ARBORETUM KÓRNICKIE
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Storage of beech (*Fagus silvatica* L.) seed for up to 5 winters

INTRODUCTION

In an earlier publication (Suszka, 1966) results were presented of studies on the after-ripening of freshly collected or stored for one winter under controlled conditions, partially dried beech (*Fagus silvatica* L.) nuts. For the studies use was made at time (1964) of nuts collected in Kórnik nr. Poznań during a good seed year which were of very high quality. They represented a lowland beech provenance.

A part of the material collected then has been further stored at —10°C for, 2, 3 and 4 winters till the spring of 1968. In 3°C the nuts were stored for 2 winters. The results are presented in the first part of this paper.

In 1968 a new lot of beech nuts was collected in a mountain region. In spite of the fact that the seeds were of poorer quality the seeds were used for a further experiment on long-term storage designed for 5 winters. The results obtained after 1, 2, 3, 4 and 5 winters of storage are also presented in this paper.

In the publication referred to earlier (Suszka, 1966) a detailed discussion is given of the literature on beech seed storage up to 1965. Since that time only very few further publications appeared on the subject. (Machaniček, 1965; Messer, 1968). The work of Vlase (1968) is also worth mentioning since he has described the action of an equipment that rapidly lowers the water content in freshly collected beech nuts using an air current at a temperature of 15°C (optimal temperature).

MATERIALS AND METHODS

Seed origin:

Lowland provenance: Kórnik nr. Poznań, (elev. 65 m) Arboretum of the Institute of Dendrology of the Polish Academy of Sciences. Collection 1 - 11. X. 1964 from the ground during seed fall. Water content after collection was 23.4% of fresh weight.

Carpathian provenance: Mt. Łomnica (elev. 900 m) near Muszyna on the Poprad, Sądecki Beskid Mts. in the Polish Carpathians. Collection 24 - 26. X. 1968 after seed fall from the trees was completed. Water content after collection was 31.4% of fresh weight.

Partial drying of the seeds: Immediately after obtaining the nuts they were partially dried in a cellar at a temperature of 15° - 20°C. The duration of the drying was follows:

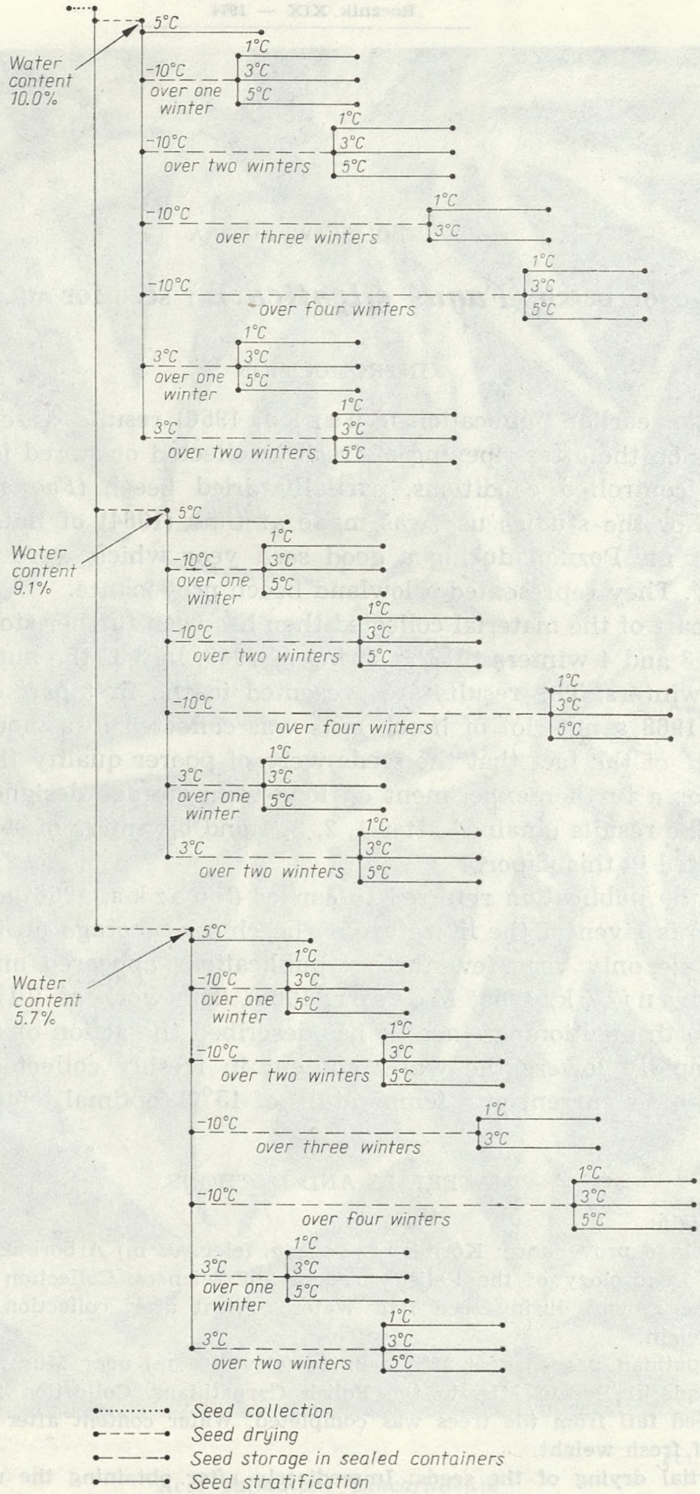

Fig. 1. Seeds of beech from the lowland provenance. Design of the experiment

Lowland provenance: to 9 - 10% of water, from 1 - 11. X. to 20 - 22. X. 1964 (11 - 22 days); to 5 - 6% of water, from 1 - 11. X. to 5. XI. 1964 (25 - 36 days).

Carpathian provenance: to 9 - 10% of water, from 28. X. to 12. XII. 1968 (45 days). After drying, nuts that were damaged mechanically or by insects as well as empty or malformed ones have been picked out by hand and discarded.

Storage of the nuts. Beech nuts of the lowland provenance have been stored in tightly sealed glass bottles while the nuts of the Carpathian provenance have been stored in tightly sealed 5 liter polystyrene canisters. The bottles and the canisters have been opened only once, after termination of the storage period designed for them.

Storage duration and temperature:

Lowland provenance: The nuts partially dried to 9.1 and 10.0% of water content have been stored from 20 - 22. X. 1964: in 3°C for 98 and 467 days (1 and 2 winters), in —10°C for 98, 467, 790 and 1192 days (1, 2, 3 and 4 winters).

The nuts partially dried to 5.6% of water content have been stored from 5. XI. 1964: in 3°C for 83 and 452 days (1 and 2 winters), in —10°C for 83, 452, 817 and 1177 days (1, 2, 3 and 4 winters).

Carpathian provenance: The nuts partially dried to 9.6% of water content have been stored from 12. XII. 1968: in —10°C for 71, 433, 790, 1154 and 1510 days (1, 2, 3, 4 and 5 winters).

Design of the experiment: lowland provenance — Fig. 1; Carpathian provenance — Fig. 2.

Estimate of viability: cutting test and in 1972 and 1973 the tetrazolium test was also used.

Estimate of water content: method of drying in 105°C for 24 hours. Water content has been expressed as percentage of the fresh weight.

Germination tests at a lowered temperature:

a) Stratification in glass jars in a moist mixture of sand with powdered peat (1 : 1 by vol.). The moisture content of the medium and the state of the seeds was controlled every 10 days. Germinated (radicle 5 mm or longer) and decayed seeds have been successively discarded. When the stratification was preparing seeds for the setting test (at a high constant temperature or at a flucuating one or in the nursery) the germinating seeds have not been removed.

b) Germination test at 3°C on moist filter paper (additionally applied in 1973 for seed of Carpathian provenance).

Dates on which the germination tests (stratification) in a low temperature (A) and the setting tests (B) in a raised temperature or in a nursery were begun.

Lowland provenance:	*A*
after drying to 9 - 10% of water content	20 - 22 X 1964
after drying to 5.7% of water content	5 XI 1964
after storage for 1 winter	27 I 1965
after storage for 2 winters	1 II 1966
after storage for 3 winters	1 II 1967
after storage for 4 winters	26 I 1968

Carpathian provenance:	*A*	*B*
after drying to 9.6% water content	12 XII 1968	3 V 1969
after storage for 1 winter	22 II 1969	7 V 1970
after storage for 2 winters	19 I 1970	6 V 1971
after storage for 3 winters	11 II 1971	16 V 1972
after storage for 4 winters	10 II 1972	26 IV 1973
after storage for 5 winters	31 I 1973	

