ACTA AGROBOTANICA
vol. 35, z. 1 – 1982
43-59

# Influence of initial seed moisture and temperature conditions during germination and emergence on seedling survival and yields of soybean (Glycine max L. Merrill)*

ADAM MARKOWSKI

The Phytotron Laboratory, Academy of Agriculture, Podłużna 3, 30-239 Kraków, Poland

(Received: August 29, 1980)

Abstract

Injury to soybean seedlings caused by low temperature (5°C) at the beginning of germination was greatly reduced when instead of chilling (10°C) a higher temperature (20°C) was applied at the end of germination and during emergence. A new interpretation of the physiological mechanism involved in this reversibility of chilling injury was proposed. Hydration in water vapour of soybean seeds with initial moisture content of from 5 to 10% to a level of 30%, dry weight basis, increased seedling survival under controlled conditions of germination and emergence at respectively 5°C and 10°C as well as under natural soil conditions in field experiments both after early and late planting dates. A modified method of seed hydration in water vapour (i.e. conditioning or hardening of seeds against cold) was developed for practical application. In field experiments conditioning of seeds increased seedling survival and thus also yields per unit area of plot but had no significant effect on yield per plant. Seed conditi ɔning may have practical significance in soybean growing and for breeding purposes when equalizing the number of plants per plot is important for comparing new varieties and breeding forms.

## INTRODUCTION

Reduced number of plants per unit area and seedling injury occurring in spring are usually caused by temperatures just above freezing point. It has been found that a decisive influence is exerted by low temperatures during imbibition and germination of seeds. This has been demonstrated in experiments with bean (P o l l o c k, 1965), crimson clover (H o v e l a n d and E l k i n s, 1965), lima bean (P o l l o c k and T o o l e, 1966), cucumber (S e g e t a and

*This research was financed by a grant from the Government Research Program PR-4, Group Problem 02, coordinated by the Institute of Breeding and Acclimatization of Plants.

T r o n i c k o v a, 1966) and cotton (C h r i s t i a n s e n, 1967). Other observations refer to soaking injury. For instance, soaking of bean seeds either entirely inhibited germination or caused considerable injuries (K i d d and W e s t 1918 quoted by O r p h a n o s and H e y d e c k e r, 1968). On the other hand, germination of bean seeds hydrated in air saturated with water vapour and then soaked for 24h was 100% (O r p h a n o s and H e y d e c k e r, 1968).

The early experiments into the problem of this research were performed using cotton seeds. Drying of seeds for 48h at 25°C and then soaking them for 48 h at 5°C was found to inhibit germination in 72% of seeds (C h r i s t i a n s e n, 1968). Reduction of the moisture content from 13 to 8% caused a proportional drop in the germinating capacity of seeds under conditions of "cold imbibition" (C h r i s t i a n s e n, 1969). Further investigations into the susceptibility of seeds to cold imbibition as related to the initial seed moisture were carried out with bean (P o l l o c k et al., 1969) and lima bean. Injuries occurring during germination at temperatures from 5°C to 10°C were greatly reduced when before germination seeds were kept in an environment saturated with water vapour (P o l l o c k, 1969).

Similarly, experiments with soybean show that injuries to plants caused by exposure to chilling temperatures during germination can be greatly reduced by increasing the initial water content of seeds by means of seed hydration in water vapour (O b e n d o r f and H o b b s, 1970). In subsequent investigations the same authors demonstrated that, when seed water content was reduced from 12 to 5% on dry weight basis seedling survival dropped linearly if germination was at 5°C, but with the same moisture contents seedling survival dropped only slightly or there were no injuries if germination was at 25°C (H o b b s and O b e n d o r f, 1972). In these experiments seed water content was controlled by placing seeds in air of different relative humidity over solutions of such substances as sulphuric acid, lithium chloride, potassium tartrate etc. Such laboratory methods of controlling seed moisture, however, are not suitable for large scale practical application. Moreover, little information is at present available about the interaction between initial seed moisture and germination temperature under natural field conditions and about the effects of these factors on the final crop. These problems were the object of experiments presented in this paper. They were carried out over a number of years under controlled and natural conditions.

## MATERIAL AND METHODS

Table 1 lists the different experimental treatments, experimental varieties, initial seed water contents, different substrates, and germination and emergence temperatures. Selected seeds, dry treated with "T" dressing, were equilibrated for

Table 1

List of experiments

| Number, year, place of experiments | 1/1977 phytotron | 2/1978 phytotron | 6/1980 phytotron | 3/1978 vegetation hall | 4/1978 field | 5/1979 field |
|---|---|---|---|---|---|---|
| Varieties | 'Warszawska' | 'Fiskeby'<br>'Warszawska'<br>'Ajma' | 'IHAR 78/B' | 'Warszawska' | 'Warszawska' | 'Fiskeby'<br>'Warszawska'<br>'IHAR 78/B' |
| Initial seed moisture content in %% of dry weight* | 5<br>8<br>15<br>15 PT** | 5 LiCl***<br>5<br>15<br>15 PT<br>30<br>50 | 5<br>7<br>8<br>9<br>10<br>30<br>50 | 5<br>15<br>30<br>50 | 5<br>15<br>30<br>50 | 5<br>30 |
| Substrate | | | | | | |
| at germination | moist paper | moist paper | soil or perlite | moist paper | soil | soil |
| at emergence | perlite | perlite | soil or perlite | perlite | soil | soil |
| Temperature (°C) | | | | | | |
| germination | 5 } 5 } 10 } 10 } 20 } | 5 } 10 } 20 } | 5/10 20 | natural thermal conditions date of sowing: April 19 | | |
| emergence | 10 20 10 20 20 | 10 20 20 | 20 20 | May 2<br>May 29 | | |
| | cf: Fig. 1 | cf: Table 2<br>: Table 3 | cf: Table 4 | cf: Fig. 2A<br>Fig. 3A | cf: Fig. 2B<br>Fig. 3A | cf: Fig. 2C<br>Fig. 3B<br>Fig. 4 |

*See Table 2; **Potassium tartrate solution as source of water vapour; ***Lithium chloride solution as source of water vapour.

their water content in exsiccators with different vapour pressures in air over saturated solutions of lithium chloride and potassium tartrate according to Winston and Bates (1960).

