Acta Agrobotanica

ORIGINAL RESEARCH PAPER Acta Agrobot 68(3):241–246 DOI: 10.5586/aa.2015.026
Received: 2015-02-16 Accepted: 2015-08-29 Published electronically: 2015-10-21

Germination of seeds of *Avena fatua* L. under different storage conditions

Denise F. Dostatny[1]*, Izabela Kordulasińska[1], Elżbieta Małuszyńska[2]

[1] National Centre for Plant Genetic Resources, Plant Breeding and Acclimatization Institute – National Research Institute, Radzików, 05-870 Błonie, Poland

[2] Department of Seed Science and Technology, Plant Breeding and Acclimatization Institute – National Research Institute, Radzików, 05-870 Błonie, Poland

Abstract

Storage conditions have a strong influence on the germination of seeds of *Avena fatua* L, especially at variable conditions, the germination decreased. Seeds stored at a constant low temperature maintained the germination capability for 5 years. Under greenhouse conditions, seeds matured and germinated more rapidly comparing to field conditions, but individuals from these seeds were weaker and produced fewer seeds. The higher temperature in the greenhouse accelerated the development and maturing of plants. Field emergence varied depending on seed storage conditions, sample, further reproduction, and weather conditions. It was observed that individual specimens of *A. fatua* were able to form ripe seeds with high thousand grain mass (TGM), regardless of the occurrence of fungal diseases. The knowledge of the biology of *A. fatua* is very important due to its status as a restricted weed in certified seed of crop plants.

Keywords: *Avena fatua*; germination; storage conditions; growing conditions; seeds

Introduction

Proper storage conditions are essential to maintain high viability of seeds, both of crops and weeds. There is a lack of information about storage conditions of weed seeds and therefore research was conducted on a very expansive weed, *Avena fatua* L. (Poaceae) a restricted weed in certified seed of crop plants [1].

Avena fatua is an annual spring plant, germinating in early spring, though some authors claim it is also a winter plant [2]. Grains of *A. fatua* are hulled, their glumes are generally dark with numerous seed hairs, and the awn grows more or less in the middle of the lemma. When mature, the ear falls apart into flowers showing the scar shaped as a horseshoe with a smooth, roller-like fold in each flower – which is the characteristic of this species [3].

Avena fatua can be observed both in alkaline and sour soils. It can spread by hairy seeds carried by wind. Seeds may germinate even at a depth of 20 cm. Grains mature irregularly and as they ripe they fall off, contaminating the soil. Some of the grains, not fully ripe, are collected together with the crop plant and contaminate the harvest, while grains left in straw may germinate immediately, without undergoing the dormancy stage.

The aim of the study was to evaluate the seed germination potential of *A. fatua* depending on storage conditions and to compare the growing period under greenhouse and field conditions.

Material and methods

A part of seed material was collected from crop fields in Poland during the expeditions organized by the National Centre for Plant Genetic Resources (from 2007 to 2008), while a part of it came from the Gene Bank collection. Seeds used in laboratory experiments and in the greenhouse were collected in crop fields. In the field experiment, in the first year of sowing seeds came from the Gene Bank and after that they were stored at room temperature (from 20 to 25°C) until the end of the experiment.

Laboratory experiment

In 2008, after determining the germination ability, seeds were placed in two types of storage conditions: treatment A – long-term storage (constant temperature: 0°C with a low humidity of 5–7%) and treatment B – variable storage conditions (ambient temperature and humidity) with variable temperature (from 5 to 30°C) and humidity (from 40 to 80%). During 5 years of storage, seeds from particular treatments were tested. Every year, the germination ability was determined and 3 × 50 seeds were sown. In accordance

* Corresponding author. Email: d.dostatny@ihar.edu.pl

Handling Editor: Elżbieta Weryszko-Chmielewska

with the current ISTA Rules [4], the percentage of normal seedlings, abnormal seedlings, dead seeds, and fresh non-germinating seeds were estimated. Figures were made using Excel software and the trend function for the studied parameters was determined to analyze the germination ability in the laboratory. An analysis of variance was conducted using R language for statistical computing (R Core Time).

