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STUDIES ON THE SIGNIFICANCE OF TH INDETERMINATE GROWTH HABIT IN BREEDING SOYBEANS

XI. Varietal Difference in the Pod Dehiscence and Moisture Content in the Stem, Pod, and Seed.**

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Abstract

Pod dehiscence of the three or four varieties including the determinate versus indeterminate growth soybeans was investigated in different conditions in field, glass houses and rooms with reference to the moisture content of the stem, pod, and seed in Sasayama, Hyogo in 1964 and 1965.

The moisture content of seed was more useful index than those in the stem and pod, in order to determine the property of varieties, and it was concluded that the variety capable of decreasing the moisture of seed till 15 percent without pod dehiscence in field is needed for machinery cultivation, because that seed moisture percentage is the limit for direct storage without after drying.

In the glass house or the room, the seed moisture decreased remarkably without pod dehiscence, especially in the room inhibiting sunshine where all of the varieties did not dehisce the pod decreasing the moisture of seed till 11 to 12 percent. Variety response in pod dehiscence in the field, glass house and room was variable and not consistent, and then was considered to be the property of ecological adaptation to cultivating area and harvesting season. Thus such methods of testing pod dehiscence without meteorological effects seemed to be not so practical as that in field, especially in Japan where is humid and rainy.

The pod dehiscence is one of the hygroscopic movement enforced physically by the difference in the moisture between the outer and inner layers of the tissue. The mechanism and process of occurrence of the pod dehiscence in the soybean are complex, and more moisture in the outer layer than in the inner layer of pods by rain or dews was considered to be very much affectable for the occurrence.

As the result of investigation of the moisture and dehiscence in the pods different in maturity time in a plant, the determinate versus indeterminate growth habit was considered to be not so affectable to pod dehiscence character of the soybean.

Introduction

There was a little interest into the pod dehiscence or shattering in breeding soybeans in Japan, though a variety named "Katazaya" meaning a hard pod had been bred in Niigata Prefectural Experiment Station,[5] the most of the varieties grown in our country have high shattering habits as appeared in the cooperative tests with the agronomists in the United States of America.[8]

In Japan, where is humid in the air at the time of harvest, farmers have picked up the soybean plants by hand or simple tools at the time as soon as the pods turned into maturity color, and plants have been dried by hanging on woods or bamboos supported by simple stanchions in field or by other methods in rooms or out door. Hence, the plants have been gradually dried and the seeds with a considerable moisture content have been threshed out from the plants and the pods. After the threshing, seeds have been dried under sunshine or by artificial hot wind. Therefore, the much shattering habit has been of not troublesome in practical cultivation.

In the United States of America, and other countries of continental climate, air at the harvest time is very dry and harvesting is

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made after the plants had decreased moisture adaptable to the combine harvesting, and seeds are gathered immediately after threshing.

In Japan, however, the methods of cultivation of crops are being improved and machinery harvesting, especially using the combine of small scale become to be of practical method of farmers, especially in rice, and also in soybeans. Thus, soybean breeding in the experiment station became to have attention into the pod dehiscence, and methods of testing and classification of varieties by the degrees of pod dehiscence are being investigated.[6,14,15,16]

In spite of the importance, the studies or experiments of pod dehiscence are not so many as those of lodging resistance which is also important for breeding soybeans adaptable to combine harvesting. Moreover, the studies carried to date in the United States and in Japan have limited attention into the nature of the pod except for the other part of plants. In Japan, we can often find pods matured and dehisced when the stem and leaves remain green, and such a plant is observed in non-adaptable varieties introduced from other regions especially from the north part to the south.[11] In the case, moisture contents of plant parts must be investieated for considering nature of pod dehiscence with special regards to the varietal difference in the maturity and dehiscence of the pods.

Thus, the author had made a few investigations on the moisture contents of the stem, pod, and seed using the varieties of different degrees of pod dehiscence, and concluded that the moisture content of seeds should be noticed well than that cf pods with reference to pod dehiscence.

In the studies of the main subject, an interrelation between the detreminate versus indeter minate growth habit and pod dehiscence was also observed though the direct or genetical association between them is not expected from the genetical studies made till the present, because the most of the indeterminate growth soybeans of Manchurian ecotype have low shattering habit, and most of the determinate growth ones of North and South Japanese ecotypes are heavy in shattering.[8] Thus, the results should be dealt with herein.

Materials and Methods

In 1964, Harosoy from the United States was used as a variety of indeterminate growth and of no shattering property, and three varieties of determinate growth and much shattering property, namely Ōyaji No.2, Tokachi Nagaha (from Hokkaido) and Shirasaya No. 1 (from Kyushu) were used. The seeds were planted on May 17 in the farm of the laboratory in Sasayama, Hyogo. The plots of experimnnt had two replications of rod rows of two meters. At the same date, the seeds were sown in the five earthen pots of 21-cm diameter per variety, and the pots were transferred into the glass house at the time of maturity where the pod dehiscence without effect of rain or dew was observed in comparison with that under natural rainy weather in field.