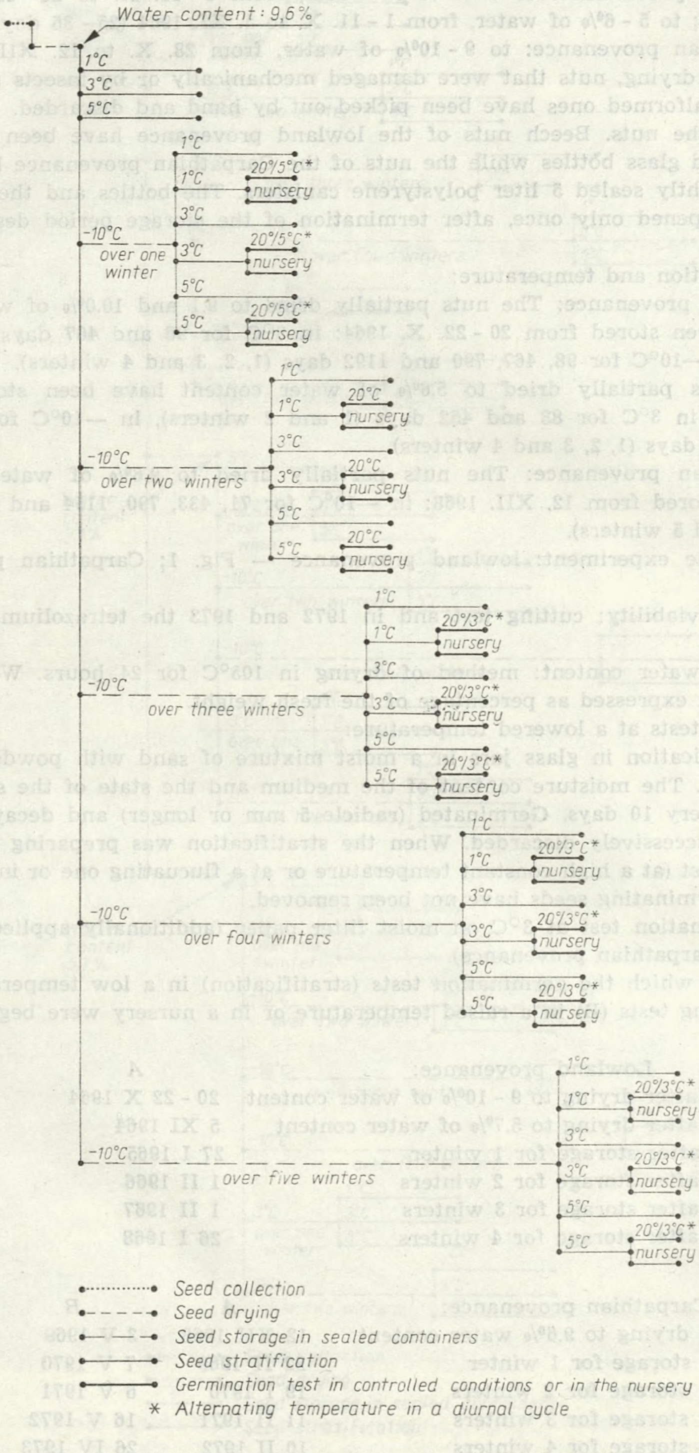

Fig. 2. Seeds of beech of the Carpathian provenance. Design of the experiment

Replicates: All the laboratory germination tests in the low and raised temperature have been conducted in 4 replicates with 50 seeds of each variant per replicate. The data obtained have been converted into percentages and means were calculated. Stratification for setting tests in the nursery have heen conducted in 5 replicates.

Setting tests in a raised constant of fluctuating temperature: Independently of the germination tests in the low temperature (cold only stratification) setting tests (sowings) were also made in the laboratory conditions and in the nursery, for which use was made of seeds separately yet simultaneously stratified in the same temperature conditions (at 1°, 3° and 5°C). After a sufficient number of germinated seeds was observed during stratification at each of these temperatures (here the germinating seeds were not removed) the seeds were segregated into 3 classes: a) with a root longer than 1 cm, b) with a root shorter than 1 cm, and c) non-germinating seeds. The seeds were sown in the laboratory and nursery conditions. The ground sowings were performed in the Zwierzyniec forest nursery near Kórnik. They were layed out in a complete block design with 5 replicates, with 50 seeds per variant of temperature and seed class. In the case of insufficient amounts of seeds from a given seed class the number of seeds in the replicates and in some cases also the number of replicates were reduced.

a) Laboratory tests: Here only the Carpathian seeds were used. In the years 1969, 1971, 1972 and 1973 tests were conducted in a variable temperature (5° or 3°C for 16 hours +8 hours at 20°C). In 1970 the laboratory tests were conducted at a constant temperature (20°C). The seeds were segregated into classes (as above) and sown in plastic boxes on a mixture of sand and peat (1 : 1 by vol.) and covered with a 1 cm layer of sand. The boxes were covered with a transparent lid with ventilation holes in it and located in the phytotron chambers at an appropriate temperature. Raising of the nut above the surface of the sand or soil was accepted as a criterion of setting (in the laboratory and in the nursery). Setting observations were conducted every 5 days.

b) Nursery tests: These were conducted in the years 1968 - 1973 for the seeds of the Carpathian origin. The seeds were divided into classes (as above) within each of the stratification variants (at temperatures of 1°C, 3°C and 5°C) and sown (50 or less) into furrows 1 cm deep and covered with the soil. The furrows were 120 cm long perpendicular to the nursery bed, 20 cm from each other. They were pressed in with a template.

Duration of the stratifications and setting tests: Until new radicles or sets cease to appear.

RESULTS

A. LOWLAND PROVENANCE

The course of seed germination during cold stratification at 1°, 3° and 5°C, begun immediately after the partial drying of the seeds to 9 - 10% and 5 - 6% percent of water content and after storage of such partially dried seeds for 1 or 2 winters at +3°C and for 1, 2, 3 and 4 winters at —10°C in sealed containers is presented together with changes in seed viability in Fig. 3. The water content and the viability of seeds after partial drying and after the completion of each of the storage periods is illustrated by the figures presented in table 1. From these data it appears

Table 1

Seeds of beech of the lowland provenance. Water content (in the fresh weight of nuts) and seed viability (cutting test) after partial drying and storing of the seeds in sealed containers for 1, 2, 3 and 4 winters at −10°C and for 1 and 2 winters at 3°C

Fresh beech nuts partially dried		Beech nuts stored at −10°C							
		after 1 winter		after 2 winters		after 3 winters		after 4 winters	
water content %	viability %	water content %	viability %	water content %	viability %	water content %	viability %	water content %	viability %
10.0	98.5	9.1	97.5	9.9	99.1	9.9	90.8	10.6	84.0
9.1	98.5	9.3	97.0	9.7	97.5	9.9	96.7	11.6	92.7
5.6	100.0	5.9	99.2	5.1	100.0	5.6	100.0	5.9	97.8

Fresh beech nuts partially dried		Beech nuts stored at +3°C							
		after 1 winter		after 2 winters		after 3 winters		after 4 winters	
water content %	viability %	water content %	viability %	water content %	viability %	water content %	viability %	water content %	viability %
10.0	98.5	10.1	98.5	9.3	100.0				
9.1	98.5	9.0	98.5	8.9	99.1	not studied			
5.6	100.0	5.4	100.0	7.1	99.1				

that during stratification of the beech nuts in sealed bottles no significant changes take place in the level of the water content. Deviations in the water content of up to 1.5% are presumably related to variability between the samples and to unevenness of the seed drying conditions.

An analysis of the germination curves demonstrates that as the time of seed storage increases beyond 2 winters, thus only at —10°C, the onset of germination is delayed (Fig. 4). This has been undoubtedly caused by the storage conditions, since it was possible to observe at all the stratification temperatures (1°, 3° and 5°C). Between the 2nd and 4th winter a delay in the onset of germination was of the order of 30 - 40 days compared to seeds stored only for 1 or 2 winters which begun to germinate already after 70 - 80 days of stratification.

The period between the beginning and end of germination became extended as the duration of storage at —10°C increased, so that when stratified at 5°C it was 90 - 100 days after 4 winters compared to 50 - 70 days after 2 winters; this however concerns only the nuts that were dried to 9 - 10% of water content. During stratification at 1° and 3°C the germination lasted for a period of time irrespective of the duration of storage, usually 70 - 80 days at 1°C and 60 - 70 days at 3°C.

With respect to the germinative capacity one should consider separately the seeds dried before storage to 10.0% and 9.1% of water content and those dried to 5.6% water content (Table 2). The former have germinated in a relatively high percentage even after 4 winters of storage while the latter were from the very beginning, that is immediately after drying,