Field experiment

A field experiment was established on soil complex 3, class III b, on experimental fields in Radzików, between 2009 and 2011. Pre-sowing fertilization was performed: NPK (= nitrogen, phosphorus + potassium). Seeds were sown in 1.5 m^2 plots, in 7 rows, 1.5 m long each. In each plot, six hundred (600) seeds were sown. No herbicides were used and weeds were removed manually. During the growing period, the following parameters were observed: dates of sowing, panicle formation, maturity, plant height (3 replications with $n = 10$ individuals each), and panicle length (3 replications with $n = 10$ individuals each). Resistance to diseases (disease assessment range: 1–9, 9 = resistant) and lodging (observed on two dates, assessment range: 1– 9, 9 = no lodging) was observed according to James (1971) [5]. Seeds were collected manually from panicles and isolation bags (which were applied to prevent seed loss), following the cutting of panicles. Seeds were sorted out manually and then the seed yield from one plot was weighted. The thousand grain mass (TGM) was determined by triple counting of 100 grains and multiplication by 10. The term "growing period" refers to the number of days from sowing until collective maturity. The climate data was taken from the weather station in Radzików.

Greenhouse experiment

In March 2012 and in June 2013, 3 × 50 seeds of *A. fatua* were submitted to germination on Petri dishes at a variable temperature from 20°C to 30°C. Once germinated, seedlings were planted in pots and moved to a greenhouse. Using 10 specimens (each year), plant growth was observed and measured, i.e.,: date of germination, panicle formation, maturity, and plant height. Finally, all seeds of each specimen were collected and 10 seeds of each specimen were weighted, then TGM was determined by multiplication: 10 grains × 100 (this was an estimated method, due to the lack of seeds).

Results

Laboratory experiment

The germination capability of the initial seed material of *A. fatua* was 64%. At the constant low temperature (treatment A), the value of germination capability increased reaching 80% in 2012 (Fig. 1). There was no significant variation in germination capability between years during seed storage in low temperature. Under the variable conditions (treatment B), the germination capability of seeds increased in 2010. A significant decrease in seed germination was observed throughout the storage time starting after two years of storage. In the fifth year, it reached zero. The analysis of variance showed that both factors – storage conditions and storage longevity as well as the conditions × longevity interaction – were highly significant for the seed germination capacity with $P < 0.000$ (Fig. 1).

In treatment A, the percentage of dead moldy seeds was constant (Fig. 2). At the variable temperature and humidity (treatment B), the germination capability decreased and the proportion of dead seeds increased. In the first two years of storage, the percentage of dead seeds was lower than in the initial material, but later it increased to a value of 99% in 2013. The analysis of variance showed that for the number of dead seeds both factors – storage conditions and storage longevity as well as the storage conditions x storage longevity interaction – were significant with $P < 0.000$ (Fig. 2).

Fresh non-germinating seeds constituted 22% of the initial material at the beginning of the experiment (Fig. 3). At the low constant temperature (treatment A), fresh non-germinating seeds gradually decreased down to 8% in 2012. Under the variable storage conditions (treatment B), the percentage of fresh non-germinating seeds fell to zero after 2 years of storage. For viable non-germinating seeds, a significant effect of storage longevity was observed (with $P < 0.000$), while the storage conditions and the storage × year interaction were not significant (Fig. 3)

Field experiment

Under field conditions, germination capability varied depending on the conditions in which seeds were stored, the sample, and further reproduction of the same research material (Tab. 1).

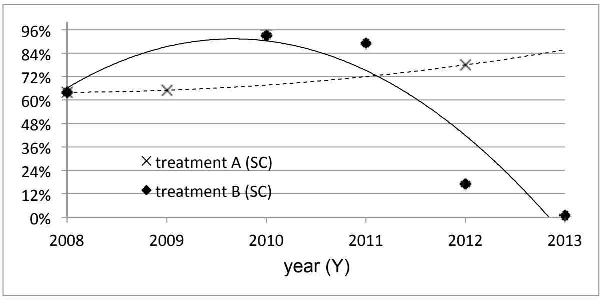

Fig. 1 Germination of seeds under long-term storage and variable storage conditions. Significance: storage conditions (SC) $P < 0.000$; year (Y) $P < 0.000$; SC × Y $P < 0.000$.