Measurements were made on September 10 to 15, two weeks after the maturity first, and on October 5 to 10, about five weeks after the maturity next. Five plants with about a hundred pods for each variety were harvested, and percentage of pod dehiscence and moisture contents in the stem, pod, and seed were measured.

In 1965, three varieties except for Ōyaji No. 2 were sown on April 25, earlier than the 1964 experiment, and in the same way in the plot and replication. At the time of maturity, the pods were marked with colored materials into three groups of early, medium, and late maturity. From Augsut 19, five plants per variety were harvested and measured on pod dehiscence percentage and moisture content in the stem, pod and seed in five day intervals. In parallel with this measurement, 80 plants per variety were picked up from the field at time of maturity, and 50 plants were placed in the glass house and dried under sunshine without rain, and the measurement was made in five day intervals. The other 30 plants per variety were stored in the room without direct sunshine, and dried by natural air only. The measurement was made on October 6. Moreover, the plants of the tested variety sown in the earthen pots in the same way as in 1964, were removed into the glass house on the day of maturity and the measurement was made on August 15 and October 20.

The measurement of moisture was made by drying for 24 hours at 70°C and thereafter for 3-5 hours at 100° to 103°C.

Results

Moisture content of the parts of plant after maturity bearing to the change of pod dehiscence percentage

1. The 1964 experiment. In the measurement in middle of September, the stem of Ōyaji No. 2 had the most moisture, and the moisture of pod and seed was also more than those in the other varieties. In contrast with the variety, Shirasaya No. 1 had the least moisture in the stem, but comparatively more in the pod and seed than those in the other two varieties, Tokachi Nagaha and Harosoy. Without correlation with the moisture content of the plant parts, the percentage of pod dehiscence was high in determinate Japanese varieties as measured to be 17 to 20 percent and low in th the indeterminate American variety, Harosoy as seen to be lees than 10 percent. In the results in field measured with the plants harvested in early October, Ōyaji No. 2 had the most moisture showing high percentage of pod dehiscence, and the other three varieties had similar moisture content without correlation with the pod dehiscence which was the highest in Shirasaya No. 1 and the lowest in Harosoy.

In the glass house where was no effect of rain in contrast with field, there was a little different result from that in field. In the result in the middle of September, Shirasaya No. 1 had the least moisture in the stem, the just same as in field, but Ōyaji No. 2 was similar to the other two varieties in the stem moisture. Percentage of pod dehiscence had no difference from that in field in order of varieties, but range of varietal difference became larger and three varieties excluding Ōyaji No. 2 were less in the degree of pod dehiscence than in field. In the result in early October, the moisture of stem and pod was different in the varaieties, but that of seed was little in varietal difference, and then the varietal differnce in percentage of pod dehiscence was very large (Fig. 1).

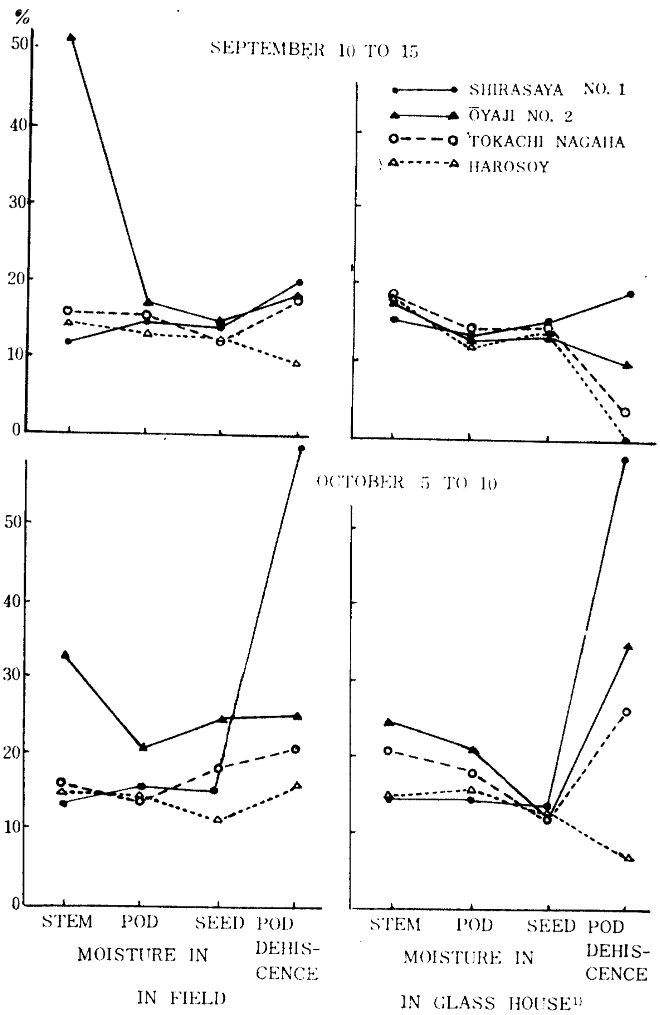

Fig. 1. Varietal difference in the moisture contents of parts of soybean plants in 1964. [1] Plants grown in pots were transferred into the glass house after maturity.

