence is a specific characteristic observed not only in soybean but also in *Brassica* species (Meakin and Roberts, 1990; Child et al., 2003), sesame (Langham and Wiemers, 2002), other pulse crops (Weeden et al., 2002) and birdsfoot trefoil (*Lotus corniculatus* L.) (Metcalf et al., 1957; Grant, 1996).

The pattern of dehiscence reveals that the tissues are under tension. Either natural or mechanical condition stimulates the tissue to separate quickly at specific point (Spence et al., 1996). In soybean, mature pods dehisce along both the dorsal and ventral sutures and scatter their seeds under low-humidity conditions (Tsuchiya, 1987). The dehiscence of soybean pods is one of the major constraints on mechanical harvest because the harvest loss increases due to seed scattering. Shattering loss during harvesting of soybean also increases as moisture decreased (Philbrook and Oplinger, 1989). While pods opened, the seeds can be lost during drying. Mechanization of soybean cultivation is limited in some countries (Langham and Wiemers, 2002). Yield losses of soybean due to the dehiscence was estimated to be 53-319 kg ha⁻¹ contributing to 37% of total loss in the South Eastern USA (Philbrook and Oplinger, 1989). Seed losses of 34-99% in susceptible cultivars and delayed harvesting after maturity are often associated

with pod shattering (Tiwari and Bhatnagar, 1991). In addition, Tukamuhabwa et al. (2002) reported that yield loss by shattering was 57-175 and 0-186 kg ha⁻¹ in susceptible and intermediately susceptible cultivars, respectively, while the resistant cultivars did not shatter even when harvested at 21 day-delayed harvesting.

Many researchers assessed the degree of pod dehiscence in the crops with pods or capsules. There are four types of assessing methods for pod dehiscence. The first is the field-screening method (Caviness, 1965; Tiwari and Bhatnagar, 1993; Helmes, 1994), the second is the desiccator method (Metcalf et al., 1957; Caviness, 1965), the third is the oven-dried method (Tsuchiya and Sunada, 1977; Tiwari and Bhatnagar, 1997; Tukamuhabwa et al., 2002) and the last one is mechanical cracking method (Kwon et al., 1991; Davies and Bruce, 1997; Morgan et al., 2000; Timothy et al., 2003).

The purposes of the present study were to establish a useful and practical method to assess the degree of pod dehiscence, and clarify the varietal difference of pod dehiscence, and to examine the effects of moisture content of pods and ambient humidity on pod dehiscence in soybean.

Table 1. Dates of flowering and maturity in 2004 and 2005 and growth habit of 25 soybean cultivars.

Cultivars	2004		2005		Growth habit
	Flowering date	Maturity date	Flowering date	Maturity date	
Japanese cultivars					
Akisengoku	Aug.21(49)*	Nov.8 (128)	Aug.25(48)	Nov.21(136)	Determinate
Akishirome	Aug.12(40)	Oct.18(107)	Aug.12(35)	Nov.8 (123)	Determinate
Chadaizu	Aug.10(38)	Oct.14(103)	Aug.13(36)	Oct.26(110)	Determinate
Fukuyutaka	Aug.16(44)	Oct.28(117)	Aug.17(40)	Nov.2 (117)	Determinate
Himeshirazu	Aug.26(54)	Nov.5 (125)	Aug.27(50)	Nov.17(132)	Determinate
Kodane	Aug.21(49)	Oct.28(117)	Aug.24(47)	Nov.8 (123)	Semi-determinate
Kosamame	Aug.23(51)	Oct.28(117)	Aug.25(48)	Nov.10(125)	Determinate
Kosuzu	Aug.9 (37)	Oct.7 (96)	Aug.10(33)	Oct.19(103)	Determinate
Nabeshima	Aug.22(50)	Nov.8 (128)	Aug.23(46)	Nov.21(136)	Semi-determinate
Nattoshoryu	Aug.12(40)	Oct.14(103)	Aug.13(36)	Oct.19(103)	Determinate
Ootsuru	Aug.9 (37)	Oct.23(112)	Aug.9 (32)	Nov.17(132)	Determinate
Sachiyutaka	Aug.10(38)	Oct.18(107)	Aug.12(35)	Oct.25(109)	Determinate
Shirotae	Aug.12(40)	Oct.28(117)	Aug.12(35)	Nov.2 (117)	Determinate
Suzuotome	Aug.14(42)	Oct.14(103)	Aug.15(38)	Oct.20(104)	Determinate
Tamahomare	Aug.9 (37)	Oct.28(117)	Aug.11(34)	Nov.2 (117)	Determinate
Tanbaguro	Aug.17(45)	Nov.8 (128)	Aug.17(40)	Nov.21(136)	Determinate
Thai cultivars					
CM2	Aug.9 (37)	Oct.12(101)	Aug.11(34)	Oct.21(105)	Semi-determinate
CM3	Aug.24(52)	Oct.23(112)	Aug.26(49)	Oct.25(109)	Semi-determinate
CM4	Aug.24(52)	Oct.23(112)	Aug.25(48)	Oct.25(109)	Semi-determinate
CM60	Aug.17(45)	Nov.6 (126)	Aug.19(42)	Nov.8 (123)	Semi-determinate
NS1	Aug.14(42)	Oct.15(104)	Aug.15(38)	Oct.20(104)	Semi-determinate
SJ4	Aug.26(54)	Nov.8 (128)	Aug.25(48)	Nov.10(125)	Semi-determinate
SJ5	Aug.26(54)	Nov.6 (126)	Aug.25(48)	Nov.10(125)	Semi-determinate
SK1	Aug.22(50)	Nov.5 (125)	Aug.24(47)	Oct.25(109)	Indeterminate
SK2	Aug.21(49)	Nov.5 (125)	Aug.23(46)	Oct.25(109)	Indeterminate

Remarks 1. (.....)* = Number of days after sowing. 2. flowering date = the date when 50% of the plants began flowering. 3. maturity date = the date when most of the pods showed a mature color.