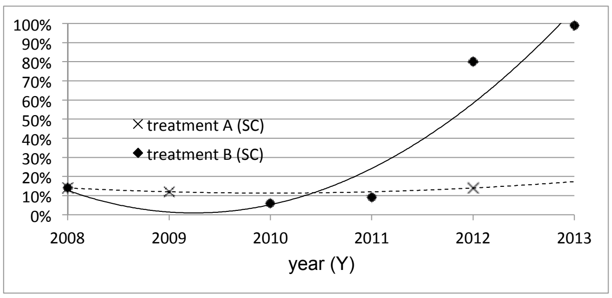

Fig. 2 Percentage of dead seeds under long-term storage and variable storage conditions. Significance: storage conditions (SC) $P < 0.000$; year (Y) $P < 0.000$; SC × Y $P < 0.000$.

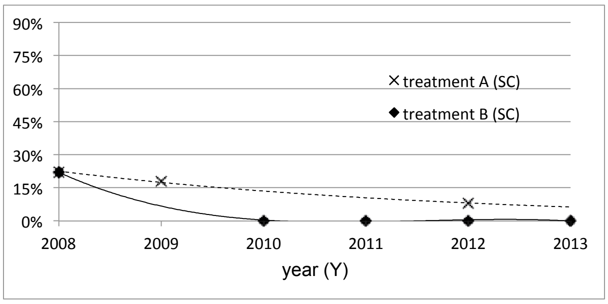

Fig. 3 Percentage of fresh non-germinating seeds under long-term storage and variable storage conditions. Significance: storage conditions (SC) $P < 0.000$; year (Y) $P < 0.000$; SC × Y $P < 0.000$.

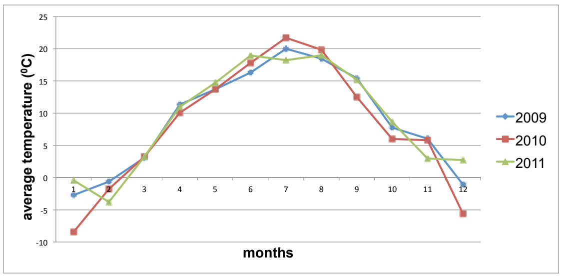

Fig. 4 Average monthly air temperature in Radzików in 2009–2011.

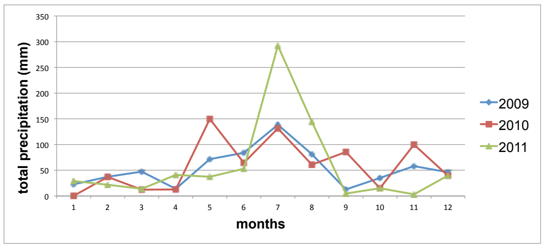

Fig. 5 Monthly precipitation in Radzików in 2009–2011.

Seeds after long-term storage (0°C) and sown directly in the field showed the worst germination. Out of 600 seeds sown in 2009, 13 581 seeds were collected (267 g harvested), while with the same number of seeds sown in 2010 and 2011, 20 590 and 37 690 seeds were collected, respectively.

Under the field conditions in 2009, a longer growing period was observed (114 days), panicles formed later, and the seed yield was poorer compared to 2010 and 2011. In 2010 the growing period was slightly shorter (by 14 days); the average air temperature (Fig. 4) during the growing season was slightly higher than in the previous year. However, in 2011 the growing period was comparable to the previous year.

In 2011, the precipitation during the growing period was very high and *Puccinia coronata* and *Septoria* diseases occurred more frequently than in the others years of the experiment. However, the weather did not affect the TGM, despite that the yield was high.

During all the research years, it was observed that plants were able to produce ripe seeds with high TGM despite the fact of being affected by fungi.