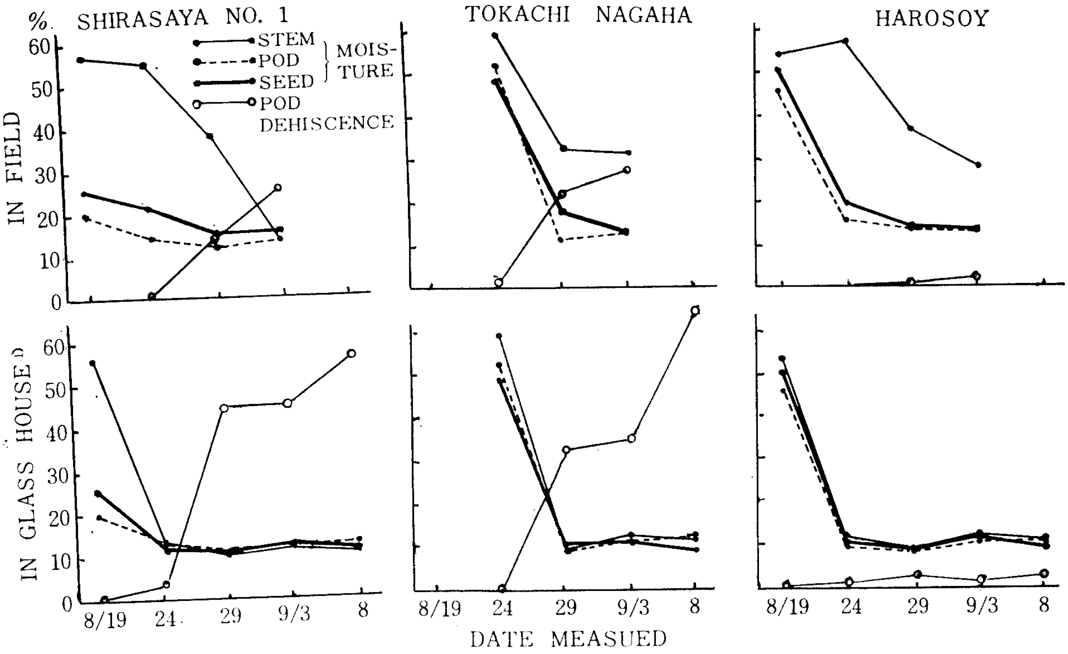

Fig. 2. Varietal difference in the moisture contents of parts of soybean plants in 1965. [1)]Plants grown in field were moved into the glass house by harvesting at the time of maturity.

2. The 1965 experiment. Although there was no result of the variety Ōyaji No. 2, the result was not coincident with that in 1964. In field, the moisture of stem remained in comparatively long period in Shirasaya No. 1 and Harosoy, and decreased rapidly in Tokachi Nagaha. The pod and seed had less moisture in Shirasaya No. 1 from the time of maturity, but more in maturity and decreased rapidly thereafter in Tokachi Nagaha and Harosoy. The percentage of pod dehiscence was the least in Harosoy in no relation to the

