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Interspecific Difference in Seed Germination of the Genus *Avena* at Various Temperatures

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Abstract

Germination of seeds in different diploid, tetraploid and hexaploid *Avena* species as affected by temperatures of 18°, 24° and 30℃ was examined. Most species of seeds stored for 5 to 6 months after harvesting showed the decrease in seed germination percentage as the temperature increased. The poor germination of seeds at 30℃ was attributed to secondary dormancy induced by exposing to a high temperature. The seeds became capable of germinating at the same temperature after having stored for 10 to 11 months.

The short-term stored seeds of *Avena hirtula* (As), *A. wiestii* (As), *A. magna* (AC), *A. murphyi* (AC), *A. fatua* (ACD) and *A. sterilis* (ACD) showed a deep secondary dormancy, while those of *A. ventricosa* (C_v), *A. strigosa* (As), *A. vaviloviana* (AsB), *A. barbata* (AsB), *A. abyssinica* (AsB), *A. byzantina* (ACD) and *A. sativa* (ACD) were nondormant or releasing from the secondary dormancy.

Germinability of seeds at various temperatures in *Avena* species is discussed in relation to genealogy of the genus *Avena*, dormancy-relating genes and ecological adaptation of the species to temperature.

Key words: Genus *Avena* · Secondary dormancy · Seed germination · Temperatures

Introduction

NISHIYAMA and INAMORI[3] studied seed germination at 27℃ with seeds of different diploid, tetraploid and hexaploid *Avena* species stored at room temperature over four months after harvesting. They reported that seeds of all diploid and tetraploid species tested showed a long period of dormancy, except for *A. abyssinica* which was not dormant. In hexaploid species a large variation among species has been found in the dormant period, ranging from 120 days for *A. fatua* to nondormant period for *A. sativa* var. Banner.

In the present study, germination of seeds (strictly speaking caryopsis) in different diploid, tetraploid and hexaploid *Avena* species, including those used in NISHIYAMA's experiments[3] was examined at constant temperatures of 18°, 24° and 30℃. The seeds used were stored at room temperature for 5 to 6 months and 10 to 11 months after harvesting.

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Materials and Methods

Seeds of 18 *Avena* species differing in ploidy level were supplied from Emeritus Prof. I. NISHIYAMA, Kyoto University and Dr. MORIKAWA, Osaka Pref. University. The diploids were *Avena hirtula* (As), *A. wiestii* (As), *A. strigosa* (As), *A. clauda* (C_c), *A. pilosa* (C_p), *A. ventricosa* (C_v), *A. longiglumis* (A_l) and *A. damascena* (A_d); tetraploids, *A. barbata* (AsB), *A. vaviloviana* (AsB) and *A. abyssinica* (AsB), *A. magna* (AC) and *A. murphyi* (AC); hexaploids, *A. fatua* (ACD), *A. sterilis* (ACD), *A. byzantina* (ACD), *A. sativa* (ACD) var. Aurora and *A. nuda* (ACD). Alphabetical letters in parentheses indicate genome groups. A preliminary genealogy of these species has been proposed by I. NISHIYAMA[2] as shown in Fig.1.