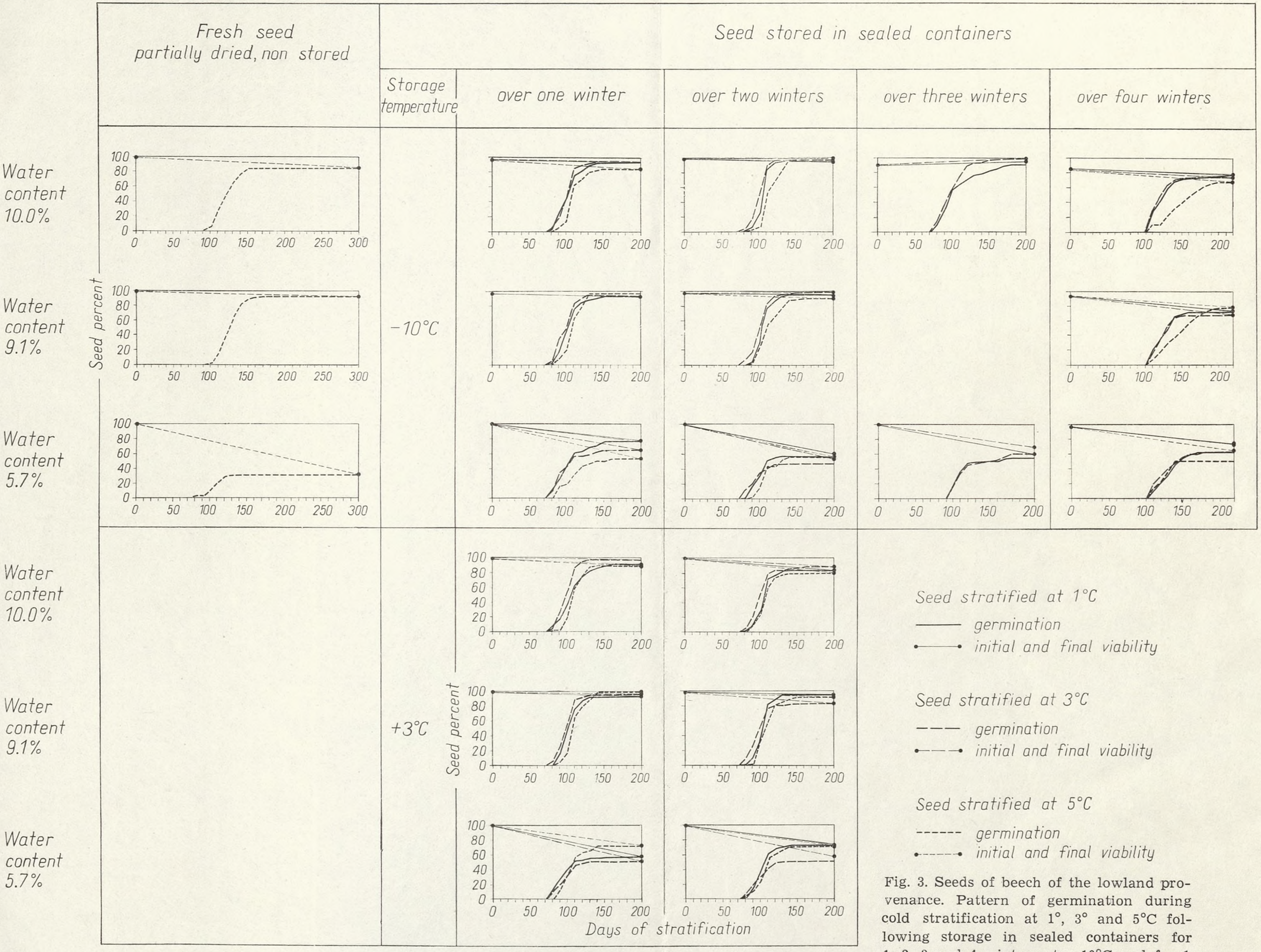

Fig. 3. Seeds of beech of the lowland provenance. Pattern of germination during cold stratification at 1°, 3° and 5°C following storage in sealed containers for 1, 2, 3 and 4 winters at —10°C and for 1 and 2 winters at 3°C

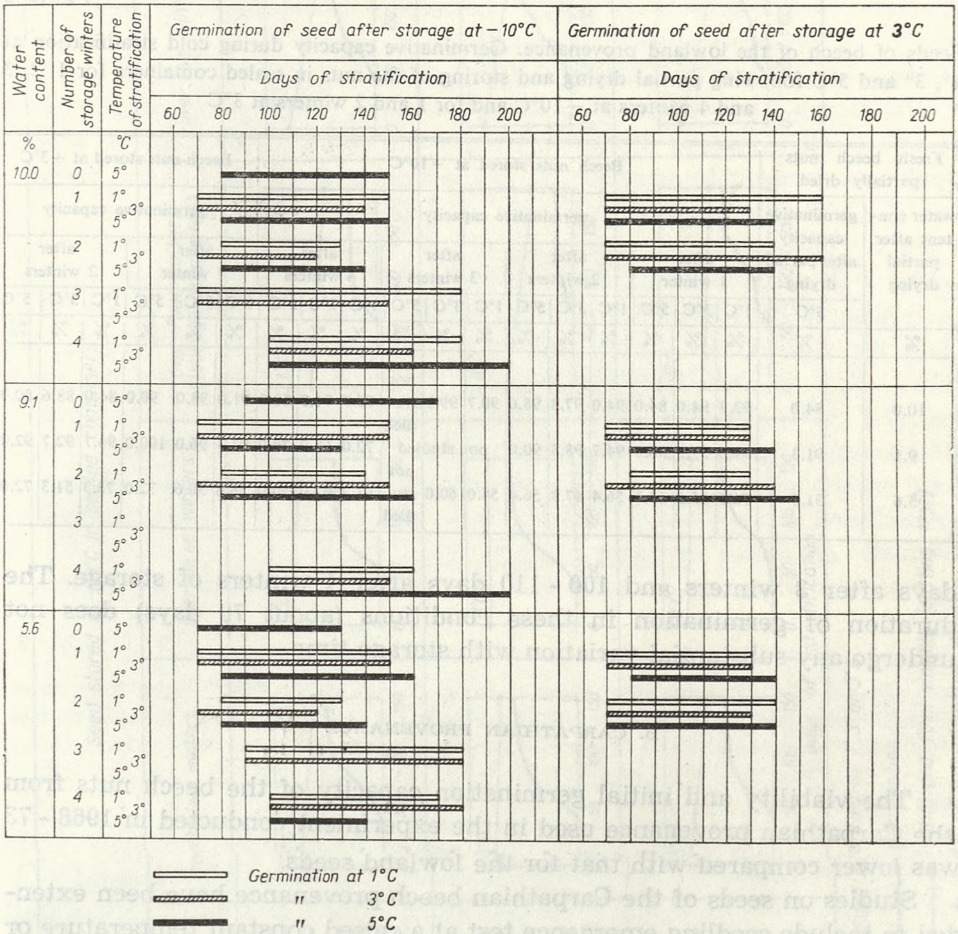

Fig. 4. Seeds of beech of the lowland provenance. Duration of the germination period during cold stratification at 1°, 3° and 5°C following storage in sealed containers for 1, 2, 3 and 4 winters at −10°C and for 1 and 2 winters at 3°C

characterized by a lowered germinative capacity. In seeds containing 9 - 10% of water a significant decline in germination capacity was observed only during storage between the 3rd and 4th winter.

From the experiments conducted in 1964 - 1968 on the storage of high quality beech nuts from a lowland provenance in sealed bottles the following conclusions can be drawn. The optimal treatment of the seeds depends on drying them partially to 9 - 10% of water content in the fresh weight and then storing them in sealed containers at —10°C (up to 2 years 3°C is also satisfactory) and later stratyfing at 1° - 3°C on termination of the storage. After 2 winters of storage at —10°C one has to expect a 20 - 30 day delay in the onset of germination which was 70 - 80 days immediately after drying or after one winter of storage, 90

Table 2

Seeds of beech of the lowland provenance. Germinative capacity during cold stratification at 1°, 3° and 5°C following partial drying and storing of the nuts in sealed containers for 1, 2, 3 and 4 winters at −10°C and for 1 and 2 winters at 3°C

Fresh beech nuts partially dried		Beech nuts stored at −10°C												Beech nuts stored at +3°C					
water content after partial drying	germinative capacity after partial drying	germinative capacity												germinative capacity					
		after 1 winter			after 2 winters			after 3 winters			after 4 winters			after 1 winter			after 2 winters		
	5°C	1°C	3°C	5°C	1°C	3°C	5°C	1°C	3°C	5°C	1°C	3°C	5°C	1°C	3°C	5°C	1°C	3°C	5°C
%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
10.0	84.0	93.3	94.0	84.0	94.0	97.3	98.0	90.7	99.3	not studied	76.7	74.0	68.0	91.0	98.0	90.0	84.0	88.6	80.0
9.1	91.3	92.0	97.3	96.0	94.7	98.3	90.0	not studied			72.0	68.0	78.0	93.3	96.0	100.0	94.7	92.7	92.0
5.6	31.3	76.6	65.5	53.3	56.4	47.9	56.4	54.0	60.0	not studied	61.3	62.0	50.0	56.6	50.6	72.0	73.3	51.3	72.0

days after 3 winters and 100 - 110 days after 4 winters of storage. The duration of germination in these conditions (about 70 days) does not undergo any substantial variation with storage time.

B. CARPATHIAN PROVENANCE

The viability and initial germination capacity of the beech nuts from the Carpathian provenance used in the experiment conducted in 1968 - 73 was lower compared with that for the lowland seeds.