A new method of hydrating seeds in air saturated with water vapour to any desired moisture content will be described together with the discussion of results of the second experiment (Table 2). Seed water contents are on dry weight basis. Seeds were germinated either on tissue paper in Petri dishes and while in the germination phase were transferred to pots filled with moist perlite or soil, or they were germinated directly in pots with perlite or soil at about 60% of water capacity. Temperature conditions at germination and emergence and during seedling growth were controlled in phytotron growth chambers. In experiments in a vegetation hall and on plots the temperature varied according to natural weather condions after three different planting dates. Damage to plants was determined from the number of germination failures and of seedling failures at the beginning of growth referred to the number of planted seeds; the sum of these two numbers was presented as "failure of emergence" in percent of planted seeds. Moreover, injuries to individual seedlings – such as cracking, yellowing and dropping off of cotyledons, and injury to or absence of leaves and stems after the development of cotyledons – were estimated according to a scale ranging from 10% to 100% and calculated in percent of all planted seeds in a treatment; these estimates were made separetely for every individual plant in successive repetitions of experimental treatments. In experiments in the phytotron growth chambers every treatment included 150 to 200 plants, 5 to 10 plants to every Mitscherlich pot. In field experiments seeds were planted in rows, 50 seeds per metre, 40 cm between rows, on plots 2.5 × 2.5 metres, in three replicates. Statistical analyses were made with the method of analysis of variance using Student's t-test for significance.

## RESULTS

The first three experiments carried out under controlled temperature conditions confirmed the findings of the authors mentioned earlier, namely that hydration of seeds in water vapour prior to planting improved germination performance, increased the number of seedlings, and reduced chilling injury as compared to germination and emergence from dry seeds. This effect depended not only on initial seed moisture, but also on temperature at germination and emergence. In the case of seeds with 5% initial moisture content the average seedlings emergence for the three experimental varieties was 20% of planted seeds at germination temperature 5°C, 70% at 10°C, and 81% at 20°C. On the other hand, for seeds equilibrated in water vapour prior to planting for the same combinations of germination and emergence temperatures, the average emergence for the three experimental varieties and for seeds water contents of 30%

and 50% was respectively 92%, 90% and 93% (Table 3). Survival of seedlings from dry seeds improved considerably, if after germination at 5°C, emergence was not under chilling conditions of 10°C, but at the higher temperature of 20°C (Fig. 1). These results confirm the results of a preliminary experiment, in which temperatures at imbibition and germination, and at seedling emergence were differentiated (M a r k o w s k i, 1976). A theoretical interpretation of these observations will be presented later together with the discussion of results.

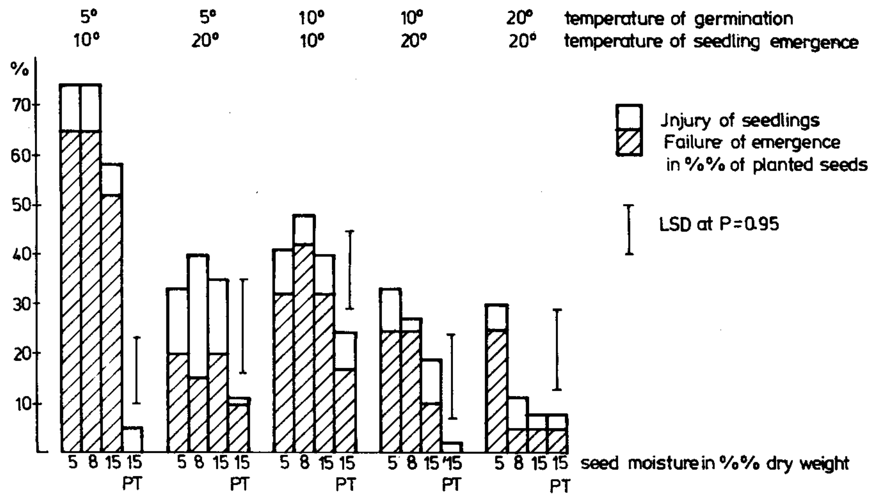


Fig. 1. Effect of seed moisture on injury of plants in experiment no. 1. PT – potassium tartrate solution as source of water vapour (see Table 1 and 2)

The method of controlling seed moisture, used in investigations referred to earlier and consisting in drying or hydrating seeds during a definite periods of time under conditions of differentiated water vapour pressures over saturated solutions, gives highly precise results but is unsuitable for practical purposes. For this reason another, simpler, method was tested and is here referred to as conditioning or hardening of seeds against chilling. It consists in hydrating seeds in exsiccators in an atmosphere saturated with water vapour over pure water for the time necessary to attain the desired seed moisture. Thes results of tests are listed in Table 2. The highest survival of seedlings was obtained after hydrating seeds with water vapour over a solution of potassium tartrate for about 400 h, resulting in seed moisture of 15%. This corresponded approximately to the effect of hydrating seeds over pure water to the level of 30% dry weight basis for about 30 h in an atmosphere saturated with water vapour (Table 3). In further experiments seed moisture was controlled either by drying to a level of from 5% to 8% or by hydration in tightly closed vessels in an atmosphere saturated with water vapour over pure water after precisely determining the time necessary to

Table 2

Soybean seed moisture equilibration with water vapour in closed container at 20°C. Initial seed moisture 8% of dry weight

| Source of diffusion of water vapour | Relative air humidity at surface of liquid | Equilibration time in hours | Final seed moisture content in %% of dry weight |
|---|---|---|---|
| Saturated lithium chloride solution (LiCl) | 12.5 | 385 | 5.5 |
| Saturated potassium tartrate solution (PT) | 75.0 | 340 | 13-15 |
| Pure water | 100.0 | 1.5-2 | 9 |
| Pure water | 100.0 | 2.5-4 | 10 |
| Pure water | 100.0 | 7-15 | 15 |
| Pure water | 100.0 | 25-40 | 30 |
| Pure water | 100.0 | 80-100 | 50 |

obtain the desired seed moisture content at a given temperature. The optimum initial seed moisture content was experimentally determined to be 30% on dry weight basis; further hydration had no significant effect on seedling injury while it excessively prolonged the conditioning treatment.