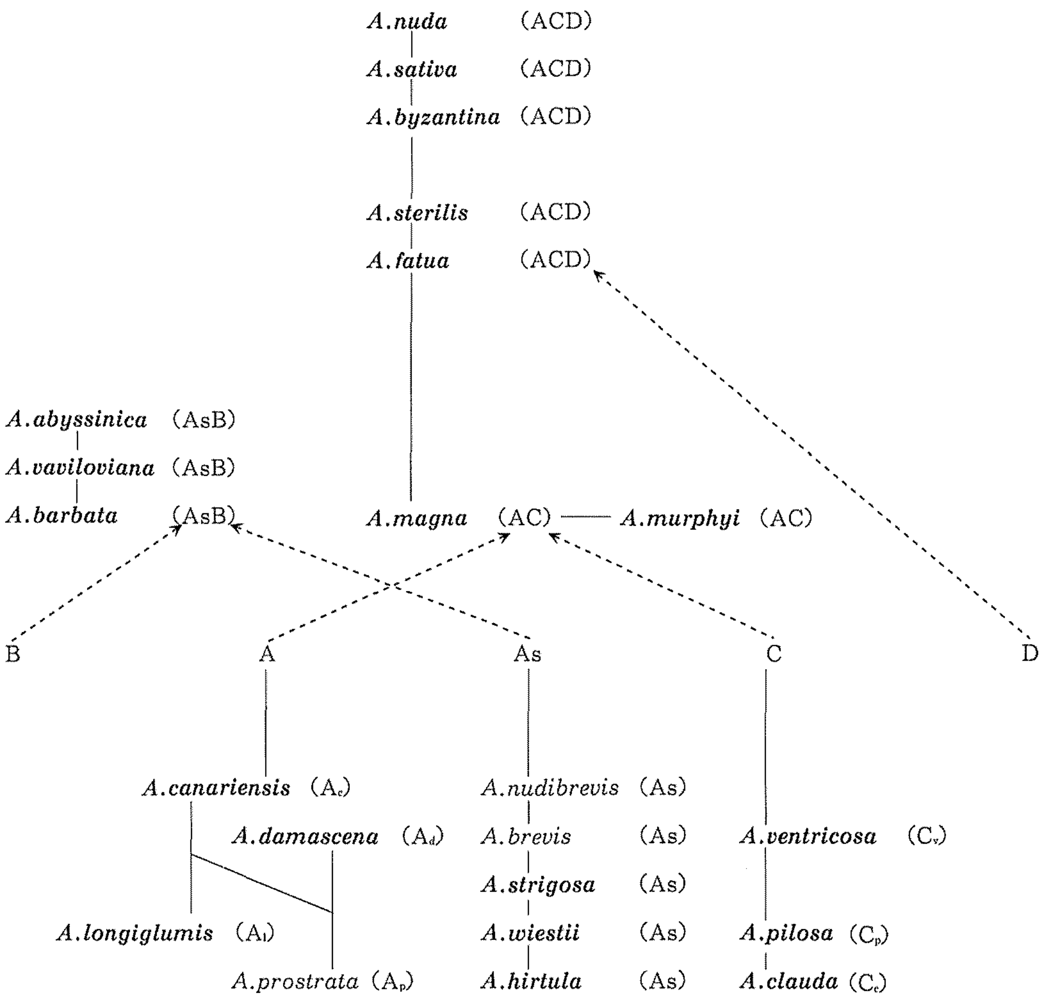

Fig. 1. Genealogy of different diploid, tetraploid and hexaploid *Avena* species[2]. The species written in bold letters were used in the present experiment. Alphabetical letters in parentheses indicate genome group.

In late autumn germinating seeds were planted in clay pots filled with a garden soil and grown in a glasshouse during winter. In early spring, the plants were transferred to the outdoors. The diploid species and *A. abyssinica* emerged their ears 2 to 3 weeks earlier than most tetraploid and hexaploid species. Diploid species produced relatively small seeds, their size being 4.5 to 7.5 mm in length, 1.0 to 2.0 mm in width and 3.0 to 10.0 mg in weight. Seed size of tetraploid species was 6.5 to 9.5 mm in length, 1.5 to 4.0 mm in width and 6.0 to 27.0 mg in weight, and those of hexaploid species was 7.0 to 9.5 mm in length, 2.0 to 3.0 mm in width and 11.5 to 27.0 mg in weight.

Husked seeds were harvested at maturity in mid-May to mid-June. They were stored for 5 to 6 months (short-term storage) and 10 to 11 months (long-term storage) at room temperature in a vinyl bag with silica gel as dessicant.