Studies on seeds of the Carpathian beech provenance have been extended to include seedling emergence test at a raised constant temperature or at a cyclically changeable temperature following a period of cold stratification. These further studies were aimed at obtaining information on the germinative capacity possible to attain in conditions more akin to those existing in a nursery. In spite of the fact however that cold stratification was always conducted in constant conditions, the setting tests were being changed each year during the first three years of the study in search of a method that would prove most satisfactory. It has to be pointed out that so far an appropriate method of making germination tests for beech has not been developed, and the method recomended by the rules of I.S.T.A. has been subjected to criticism in an earlier paper (Suszka, 1966). The conditions of the emergence test used in this study have been the following for the various years:

after 1 winter — a cyclically changeable temperature between 20° and 5°C (8+16 hrs.), with a 1 cm sand cover;

after 2 winters — constant temperature at 20°C, with a 1 cm sand cover;

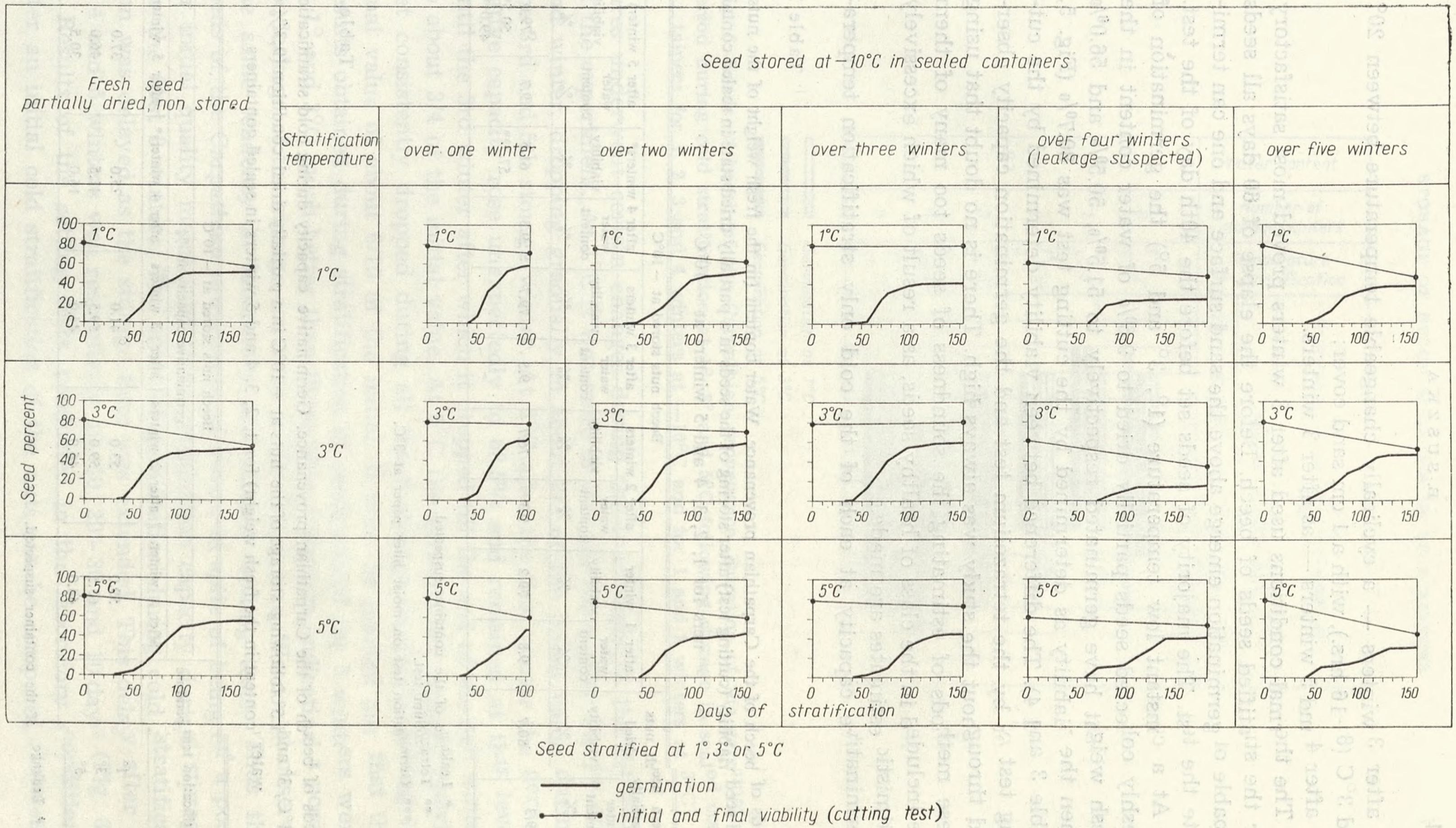

Fig. 5. Seeds of beech of the Carpathian provenance. Pattern of germination during cold stratification at 1°, 3° and 5°C following storage at —10°C in sealed containers for 1, 2, 3, and 4 winters

after 3 winters — a cyclically changeable temperature between 20° and 3°C (8+16 hrs.), with a 1 cm sand cover;

after 4 and 5 winters — as after 3 winters.

The thermal conditions used after 3 winters proved most satisfactory for the stratified seeds of beech. Before the elapse of 60 days all seeds capable of germination emerge above the sand surface and one can terminate the test. The majority of seeds set before the 40th day of the test.

At a constant low temperature (1°, 3° and 5°) the germination of freshly collected seeds partially dried to 9.6% of water content in the fresh weight have germinated respectively to 51.5%, 50.5% and 56.0% when the viability as determined by the cutting test was 80.7% (Fig. 5, Table 3 and 4). The difference between viability determined by the cutting test or by the tetrazolium test and the germination capacity observed throughout the study was always high. There is no doubt that using these methods of estimating the soundness of seeds too many of them are included in the class of healthy seeds, as a result of which excessively optimistic estimates are made.

Germinative capacity at each of the cold only stratification tempera-

Table 3

Seeds of beech of the Carpathian provenance. Water content (in the fresh weight of the nuts) and seed viability (cutting test) after storing of the seeds in a partially dried state in sealed containers for 1, 2, 3, 4 and 5 winters at −10°C

Fresh beech nuts partially dried		Beech nuts stored at −10°C									
		after 1 winter		after 2 winters		after 3 winters		after 4 winters*		after 5 winters	
water content %	viability %	water content %	viability %	water content %	viability %	water content %	viability %	water content %	viability %	water content %	viability %
9.3	80.7	9.8	79.2	9.3	76.7	9.5	79.7	9.5	61.5 57.3**	9.7	79.0 50.5** 49.0***

* Leakage of the container suspected.
** Tetrazolium test.
*** Germination test on moist filter paper at 3°C.

Table 4

Seeds of beech of the Carpathian provenance. Germinative capacity during cold stratification at 1°C, 3° and 5° following storage of the nuts at −10°C in a partially dried condition (9,3% of water content in the fresh weight) for 1, 2, 3, 4 and 5 winters in sealed containers

Stratification temperature	Beech nuts stored at −10°C germinative capacity in %				
	after 1 winter	after 2 winters	after 3 winters	after 4 winters*	after 5 winters
1°	59.0	53.0	41.0	25.0	37.0
3°	63.5	59.0	59.5	41.5	46.0
5°	48.0	46.0	44.0	16.0	30.5

* Leakage of the container suspected.

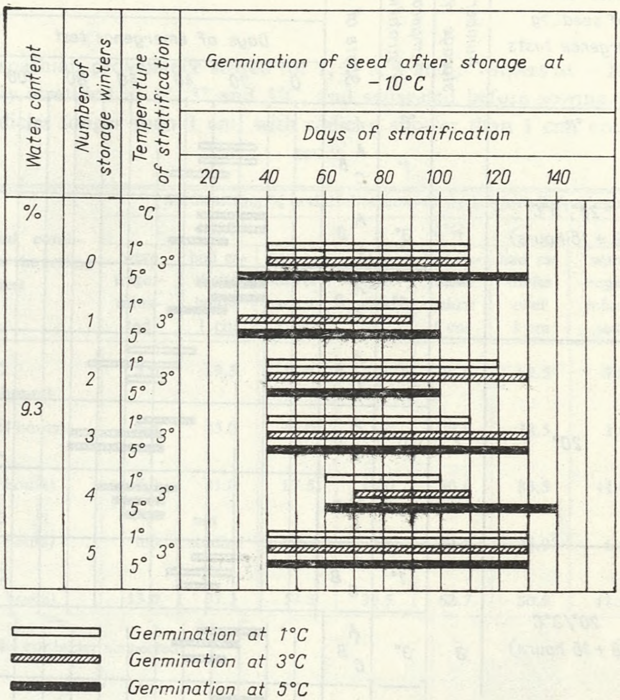

Fig. 6. Seeds of beech of the Carpathian provenance. Duration of the germination period during cold stratification at 1°, 3° and 5°C following storage in sealed containers for 1, 2, 3 and 4 winters at —10°C and for 1 and 2 winters at 3°C

tures underwent certain changes during the four years of the duration of the experiment. At 1°C it was more or less the same after the 1st and 2nd winter, dropping gradually to about 2/3 of the initial value during the 3rd and 5th storage winter. At 3°C after the first winter the germinative capacity rose unexpectedly to 63.5% and remained at this level until the 3rd winter after which it dropped till the end of the 5th winter to about 3/4 of the initial value. At 5°C the germination capacity slowly yet consistently dropped during all the 5 storage winters reaching its final value of about 6/10 of the initial. It must be pointed out that the results obtained during stratification of seeds stored for 5 winters were at 1° and 3°C much better than those after 4 winters, indicating a possible leakage of the storage container in the latter case. We could observe the same tendency in laboratory and nursery setting tests. Thus the seeds of the Carpathian provenance of beech, in spite of being of a poorer initial quality maintained their germination capacity during storage for the first 3 winters. The onset of germination during cold stratification was delayed as the storage time was extended. This delay after 2, 3, 4 and 5 winters was respectively 10, 10, 20 - 30 and 10 days (Fig. 6).