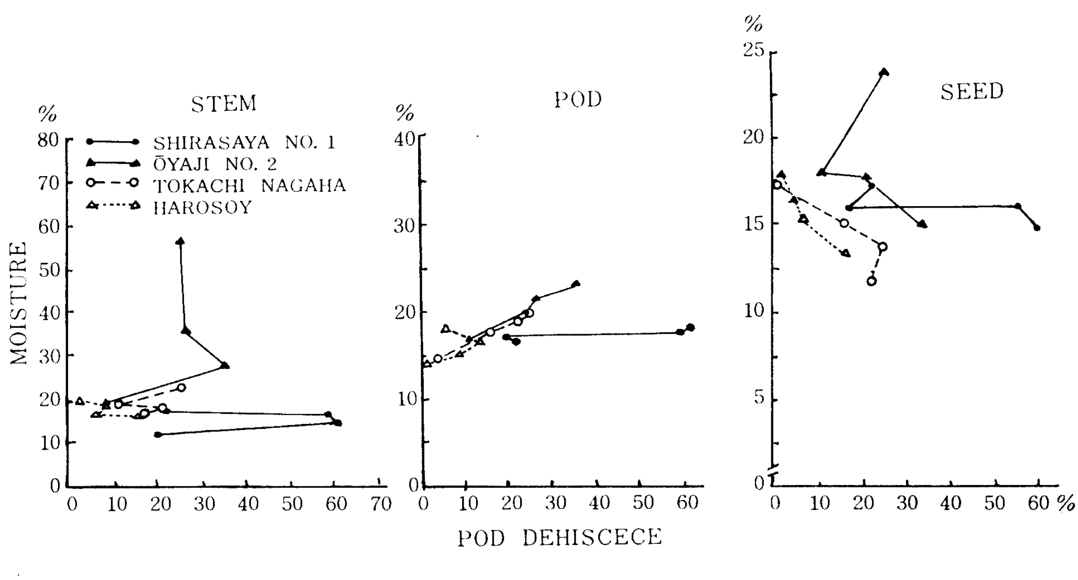

Fig. 3. Relations between the pod dehiscence percentage and moisture contents in the stem, pod and seed in field and the glass house in 1964(see Fig. 1).

moisture contents in each of the plant parts, but that of Tokachi Nagaha and Shirasaya No. 1 seemed to be similar, and increased corresponding to decrease of the moisture in pods and seeds, in different trend from that in 1964.

In the glass house, the moisture in the stem decreased rapidly after the time harvested and moved into the house in different way from that in field, and also that in pod and seed decreased rapidly. In parallel with the decrease of the moisture, the pod dehiscence percentage increased, and the incerease was significant in Shirasya No. 1 and Tokachi Nagaha, but not in Harosoy (Fig. 2).

Through both experiments in field and the glass house in 1965, it was noticed as a general trend that the decrease of moisture content of the plant parts became the cause of the increase of pod dehiscence though there was a varietal difference in the interrelation between them. The interrelation, however, was different in field and the glass house, and then Shirasaya No. 1 and Tokachi Nagaha dehisced when decreased the moisture of seed till 20 percent in field, but did not dehisce so heavily when the moisture of seed became lower than 20 percent in August 24, and after August 29 dehisced heavily when the moisture did not decrease below that on August 24 in the glass house.

3. Interrelation among the pod dehiscence and the moisture in the parts of plant and its varietal difference. As shown in Fig. 3 made from the results in 1964, the moisture of stem and pod had no correlation with the pod dehiscence especially in Ōyaji No. 2 in both of field and the glass house. The moisture of seed, however, had a intimate relation to the pod dehiscence showing significant varietal difference. Harosoy variety was few in pod dehiscence in decreasing the moisture of seed till 15 percent. Tokachi Nagaha variety had increased the pod dehiscence percentage when the moisture of seed became 15 percent. Shirasaya No. 1 and Ōyaji No. 2 was heavier in pod dehiscence than Tokachi Nagaha variety when the moisture of seed became less than 20 percent.