Materials and Methods

1. Preparations of plants used for analyses

Twenty-five cultivars of soybean [*Glycine max* (L.) Merrill] were sown in the experimental field of Mie University on July 3, 2004 and July 8, 2005 (Table 1). Three seeds per hill were sown at 20 cm-spacing in a row of approximately 6 m long with 70 cm row spacing. Two or three rows per cultivar were prepared. The seedling were thinned to one seedling per hill at two weeks after sowing. Compound fertilizer (N:P₂O₅:K₂O = 3:10:10) at 100 g m⁻² and CaCO₃ at 100 g m⁻² were applied as basal dressing. The representative pods were harvested when the pods showed a matured color, of brown or black.

2. Measurement of the degree of pod dehiscence and moisture content of pods

The pod dehiscence character was assessed by

keeping the pods in a desiccator for 35 days (desiccator method), and by exposing the pods to 60°C for 7 hrs in an oven (oven-dried method). After the treatment, the moisture content of pods was determined by keeping the pods in a hot-air oven at 105 ± 1°C for 24 hrs.

For the desiccator method, 30 pods of each cultivar, each with two seeds, were harvested with three replications, and they were placed in a desiccator cabinet at room temperature. Degree of pod dehiscence was recorded at 3, 5, 7, 14, 21, 28 and 35 days after placing in the desiccator (DAD). The moisture contents at harvesting and at 80% pod dehiscence (80% of the pods dehiscenced) were measured after drying in a hot-air oven at 105 ± 1°C for 24 hrs. For the oven-dried method, 30 pods of each cultivar, each with two seeds, were exposed to 60°C in an oven. The degree of pod dehiscence and moisture content of pods were recorded at 2, 4 and 7 hrs after placing in the oven.

For the strain gauge method, 30 soybean pods of

Table 2-1. Degree of pod dehiscence at 3, 5, 7, 14, 21, 28, 35 days after placing in desiccator (DAD) in 25 soybean cultivars in 2004.

Cultivars	Pod dehiscence (%)						
	3 DAD	5 DAD	7 DAD	14 DAD	21 DAD	28 DAD	35 DAD
Japanese cultivars							
Akisengoku	0 e*	0 d	0 d	36.7 d	66.7 b	66.7 d	70.0 c
Akishrome	0 e	86.7 a	93.3 ab	96.7 a	96.7 a	96.7 ab	96.7 a
Chadaizu	76.7 b	100 a	100 a	100 a	100 a	100 a	100 a
Fukuyutaka	0 e	0 d	6.7 d	80.0 bc	86.7 a	90.0 abc	96.7 a
Himeshirazu	23.3 d	90.0 a	100 a	100 a	100 a	100 a	100 a
Kodane	0 e	13.3 d	46.7 c	93.3 ab	100 a	100 a	100 a
Kosamame	0 e	0 d	6.7 d	70.0 c	70.0 b	80.0 c	100 a
Kosuzu	93.3 a	96.7 a	96.7 a	96.7 a	96.7 a	96.7 ab	96.7 a
Nabeshima	0 e	0 d	0 d	96.7 a	96.7 a	100 a	100 a
Nattoshoryu	100 a	100 a	100 a	100 a	100 a	100 a	100 a
Ootsuru	0 e	36.7 c	60.0 c	86.7 ab	86.7 a	86.7 bc	86.7 b
Sachiyutaka	3.3 e	93.3 a	93.3 ab	93.3 ab	93.3 a	93.3 ab	93.3 ab
Shirotae	0 e	0 d	6.7 d	80.0 bc	90.0 a	96.7 ab	96.7 a
Suzuotome	0 e	0 d	0 d	0 e	0 d	0 g	0 f
Tamahomare	0 e	33.3 c	46.7 c	80.0 bc	90.0 a	96.7 ab	96.7 a
Tanbaguro	0 e	0 d	6.7 d	96.7 a	96.7 a	100 a	100 a
Thai cultivars							
CM2	3.3 e	6.7 d	6.7 d	13.3 e	13.3 d	13.3 f	13.3 e
CM3	0 e	0 d	0 d	0 e	0 d	0 g	0 f
CM4	0 e	0 d	0 d	0 e	0 d	0 g	0 f
CM60	0 e	0 d	0 d	0 e	0 d	0 g	0 f
NS1	66.7 c	66.7 b	80.0 b	100 a	100 a	100 a	100 a
SJ4	0 e	0 d	0 d	0 e	0 d	0 g	0 f
SJ5	0 e	0 d	0 d	0 e	0 d	0 g	0 f
SK1	0 e	0 d	0 d	33.3 d	33.3 c	36.7 e	36.7 d
SK2	0 e	0 d	0 d	0 e	0 d	0 g	3.3 f

*Mean followed by the same letters in each column are not significantly different at 5% level, as determined by Duncan's Multiple Range Test (DMRT).

each cultivar, each with two seeds, were used. The force required to separate the valves of pod at the septum was considered to be less than 1 kg weight. A single pod was set on the fixed base, pressed with a bar connected to the strain gauge and cracked at less than 1 kg pressure, by which some pods dehisced but others did not. The pods dehisced and not dehisced were separated, and their moisture contents were measured after drying in hot-air oven at 105 ± 1 °C for 24 hrs.

3. Effects of ambient humidity on pod dehiscence

Ambient humidity was adjusted to 15, 25, 50 and 60% relative humidity (RH) in a desiccator by changing the concentrations of potassium acetate, sodium chloride and silica gel. Thirty pods, each with two seeds, of five soybean cultivars, SJ5, Shirotae, Tamahomare, CM60 and Fukuyutaka, were stored at each RH at room temperature. The degree of pod dehiscence was measured at intervals, and the moisture

content of the pods was also measured after drying in a hot-air oven at 105 ± 1 °C for 24 hrs.