Results of the setting tests, conducted in the laboratory conditions after an initial cold stratification of the nuts can be compared between

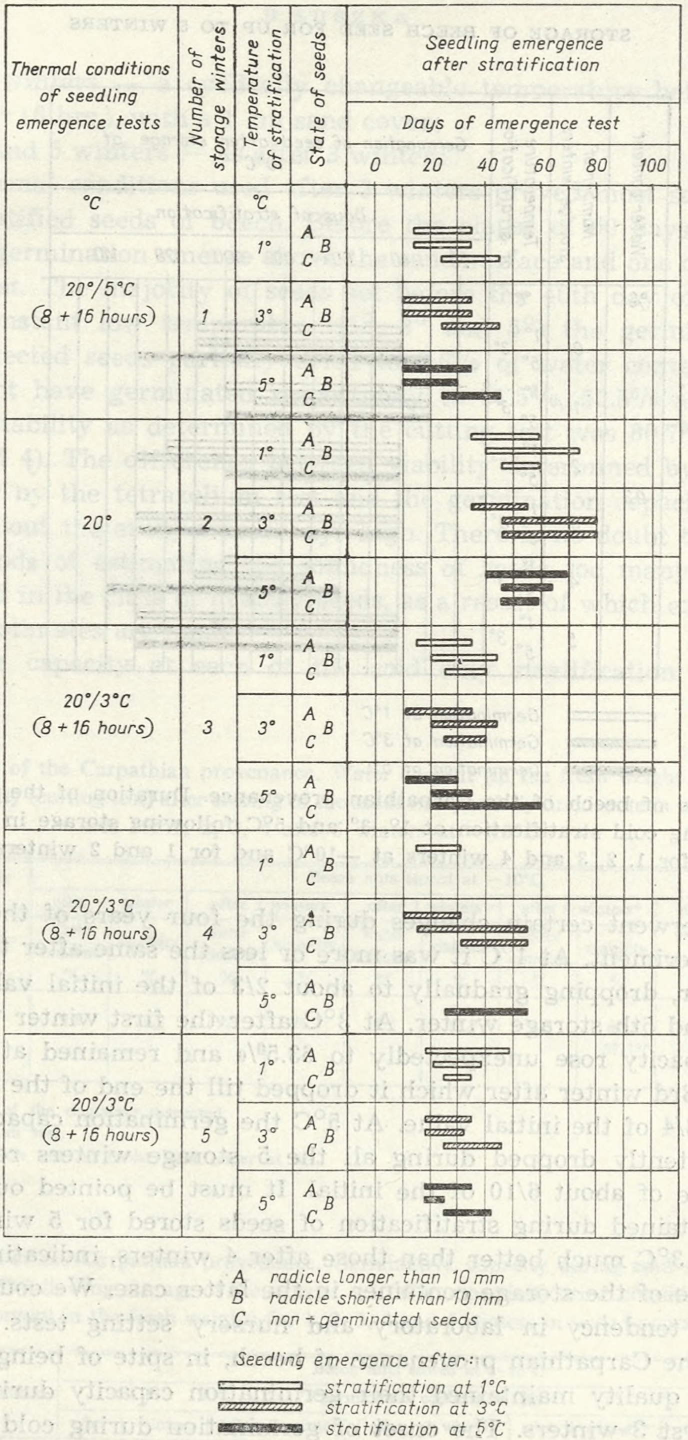

Fig. 7. Seeds of beech of the Carpathian origin stored for 1, 2, 3, 4 and 5 winters at —10°C in sealed containers. Duration of the period of seedling emergence laboratory tests, conducted using seeds that were previously stratified at 1°, 3° and 5°C, separated before sowing into seeds with radicles longer than 1 cm seeds with radicles shorter than 1 cm and non-germinating seeds. The seeds were covered by 1 cm of sand.

Table 5

Seeds of the Carpathian provenance stored for 1, 2, 3, 4 and 5 winters at −10°C in sealed containers previously stratified at 1°, 3° and 5°C, and separated before sowing into the following classes: with radicles longer than 1 cm, with radicles shorter than 1 cm, and non-germinating seeds

No. of storage winters at −10°C	Thermal conditions for the setting test	Seeds setting % in the laboratory of seeds which following stratification at								
		1°C			3°C			5°C		
		were ungerminated	had radicles below 1 cm	had radicles over 1 cm	were ungerminated	had radicles below 1 cm	had radicles over 1 cm	were ungerminated	had radicles below 1 cm	had radicles over 1 cm
1	5°/20°C (16+8 hours)	3.0	59.5	41.5	12.0	73.5	62.5	7.0	71.0	62.0
2	20°C (24 hours)	6.5	45.0	46.0	5.0	29.5	38.5	1.0	29.0	37.5
3	3°/20°C (16+8 hours)	7.0	81.0	87.5	16.0	80.6	83.5	11.0	67.0	74.4
4*	3°/20°C (16+8 hours)	0.0	not studied	48.0	2.5	12.5	25.0	6.5	not studied	
5	3°/20°C (16+8 hours)	13.0	37.3	53.5	30.5	62.7	50.5	11.5	30.4	9.0

* Leakage of the container suspected.

the various years only after the differences in the warm conditions supplied are taken into consideration. The most satisfactory results have been obtained at the cyclically changeable temperatures (Fig. 7), and these were better at 3°/20° after the third storage winter than at 5°/20°C after the first storage winter (Table 5). Nuts with radicles at the time of sowing shorter than 1 cm have continued germination and emerged to 74.4 - 87.5% (the highest value being after the stratification at 1°C), the seeds with radicles longer than 1 cm following stratification at 1° and 3°C have emerged to 81.0 and 80.6% respectively while after stratification at 5°C the setting percentage was only 67.0%. Seeds which in spite of the stratification were not germinated at the time of sowing have set to only 7 - 16%, the maximum being following stratification at 3°C.

The optimal conditions for the setting test were used also after the 4th storage winter, however as a result of a general lowering of seed viability (leakage of the container suspected) any benefits of that method were not demonstrable. At that time the best results were obtained following stratification at 1°C after which the seeds with a radicle shorter than 1 cm gave a setting percentage of only 48%. After 5 winters the results obtained in the laboratory tests were again much better for all temperatures and seed classes than after 4 winters, but for pregerminated seeds always worse than after 3 winters of storage.

When the span of the cyclically changeable temperatures was less (5°/20°C) as used after the first storage winter the setting results were

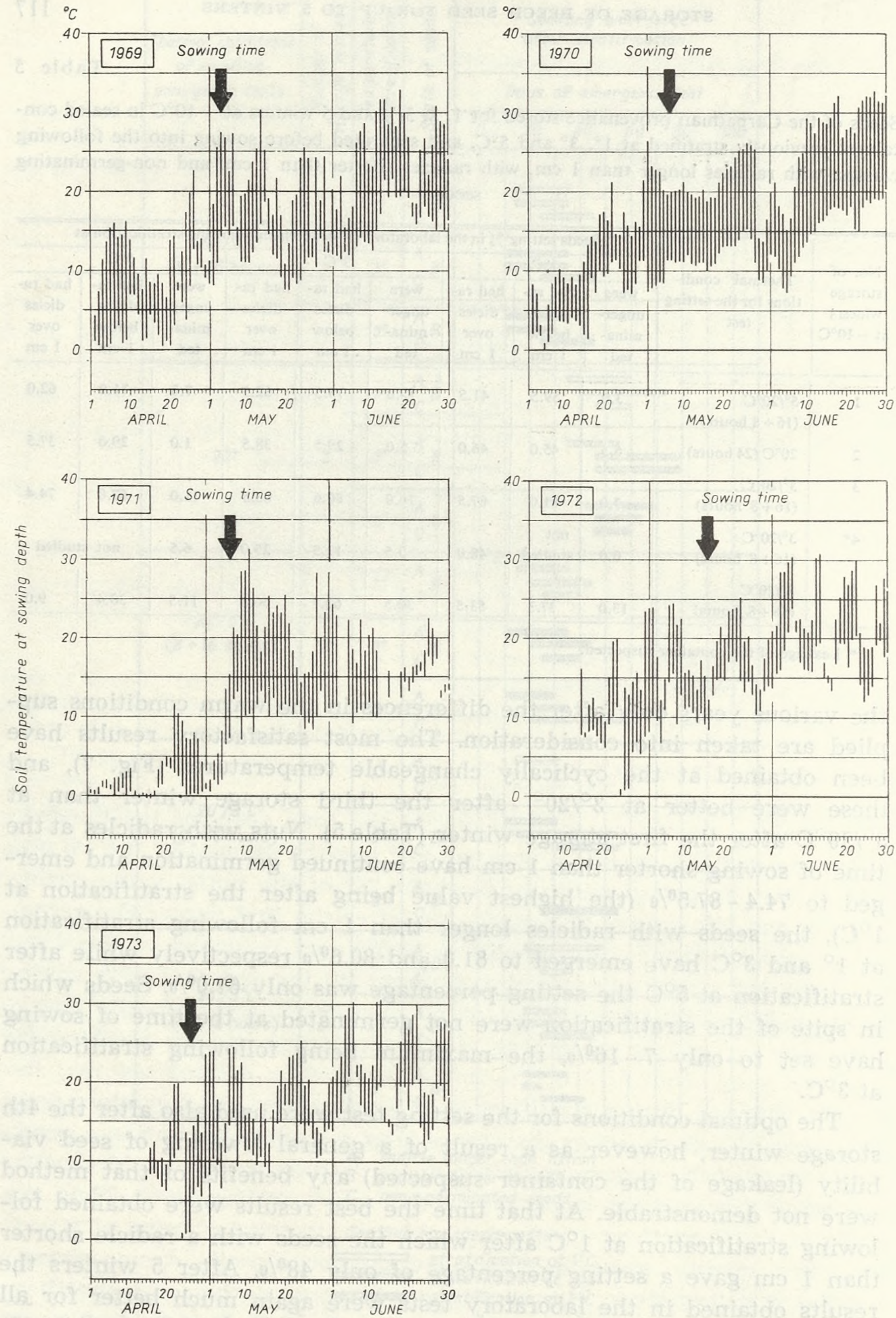

Fig. 8. Diurnal temperature fluctuations in the nursery soil at sowing depth for the seeds of the Carpathian beech provenance in the years 1969 - 1973. The data for 1969 come from a locality 1.5 km away from the nursery and therefore are only indicatory in nature

somewhat poorer. However at both the cyclically changeable temperature schemes (with the exception of storage over 4 winters) the results were superior to those obtained at a constant temperature of 20°C, which was used after 2 winters of storage.