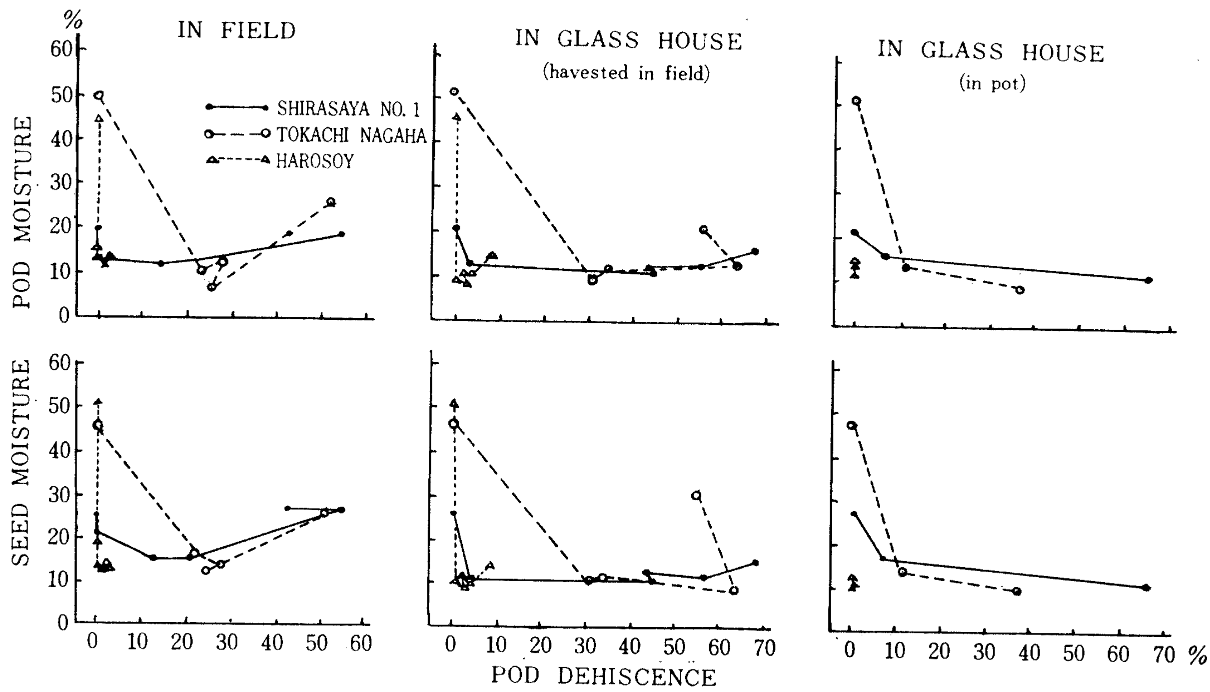

Fig. 4. Relations between the pod dehiscence percentage and moisture contents in the stem, pod and seed in field and the glass house in 1965. In glass house (harvested in jield)-plants grown in field were moved into the glass house by harvesting at the time of maturity, In glass house (in pot)-plants grown in pots were transferred into the glass house after maturity.

Table 1. Varietal difference in the moisture contents in parts of plant and the force for crushing pods when the plants were dried in room without sunshine in 1965.

Trait	Shirasaya No. 1	Tokachi Nagaha	Harosoy
Moistue in	%	%	%
Stem	15.2	13.3	13.8
Pod	13.7	13.9	13.2
Seed	12.8	11.9	11.6
Crushing pod			
No. pods	93	132	79
Force	856g	821g	862g

All of pods did not dehisce in room.

In the 1965 experiment as shown in Fig. 4, the moisture of pod had fairly clear relation to the pod dehiscence and then the variety Shirasaya No. 1 and Tokachi Nagaha increased pod dehiscence when the moisture of pod became less than 15 percent but the variety Harosoy did not increase so much as in the former two varieties. The moisture of seed behaved similar to that of pod especially in the plant dried in the glass house. In field, the moisture of seed showed clearer varietal difference in the relation to pod dehiscence than that of pod. Shirasaya No. 1 and Tokachi Nagaha increased pod dehiscence greatly when the seed moisture decreased below 20 percent and 15 percent moisture seemed to be a critical point. In field where was more humid by rain and dews than in the glass house, the pod dehiscence was begun in the point of more moisture than in the glass house and such a difference was clear in Shirasaya No. 1. It should be also noticed that Tokachi Nagaha caused heavier pod dehiscence in field and the glass house than Shirasaya No. 1, and such a trend was the very reverse to that in 1964.

In the case where the plant was grown in the pot and entered in the glass house at the maturity in the same way as in 1964, the relations of pod dehiscence to the moisture contents of pod and seed were shown in the left ones in Fig. 4. The varietal difference in reference to the relation noted above was similar to that in field in 1965 and not in the glass house in the same year where harvested plants were moved from field. A little difference, however, was found as follows: Harosoy did not dehisce in 10 percent moisture of pod and seed, and Tokachi Nagaha was rather hard to dehisce in comparison with the variety Shirasaya No. 1.

In Table 1, the results of measurement of moisture content of parts of the plant and pod dehiscence perecentage and the weight to dehisce the pod mechanically by using a grain rigidity tester when the plants were stored in room without direct sunshine till the beginning of October were shown. The plants of three varieties were dried till the moisture percentage which caused pod dehiscence under direct sunshine in two Japanese varieties, but there was no dehisced pod in all of three varieties. There was also no difference between the critical weight for crushing and dehiscence of pods.

Difference in the moisture of pods and seeds different in their maturity date

The varieties of indererminate growth habit have long flowering period and consistently uneven in maturity of pods of a plant. The wild soybean, *Clycine soja* SIEB. *et* ZUCC., is frequently seen to be irregular in the maturity and dehiscence of pods so that the earliest matured pods have dehisced and the latest ones remained green or yellow. Such a fundamental character is an important question in breeding indeterminate growth soybeans.

The result in the 1965 experiment, in which the pods were classified into three groups, namely early, medium, and late matured ones, is shown in Fig. 5. After the maturity, the moisture of pod and seed, was more in the earlier matured pods than in later matured ones in early period, but the difference became small as time goes on.