Another investigated problem was the range of initial moisture contents of "dry" seeds that necessitated their conditioning in water vapour. Experiments discussed so far have shown that when seed moisture content after conditioning at the water vapour saturation point was 15%, germination and emergence were somewhat lower than when seed moisture content was 30%, i.e. the level established as the optimum. In experiment no 6 a broader range of initial seed water content was investigated in plants grown in pots filled with perlite or mineral soil under controlled temperature conditions at germination and emergence. The results show that not only seeds dried to 5% of water content, but also air dry seeds with 8% water content and even conditioned seeds with 9% or 10% water content manifested an inferior germination performance at temperature from 5°C to 10°C than seeds conditioned in water vapour to 30% of moisture content. The differences in the proportion of surviving seedlings amounted to from 20% to 50% of planted seeds and were greater for emergence in pots filled with perlite, but were also statistically significant after germination and emergence in pots with mineral soil (Table 4).

These results, as well as those obtained in previous experiments, confirm the need of hydrating seeds with water vapour prior to sowing and may help developing methods of conditioning seeds for breeding and farming purposes.

The aim of a further series of experiments was to check the effectiveness of the method of conditioning seeds prior to sowing under natural soil and climatic conditions. In order to differentiate the temperature factor at the beginning of growth, seeds were planted on three different dates: early planting on April 19, and later plantings on May 2 and 29 when the effects of cold weather were limited (Fig. 3). These experiments have shown that hydration of seeds in water vapour significantly improved germination rates and seedlings survival, though this effect was somewhat weaker than under controlled temperature conditions. When comparing the results of experiments, in which plants were grown in pots, with those of corresponding field experiments we see that the extent of injuries in plants sown out on the earliest date under natural soil conditions was somewhat smaller. Emergence rates in pots of seeds with initial moisture of 5% and 15% were respectively 20% and 63%, whereas under natural soil conditions emergence rates were respectively 54% and 84%. These differences could be caused by the different conditions of germination. The beginning phase of germination in pot experiments was on tissue paper in Petri dishes and then seeds were transferred to pots; in field experiments, because of a lower soil moisture content, the process of imbibition and germination was slower and this may have been the cause of reduced injuries in seedlings grown out from the driest seeds. On the other hand, in the case of the later sowing dates under field conditions the difference in survival rates between seedlings from dry and conditioned seeds was greater than in pot experiments; this indicates that further investigations are necessary into the interaction between different soil moisture contents and the temperature conditions of germination and emergence (Fig. 2 A and B).

In the next field experiments dry (5%) and water vapour conditioned (30%) seeds of three different varieties were planted on the same dates as previously. The marked drop of yields from all plots of the second planting date was caused by a prolonged drought at that time. In all nine cases (3 varieties and 3 planting dates) the number of plants from dry seeds was significantly smaller than from conditioned seeds. This relation was apparent in the case of the first and second planting dates, when day temperatures were low, but also for the third planting date, when day temperatures were higher (Fig. 2 C and 3 B). This confirms the need of further investigations into the interaction of initial seed moisture, the different germination and emergence temperatures, and soil moisture. But already the present results demonstrate the importance of conditioning seeds in water vapour prior to sowing in order to obtain optimum conditions for germination and seedling growth in the field.

In these series of experiments the different elements of the crop, i.e. the number of side shoots and pods, and the number and weight of seeds, were also analysed. The analysis reveals a significant drop of yields from a unit area in plants of all three varieties grown from dry seeds. The drop is easily accounted for, in so far as in these treatments the number of plants on a unit area was found to be

Table 3

Injury of plants in experiment no. 2

| Initial seed moisture in %% of dry weight* | Temperatures of germination/emergence | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5°/10° | | | 10°/20° | | | 20°/20° | | |
| | failure of emergence in %% of planted seeds | % of injuries of seedlings | total injuries (2 + 3) | failure of emergence in %% of planted seeds | % of injuries of seedlings | total injuries (2 + 3) | failure of emergence in %% of planted seeds | % of injuries of seedlings | total injuries (2 + 3) |
| 1 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 'Fiskeby' | | | | | | | | | |
| 5% LiCl | 93.6 | 1.4 | 95.0 | 30.9 | 16.6 | 47.5 | 9.1 | 19.0 | 28.1 |
| 5% | 79.1 | 3.7 | 82.8 | 24.5 | 19.0 | 43.5 | 5.0 | 23.7 | 28.7 |
| 15% | 52.3 | 9.1 | 61.4 | 17.3 | 10.4 | 27.7 | 7.3 | 10.2 | 17.5 |
| 15% PT | 0.9 | 5.1 | 6.0 | 16.4 | 8.9 | 25.3 | 0.9 | 0.7 | 1.6 |
| 30% | 7.3 | 6.3 | 13.6 | 1.4 | 4.3 | 5.7 | 0 | 7.5 | 7.5 |
| 50% | 0 | 1.7 | 1.7 | 4.1 | 6.6 | 10.7 | 0.9 | 0.8 | 1.7 |
| LSD at P = 0.95 | | | 5.30 | | | 6.12 | | | 3.65 |
| 'Warszawska' | | | | | | | | | |
| 5% LiCl | 72.3 | 8.8 | 81.1 | 28.2 | 22.3 | 50.5 | 15.4 | 21.1 | 36.5 |
| 5% | 79.5 | 6.8 | 86.3 | 23.6 | 22.2 | 45.8 | 6.8 | 13.2 | 20.0 |
| 15% | 44.1 | 14.0 | 58.1 | 25.9 | 14.4 | 40.3 | 5.4 | 11.4 | 16.8 |
| 15% PT | 1.8 | 13.9 | 15.7 | 4.5 | 12.3 | 16.8 | 0.4 | 3.4 | 3.8 |
| 30% | 7.7 | 13.7 | 21.4 | 5.4 | 14.9 | 20.3 | 1.4 | 13.4 | 14.8 |
| 50% | 2.7 | 10.8 | 13.5 | 2.3 | 14.5 | 16.8 | 2.3 | 2.3 | 4.6 |
| LSD at P = 0.95 | | | 5.11 | | | 5.06 | | | 3.99 |