The results obtained in the nursery after sowing of the stratified seeds have been determined by the temperature in the soil. In Fig. 8 data is given on the soil temperatures in the nursery during the growing periods for the years when the seeds of the Carpathian beech provenances were sown following storage at —10°C for 1, 2, 3, 4 and 5 winters. These graphs illustrate a considerable variability of the thermal conditions between the individual years, both as regards the occurrence of cold and warm periods and with respect to the amplitude of the daily temperatures.

The setting percentages obtained in the nursery were mostly lower (for any given seed lot) than in the laboratory (Tables 5 and 6). Only after the 2 storage winters, when in the laboratory the less satisfactory setting test was used at a constant 20°C temperature and after the 5 storage winters most of the results in the laboratory and in the nursery were very close.

After 1, 2, 3 and 5 storage winters, when the viability of seeds was still relatively high, the seeds germinated later (radicle less than 1 cm) during the 1° and 3°C stratification, have nearly always had a lower setting percentage in the nursery than seeds that have germinated earlier (radicles longer than 1 cm) while after stratification at 5°C the reverse was true. It turned out also after 1-3 winters that in the nursery only about a half or less on the seeds that were sown in a partially germinated state have emerged, and this irrespective of the stratification temperature that preceded the sowing. The rest of the seeds has lost its

Table 6

Seeds of the Carpathian provenance stored for 1, 2, 3, 4 and 5 winters at −10°C in sealed containers. Results of seed setting in the nursery. Before sowing the seeds were stratified at 1°, 3° or 5°C and then separated into the following classes: with radicles longer than 1 cm, with radicles shorter than 1 cm, and non-germinating seeds

No. of storage winters at −10°C	Seed setting % in the nursery of seeds which following stratification at								
	1°C			3°C			5°C		
	were ungerminated	had radicles below 1 cm	had radicles over 1 cm	were ungerminated	had radicles below 1 cm	had radicles over 1 cm	were ungerminated	had radicles below 1 cm	had radicles over 1 cm
1	6.4	32.4	44.4	21.3	51.2	62.8	26.4	63.2	59.2
2	7.6	36.8	49.6	15.0	28.5	36.4	27.5	46.0	32.0
3	2.8	39.2	58.8	19.2	50.0	56.0	20.0	55.2	47.5
4*	0.8	2.8	17.2	0.4	4.4	8.0	4.0	not studied	
5	7.6	38.6	46.4	11.2	58.0	48.0	6.4	30.0	23.2

* Leakage of the container suspected.

viability in the soil and died. For comparison it needs to be remembered that after 3 storage winters, when the most satisfactory setting test was used with a 3°/20°C temperature pattern and following stratification at 1° and 3°C about 80% or almost 90% of the germinated seeds have emerged in the laboratory from the medium. After stratification at 5°C the respective values were about 10% lower. A very low percentage of the seeds that were sown in an ungerminated state have set in the laboratory test. The partially germinated seeds that have not set in the tests have decayed. The ones that have not germinated in spite of the stratification were from the very beginning empty or dead.

To summarize the results of the studies on the storage of beech nuts from the Carpathian provenance that had an initially lower viability and germination capacity it can be said that after storing them in a partially dried (9.6% of water) state for the first 3 winters at —10°C, their viability and germination capacity does not undergo any greater changes regardless whether they were later stratified at 1°, 3° or 5°C. Partially germinated seeds stratified earlier at 1°, 3° or 5°C have set more or less evenly after sowing, and the values were always higher in the laboratory than in the nursery. In the laboratory conditions the best results were obtained with partially germinated seeds regardless whether the radicles were longer or shorter than 1 cm, when the temperature had a diurnal cyclic fluctuation (3°C 16 hrs, 20°C 8 hrs). In the nursery the results were nearly always better for seeds stratified at 1° or 3°C when the radicles at sowing time were longer than 1 cm and when in the first weeks after sowing the diurnal fluctuations of soil temperature were within the limits from 10 - 15°C to 25 - 30°C.

DISCUSSION

This paper is the first Polish report on a satisfactory storage of beech nuts under controlled conditions for 2, 3, 4 and 5 winters. About storage for one winter in such conditions, and the germination thereafter the author has reported earlier (Suszka, 1966). As regards earlier attemps, made in Poland Tyszkiewicz (1964) reports that the Kraków Forest Region in cooperation with the Seed and Selection Laboratory of the Forest Research Institute in Warsaw have attempted to store 4.18 tons of beech nuts in cold storage at +2°C to —2°C, in open and closed containers. Storage was begun in April 1959, about 6 months after collection. A part of the seeds was sown in a nursery in the spring of 1960 that is after a year and a half of storage. During that investigation it was found temperature control was sown in the autumn of the same year, i.e. in 1960 after a year and a half of storage. During that investigation it was found that only the nuts that have been maximally dried (to 16% of water content) have maintained in the closed containers an almost unchanged viability. Nuts stored in the open containers until the summer 1960 (for about 15 - 16 months) had a viability that was only slightly lowered compared with the initial value. Further data about this prematurely terminated experiment is unfortunately lacking: For example nothing is known about the germinative capacity of these seeds in laboratory or nursery conditions.

On the basis of data from foreign literature it is known that storing of beech nuts for several years, after drying to about 10% of water content, is possible in tightly sealed containers and at a temperature below 0°C. This has been reported by Nyholm (1960), Buszewicz (1964), Schönborn (1964) and Machaníček (1965). Presently it has been possible to show for the first time on high quality seed material of a Polish lowland provenance, that here also it is possible to store beech nuts for 4 winters, that is for 3½ years.

It has to be stressed however that the nuts of beech from the lowland provenance used here have been collected during seed fall and immediately subjected to drying at a temperature of about 20°C that is in conditions at which the after-ripening process could not have started. This differentiates the presented studies from all others known to the author on the storage of beech nuts. In the other studies use was made of nuts that after falling from the trees have been subjected for various lengths of time to the action of low temperatures of the autumn-winter period, which together with the initially high water content in the seeds must have resulted in the onset of the after-ripening process to an extent usually unkown to the investigator. As a result attempts at estimating the stratification period needed for the germination of beech seeds have led to completely diverse results. The method used by Machaníček (1965) is worth discussing here. Before drying the nuts he has kept them for 2 - 3 months at about 4°C with a rather high relative humidity of the air (about 75 - 80%) and taking care to maintain that humidity (shuffling of nuts having more than 20% of water content, and sprinkling those with less than 10%). As a result the seeds following partial drying to about 9 - 12% of water content and storage for any length of time up to 29 months required only a short, about 1 month long period of stratification at 4°C to attain a full germinative capacity.

In the present study beech nuts of lowland origin after a short storage period required a full stratification, since after falling from the trees the seeds were deliberately protected from low temperature until the partial drying was completed.

Beech nuts of the Carpathian provenance have germinated much earlier during the cold stratification than the nuts from the lowland provenance, the first radicles appearing after 30 - 40 days of the action of the low temperatures. In comparison with the seeds of the lowland provenance the onset of germination was therefore accelerated also by about 30 - 40 days. Since seed collection was made from the ground after the nuts have all completely fallen from the trees, one cannot say with any certainty, whether the seeds of the Carpathian provenance of beech have not undergone a partial after-ripening already while on the ground in the cold autumn conditions of the mountain region. It should be pointed out that during the last day of beech nut collection (26th October 1964) the first snow fell in the region of the Łomnica Mt. It is also possible that in view of the fact that in the mountain region the period between seed fall and onset of winter is shorter, the dormancy of nuts from mountain provenances may break earlier in low temperatures than is the case in seeds from ecotypes growing in the lowland regions of the species range. In our case both these factors could have acted simultaneously in the same direction.

The beech nuts from the Carpathian provenance, in spite of the fact that they were of much poorer quality, proved satisfactory for storage during the first three winters without major losses. This would indicate that when nuts of the highest quality are missing it is possible to store poorer ones. However then the cost of storage would include also the additional expense of storing the non-viable seeds that are difficult to separate out from the healthy ones.

It is worth noting that a delay in the onset of germination is observable during cold stratification of the lowland nuts after 3 or more winters of storage.

In the forest nursery practice the aim is to obtain a most energetic germination in the nursery. During cold stratification the germination takes too long. Seeds that have been previously stratified and then sown into a nursery soil, find thermal conditions that are not always satisfactory for energetic germination and rapid setting of all the seeds. In the present study it was shown that in the laboratory conditions the partially germinated seeds (during cold stratification) are capable of the earliest emergence, after 10 - 25 days, if after sowing the low stratification temperature is maintained, except that each day it raised for about 1/3 of the day, that is for 8 hours, to 20°C. Placing the seeds into a constant raised temperature (20°C) has resulted in delaying the onset of setting and an extension of its duration.