In ficld, the difference remained during the period of 10 to 15 days, but of 5 to 10 days in the glass house. On the difference in the decrease of moisture by the maurity time of pod, it was found that there was no difference between the varieties of the determinate and

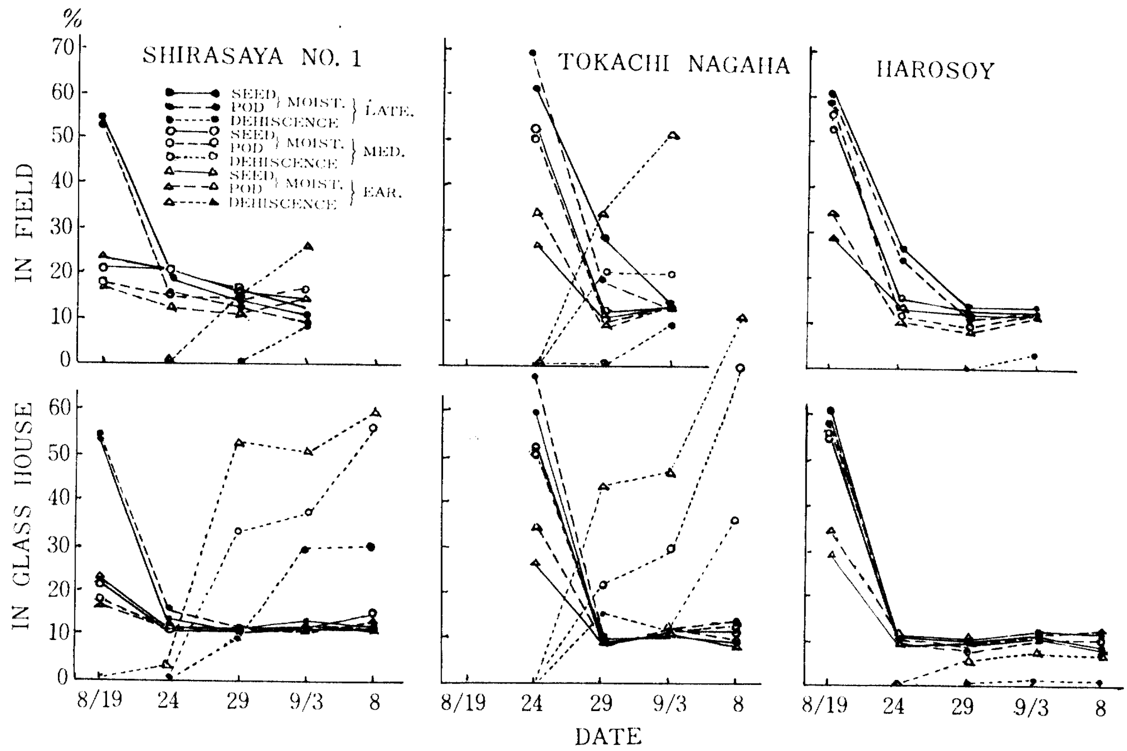

Fig. 5. Varietal difference in change of moisture contents of the seed and pod, and dehiscence of pod in the pods classified by maturity time. Late, med, and ear show late, medium and early matured groups of pods respectively.

the indeterminate growth in general. There was, however, a little difference between Shirasaya No. 1 and Tokachi Nagaha of determinate growth habit, and Harosoy of indeterminate growth was similar to Tokachi Nagaha. Shirasaya No. 1 is the variety grown as a short season crop in South Japan and harvested in late summer, and the other two varieties are

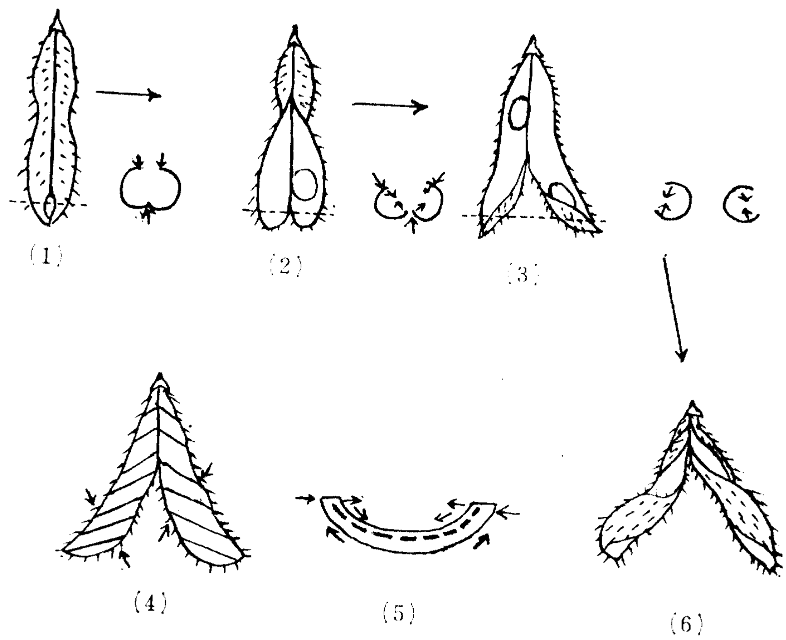

Fig. 6 Appearance of pod dehiscence and schematic explanation of mechanism of its hygroscopic movement.

grown as a full sesson crop in the north parts of Japan and the United States, and harvested in autumn. Shirasaya No. 1 has decreased rapidly the moisture of pod and seed, and also the difference in the moisture by the time of maturity in comparison with the other varieties. Consequently, such differences seemed to be caused by the ecological nature adaptable to the climate and meteorological conditions of the cultivated regions, and not by the growth habit.