'Ajma'

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5% LiCl | 83.2 | 3.2 | 86.4 | 41.8 | 12.4 | 54.2 | 38.6 | 8.5 | 47.1 |
| 5% | 60.9 | 8.9 | 69.8 | 27.7 | 13.2 | 40.9 | 37.3 | 15.0 | 52.3 |
| 15% | 24.5 | 7.9 | 32.4 | 14.1 | 8.0 | 22.1 | 16.4 | 19.9 | 36.3 |
| 15% PT | 7.3 | 19.6 | 26.9 | 8.2 | 2.7 | 10.9 | 4.5 | 3.7 | 8.2 |
| 30% | 10.0 | 24.4 | 34.4 | 22.3 | 4.1 | 26.4 | 19.1 | 21.6 | 40.7 |
| 50% | 18.6 | 14.5 | 33.1 | 22.7 | 9.8 | 32.5 | 16.4 | 1.0 | 17.4 |
| LSD at P = 0.95 | | | 6.52 | | | 6.97 | | | 6.52 |

*See Table 2.

Table 4

Injuries in soybean var. 'IHAR 78/B' in experiment no 6.

| | Germination temperatures: 5° for 7 days, 10°C for 7 days; seedling growth: 20°C | | | | | | Germination of seeds and seedling growth temperature 20°C | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial seed moisture in %% of dry weight | failure of emergence in %% of planted seeds | % of injuries of seedlings | total injuries (1 + 2) | failure of emergence in %% of planted seeds | % of injuries of seedlins | total injuries (1 + 2) | failure of emergence in %% of planted seeds | % of injuries of seedlings | total injuries (1 + 2) | failure of emergence in %% of planted seeds | % of injuries of seedlings | total injuries (1 + 2) |
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 5 | 23.3 | 12.9 | 36.2 | 60.0 | 11.1 | 71.1 | 5.0 | 8.9 | 13.9 | 3.3 | 23.7 | 27.0 |
| 7 | 26.7 | 15.0 | 41.7 | 50.0 | 10.5 | 60.6 | 5.8 | 10.8 | 16.6 | 0.8 | 10.8 | 11.6 |
| 8 | 35.0 | 15.9 | 50.9 | 50.0 | 13.0 | 63.0 | 7.5 | 16.0 | 23.5 | 0.8 | 7.8 | 8.6 |
| 9 | 32.5 | 13.6 | 46.1 | 69.2 | 8.7 | 77.9 | 5.0 | 14.3 | 19.3 | 1.7 | 8.3 | 10.0 |
| 10 | 21.7 | 18.4 | 40.1 | 45.0 | 15.2 | 60.2 | 0 | 5.8 | 5.8 | 5.8 | 14.8 | 20.6 |
| 30 | 3.3 | 3.3 | 6.6 | 2.5 | 9.0 | 11.5 | 2.5 | 3.5 | 6.0 | 0 | 6.2 | 6.2 |
| 50 | 0 | 0.3 | 0.3 | 1.7 | 2.0 | 3.7 | 2.5 | 0.8 | 3.3 | 0.8 | 0.1 | 0.9 |
| LSD at P = 0.95 | | | 8.06 | | | 8.36 | | | * | | | * |

* – Difference non significant.