Results and Discussion

1. Varietal difference in pod dehiscence

The degree of pod dehiscence in 25 soybean cultivars was measured by the desiccator method in 2004 and 2005 (Table 2-1 and 2-2). The pattern of pod dehiscence was nearly the same in 2004 and 2005. At 14 DAD, most of the Japanese cultivars and Thai cultivar NS1 reached 66.7% pod dehiscence in 2004, and 66.7% pod dehiscence in 2005. At 21 DAD, all of these cultivars showed 66.7% pod dehiscence in 2004 and 2005. On the other hand, Japanese cultivar Suzuotome and all Thai cultivars excepting NS1 did not dehisce or scarcely dehisced even at 35 DAD.

Thus the 25 soybean cultivars were clearly divided into two groups. In one group (susceptible group) consisting of Akisengoku, Akishrome, Chadaizu,

Table 2-2. Degree of pod dehiscence at 3, 5, 7, 14, 21, 28, 35 days after placing in desiccator (DAD) in 25 soybean cultivars in 2005.

Cultivars	Pod dehiscence (%)						
	3 DAD	5 DAD	7 DAD	14 DAD	21 DAD	28 DAD	35 DAD
Japanese cultivars							
Akisengoku	0 f*	93.3 ab	93.3 a	93.3 ab	93.3 ab	93.3 ab	93.3 ab
Akishirome	0 f	0 e	90.0 a	96.7 ab	96.7 ab	96.7 ab	96.7 ab
Chadaizu	63.3 bc	66.7 cd	66.7 b	73.3 c	83.3 c	83.3 c	83.3 c
Fukuyutaka	53.3 cd	93.3 ab	100 a	100 a	100 a	100 a	100 a
Himeshirazu	90.0 a	90.0 ab	90.0 a	90.0 b	90.0 bc	90.0 bc	90.0 bc
Kodane	23.3 e	70.0 bc	93.3 a	100 a	100 a	100 a	100 a
Kosamame	0 f	90.0 ab	96.7 a	96.7 ab	96.7 ab	96.7 ab	96.7 ab
Kosuzu	6.7 f	80.0 abc	93.3 a	93.3 ab	93.3 ab	93.3 ab	93.3 ab
Nabeshima	6.7 f	96.7 a	100 a	100 a	100 a	100 a	100 a
Nattoshoryu	0 f	96.7 a	96.7 a	96.7 ab	96.7 ab	96.7 ab	96.7 ab
Ootsuru	0 f	70.0 bc	100 a	100 a	100 a	100 a	100 a
Sachiyutaka	70.0 bc	96.7 a	96.7 a	96.7 ab	96.7 ab	96.7 ab	96.7 ab
Shirotae	10.0 f	93.3 ab	96.7 a	96.7 ab	96.7 ab	96.7 ab	96.7 ab
Suzuotome	0 f	0 e	0 c	0 d	0 d	0 e	0 e
Tamahomare	46.7 d	93.3 ab	96.7 a	96.7 ab	96.7 ab	96.7 ab	96.7 ab
Tanbaguro	0 f	70.0 bc	100 a	100 a	100 a	100 a	100 a
Thai cultivars							
CM2	0 f	0 e	0 c	0 d	0 d	0 e	0 e
CM3	0 f	0 e	0 c	0 d	0 d	0 e	0 e
CM4	0 f	0 e	0 c	3.3 d	3.3 d	3.3 e	6.67 de
CM60	0 f	0 e	0 c	0 d	0 d	0 e	0 e
NS1	0 f	46.7 d	66.7 b	100 a	100 a	100 a	100 a
SJ4	0 f	0 e	0 c	0 d	0 d	0 e	0 e
SJ5	0 f	0 e	0 c	0 d	0 d	0 e	0 e
SK1	0 f	0 e	0 c	0 d	0 d	13.3 d	13.3 d
SK2	0 f	0 e	0 c	3.3 d	3.3 d	13.3 d	13.3 d

*Mean followed by the same letters in each column are not significantly different at 5% level, as determined by Duncan's Multiple Range Test (DMRT).

Fukuyutaka, Himeshirazu, Kodane, Kosamame, Kosuzu, Nabeshima, Nattoshoryu, Ootsuru, Sachiyutaka, Shirotae, Tamahomare, Tanbaguro and NS1, most of the pods dehiscence. In the other group (resistant group) consisting of CM2, CM3, CM4, CM60, SJ4, SJ5, SK1, SK2 and Suzuotome, most of the pods did not dehiscence. All the susceptible cultivars showed above 66.7% dehiscence at 21 DAD (average of 16 cultivars at 35 DAD was 95.6% in 2004 and 96.2% in 2005). On the other hand, all the resistant cultivars showed below 40% dehiscence even at 35 DAD (average of 9 cultivars at 35 DAD was 5.9% in 2004 and 2005).

There was little difference among the dehiscence pattern of the susceptible group; Akisengoku, Fukuyutaka, Himeshirazu, Kodane, Kosamame, Nabeshima, Ootsuru, Sachiyutaka, Shirotae, Tamahomare and Tanbaguro dehiscence earlier in 2005 than in 2004. While Akishirome, Chadaizu, Kosuzu, Nattoshoryu and NS1 dehiscence earlier in 2004 than in 2005. At 14 DAD, the percentage of pod

dehiscence in Akisengoku was lower than in the others while at 21 DAD all cultivars showed nearly the same percentages in both 2004 and 2005.

In another experiment, the varietal differences of pod dehiscence were examined by the oven-dried method (Tsuchiya and Sunada, 1977). The results were similar to those obtained by the desiccator method, and the ranking of genotypes for pod dehiscence determined by the two methods was the same (Table 3). A significant correlation was observed between the degree of pod dehiscence by the desiccator and oven-dried method. It was found that the relative of dehiscence at 5, 7, 14, 21, 28 and 35 days in the desiccator was positively correlated with that measured by the oven-dried method (Table 4). Thus, varietal difference of the degree of pod dehiscence became clear by using the results of both methods.

The previous researchers used various techniques to measure the degree of pod dehiscence. The field

Table 3. Degree of pod dehiscence and the moisture content of pods of 25 soybean cultivars measured after oven-drying at 60 °C for 2, 4 and 7 hrs in 2005.