Nevertheless, it is of importance to be noticed herein that difference in the percentage of pod dehiscence by the maturity time became clearer and larger about 5 to 10 days after maturity when the pod dehiscence was very low, and that difference in pod dehiscence became very clear 15 to 20 days after maturity when the pods were all the same in moisture content and the difference became also clearer in the glass house than in field.

Varietal difference in the percentage of pod dehiscence by the time of maturity was not significant. The indeteminate variety Harosoy did not show the difference in pod dehiscence percentage by maturity time, since all of the groups were low in the percentage. Between the varieties of determinate growth, Shirasaya No. 1 and Tokachi Nagaha, the difference mentioned above was not found, though both of the varieties were sevear in pod dehiscence and the difference by maturity time was significant. These two varieties showed higher percentages of pod dehiscence and the percentage was higher in earlier matured pods than in later matured ones significantly, but behaved in a similar way in the difference. Such a difference was very clear in the glass house where the moisture of pods and seeds different in maturity time became uniform in short period.

The appearance and mechanism of pod dehiscence

For considering the results obtained in two years, an observation on the appearance of the pod dehiscence was made. As shown in Fig. 6, the pod dehisced in the end of the inner or ventral suture first (1), and was opened and separated to the left and right halvs of the carpel by spreading the dehisced inner suture (2). At the time of beginning of dehiscence, the force occured in the pod seemed to be in two directions as shown in the figure (1); one is from upside to the bottom in the inner suture, another from bottom to the upper part in the outer or dorsal suture (1). Thus, each of half of the pod become cylindrical. Thereafter two halvs are separated and opened, but those are gathered first and doubled next, and bent backward finally in the outer suture (2). In correspondence with enlarging the opened inner suture, the terminal parts of the pod were rolled up (3).

The pod has the cuticular fibrous cell layer composing the endocarp which are arranged in a diagonal direction to the axis of inner suture and opposite to the fibrous cells of exocarp as noted by Esau[4] and shown schematically in Fig. 6 (4, 5). Pod dehiscence is surely a phenomenon of hygroscopic movement occurred by the difference in the physical forces in the exocarp and endocarp, which are originating in moisture content of the carps. The bending movement, however, occurs in vertical direction to the arrangement of the cuticular fibrous cell layer in the endocarp, namely to the diagonal direction to the inner suture (4). As the result of the balance of bending moments, the pod is rolled up separately in left and right halves of the pod (6).

Discussion

Testing of pod dehiscence is being carried under controlled humidity [1,7,12] by artificial heating[6,15,16] and by crushing weight of the pod,[6,14] in addition to that in field where the percentage of dehisced pod was measured on a given day after maturity[3] or days from maturity to the day of pod dehiscence.[2] Through these methods of testing, attentions were made on the pod for considering dehiscence phenomena, especially on the moisture of pod, though Prine *et al.*[13] had made an observation on the moisture content of seed in relation to the row direction of soybean cultivation. But the moisture of seed was ascertained to be the most useful factor for the consideration on practical methods of selecting strains for pod dehiscence and on its physical mechanism. In the experiments, variety Harosoy was capable of drying the seeds lower than 15 percent in field, but other Japanese varieties were difficult to decrease the moisture of seeds till 15 percent without pod dehiscence in field. The moisture of 15 percent is, of course, the limit of soybean seeds adaptable for storage without drying after harvest. In machinery cultivation, breeding of the variety capable of drying the seeds till 15 percent moisture in field without pod dehiscence should be of necessity. Harosoy and other varieties in the United States seemed to have been bred satisfying with this requirement. In our country, the varieties are suitable for hand harvesting and drying after harvest. In the experiments, Japanese varieties especially Shirasaya No. 1 showed the property adaptable to the after harvest drying, because the soybean was capable of drying in the glass house below 15 percent moisture of seeds without pod dehiscence. In room inhibiting direct sunshine, namely shadow drying, the moisture of seeds could be lowered till 11 to 12 percent. The seeds in the plant dried under shade were useful for direct storing. It is also interestful result, though not sufficient for introducing a general conclusion, that Harosoy is easily threshed as measured about the weight for shattering the pods dried under shade. It is frequently said that the non-shattering variety is not so easy to thresh as in shattering varieties. This experiment seems to show the non-shattering variety is not difficult for threshing when dried well.

It is also very much interesting physiologically and ecologically that the interrelation among the moitures in the stem, pod, and seed, and the percentage of pod dehiscence are different by the year and method of drying. In the experiments, field was of course under the Japanese climate and weather, whereas the glass house transfered the plants sown in pots seemed to be similar to the climate and weather in the United States and in other continental climate regions. In Japan, all of the territory is humid in the air and has much and frequent rains in contrast with the dry weather of continental lands in the period of harvesting. The glass house entered harvested plants in 1965 is similar to the continental lands and after drying succeeding to the harvest in Japan. The drying plants in room without sunshine is similar to that carried out carefully in Japan, where the heavy shattering varieties are dried under shade occasionally, and thereafter the plants are dried one or two days in the yard in front of the farmer's house, and threshed with simple tools.