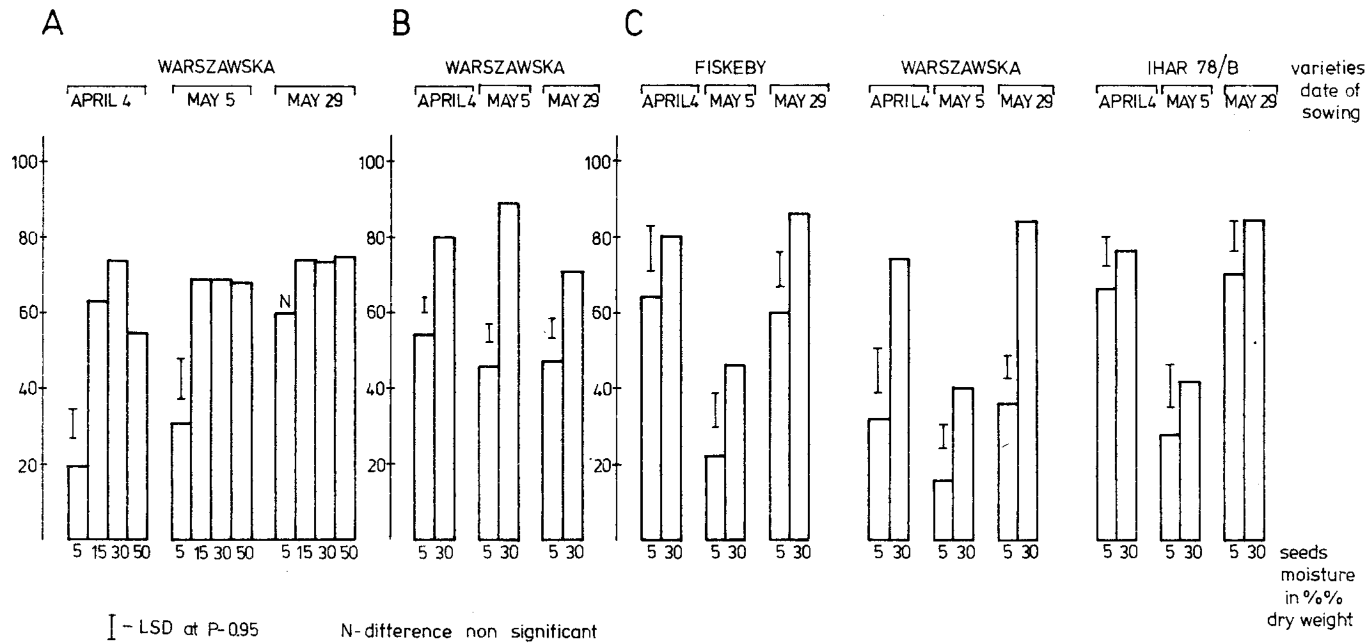


Fig. 2. Seedlings emergence of soybaen in %% planted seeds in experiment no. 3 (A), no. 4 (B) and no. 5 (C) – see Table 1

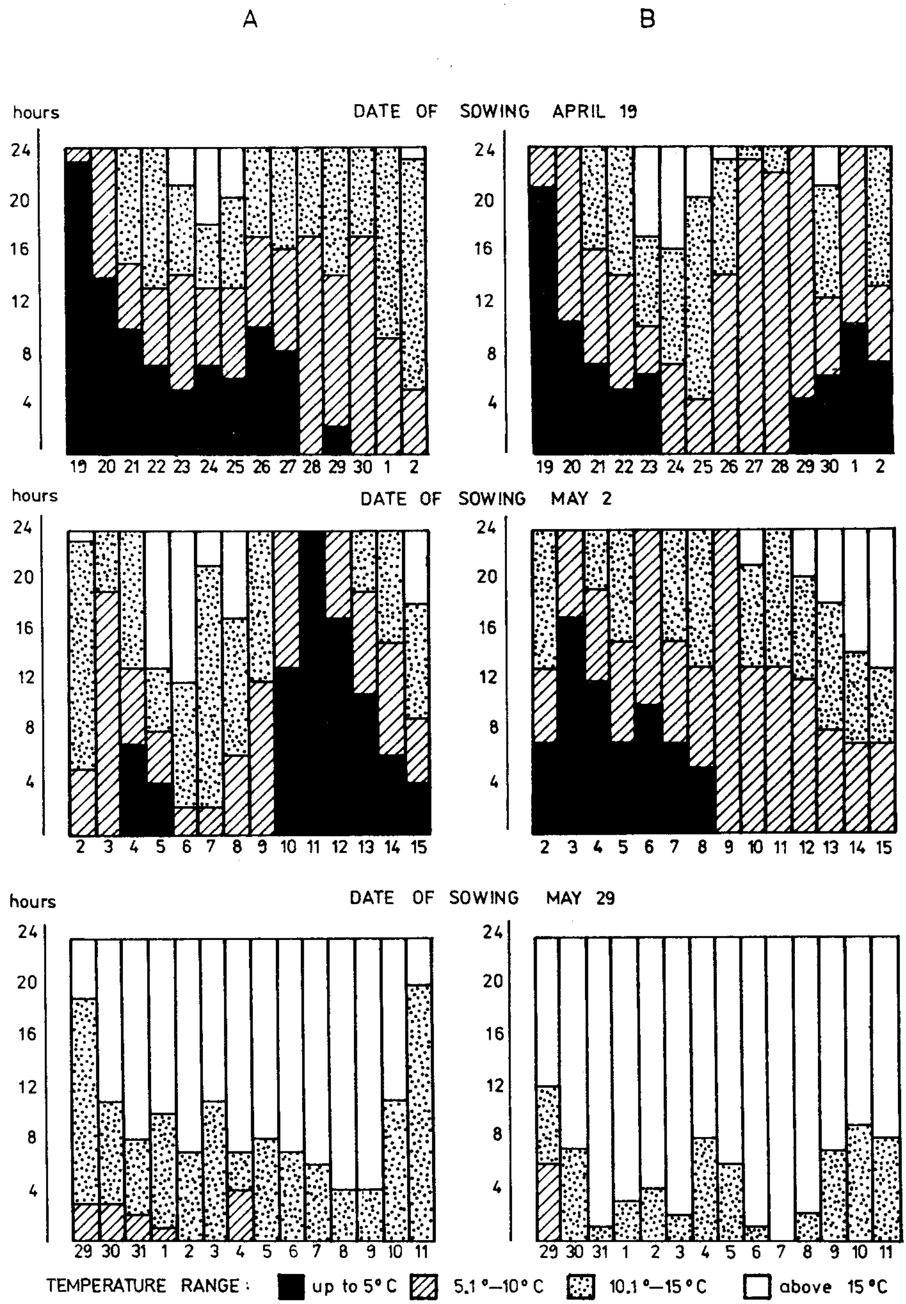


Fig. 3. Temperatures during first 14 days after sowing in experiment no. 3 and 4 (A) and no. 5 (B)