Cultivars	At harvesting		Drying 2 hrs		Drying 4 hrs		Drying 7 hrs	
	%PD	%MC	%PD	%MC	%PD	%MC	%PD	%MC
Japanese cultivars								
Akisengoku	0 a*	10.2 f-k	96.7 a	5.0 fgh	96.7 a	3.8 e-h	96.7 ab	3.1 g-l
Akishirome	0 a	11.5 c-g	0 d	8.4 a	50.0 cde	5.8 abc	80.0 c	4.7 b-e
Chadaizu	0 a	12.7 c	0 d	5.3 e-h	33.3 d-g	5.1 a-e	80.0 c	4.1 d-g
Fukuyutaka	0 a	12.1 cde	0 d	7.2 abc	66.7 bc	5.3 a-d	96.7 ab	3.4 f-i
Himeshirazu	0 a	9.1 lk	70.0 b	4.0 hi	90.0 a	2.6 h	96.7 ab	2.3 jk
Kodane	0 a	12.0 cde	13.3 d	5.8 d-g	63.3 c	5.0 a-e	96.7 ab	4.1 def
Kosamame	0 a	10.2 f-k	46.7 c	5.1 fgh	86.7 ab	4.7 b-f	93.3 ab	4.5 cde
Kosuzu	0 a	17.0 a	0 d	8.3 a	30.0 e-h	6.1 ab	86.7 bc	4.7 b-e
Nabeshima	0 a	10.6 e-k	36.7 c	5.1 fgh	93.3 a	4.0 d-g	96.7 ab	3.9 e-h
Nattoshoryu	0 a	11.5 c-g	0 d	6.3 c-f	13.3 ghi	6.2 a	93.3 ab	4.8 b-e
Ootsuru	0 a	11.2 c-h	86.7 a	4.5 ghi	96.7 a	3.5 f-h	100 a	3.0 h-k
Sachiyutaka	0 a	11.0 d-i	10.0 d	6.7 bcd	53.3 cd	5.0 a-e	93.3 ab	3.0 h-k
Shirotae	0 a	12.6 c	3.3 d	7.4 abc	66.7 bc	5.9 abc	96.7 ab	3.8 e-h
Suzuotome	0 a	10.7 e-j	0 d	4.7 ghi	0 i	4.1 d-g	0 e	3.8 e-h
Tamahomare	0 a	12.4 cd	3.3 d	7.3 abc	26.7 fgh	6.0 abc	86.7 bc	3.8 e-h
Tanbaguro	0 a	11.6 c-f	10.0 d	6.3 c-f	46.7 c-f	5.0 a-e	70.0 d	4.4 cde
Thai cultivars								
CM2	0 a	11.6 c-f	0 d	7.3 abc	0 i	6.2 a	0 e	5.9 a
CM3	0 a	8.4 k	0 d	4.6 ghi	0 i	4.4 c-f	0 e	2.1 k
CM4	0 a	9.3 j-k	0 d	5.2 e-h	0 i	4.2 d-f	0 e	3.2 f-l
CM60	0 a	15.6 b	0 d	7.7 ab	0 i	5.8 abc	0 e	5.5 ab
NS1	0 a	9.6 i-l	0 d	3.5 i	10.0 hi	2.7 gh	93.3 ab	2.5 i-k
SJ4	0 a	10.8 e-j	0 d	5.7 d-g	0 i	5.3 a-d	0 e	5.3 abc
SJ5	0 a	11.3 c-h	0 d	6.5 b-e	0 i	5.4 a-d	0 e	5.0 a-d
SK1	0 a	9.8 h-l	0 d	5.4 d-h	0 i	4.9 a-e	0 e	2.9 h-k
SK2	0 a	10.0 g-k	0 d	6.2 c-f	0 i	5.4 a-d	0 e	2.9 h-k

*Mean followed by the same letters in each column are not significantly different at 5% level, as determined by Duncan's Multiple Range Test (DMRT).

%PD = percentage of pod dehiscence, %MC = moisture content in percentage.

screening method was used for quantifying the degree of pod dehiscence in soybean (Caviness, 1965; Tiwari and Bhatanagar, 1991), desiccator method was also used for measuring the number of dehisced pods in soybean (Caviness, 1965) and in birdsfoot trefoil (Metcalf et al., 1957). Oven-drying at 60°C for 7 hrs (Tsuchiya and Sunada, 1977), oven-drying at 40°C for 24 hrs (Tiwari and Bhatnagar, 1997) and oven-drying at 80°C for 5 hrs (Tukamuhabwa et al., 2002) were used to determine the degree of pod dehiscence in soybean. On the other hand, a pendulum machine was used to assess the degree of shattering in *Brassica rapa* (Liu et al., 1994). A tensile separation test was used to measure the easiness of pod values of individual pod in oilseed rape (Davies and Bruce, 1997; Morgan et al., 2000). The strain gauge method was also used to measure the degree of pod dehiscence of individual pod in rape

Table 4. Coefficient of correlation between pod dehiscence of measured by desiccator and oven-drying in 25 soybean cultivars in 2005.

Desiccator method	Correlation coefficient (r)
3 days	0.427ns
5 days	0.907**
7 days	0.979**
14 days	0.988**
21 days	0.989**
28 days	0.986**
35 days	0.986**

** indicates significant difference at 1% levels, ns not significant.

Table 5. Moisture content of pods at harvesting and at 80% pod dehiscence, and the number of days to 80% pod dehiscence, in 25 soybean cultivars.