Thermal conditions satisfactory for energetic seeds setting can be supplied for the seeds by an appropriately early sowing, however in view of the considerable sensitivity of the young beech seedlings to late frosts this method would be too risky. An analysis of the changes and diurnal fluctuations in the soil temperatures in the nursery at the sowing depth leads to the conclusion that the best results (emergence of about 60% of the partially germinated seeds) were obtained in the year (1971) in which in the first weeks after sowing the lower limit of the diurnal temperature fluctuations was about 10°C and the upper limit about 25° - - 30°C. When the lower limit of the diurnal fluctuations was around 15°C (as in 1972) then the percentage of setting in relation to the number of seeds sown was much lower. Thus the exceptionally high spring temperature reduce the chances of setting even in the completely healthy and germinable seeds.

The program of studies on the seeds of beech has not been completed yet. It still remains to investigate such problems as the possibility of stratification in two stages, after collection but before partial drying aimed at long term storage and then after storage once again, in order to complete the after-ripening process that has been interrupted by the drying and the low storage temperatures.

Regardless of that there exist sufficient indications to merit a decision in the Polish conditions to equip the forest service with one or several smaller cold storage plants for the long-term storage of beech mast. In such cold storage units it would be possible to keep a seed reserve for 2 or even 3 years. Tyszkiewicz (1964) estimates that the annual beech seed reserve needed for the country, and assuming a rational and thrifty management is 25 tons. Thus the cold storage plants should hold 50 tons (for 2 years) or 75 tons (for 3 years) of seeds. Near such cold storage units equipment should be provided for rapid drying of large quantities of beech nuts at relatively low temperatures.

SUMMARY

1. Seeds of a lowland beech (*Fagus silvatica* L.) provenance of a high quality (germinative capacity above 90%), partially dried to 9 - 10% of water content in the fresh weight immediately after falling off the trees, have maintained their high germinative capacity in storage ar 3°C for at least 2 winters and at −10°C for 3 winters, while after 4 winters of storage at —10°C their germination capacity declined by about 1/4 to 1/5 of the initial value as estimated after the partial drying.

2. Similar seeds partially dried to 5.6% of water content were characterized by a lowered germinative, capacity, compared to the seeds kept at 9 - 10% of water content, and this difference was maintained during storage at 3°C for 1 and 2 winters and during storage at —10°C for 1, 2, 3 and 4 winters.

3. Seeds of a mountain (Carpathian) beech provenance, of a poorer initial quality (viability 81%, germinative capacity after partial drying 50 - 56%), which have been partially dried to 9,3% of water content in the fresh weight were characterized during the first 3 winters of storage at —10°C by a germination capacity similar to the initial value. Seed

stored over 5 winters begun to show a decline in germinative capacity particularily when stratified after storage at 5°C.

4. For the stratification of freshly collected and partially dried seeds or for those that were stored, the temperatures 1° and 3°C were equally satisfactory and somewhat better than the temperature 5°C.

5. The best conditions for the energetic setting of seeds that were stratified earlier and the majority of which was partially pregerminated at the time of sowing, is provided not by a constant high temperature but one that has cyclic diurnal fluctuations. A cycle of 16 hrs at the stratification temperature of 3°C and 8 hrs at a raised temperature of 20°C proved satisfactory. In these conditions the seeds sown on a germination medium (sand with peat 1 : 1) and covered with a 1 cm layer of sand emerged first, i.e. all were out between the 10 - 25 and 35 - 55th day of the seed setting test.

6. The best results of energetic and massive (up to 60%) seedling emergence seeds in the ground were obtained when the seeds that were stratified and the majority of which was partially pregerminated, were sown in the nursery to a depth of 1 cm and when the weather conditions allowed for diurnal temperature fluctuations in the soil with the lower temperature limit being at about 10°C and the upper one at around 25°-30°C, and while the moisture conditions in the soil were satisfactory.

7. The seeds of beech from the lowland provenance, that were collected and partially dried to 9 - 10% of water content immediately after falling off the trees, and stratified at 1°, 3° or 5°C after being stored for 1, 2, 3 or 4 winters have started to germinate after 70 - 80, 70 - 80, 90 and 100 - 110 days of stratification respectively.

The seeds of beech from the mountain provenance (time of seed fall prior to their collection unknown) following 1, 2, 3, 4 and 5 winters of storage, have started to germinate much earlier, during cold stratification on the above mentioned conditions, namely after 30 - 40, 30 - 40, 40, 60 - 70 and 40 days of stratification respectively. Particularily for the lowland provenance it was established that as the duration of storage was extended the germination during cold stratification was delayed.

From the data presented above the following general conclusion can be drawn:

Storing of partially dried nuts of beech in tightly sealed containers and in low temperatures on a commercial scale is possible for 1, 2 and 3 winters and in the case of seed of high quality even for the 4th winter, and should be employed in the forest practice. In this way reserves could be accumulated during seed years and maintained for several years having in mind the fact that periods without a beech mast can be long lasting.

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BOLESŁAW SUSZKA

Przechowywanie nasion buka zwyczajnego (Fagus silvatica L.) do 5 wiosny po zbiorze

Streszczenie

W Zakładzie Dendrologii i Arboretum Kórnickim Polskiej Akademii Nauk w Kórniku prowadzono w latach 1964 - 1973 badania nad wieloletnim przechowywaniem nasion buka zwyczajnego (*Fagus silvatica* L.). W latach 1964 - 1968 użyto do badań bukwi wysokiej jakości. Zebrano ją w Kórniku koło Poznania (65 m n.p.m., proweniencja nizinna), w miarę opadania z drzew i natychmiast podsuszono w około 20°C do 10,0%, 9,1% i 5,7% zawartości wody w świeżej masie. Następnie przechowywano nasiona w szczelnie zamkniętych butlach szklanych w 3°C (±0,5°C) przez 1 i 2 zimy oraz w —10°C (±1°C) przez 1, 2, 3 i 4 zimy. Butle otwierano tylko jeden raz po zakończeniu każdego okresu przechowywania. Nasiona stratyfikowano w wilgotnej mieszaninie piasku z przetartym torfem (1 : 1) w 1°, 3° i 5°C zaraz po podsuszeniu oraz po każdym sezonie przechowywania w celu ustalenia zdolności kiełkowania w obniżonej temperaturze.

W latach 1968 - 1973 użyto do badań nasion gorszej jakości, zebranych już po opadnięciu z drzew na górze Łomnicy w Beskidzie Sądeckim w okolicy Muszyny nad Popradem (900 m n.p.m., proweniencja karpacka). Orzeszki podsuszono niezwłocznie w 15° - 20°C do 9,3% zawartości wody w świeżej masie i przechowywano w —10°C w szczelnie zamkniętych pojemnikach z polistyrenu, otwieranych tylko jeden raz po zakończeniu przechowywania. Zaraz po podsuszeniu i po przechowywaniu podsuszonej bukwi przez 1, 2, 3, 4 i 5 zim orzeszki stratyfikowano w 1°, 3° i 5°C w celu określenia zdolności kiełkowania w temperaturze obniżonej. Niezależnie od tego, po nagromadzeniu się większej ilości nasion podkiełkowanych podczas innej równoczesnej stratyfikacji, jedną ich część wysiewano w szkółce w układzie bloków losowanych z 5 powtórzeniami (po 50 lub w niektórych przypadkach poniżej 50 orzeszków na każdy wariant i powtórzenie), a drugą umieszczano w kon-

trolowanych warunkach laboratoryjnych w kiełkownikach wypełnionych mieszaniną piasku z torfem, gdzie były przykrywane 1-centymetrową warstwą piasku. Badania laboratoryjne, w których zastosowano temperaturę stałą (20°C) albo zmienną w cyklu dobowym (5°/20°C lub 3°/20°C, 16+8 godzin) miały na celu ustalenie możliwie najlepszych warunków termicznych dla próby wschodzenia stratyfikowanych i w swej większości podkiełkowanych nasion. Większość stratyfikacji i prób laboratoryjnych przeprowadzono w 4 powtórzeniach po 50 nasion każde. Wyniki badań przedstawiają się następująco:

1. Nasiona buka wysokiej jakości (proweniencja nizinna, zdrowotność i zdolność kiełkowania powyżej 90%), podsuszone zaraz po opadnięciu z drzew do 9 - 10% zawartości wody w świeżej masie, zachowywały podczas przechowywania w zamkniętych szczelnie pojemnikach przez pierwsze 2 zimy w 3°C i przez pierwsze 3 zimy w —10°C niezmienioną zdolność kiełkowania (powyżej 90%). Po 4 zimach przechowywania w —10°C ich zdolność kiełkowania obniżyła się o 1/4 - 1/5 wartości początkowej (po podsuszeniu).

2. Takie same nasiona podsuszone do 5,6% zawartości wody charakteryzowały się obniżoną zdolnością kiełkowania, która podczas przechowywania w 3°C przez 1 i 2 zimy, a w —10°C przez 1, 2, 3 i 4 zimy utrzymywała się na niższym poziomie niż zdolność kiełkowania nasion podsuszonych do 9 - 10% zawartości wody.