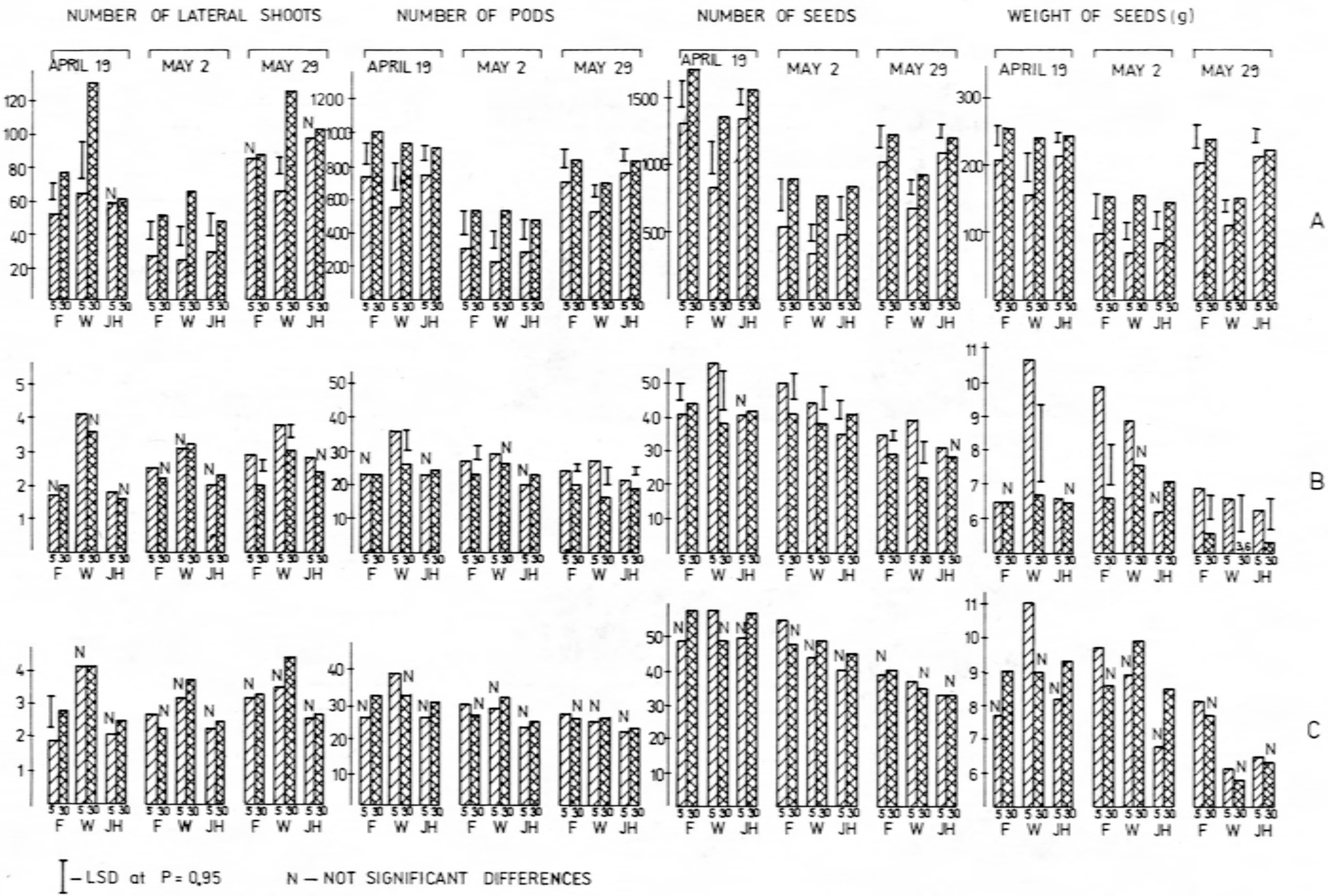


Fig. 4. Structures of yield in experiment no. 5. A — per 1 m² of field area, B — per plant, C — per plant after equalization of number of seedlings per unit area, (F — var. 'Fiskeby', W — var. 'Warszawska', IH — 'IHAR' 78/B)

significantly reduced. If, however, the particular elements of the crop structure are referred to individual plants, then the influence of initial seed moisture is seen to be much smaller, and in some instances of the 'Warszawska' variety, and to some extent also of the 'Fiskeby' variety, the yields from individual plants grown from dry seeds were even significantly higher. This was due, first of all, to the fact that there were fewer plants on a plot and/or, in the case of uneven seeds material, the more severe selection and elimination of weaker seedlings grown from dry seeds. The differences between yields from induvidual plants disappeared when the number of plants on a unit area was the same; this was the case on those plots, on which excess plants from conditioned seeds were removed immediately after emergence in order to equalize their number with that of plants from dry seeds (Fig. 4).

The present results also permit to establish varietal differences in the response to different initial seed moisture. In this respect the performance of the 'Warszawska' variety as compared with that of the others, i.e. 'Fiskeby' and 'IHAR 78/B', was particularly noteworthy. Yields per unit area from dry seeds of var. 'Warszawska' were much lower because of the smaller number and weight of seeds. The seed material of this variety, which had not been selected for many years, was much inferior and consequently the germinating capacity of initially dry seeds was low thus leading to a smaller number of plants.

Var. 'Warszawska', however, has more numerous side shoots than var. 'Fiskeby' and 'IHAR 78/B' and if after conditioning the number of plants on plots was similar, then after the first two planting dates it produced a similar crop as the other varieties. Digressing from our main considerations we may note that if, in comparative experiment with different varieties, the seed material is somatically differentiated, then planting of dry seeds may cause random differences in the number of emerging plants of the varieties being compared and thus distort the yields from unit area. This may make difficult a correct evaluation of the genetic value of the compared varieties or breeding forms.

## DISCUSSION

The positive effect – demonstrated in this research – of conditioning of seeds before planting has on the final yield from a unit area confirms the results of Philips and Youngman (1971) who reported a significant increase in the yield of sorghum grain in kilograms per hectare when the seed water content was controlled by means of hydration in water vapour over saturated solutions according to Winston and Bates (1960). The method, however, is unsuitable for large scale application in practice. For this reason the simpler and quicker method described here of hydrating seeds in air saturated with water vapour in closed containers deserves recommendation, provided that further practical improvements are developed.

Further investigations are also necessary into the interaction, observed in the present research, of different, natural soil and climatic conditions with the conditioning of seeds of soybean and other warm-climate plants cultivated in our climatic conditions. Another noteworthy observation is that by means of seed conditioning it is possible to equalize the number of plants on plots when testing the relative genetic value of different breeding forms and varieties of cultivated plants.