Cultivars	2004			2005			
	Moisture content(%)		# days to 80% pod dehiscence	Moisture content(%)			# days to 80% pod dehiscence
	At harvesting	80%		At harvesting	80%	35 DAD	
Japanese cultivars							
Akisengoku	9.7	7.0	42	10.2	7.4	-	5
Akishirome	9.1	7.8	5	11.5	8.9	-	7
Chadaizu	8.6	6.8	3	12.7	6.1	-	21
Fukuyutaka	10.3	7.9	14	12.1	7.4	-	5
Himeshirazu	11.2	9.6	5	9.1	6.0	-	3
Kodane	9.1	8.6	14	12.0	7.6	-	7
Kosamame	15.5	7.2	21	10.2	7.5	-	5
Kosuzu	15.4	7.1	3	17.0	8.1	-	5
Nabeshima	13.9	6.9	14	10.6	7.1	-	5
Nattoshoryu	8.9	6.7	3	11.5	8.9	-	5
Ootsuru	9.7	6.6	14	11.2	7.2	-	7
Sachiyutaka	10.8	8.4	5	10.9	7.7	-	5
Shirotae	10.6	5.9	14	12.6	7.2	-	5
Suzuotome*	7.6	-	-	10.4	-	5.9	-
Tamahomare	12.9	7.9	14	12.4	7.4	-	5
Tanbaguro	9.4	8.7	14	11.6	7.6	-	7
Thai cultivars							
CM2*	14.7	-	-	11.7	-	6.9	-
CM3*	7.2	-	-	8.4	-	6.9	-
CM4*	8.6	-	-	9.3	-	7.1	-
CM60*	15.8	-	-	11.3	-	6.3	-
NS1	11.5	7.3	7	9.6	7.2	-	14
SJ4*	9.1	-	-	10.8	-	6.4	-
SJ5*	9.8	-	-	11.3	-	6.9	-
SK1*	13.1	-	-	9.8	-	7.5	-
SK2*	9.9	-	-	9.9	-	6.9	-

*Resistance cultivars. In these cultivars, percentage of pod dehiscence was lower the 80% until 35 DAD, and the moisture content was measured at the end of the experiment.

(Kwon et al., 1991), and a random impact test (RIT) was used to detect the shattering habit of many pods (Davies and Bruce, 1997). The variable-speed pod splitter (VPS) was also developed for quantifying pod dehiscence of *Brassica napus* and *B. rapa* (Timothy et al., 2003). Each technique has been developed for specific crops to allow either accurate or rapid measurement.

However, there is no common method. It seems that placing the pods in a desiccator for 14 days or exposing the pods to 60°C in an oven 7 hrs are useful methods for soybean.

2. Moisture content and pod dehiscence

The moisture content of pods gradually decreases as they mature reaching 13 - 20% in all the cultivars of soybean (Tsuchiya, 1987). When harvest is delayed due

to unsuitable weather, or when pod moisture decreases below 10 or 11 percent, pod dehiscence may occur in the field.

Table 5 shows the moisture content of pods of 25 soybean cultivars at harvesting and at 80% pod dehiscence in 2004 and 2005. The average initial moisture content of fresh pod was 10.9%, varying from 7.2 to 15.8% in 2004 and 11.1%, varying from 8.4 to 17.0% in 2005. The large variation in the moisture content of pods in each cultivar might depend on the difference in environmental conditions at harvesting time. The moisture content of pod is a major indicator of pod dehiscence. The moisture content of pods at 80% pod dehiscence was nearly the same in 2004 and 2005. In 2004, all of the susceptible cultivars reached 80% pod dehiscence when moisture content of pods

Table 6. Moisture content of the pods measured by strain gauge method at harvesting and after storage at room temperature for 7 days, in 25 soybean cultivars in 2005.

Cultivars	At harvesting				After storage at room temperature			
	Dehisced		Not dehisced		Dehisced		Not dehisced	
	No. of pods	%MC	No. of pods	%MC	No. of pods	%MC	No. of pods	%MC
Japanese cultivars								
Akisengoku	30	7.9	0	-	30	7.5	0	-
Akishirome	15	9.3	15	10.1	30	8.5	0	-
Chadaizu	6	9.5	24	12.1	ND	ND	ND	ND
Fukuyutaka	0	-	30	12.1	ND	ND	ND	ND
Himeshirazu	28	9.0	2	12.8	30	7.3	0	-
Kodane	22	9.6	8	11.8	30	7.3	0	-
Kosamame	26	8.8	4	10.1	30	7.1	0	-
Kosuzu	2	8.6	28	15.2	30	8.8	0	-
Nabeshima	9	9.6	21	11.2	30	8.4	0	-
Nattoshoryu	6	9.4	24	10.1	30	8.4	0	-
Ootsuru	25	9.4	5	10.7	30	8.1	0	-
Sachiyutaka	27	9.2	3	10.4	ND	ND	ND	ND
Shirotae	0	-	30	12.1	ND	ND	ND	ND
Suzuotome	12	7.7	18	9.3	30	8.9	0	-
Tamahomare	0	-	30	11.4	ND	ND	ND	ND
Tanbaguro	17	9.4	13	10.7	30	8.0	0	-
Thai cultivars								
CM2	9	11.2	21	12.2	30	8.8	0	-
CM3	13	8.6	17	9.1	ND	ND	ND	ND
CM4	11	7.8	19	8.6	ND	ND	ND	ND
CM60	9	8.0	21	9.3	30	8.2	0	-
NS1	30	7.8	0	-	30	7.2	0	-
SJ4	8	9.1	22	9.5	30	7.4	0	-
SJ5	5	8.2	25	8.6	30	8.9	0	-
SK1	11	8.3	19	8.4	ND	ND	ND	ND
SK2	15	7.3	15	8.5	ND	ND	ND	ND

ND = not investigated by the strain gauge method.

%MC = moisture content in percentage.

reached 5.9 to 9.6% (average 7.5%), and none of the resistant group reached 80% pod dehiscence. In 2005, all of the susceptible cultivars reached 80% dehiscence when the moisture content of the pods reached 6.0 to 8.9% (average 7.5%). These values are similar to those in birdsfoot trefoil reported by Hughes (1982), in which the average moisture content of birdsfoot trefoil pods at dehiscence was $7.8 \pm 0.2\%$. In addition, the moisture content of the pods critical for pods dehiscence in birdsfoot trefoil clone B74 was 10.0% when ambient RH was 29.5% (Metcalf et al., 1957). The critical moisture content of pods in the susceptible group of soybean seems to be the same as in birdsfoot trefoil. Thus, the most important

factor for pod dehiscence is moisture content of pods (Hughes, 1982) and ambient humidity (Anderson, 1955; Metcalfe et al., 1957). However, low humidity, high temperature, rapid temperature change and alternating wetting and drying are common factors that induce pod dehiscence in soybean (Tsuchiya, 1987).