After storage, 20−30 dehusked seeds were placed on a sheet of filter paper (Toyo No.3) moistened with 5 ml of distilled water in a flat petri dish of 9 cm in diameter. They were kept at temperatures of 18°, 24° and 30℃ of dark chambers. Germination was assessed daily for 7 days after imbibition, seed germination being defined as the emergence of the coleoptile or coleorrhiza from the seed coat. Germinated seeds are given as a percentage to total number of seeds tested.

Results

Diploids

Germination percentages at 18°, 24° and 30℃ for short-term stored seeds of different diploid *Avena* species are shown in Fig. 2-a, b and c, respectively.

At 18℃, *A. ventricosa* and *A. strigosa* seeds showed 100% germination within 2 days. Germiation of *A. pilosa*, *A. wiestii* and *A. clauda* seeds also took place one day after imbibition and reached 100% within 5 days. Germination of *A. longiglumis*, *A. damascena* and *A. hirtula* seeds occurred within 2 days and reached 50 to 70% after 4 days and levelled off thereafter.

At 24℃, it took 3 to 4 days for 100% germination in *A. strigosa*, *A. ventricosa* and *A. pilosa* seeds and 6 days were needed in *A. clauda* seeds. The germination of *A. longiglumis*, *A. damascena*, *A. hirtula* and *A. wiestii* seeds reached a plateau at 40 to 70% after 4 and 5 days. As a whole, germination of all diploid species seeds at 24℃ was inhibited compared to that at 18℃ except for *A. longiglumis* seeds whose germination became higher by about 20% at 24℃ than at 18℃.

In contrast, temperature of 30℃ greatly inhibited seed germination in all species. For instance, the maximum germination percentages of *A. ventricosa* and *A. strigosa* seeds were 60 to 70% and those of *A. pilosa*, *A. damascena*, *A. longiglumis* and *A. clauda* seeds were 40% or lower. *A. hirtula* and *A. wiestii* seeds did not germinate at all even after 7 days.

When the long-term stored seeds were tested for their germination at either 18° or 30℃, seeds of all diploid species showed 100% germination within 3 days at both temperatures except for *A. wiestii* seeds whose germination reached 50% after 7 days at 30℃ (Fig. 2-d).