For a molecular interpretation of the mechanism underlying the results of the present experiments the following questions have to be considered: (1) the mechanism of chilling injury in sensitive plants; (2) the physiological meaning of seed hydration in water vapour before planting for the process of hardening plants against cold. Contrary to earlier controversial opinions (Pollock and Toole, 1966; Pollock et al., 1969; Christiansen, 1968) there is a tendency today to accept the view that chilling temperatures ranging from 0°C and 10°C affect first the physical state of cell structures and these changes then disturb the metabolic physiological processes and cause anatomically detected injuries to tissues and organs of plants sensitive to low temperatures. The stoppage of protoplasmic streaming in cells (Lewis, 1956) is a visible reaction of sensitive plants. The lipo-protein complex of mitochondrial membranes allows a phased transition from liquid crystal structures to coagulates but a change of the thermal parameter may cause the crystallization of hydrocarbon chains and modify physiological functions (Luzzati and Husson, 1962, quoted after Lyons and Raison, 1970). With reference to analogical differences in mitochondrial membranes in cells of warm- and coldblooded animals (Richardson and Tappel, 1962) it has been demonstrated that these membranes in cold-resistant plants (cauliflower, turnip, pea) are more flexible, i.e. have a greater swelling ability, than in sensitive plants (sweet potato, tomato). Moreover, resistant mitochondria have been found to have a higher content of unsaturated fatty acids than those in sensitive species (Lyons et al., 1964). Even a small increase in the value of the ratio of unsaturated to saturated fatty acids considerably lowers the solidification point and this may influence the flexibility of membranes (Lyons and Asmundson, 1965). Differences of flexibility and the related swelling ability of cytoplasmic membranes must also affect other physical traits of membranes, i.e. their permeability. This is indicated by a greater leakage of ions, primarily potassium ions, from tissues exposed to chilling temperatures (Lewis and Workman, 1964; Powell, 1969) and by leakage of organic substances (Pollock, 1969). The effect of cold on cell metabolism was studied primarily with reference to changes in the respiration rate, oxidative and phosphorylative activities, and the formation of ATP. Because of differences in the experimental material and different measuring techniques the overall image of all these changes is often contradictory. It has been found that during storage, respiration of fruits of cold-sensitive plants increased at first (W a t a d a and M o r r i s, 1966), but after several days dropped again together with the spread of injuries (E a k s and M o r r i s, 1956). The oxidative phosphorylative activities of mitochondria of roots of sweet potatoes stored at 7°C dropped after 10 weeks of storage but showed little change when kept at 15°C (L i e b e r m a n et at., 1958). The effects of chilling on fruit tissue seem to indicate an uncoupling of oxidative phosphorylation (L e w i s and W o r k m a n, 1964). The decrease of the value $Q_{10}$ for respiration and substrate oxidation processes, established on Arrhenius plots as a function of temperatures ranging from 30°C to 1°C, was accelerated at temperatures below 10°C in cold-sensitive species, but the corresponding drop was linear in cold-resistant species (L y o n s and R a i s o n, 1970). The harmful effect of cold on processes connected with respiration may consist in an accumulation of metabolic intermediates (M u r a t a and K u, 1966, quoted after L y o n s and R a i s o n, 1970) but it also may be due to a drop in the rate of ATP production below the level necessary to maintain the metabolic integrity of cytoplasm (S t e w a r t and G u i n n, 1969).

The physiological mechanism involved in the hardening of plants against cold by means of hydrating seeds before planting has not as yet been thoroughly investigated. The decisive factor may be the almost hundred times lower rate of hydration of cellular colloids after seed hydration in water vapour as compared to imbibition in water. Sudden hydration coupled with the destructive effects of cold may act synergically on the occurrence of partial or irreversible damage in cytoplasmic membranes, while gradual hydration improves the initial condition of membranes and thereby hardens the germ against chilling temperatures. The negative effects of rapid imbibition of dry seeds may be greatly limited if an initial period of cold is followed before the end of germination and during emergence by a period of temperatures higher than those causing injury (Table 3, 4). This "healing" effect of higher temperatures seems to indicate that, in agreement with reports of other authors, chilling injuries are reversible (C a s a s et al., 1965; C r e n c i a and B r a m l a g e, 1971). A different interpretation, however, is also possible; the synergic effect of sudden imbibition and cold at the beginning of germination damages only the initial meristematic cells of the germ but with the onset of higher temperatures these cells may divide to give healthy undamaged cells. In this way the effects of injuries to cytoplasmic membranes produced by chilling during imbibition and at the beginning of germination would gradually disappear with the progress of germ and seedling growth in higher temperatures.

Acknowledgement

My sincere gratitude is due to Miss Kazimiera Hajduk for her consciencious assistance during the experiments and the processing of results.

## REFERENCES

C a s a s I. A., R e d s h a w E. S., I b a n e z M. L., 1965. Respiratory changes in the cacao seed cotyledon coincident with seed death. Nature 208: 1348-1349.

C r e n c i a R. P., B r a m l a g e W. J., 1971. Reversibility of chilling injury to corn seedlings. Plant Physiol. 47: 389-392.

C h r i s t i a n s e n M. N., 1967. Periods of sensitivity to chilling in germinating cotton. Plant Physiol. 42: 431-433.

C h r i s t i a n s e n M. N., 1968. Induction and prevention of chilling injury to radicle tips of imbibing cottonseed. Plant Physiol. 43: 743-746.

C h r i s t i a n s e n M. N., 1969. Seed moisture content and chilling injury to imbibing cottonseed. Proc. 23rd. Ann. Cotton Defol. Physiol. Conf. National Cotton Council, Memphis, Tenn. 50-51.

E a k s I. L., M o r r i s L. L., 1956. Respiration of cucumber fruits associated with physiological injury at chilling temperatures. Plant Physiol. 31: 308-314.

H o b b s P. R., O b e n d o r f R. L., 1972. Interaction of initial seed moisture and imbibitional temperature on germination and productivity of soybean. Crop Sci. 12: 664-667.

H o v e l a n d C. S., E l k i n s D. M., 1965. Germination response of arrowleaf, ball, and crimson clover varieties to temperature. Crop Sci. 5: 244-246.

K i d d F., W e s t C., 1918. The effects of soaking seeds in water. Ann. appl. Biol. 5: 1-10.