The moisture content of pods in relation to pod dehiscence was investigated by strain gauge method in 25 soybean cultivars in 2005 (Table 6). The samples were collected and cracked by pressing a pod at less than 1 kg weight. Then, the pods dehisced and not dehisced were separated, and their moisture contents were measured after drying in the hot-air oven at

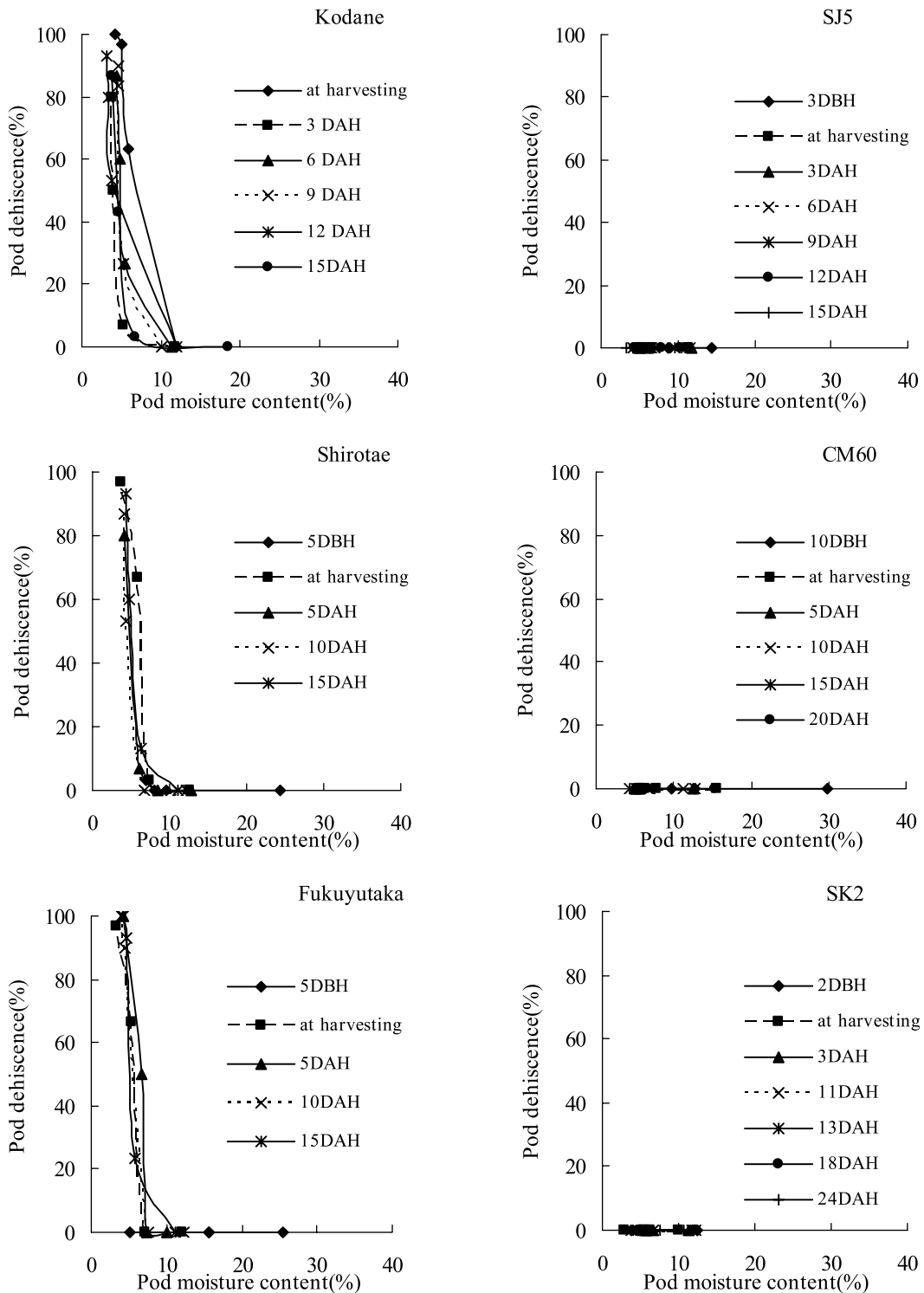


Fig. 1. Relation between moisture content and % of pod dehiscence of Kodane, SJ5, Shirotae, CM60, Fukuyutaka and SK2 in 2005. DAH : days after harvesting, DBH : days before harvesting.

105 ± 1°C for 24 hrs. The number of dehised pods varied with the cultivar, but was not correlated with the susceptibility or resistance to pod dehiscence of cultivars (compare Table 2 and 6).

In most cultivars, the moisture contents of

dehised pods were lower than 10.0%, although the moisture content was 11.2% in CM2 (Table 6). The pods of Fukuyutaka, Shirotae and Tamahomare were not dehised by the strain gauge method, and their moisture content was 12.1, 12.1 and 11.4%,