Greenhouse experiment

Avena fatua individuals in the greenhouse had a shorter growing period compared to plants growing in the field. The number of days from sowing to panicle formation ranged from 47 to 56, whereas in the field from 68 to 82 (Tab. 1, Tab. 2). However, the number of days from sowing to maturity varied from 70 to 84 days, while in the field ranged from 86 to 114 days.

Under the greenhouse conditions, the height of *A. fatua* specimens was in the range of 44–69 cm (Tab. 2), whereas in the field varied from 118 to 138 cm.

In the greenhouse, where the temperature is much higher than in the field (both during the day and at night), every single plant of the *A. fatua* species developed weaker and produced fewer seeds. However, the mass of 10 seeds (converted into the "thousand grain mass") of each specimen was between 19.2 to 26.3 g, while in the field varied from 19.7 to 27.2 g. The above calculation indicates that the TGM of the plants in the greenhouse is similar to the TGM of plants that grew under natural conditions in the field.

Discussion

The results of current research show that *A. fatua* seeds germinated at the higher temperature, which is in agreement with Kieć [6] and other authors who write that seeds

Tab. 1 Growing period of *Avena fatua* under field conditions.

Year	Sample No.	Sowing date	Date of panicle formation	No. of days until panicle	Panicle length (cm)	Plant height (cm)	M	Pc	Pg	S	Average lodging	No. of days until maturity	Yield (g)	TGM (g)
2009	01	06.04	26.06	82	34	122	7	6	9	0	9.0	114	267	19.7
2010	01	12.04	28.06	78	23	125	9	6	9	3	9.0	100	481	23.4
2011	01	04.04	10.06	68	22	131	9	2	9	3	5.5	106	854	22.7
	02	04.04	13.06	71	16	118	9	5	9	2	7.0	-	993	22.2
	03	04.04	13.06	71	27	136	9	5	9	6	7.5	-	596	23.4

M – mildew; Pc – *Puccinia coronata*; Pg – *Puccinia graminis*; S – *Septoria*; TGM – thousand grain mass.

Tab. 2 Growing period of *Avena fatua* under greenhouse conditions (mean $n = 10$ individuals in 2012 and 2013).

Year	Sowing date	No. of days until panicle	Panicle length (cm)	Plant height (cm)	No. of days until maturity	TGM (g)
2012	03.03	51–55	15–23	51–65	72–80	20.2–25.3
2013	23.05	47–56	17–28	44–69	70–84	19.2–26.3

of this species germinate better in the temperature range 0–30°C. Grains are produced by the species in a wide range of temperature, yet the maximum is obtained at +22/16°C [7] and those produced at a higher temperature (+20°C) prove to have higher germination capability [8].

The germination capability of the initial material was only 64% in ambient conditions and then it gradually increased to reach the maximum (92%) after 2 years. This happened because of breaking dormancy due to variable temperature and humidity. This is confirmed by Kieć's [6] who reported that approximately 90% of live grains of wild oat at the maturity stage are in dormancy whose aim is to prevent autumn germination and freezing of young seedlings. According to the same author, dormancy depends on 3 genes and air temperature during grain maturation and later. A low temperature at the time of maturation extends the dormancy, although after maturity the dormancy period shortens. This has an impact on whether grains will be in dormancy in the next year or longer, while it must be remembered that dormancy may be shortened by different external factors, such as high temperature, damage of grains, etc. The extreme flexibility of this species was shown in the field research in Radzików (Tab. 1) where the same sample, i.e., the same material, behaved differently in individual years, producing a non-uniform thousand grain mass, a different yield or a different height of individual specimens. This is supported by the research of Trzcińska-Tacik [2] and Trzcińska-Tacik and Stachurska-Swakoń [9].

Seeds taken directly from low-temperature storage germinated worse in the field (Tab. 1: sample No. 01 in 2009), whereas in the next years 2010 and 2011, when seeds were stored at room temperature, seeds germinated much better. According to Foley [10], seeds of this species must experience a warm and dry period to germinate. In the present research, where temperature and humidity were changeable, an increase in germination ability was observed in the first two years. However, while the germination ability of seeds stored at constant temperature increased more slowly, but it was maintained throughout the entire duration of the experiment, i.e., for 5 years.