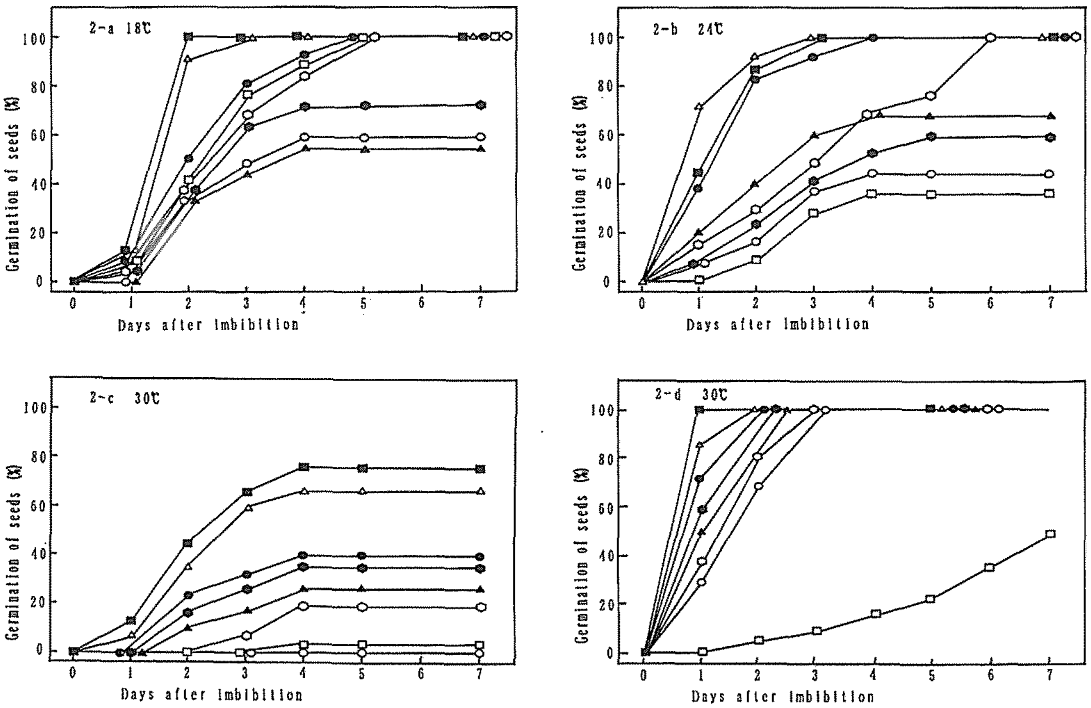

Fig. 2. Germination of diploid *Avena* species seeds at various temperatures after storage for 5 to 6 months (2-a : 18℃, 2-b : 24℃, 2-c : 30℃) at 30℃ after storage for 10 to 11 months (2-d). *A. hirtula* (○), *A. wiestii* (□), *A. strigosa* (△), *A. clauda* (⬡), *A. pilosa* (●), *A. ventricosa* (■), *A. longiglumis* (▲) and *A. damascena* (⬢).

Tetraploids

Germination percentages at 18°, 24° and 30℃ in short-term stored seeds of different tetraploid *Avena* species are shown in Fig. 3-a, b and c, respectively.

At 18℃, *A. abyssinica, A. vaviloviana, A. barbata* and *A. murphyi* seeds showed 100% germination within 2, 4, 5 and 6 days, respectively. Germination of *A. magna* seeds reached 55% after 5 days and levelled off thereafter.

At 24℃, *A. abyssinica, A. vaviloviana* and *A. barbata* seeds germinated with a similar pattern to those at 18 ℃, while *A. magna* and *A. murphyi* seeds showed low germination percentages of 40 and 20% after 5 days, respectively.

At 30℃, *A. abyssinica* seeds showed 100% germination within one day and *A. vaviloviana* and *A. barbata* seeds gave 60 to 70% germination after 5 days and levelled off thereafter. The germination percentages of *A. magna* and *A. murphyi* seeds were lower than 20% after 5 days and no seeds germinated thereafter.

In contrast, *A. abyssinica, A. vaviloviana* and *A. barbata* seeds stored for the long term showed 100% germination within 2 days at either 18° or 30℃. *A. murphyi* and *A. magna* seeds also gave 100% germination at 18℃ within 3 days, but they showed lower germination percentages of 60 to 70% at 30℃ after 6 days (Fig. 3−d).