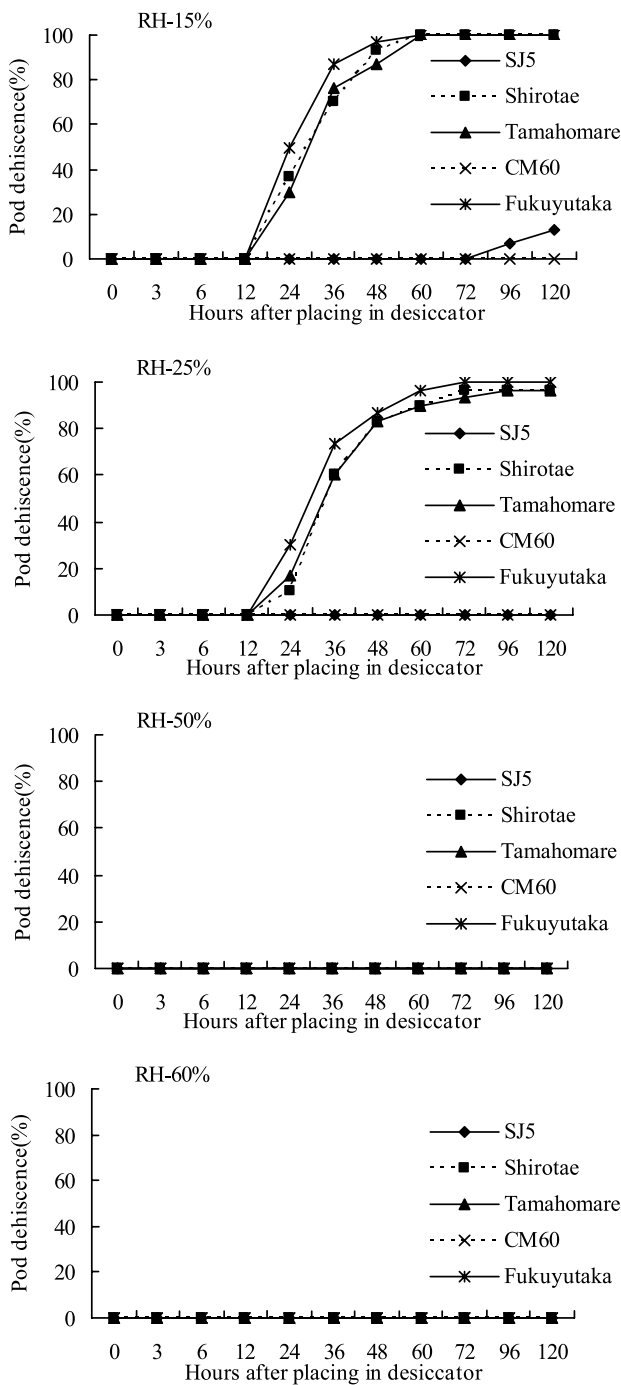


Fig. 2. Changes of % pod dehiscence in SJ5, Shirotae, Tamahomare, CM60 and Fukuyutaka under different relative humidities in 2005.

respectively. The moisture contents of the pods not dehisced were 8.4-15.2% (average 10.6%). After storage at room temperature for 7 days, all pods were dehisced by the strain gauge method, and their moisture contents were lower than 8.9%.

Fig.1 shows the relationship between moisture content and dehiscence of three susceptible cultivars, Kodane, Shirotae and Fukuyutaka, and three resistant cultivars, SJ5, CM60 and SK2, examined in 2005. The

pods were sampled before harvesting, at harvesting and after harvesting, and their moisture contents were determined after drying at 60°C for 7 hrs. The moisture contents of pods at harvesting of Kodane, Shirotae, Fukuyutaka, SJ5, CM60 and SK2 were 12.0, 12.6, 12.1, 11.3, 15.6 and 10.0%, respectively. The pods with above 10.0% moisture content did not dehisce in all cultivars. The pods of susceptible cultivars, Kodane, Shirotae and Fukuyutaka, showed more than 80% dehiscence when the moisture content of pods was below 10%. In contrast, the pods of resistant cultivars, SJ5, CM60 and SK2 did not dehisce even when the moisture content of the pods was less than 6% (4.5, 5.3 and 4.6%, respectively). After exposure to 60°C for 7 hrs, the degree of pod dehiscence in Kodane (89.0%), Shirotae (90.6%) and Fukuyutaka (99.3%) was much higher than that in SJ5, CM60 and SK2 (Table 3).

3. Effects of ambient humidity on pod dehiscence

Three susceptible cultivars, Shirotae, Tamahomare and Fukuyutaka, and two resistant cultivars, SJ5 and CM60, were used in this experiment. At 15 and 25% RH, the pods of the susceptible cultivars started to dehisce 24 hrs after the start of the treatment, and all of them dehisced at 60 hrs. However, the pods of the resistant cultivars did not dehisce at 15 and 25% RH even at 72 hrs. At 50 and 60% RH, all the cultivars did not dehisce for 120 hrs (Fig.2). In birdsfoot trefoil, the pods dehisced at 29.5% RH but not at 35% or higher RH (Metcalf et al., 1957). In soybean, 15 - 20% RH was found to be suitable for identification of resistant genotypes (Caviness, 1965).

Table 7 shows the moisture contents of pods kept at different humidities for 120 hrs. Average initial moisture content of the pods varied with the cultivar only slightly; 10.5% in SJ5, 10.7% in Shirotae, 10.8% in Tamahomare, 11.4% in CM60 and 10.5% in Fukuyutaka. The moisture content of the pods of each cultivar at the end of the treatment varied with the RH. The higher the RH, the higher was the moisture content of pods. The pods with higher than 10% moisture content did not dehisce (Table 7). Therefore, both the moisture content of pods and ambient humidity seem to be the important factors for the pod dehiscence.

Conclusions

The varietal difference of the degree of pod dehiscence was examined by the desiccator and oven-dried methods. Twenty-five soybean cultivars examined were divided into two groups, susceptible cultivars, Nattoshoryu, Kosuzu, Chadaizu, Sachiutaka, Himeshirazu, Akishirome, NS1, Nabeshima, Tanbaguro, Kodane, Ootsuru, Fukuyutaka, Shirotae, Tamahomare, Kosamame, and Akisengoku, and resistant cultivars, Suzuotome, SK1, CM3, CM4, CM60, SJ4, SJ5, SK2 and CM2. The effective and practical

Table 7. Moisture content of the pods kept at different relative humidities for 120 hrs in 2005.