L e w i s D. A., 1956. Protoplasmic streaming in plants sensitive and insensitive to chilling temperatures. Science, 124: 75-76.

L e w i s T. L., W o r k m a n M., 1964. The effect of low temperature on phosphate esterification and cell membrane permeability in tomato fruit and cabbage leaf tissue. Aust. J. Biol. Sci. 17: 147-152.

L i e b e r m a n M., C r a f t C. C., A u d i a W. V W i l c o x M. S., 1958. Biochemical studies of chilling injury in sweet potatoes. Plant Physiol. 33: 307-311.

L u z z a t i V., H u s s o n F., 1962. The structure of the liquid crystalline phases of lipid-water system. J. Cell Biol. 12: 207-219.

L y o n s J. M., W h e a t o n T. A., P r a t t H. R., 1964. Relationship between the physical nature of mitochondrial membranes and chilling sensitivity in plants. Plant Physiol. 39: 262-268.

L y o n s J. M., A s m u n d s o n C. M., 1965. Solidification of unsaturated/saturated fatty acid mixtures and its relationship to chilling sensitivity in plants. J. Amer. Oil Chem. Soc. 42: 1056--1058.

L y o n s J. M., R a i s o n J. K., 1970. Oxidative activity of mitochondria isolated from plant tissues sensitive and resistant to chilling injury. Plant Physiol. 45: 386-389.

M a r k o w s k i A., 1976. Współdziałanie temperatury i uwodnienia nasion w procesie imbibicji oraz wpływ następczy tych czynników na kiełkowanie i wzrost siewek soi w różnych warunkach termicznych. Sprawozdanie roczne, temat PR-4 02-01, Archiwum IHAR Radzików.

M u r a t a T., K u H. S., 1966. Studies on post harvest ripening and storage of banana fruits. Part 5. Physiological studies of chilling injuries in bananas (Part 2). J. Food Sci. Tech. 13: 466-471 (In Japanese).

O b e n d o r f R. L., H o b b s P. R., 1970. Effect of seed moisture on temperature sensitivity during imbibition of soybean. Crop Sci. 10: 563-566.

O r p h a n e s P. I., H e y d e c k e r W., 1968. On the nature of the soaking injury of *Phaseolus vulgaris* seeds. J. exp. Bot. 19. 61: 770-784.

P h i l l i p s J. C., Y o u n g m a n V. E., 1971. Effect of initial seed moisture content on emergence and yield of grain sorghum. Crop Sci. 11: 354-357.

P o l l o c k B. M., 1965. Imbibition – a critically temperature-sensitive stage in been germination. Abstr. Am. Soc. Hort. Sci., 62nd Annual Meetings, 46: 159.

Pollock B. M., Toole V. K., 1966. Imbibition period as the critical temperature sensitive stage in germination of lima bean seeds. Plant Physiol. 41: 221-229.
Pollock B. M., Ross E. E., Manalo J. R., 1969. Vigor of garden bean seeds and seedlings influenced by initial seed moisture, substrate oxygen, and imbibition temperature. J. Am. Soc. Hort. Sci., 94: 577-584.
Pollock B. M., 1969. Imbibition temperature sensitivity of lima bean seeds controlled by initial seed moisture. Plant Physiol. 44: 907-911.
Powell R. D., 1969. Permeability changes in leaf disks as affected by low temperatures. Plant Physiol. 44: S-75.
Richardson T., Tappel A. L., 1962. Swelling of fish mitochondria. J. Cell Biol. 13: 43-54.
Segeta V., Tronickova E., 1966. Ecology and physiology of the resistance to the cold of germinating cucumbers. II. Physiological reaction of seeds and seedlings of cucumbers to low temperatures. Rostlinna Vyroba, 39: 1113-1125.
Stewart J. McD., Guinn G., 1969. Chilling injury and changes in adenosine triphosphate of cotton seedlings. Plant Physiol. 44: 605-608.
Watada A. E., Morris L. L., 1966. Effect of chilling and non chilling temperatures on snap bean fruits. Proc. Amer. Soc. Hort. Sci. 89: 368-374.
Winston P. W., Bates D. H., 1960. Saturated solutions for the control of humidity in biological research. Ecology, 41, 1: 232-237.

# Wpływ początkowej wilgotności nasion oraz warunków termicznych w czasie kiełkowania i wschodów na przeżywalność siewek i plonowanie soi (*Glycine max* L. Merrill)

Streszczenie

Uszkodzenia siewek soi wywołane chłodami na początku kiełkowania w temperaturze 5°C znacznie się zmniejszały, jeśli zakończenie kiełkowania oraz wschody siewek odbywały się nie w warunkach chłodu tj. 10°C lecz w temperaturze wyższej, tj. 20°C. Zaproponowano nową interpretację fizjologicznego mechanizmu tej odwracalności uszkodzeń spowodowanych chłodem. Nawilżanie nasion soi o zawartości wody od 5% do 10% parą wodną do poziomu wilgotności 30% suchej masy zwiększało przeżywalność siewek zarówno w kontrolowanych warunkach kiełkowania i wschodów w temperaturze 5°/10°, jak i w naturalnych warunkach glebowych w doświadczeniach polowych po wczesnych jak i późniejszych terminach siewu. Opracowano modyfikację metody nawilżania nasion parą wodną (tj. kondycjonowania nasion, względnie hartowania nasion na chłód) w celu przystosowania tej metody do potrzeb praktyki rolniczej. Kondycjonowanie nasion w doświadczeniach polowych zwiększało przeżywalność siewek, a tym samym zwiększało plon nasion na jednostkę powierzchni pola, lecz nie miało większego wpływu na plon nasion w przeliczeniu na 1 roślinę. Wykazano, że kondycjonowanie nasion może mieć nie tylko znaczenie w agrotechnice, lecz również w hodowli roślin dla wyrównania liczby roślin w polowych doświadczeniach porównawczych nowych odmian i form hodowlanych.