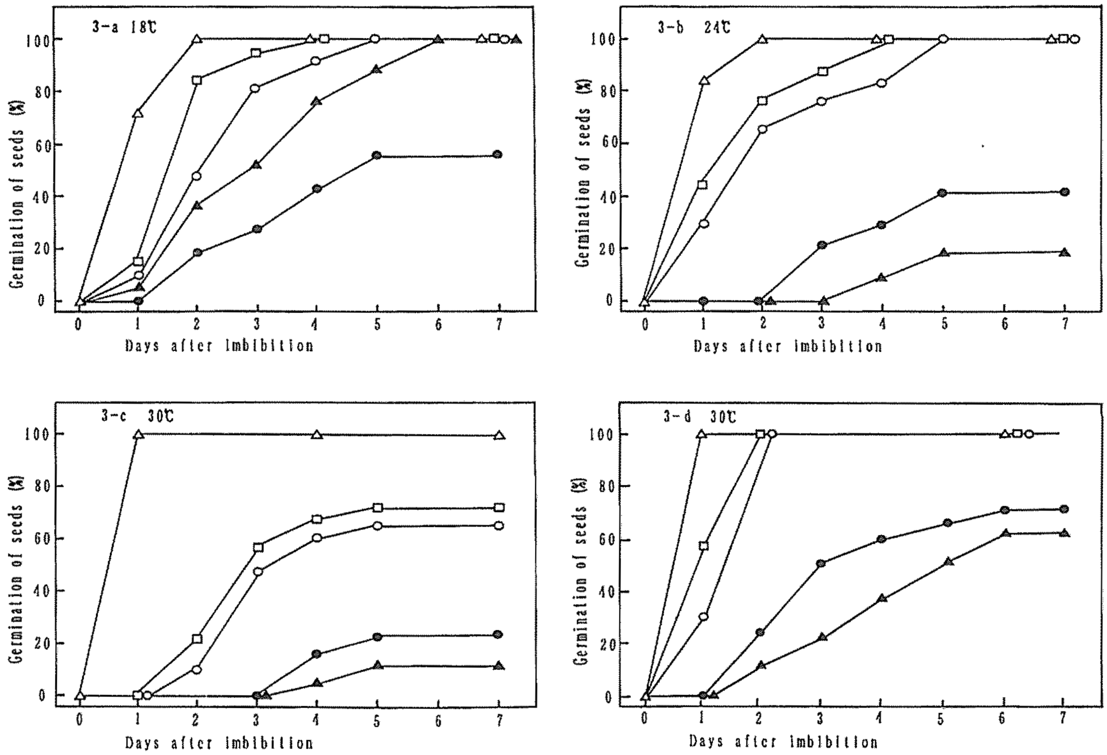

Fig. 3. Germination of tetraploid *Avena* species seeds at various temperatures after storage for 5 to 6 months (3-a : 18℃, 3-b : 24℃, 3-c : 30℃) and at 30℃ after storage for 10 to 11 months (3-d). *A. barbata* (○), *A. vaviloviana* (□), *A. abyssinica* (△), *A. magna* (●) and *A. murphyi* (▲).

Hexaploids

Germination percentages at 18°, 24° and 30℃ in short-term stored seeds of different hexaploid *Avena* species are shown in Fig. 4-a, b and c, respectively.

A. sativa, *A. byzantina* and *A. nuda* seeds showed 100% germination within 2 and 3 days at 18° as well as at 24℃. However, *A. sterilis* and *A. fatua* seeds gave only 45 and 28%, respectively, even at 18℃. Germination of *A. sterilis* and *A. fatua* seeds was further inhibited at higher temperatures; the former species seeds gave 30% germination at 24℃ and no seeds germinated at 30℃. The latter species seeds did not germinate at all at either 24°or 30℃. In contrast, *A. sativa* seeds showed 100% germination within 3 days even at 30℃, and *A. byzantina* and *A. nuda* seeds gave about 60 and 40% germination after 5 days, respectively.

The long-term stored seeds showed an increase in germination percentages compared to the short-term stored seeds. For instance, *A. sativa*, *A. byzantina* and *A. nuda* seeds showed 100% germination within one day at either 18°or 30℃. *A. sterilis* and *A. fatua* seeds also showed 100% germination within 4 days at 18℃. But at 30℃ the former species seeds gave 60% germination after 5 days and the latter species ones did not germinate at all (Fig. 4-d).