Cultivars	Moisture content (%)				
	At harvesting	RH-15%	RH-25%	RH-50%	RH-60%
SJ5	10.5 a*	7.2 a	7.2 ab	10.1 a	10.5 b
Shirotae	10.7 a	6.4 ab	7.4 a	10.2 a	10.3 b
Tamahomare	10.8 a	6.2 b	6.7 b	10.0 a	10.6 b
CM60	11.4 a	6.8 ab	7.8 a	10.4 a	11.5 a
Fukuyutaka	10.5 a	6.4 ab	7.3 ab	10.3 a	10.8 ab
Average	10.8	6.6	7.3	10.2	10.7

*Mean followed by the same letters in each column are not significantly different at 5% level, as determined by Duncan's Multiple Range Test (DMRT).

methods to discriminate between the two groups are the desiccator method (14 days in a desiccator), and oven-dried method (at 60°C for 7 hrs). By the strain gauge method we found that the pod with a moisture content of more than 10% did not dehisce. Keeping the ambient humidity at less than 25% RH enhanced the dehiscence and keeping at a high humidity (higher than 50% RH) inhibits pod dehiscence. The moisture content of pods and the ambient humidity were found to be closely correlated with the degree of pod dehiscence.

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References

- Anderson, S.R. 1955. Development of pods and seeds of birdsfoot trefoil, *Lotus corniculatus* L., as related to maturity and to seed yields. *Agron. J.* 47 : 483-487.
- Caviness, C.E. 1965. Effects of relative humidity on pod dehiscence in soybeans. *Crop Sci.* 5 : 511-513.
- Child, R.D., Summers, J.E., Babij, J., Farrent, J.W. and Bruce, D.M. 2003. Increased resistance to pod shatter is associated with changes in the vascular structure in pods of a resynthesized *Brassica napus* line. *J. Exp. Bot.* 54 : 1919-1930.
- Davies, G.C. and Bruce, D.M. 1997. Fracture mechanics of oilseed rape pods. *J. Mater. Sci.* 32 : 5895-5899.
- Grant, W.F. 1996. Seed pod shattering in the genus *Lotus* (Fabaceae) : A synthesis of diverse evidence. *Can. J. Plant Sci.* 76 : 447-456.
- Helms, T.C. 1994. Greenhouse and field evaluation of pod dehiscence in soybean. *Can. J. Plant Sci.* 74 : 699-701.
- Hughes, M. A. 1982. The effects of misting upon seed yield of birdsfoot trefoil, *Lotus corniculatus* L., and the relationship of moisture content of pod, seed and fruit at dehiscence. M. SC. thesis, Montana State University, Bozeman, MT. 1-42.
- Kwon, Y.W., Umezaki, T. and Inouye, J. 1991. Relationship between moisture content in pod and pod dehiscence in rape. *Korean J. Crop Sci.* 36 : 540-544.
- Langham, D.R. and Wiemers, T. 2002. Progress in mechanizing sesame in the US through breeding. In J. Janic and A. Whipkey eds., *Trends in New Crops and New Uses*. ASHS Press, Alexandria, VA. 157-173.
- Liu, X.Y., Macmillian, R.H., Burrow, R.P., Kadkol, G.P. and Halloran, G.M. 1994. Pendulum test for evaluation of the rupture strength of seed silique. *J. Texture Stud.* 25 : 179-189.
- Meakin, P.J. and Roberts, J.A. 1990. Dehiscence of fruit in oilseed rape (*Brassica napus* L.). I. Anatomy of pod dehiscence. *J. Exp. Bot.* 41 : 995-1002.
- Metcalf, D.S., Johnson, I.J. and Shaw, R.H. 1957. The relation between pod dehiscence, relative humidity and moisture equilibrium in birdsfoot trefoil, *Lotus corniculatus*. *Agron. J.* 49 : 130-134.
- Morgan, C.L., Ladbroke, Z.L., Bruce, D.M., Child, R. and Arthur, A.E. 2000. Breeding oilseed rape for pod shattering resistance. *J. Agri. Sci.* 135 : 347-359.
- Philbrook, B. and Oplinger, E.S. 1989. Soybean field losses as influenced by harvest delays. *Agron. J.* 81 : 251-258.
- Spence, J., Vercher, Y., Gates, P. and Harris, N. 1996. Pod shatter in *Arabisopsis thaliana*, *Brassica napus* and *B. juncea*. *J. Microscopy.* 181 : 195-203.
- Timothy, M.S., Macro, L.H.G., Rong, Z., Shahab, S., Suzanne, R.A. and Adrian, J.C. 2003. Dehydration and dehiscence in siliques of *Brassica napus* and *Brassica rapa*. *Can. J. Bot.* 81 : 248-254.
- Tiwari, S.P. and Bhatnagar, P.S. 1991. Pod-shattering as related to other agronomic attributes in soybean. *Tropical Agri.* 68 : 102-103.
- Tiwari, S.P. and Bhatnagar, P.S. 1993. Consistent resistance for pod-shattering in soybean (*Glycine max*) varieties. *Indian J. Agri. Sci.* 63 : 173-174.
- Tiwari, S.P. and Bhatnagar, P.S. 1997. Screening methods for pod-shattering in soybean. In *Proceedings World Soybean Research Conference V*, Chiang Mai, Thailand. 24-25.
- Tsuchiya, T. and Sunada, K. 1977. Shattering of pods in soybean breeding. I. Relations between degree of shattering and moisture content in pods. *Bull. Hokkaido Pref. Agr. Exp. Sta.* 37 : 17-24.
- Tsuchiya, T. 1987. Physiological and genetic analysis of pod shattering in soybean. *JARQ* 21 : 166-175.
- Tukamuhabwa, P., Dashiell, K.E., Rubaihayo, P. and Nabasirye, M. 2002. Determination of field yield loss and effect of environment on pod shattering in soybean. *Afri. Crop Sci. J.* 10 : 203-209.
- Weeden, N.F., Brauner, S. and Przyborowski, J.A. 2002. Genetic analysis of pod dehiscence in pea (*Pisum sativum* L.). *Cell. Mol. Biol. Letters* 7 : 657-663.