In field, weather is not constant and varies by the year. In the experiment in 1964, Tokachi Nagaha was less in pod dehiscence percentage, but in 1965, was same or rather more in the percentage, in comparison with Shirasaya No. 1. Although there is no exact analysis of meteorological data, harvested time was delayed by May planting and much rains after harvest in 1964, whereas the harvest time became earlier by April planting and comparatively less in precipitation in 1965. In the 1965 experiment, the meteorological conditions were similar to those at harvesting time of Shirasaya No. 1 in southern part of Japan, Kyūshū where Shirasaya No. 1 is harvested in August as a short season crop. Meteorological data in the experiment in 1964 showed a little difference from those in Kyushu, and rather approached to those in Tokachi Nagaha in Hokkaido where the harvesting is carried in October.

Thus, the difference in the relation between the years 1964 and 1965 seems to show the varietal difference in the adaptability to the habitat and growing season. The author had reported that the Shirasaya No. 1 was different from Ōyaji No. 2 in the process of increasing pod dehiscence percentage after maturity in field.[9,10] It is sure that there are various patterns of pod dehiscence in relation to the variety, locality, and harvesting time. Therefore, we must consider such patterns in testing the degrres of pod dehiscence in field.

For considering on the difference in the varietal response on the pod dehiscence to the conditions settled in the experiments, appearance of pod dehiscence was observed and mechanism of it was considered. The pod dehiscence is a hygroscopic movement resulted from the difference in moisture content between outer and inner layers of tissue, namely the exocarp, mesocarp and endocarp of the carpel. But the mechanism of the hygroscopic movement of pods is rather complex and the inner layer is shortened and the outer layer enlarged, and then less moisture of the inner layer than in the outer layer cause the dehiscence. Hence direct sunshine in the glass house or dried air in room can decrease seed moisture without dehiscence since the both layers of pod are dried uniformly. In field, the outer layer of pod is moistened by the rain or dews, and so the seeds remain in much moisture when the pod dehisced.

Therefore, testing the pod dehiscence in room or the glass house is not so reliable for determination of the degrees of dehiscence in field, especially in Japan where is much rain and humid in air. As mentioned above, the degrees of pod dehiscence is variable by the year, season, weather and variety. Heritability of the degrees of pod dehiscence in field of Japan seems to be low, though the heritability was estimaed high in the United States.[2]

On the difference in pod dehiscence percentage by the time of maturity of pod, a small experiment had been made. Within the experiment, it was observed that indeterminate growth habit had no relation to the pod dehiscence. Uniformity of the maturity of pods is not so much affected by the growth habit in the varieties of present cultivation, and so much care seemed to be not needed on the pod dehiscence in breeding indeterminate growth soybeans.

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ダイズの無限伸育性の育種学的意義

第11報 裂莢と茎，さや，種子の水分含量についての品種間差異

永 田 忠 男

要 約

1964，1965両年度に，兵庫県篠山町で，有限，無限伸育性品種計3～4を用いて，圃場，硝子室，室内の各種条件下での裂莢，とくに茎，さや，種子の水分含量との関係で調査研究した。

その結果，品種の裂莢性を考えるためには，種子の水分がもっとも重要な指標となり得ること，機械栽培に適する品種としては，圃場で種子水分を15%まで，裂莢なしにさげることができ，そのまま脱穀，収納できることが望ましいことを結論とした。

硝子室や室内では裂莢なしにかなり種子水分を下げることができ，とくに室内で陰乾した場合は供試品種のいずれも裂莢なしに種子水分を11～12%まで下げることができた。圃場，硝子室，室内の裂莢と品種との関係は一様でなく，年次によっても異った。それ故ダイズの裂莢は，栽培地域，収穫期に対する生態的適応形質と考えなければならない。従って，とくに多雨で空気湿度の高い日本では，気象条件の影響を受けない室内での裂莢の検定は，圃場の結果とは一致しないことがあり，実際的にはその点を充分考慮する必要があろう。

裂莢の現象は，莢の組織の内外層の水分の差によっておこる物理的な乾湿運動の1種である。しかし，ダイズの裂莢の発生機構はかなり複雑であり，外層の水分が，雨露の影響で比較的多い場合には，種子の水分がかなり多い中に裂莢をおこすものと考えられる。

1個体内のさやを熟期の早晩によって分けて，裂莢の発生を調べた結果，有限，無限伸育性は，現在の栽培品種については裂莢にあまり関係がないものと思われた。