In the field experiment, the kernels taken directly from long-term storage produced individuals with small grains (TGM 19.7 g; Tab. 1). The same seeds sown in the next year produced plants with bigger seeds (TGM 23.4 g). It is not confirmed by Peters [11] who found that the germination capability of *A. fatua* also depends on the size of grains; the bigger they are the weaker their dormancy stage, the higher germination capability, and the bigger plants they form.

At the beginning (2008–2010) of the laboratory experiment under different storage conditions, the germination capability increased, while the dormancy of seeds was breaking. The number of fresh non-germinated seeds decreased to reach zero in 2010. After 2010 seed viability at ambient temperature (treatment B) decreased, because the proportion of dead (moldy) seeds increased. This situation was caused by the development of storage fungi to which variable humidity and ambient temperature contribute [12].

Rooney et al. [13] claim that the growth and production of the dry mass of above-ground parts depend mainly on light, whereas temperature impacts root development, which will be better in lower temperature. The smaller amount of light in the greenhouse could explain why plants developed less abundantly in the greenhouse than in the field [14]. Irrespective of this fact, plants produced a high thousand grain mass, which suggests that they accumulated their energy to develop the generative part instead of the vegetative one. Therefore, in the greenhouse we had shorter individuals with a similar TGM as in the field.

Under the field conditions in 2009, a longer growing period was observed (114 days), panicles were formed later, and the seed yield was lower compared to the next years of the research. In 2010 the growing period was slightly shorter (by 14 days) and most probably the better weather conditions caused the formation of more ripe seeds with a higher TGM. In 2011 the average total precipitation during the growing season, mostly in April, was higher than in the preceding years and additionally *Puccinia coronata* and *Septoria* occurred. However, this had no impact on the yield. It was observed that plants were able to produce ripe seeds with a high TGM despite the fact of being affected by fungi.

Avena fatua has been of limited use in breeding. It can however be a valuable donor of a number of interesting genes. This species may constitute a source of genes determining the earliness of maturing, rapid growth, ripeness of grains, a high content of proteins, and resistance to *Puccinia graminis* and *Puccinia coronata*. There are attempts to transfer the above properties onto crop plants to improve their quality [15–20].

It must be reminded that *A. fatua* is a restricted weed in certified seed of crop plants. All guidelines may be found in the ordinance of the Ministry of Agriculture and Rural Development dated April 18, 2013 [1]. We can read the following guidelines: the produced seed material of crop plants or fodder plants is considered meeting all special conditions as regards the content of wild oat seeds (*Avena fatua* and *A. sterilis*) if: 1. during an official field assessment it was found that the seed plantation is free from wild oat plants (*Avena fatua* and *A. sterilis*); 2. no presence of wild oat seeds (*Avena fatua* and *A. sterilis*) was observed in the official sample.

Conclusions

Storage conditions significantly affected the seed germination of *Avena fatua* which decreased with increasing the time of storage. Seeds stored in ambient conditions (variable temperature and humidity) exhibited the growing number of dead moldy seeds. After five years of such storage, the loss of viable seeds was 80%. However, seeds stored at constant low temperature were able to maintain their germination capability for a long time – above five years.

Under field conditions, seeds germinated depending on the weather and seed storage conditions. Seeds stored at constant low temperature did not germinate all at once in the first year of sowing. A high percentage of such seeds remained in dormancy. In the following years, seeds germinated better despite of the occurrence of field pathogens and *A. fatua* plants produced seeds with a higher TGM.

In the greenhouse, the life cycle of *A. fatua* was shorter by almost one month than in the field. Greenhouse specimens were weaker and produced fewer seeds, yet the seeds were well-formed and with a TGM similar to those growing in the field. The higher temperature in the greenhouse accelerated the development and maturation of plants which did not concentrate on the development during the vegetative phase but on forming ripe seeds (generative phase).

The knowledge of the biology of *A. fatua* is very important due to its status as a restricted weed in certified seed of all crop plants.