3. Nasiona buka niższej jakości (proweniencja karpacka, zdrowotność nasion 81%, zdolność kiełkowania 50 - 56% po podsuszeniu), podsuszone po zbiorze do 9,3% zawartości wody w świeżej masie, charakteryzowały się przez pierwsze 3 zimy przechowywania w —10°C zdolnością kiełkowania zbliżoną do wyjściowej lub od niej maksymalnie o 1/5 wyższą lub niższą. U nasion przechowywanych przez 5 zim spadek zdolności kiełkowania był wyraźny, zwłaszcza jeśli po zakończeniu przechowywania stratyfikowano je nie w 1° lub 3°C, lecz w 5°C.

4. Dla stratyfikacji świeżo zebranych i podsuszonych, jak i przechowywanych nasion buka, temperatury 1° i 3°C były jednakowo przydatne i nieco bardziej korzystne niż temperatura 5°C.

5. Najlepsze warunki dla energicznego wzejścia stratyfikowanych uprzednio i w swej większości podkiełkowanych nasion buka zabezpiecza po wysiewie temperatura zmienna w cyklu dobowym. Każdy cykl obejmuje 16 godzin w temperaturze stratyfikacji (3°C) i 8 godzin w temperaturze podwyższonej (20°C). W tych warunkach nasiona wysiane w kiełkownikach (piasek z torfem 1 : 1) i pokryte warstwą piasku grubości 1 cm wschodziły najwcześniej, bo między 10 - 25 (początek) a 35 - 55 (koniec) dniem próby wschodzenia.

6. Dobre warunki dla energicznego i masowego (do 60%) wschodzenia w gruncie znajdowały stratyfikowane uprzednio i podkiełkowane w swej większości nasiona buka, wysiane w szkółce na głębokości 1 cm w latach, w których dolna granica dobowych wahań temperatury gleby była w pierwszych tygodniach po wysiewie zbliżona do 10°C, a wahania temperatury przy zadowalającej wilgotności gleby były duże (górna granica 25° - 30°C).

7. Nasiona buka proweniencji nizinnej, zebrane i zaraz po opadnięciu drzew podsuszone do 9 - 10% zawartości wody oraz po przechowaniu przez 1, 2, 3 i 4 zimy stratyfikowane w 1°, 3° lub 5°C, rozpoczynały kiełkowanie odpowiednio po: 70 - 80, 70 - 80, 90 i 100 - 110 dniach stratyfikacji. Nasiona buka proweniencji górskiej, po 1, 2, 3, 4 i 5 zimach przechowywania kiełkowały podczas stratyfikacji w podanych wyżej warunkach znacznie wcześniej, bo odpowiednio po: 30 - 40, 30 - 40, 40, 60 - 70 i 40 dniach stratyfikacji. Stwierdzono więc, że w miarę upływu okresu przechowywania kiełkowanie podczas stratyfikacji chłodnej rozpoczynało się w przypadku proweniencji nizinnej coraz później, zwłaszcza po 3 i 4 zimie.

Z przedstawionych powyżej wyników można wyciągnąć następujący wniosek generalny: Przechowywanie podsuszonych orzeszków buka w szczelnie zamkniętych pojemnikach i w obniżonej temperaturze na skalę masową przez 1, 2 i 3 zimy, a w przypadku nasion wysokiej jakości nawet przez 4 zimy jest możliwe i powinno znaleźć zastosowanie w gospodarce leśnej. Można by w ten sposób gromadzić wieloletnie rezerwy nasienne, mając na uwadze długotrwałość okresów nieurodzaju nasion.

БОЛЕСЛАВ СУШКА

Хранение семян бука европейского (Fagus silvatica L.) до 5 весны после сбора

Резюме

В Институте дендрологии в Курницком арборетуме Польской академии наук (Курник) в 1964 - 1973 гг. изучалось многолетнее хранение семян бука европейского (*Fagus silvatica* L.). В 1964 - 1968 гг. для опытов были взяты буковые орехи высокого качества. Собирали их в Курнике около Познани (65 м над ур. м., происхождение низинное) по мере опадения с деревьев их немедленно подсушивали при температуре около 20°C до 10,0%, 9,1% и 5,7% содержания воды в свежей массе. После этого семена хранили в герметически закрытых стеклянных бутылях при 3°C (± 0,5°) в течение одной и двух зим и при — 10°C (±1,0°) в течение одной, двух, трёх и четырёх зим. Бутыли открывались только один раз — после завершения каждого срока хранения. Семена стратифицировались сразу после подсушивания и после каждого сезона хранения в целях выяснения способности к прорастанию в пониженной температуре.

В 1968 - 1973 гг. для опытов брались семена худшего качества, собранные после их опадения с деревьев на горе Ломнице в Сондецких Бескидах (Польские Карпаты) в окрестностях Мушины на Попраде. Орехи сразу подсушивались при 15° - 20°C до 9, 3% содержания воды в свежей массе и далее хранились в герметически закрытых сосудах из полистирена, которые открывались однократно — после окончания хранения. Сразу после подсушивания орехов и после хранения их в сосудах в течение одной, двух, трёх, четрыёх и пяти зим они подвергались стратификации при 1°, 3° и 5°C, также в целях определения их прорастаемости при пониженной температуре. Независимо от этого, после накопления достаточно большого количества проросших семян, часть из них высевалась в питомнике в порядке, определённом жеребьёвкой (рандомизированные блоки), и в пяти повторностях (по 50 орехов на каждый вариант и повторность). Кроме того, семена помещали в контролируемых лабораторных условиях в специальные сосуды для прорастания, заполненные смесью песка и торфа; при этом семена прикрывались слоем песка в 1 см. Лабораторные исследования проводились при постоянной температуре (20°C) или при переменной — с суточным циклом (5°/20°C или 3°/20°C, по 16+8 часов). Они имели целью установление оптимальных температурных условий для изучения всхожести стратифицированных и в своём большинстве проклюнувшихся семян. Стратификация и лабораторные опыты во всех случаях проводились в четырёх повторностях по 50 семян в каждой. Исследования приводят к следующим результатам:

1. Семена бука европейского высокого качества (происхождение низинное, жизненность и способность к прорастанию выше 90%), просушенные сразу после падения с деревьев до 9 - 10% содержания воды в свежей массе, при хранении их в герметически закупоренных сосудах при температуре 3°C сохраняют способность к прорастанию в течение первых двух зим, а при — 10°C — в течение трёх зим. После хранения при — 10°C в течение четырёх зим прорастаемость падает на 20 - 25% по сравнению с начальной (после подсушивания).

2. Те же самые семена, подсушенные до 5,6% содержания воды, характеризова-

лись пониженной способностью к прорастанию. При хранении семян при 3°C в течение одной и двух зим, а при — 10°C от одной до четырёх зим она была на более низком уровне, чем у семян, подсушенных до 9 - 10% содержания воды.

3. Семена бука низкого качества (происхождение карпатское, жизненность семян — 81%, способность к прорастанию после подсушивания — 50 - 56%), подсушенные после сбора до 9,3% содержания воды в свежей массе характеризуются в течение первых трёх зим хранения при — 10°C способностью прорастания, близкой к исходной. У семян, хранимых в течение 5 зим, было выразительное падение способности к прорастанию, в особенности, если после срока хранения они стратифицировались не при 1°C либо 3°C, а при 5°C.

4. Для стратификации свежесобранных и подсушенных семян бука а также семян подвергнутых хранению, одинаково благоприятны как 1°C, так и 3°C; несколько менее благоприятна температура 5°C.

5. Оптимальные условия для энергичного всхода предварительно стратифицированных и в своём большинстве наклюнувшихся семян бука создаёт переменная температура суточного цикла. Каждый цикл охватывает 16 часов низкой температуры стратификации (3°C) и 8 часов повышенной температуры (20°C). В этих условиях раньше всего всходят семена, высеянные в смесь песка с торфом (1 : 1) и покрытые слоем песка полщиной в 1 см, а именно — между 10 - 25 и 35 - 55 днями опыта.

6. Оптимальные условия для энергичного появления всходов у предварительно стратифицированных и в своём большинстве наклюнувшихся семян бука создаются при их высеве в питомниках на глубину 1 см. Это имело место в те годы, когда нижняя граница суточных колебаний температуры почвы была в перые недели после высева близка к 10°C, а сами колебания были при нормальной влажности почвы довольно большими (верхняя граница равна 25° - 30°C).

7. Семена бука с деревьев низинного происхождения, собранные сразу же после опадения с деревьев, подсушенные до 9 - 10% содержания воды, а также после хранения их от одной до четырёх зим при стратификации их в температурных условиях 1°, 3° и 5°C начали прорастать соответственно через 70 - 80, 70 - 80, 90 и 100 - 110 дней с начала стратификации. Семена бука из горных районов после хранения их от одной до пяти зим и стратификации в указанных выше условиях прорастали значительно раньше, а именно — через 30 - 40, 30 - 40, 40, 60 - 70 и 40 дней. Следовательно, в обоих вариантах при длительном хранении семян их прорастание наступает всё позже, особенно у семян низинного происхождения после третьей и четвёртой зимы.

Из представленных выше результатов можно сделать следующий общий вывод: Хранение подсушенных орешков бука в герметически закрытых сосудах в массовом масштабе в продолжение 1, 2 и 3 зим, а в случае высокого качества семян даже в продолжение 4 зим в контролированных условиях в холодильниках является возможным и должно применяться в лесном хозяйстве. Таким способом можно было бы накоплять многолетние семенные запасы, принимая во внимание продолжительность периода неурожая семян.