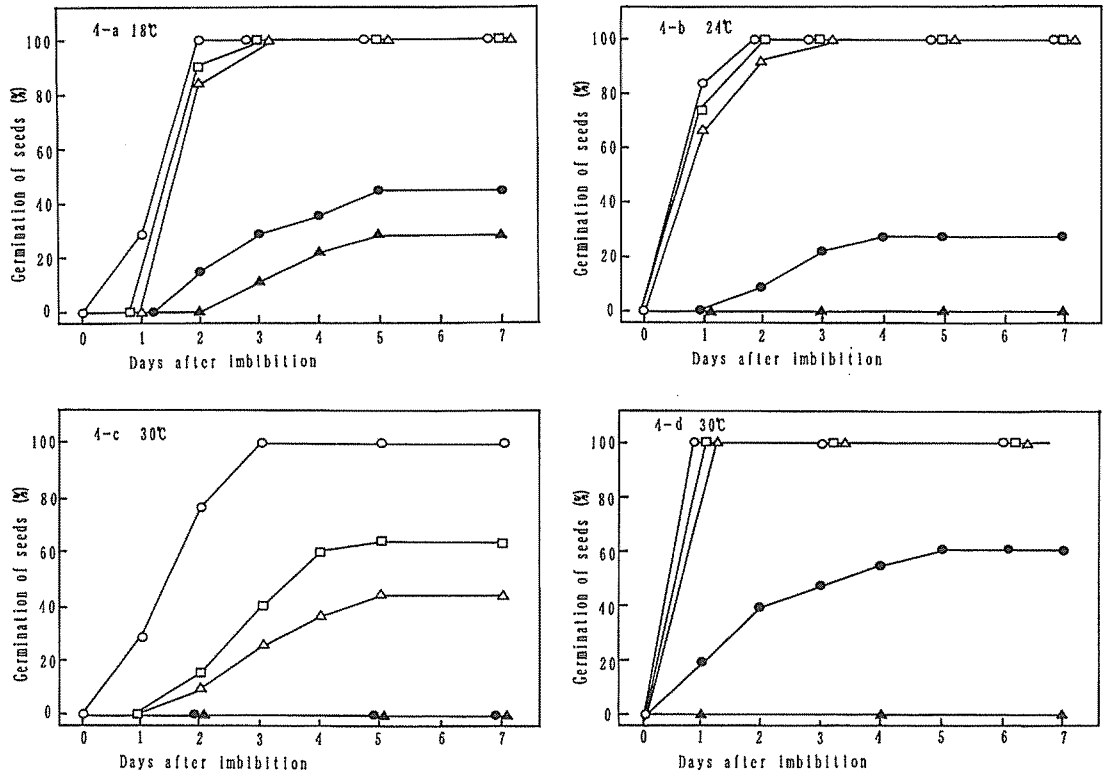

Fig. 4. Germination of hexaploid *Avena* species seeds at various temperatures after storage for 5 to 6 months (4-a : 18℃, 4-b : 24℃, 4-c : 30℃) and at 30℃ after storage for 10 to 11 months (4-d). *A. fatua* (▲), *A. sterilis* (●), *A. byzantina* (□), *A. sativa* (○) and *A. nuda* (△).

Discussion

Seeds of most *Avena* species of any ploidy levels were able to germinate well at 18℃ (80−100%) after 5 to 6 months storage. However, the seed germination was greatly inhibited at 30℃. The seeds ungerminated in the incubation period never germinated ever thereafter so long as the seeds were placed at 30℃. This poor germination at 30℃ in these species was largely relieved by extending a storage period to 10 to 11 months. Furthermore, the short-term stored seeds that germinated at any temperature showed a vigorous growth of seedlings. These evidence suggests that temperature of 30℃ per se is not hyperthermic for either seed germination or seedling growth in *Avena* species. Therefore, poor germination at 30℃ in the short-term stored seeds must have resulted from secondary dormancy induced by exposing to such high temperature, as described previously for *A. fatua*.[4] It is well known that the last phase of the dormancy of seeds and buds, which is not yet terminated, be reversed by some environmental conditions, resulting in entering in true dormancy again[7]. This phenomenon is termed as secondary dormancy[8]. From this, it may be concluded that in most *Avena* species tested the storage of seeds for 5 to 6 months at room temperature is insufficient for termination of their secondary dormancy and the storage period of 10 months or more is necessary. Indeed, *A. fatua* seeds required more than 32 months to terminate the secondary dormancy[4].

The diploid *Avena* species mostly grow as wild and weed population in dry steppes and fields of Mediterranean regions extending from Morocco and Spain to Israel and Iran[1,9]. In the native habitat, seeds of these species would be in a dormant state under hot and dry conditions throughout the summer of several months after seed maturation, during which the seeds undergo afterripening. Then, they become capable of germinating under autumnal low temperature conditions with rain.

The short-term stored seeds of tetraploid species such as *A. abyssinica*, *A. vaviloviana* and *A. barbata*, all belong to the AsB genome group, were able to germinate well even at 30℃. This is consistent with our previous finding with *A. abyssinica*[3,5]. Thus, the AsB genome probably carries the least numbers of dormancy-relating genes. On the other hand, the short-term stored seeds of tetraploids, *A. magna* and *A. murphyi* (AC) showed poor germinability at 30℃. Furthermore, hexaploids, *A. fatua* and *A. sterilis* (ACD), showed the lowest seed germination at 30℃ among all species tested. These results suggest that the AC genome carries abundant dormancy-relating genes. Alternatively, dormancy-relating genes in the AC genome are frequently expressed upon exposure to 30℃ unless the seeds are completely released from dormancy. It has been proposed that *A. magna* and *A. murphyi* are tetraploidal parents of hexaploid *A. fatua* and *A. sterilis*[1,9]. Short-term stored seeds of *A. ventricosa* and *A. strigosa* were able to germinate at 30℃. These species grow wild in Algeria and Lybia and the latter species is the only diploid species that is cultivated[9]. A tetraploid *A. abyssinica* and a hexaploid *A. byzantina* whose seeds of short-term storage were capable of germinating well at 30℃ are also a cultivated type, and the former species grows wild in the steppes of Ethiopia[1,9]. The ability of these species seeds to germinate well at such high temperature could be attributable to a small number of active dormancy-relating genes in the genome and to high adaptation of these species to temperatures prevailing in the cultivation areas.

Probably, the same is the case for *A. sativa*. This species is a well-known cultivated species, and the seeds showed high germination percentages at 30℃ irrespective of the storage period. It has been proposed that *A. sativa* has been established from many wild species including *A. fatua*, *A. sterilis* and *A. byzantina* through natural crossing among them as well as artificial selection[1,9]. Identification and characterization of dormancy-relating genes are prerequisite to description about the physiological basis of the gene action on the seed germination at high temperature in different species of the genus *Avena*.

Acknowledgments

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エンバク属の種子発芽の温度反応における種間差異について

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収穫後5−6ヶ月間または10−11ヶ月間室温で保存した2倍種，4倍種および6倍種のエンバク属の各種の種子（えい果）を用いて，18°，24°，30℃での発芽を調査した．大部分の種の5−6ヶ月保存種子は18℃でほぼ80%以上発芽した．しかし，30℃で全般に抑制された．10−11ヶ月保存した種子の30℃での発芽率は増加した．このことから5−6ヶ月保存種子が30℃で発芽率が低いのは高温遭遇によって二次休眠が誘導されたことに因ると考えられる．

5−6ヶ月保存種子の二次休眠の程度は種によって異なり，*Avena hirtura* (As)，*A. wiestii* (As)，*A. magna* (AC)，*A. murphyi* (AC)，*A. fatua* (ACD)，*A. sterilis* (ACD) の種子は深い二次休眠を示した．他方，*A. ventricosa* (C_v)，*A. strigosa* (As)，*A. barbata* (AsB)，*A. vaviloviana* (AsB)，*A. abyssinica* (AsB)，*A. byzantina* (ACD)，*A. sativa* (ACD) の種子は二次休眠がないか又は浅い二次休眠を示した．

これらのエンバク属の種子発芽の温度反応から，種の系統，休眠関連遺伝子の活性，原生地での生態的適応性について考察した．

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