Acknowledgments
Research supported by the Ministry of Agriculture and Rural Development of Poland as part of the “Multi-year program – IHAR – PIB 2008–2013” and also as part of the statutory activities of IHAR – PIB. The authors are also thankful to their colleague researcher, Mariusz Chojnowski, for his valuable comments on this paper.

Authors' contributions
The following declarations about authors' contributions to the research have been made: concept of the study: DFD, EM, IK; greenhouse experiment: DFD; field experiment: IK; laboratory experiment: EM; statistical analysis: DFD, EM; writing of the manuscript: DFD, EM.

Competing interests
No competing interests have been declared.

References

1. Rozporządzenie Ministra Rolnictwa i Rozwoju Wsi z dnia 18 kwietnia 2013 r. w sprawie terminów składania wniosków o dokonanie oceny polowej materiału siewnego poszczególnych grup roślin lub gatunków roślin rolniczych i warzywnych oraz szczegółowych wymagań w zakresie wytwarzania i jakości materiału siewnego tych roślin. Dz. U. z 2013 r., poz. 517.
2. Trzcińska-Tacik H. Dwa typy zmian w zbiorowiskach chwastów zbóż w południowej części Wyżyny Małopolskiej. Zesz Nauk Akad Rol im H Kołłątaja Krak Ses Nauk. 1992;261(33):139–155.
3. Stanton TR. Oat identification and classification. Washington, DC: United States Department of Agriculture; 1955.
4. International Seed Testing Association. Międzynarodowe Przepisy Oceny Nasion. Wersja polska. Radzików: Zakład Nasiennictwa i Nasioznawstwa Instytutu Hodowli i Aklimatyzacji Roślin – Państwowego Instytutu Badawczego; 2008–2013.
5. James WC. An illustrated series of assessment keys for plants diseases, their preparation and usage. Can Plant Dis Surv. 1971;2(51):39–65.
6. Kieć J. Zróżnicowanie morfologiczne, ekologiczne i enzymatyczne gatunku *Avena fatua* L., występującego na polach Polski południowo-wschodniej. Zesz Nauk Akad Rol Krak Rozpr. 2000;260:1–83.
7. Wall DA. Comparison of green foxtail *Setaria viridis* and wild oat *Avena fatua* growth, development, and competitiveness under three temperature regimes. Weed Sci. 1993;41(3):369–378.
8. Somody CN, Nalewaja JD, Miller SD. The response of wild oat (*Avena fatua*) and accessions to photoperiod and temperature. Weed Sci. 1984;32(2):206–213.
9. Trzcińska-Tacik H, Stachurska-Swakoń A. Zmiany we florze chwastów upraw zbożowych w latach 1950–2010: badania na terenie i w otulinie Ojcowskiego Parku Krajobrazowego. In: Partyka J, editor. Granice ingerencji człowieka na obszarach chronionych. Zasady i modele gospodarowania. Ojców: Ojcowski Park Narodowy, Muzeum im. Prof. Władysława Szafera; 2010. p. 397–408. (Prądnik. Prace i Materiały Muzeum im. Prof. Władysława Szafera; vol 20).
10. Foley ME. Temperature and water status of seed affect after ripening in wild oat (*Avena fatua*). Weed Sci. 1994;42(2):200–201.
11. Peters NCB. Competitive effects of *Avena fatua* L. plants derived from seeds of different weights. Weed Res. 1985;25(1):67–77. http://dx.doi.org/10.1111/j.1365-3180.1985.tb00619.x
12. Gabińska K, Narkiewicz-Jodko M, Schneider J. Wpływ wieloletniego przechowywania na wartość siewną pszenżyta ozimego. Biul IHAR. 1991;180:43–52.
13. Rooney J, Brain P, Loh S. The influence of temperature on leaf production and vegetative growth of *Avena fatua*. Ann Bot. 1989;64(4):469–479.
14. Stokłosa A. Wpływ światła i temperatury na kiełkowanie odmian botanicznych owsa głuchego (*Avena fatua*). Ann Univ Mariae Curie-Skłodowska E Agric. 2007;62(2):56–69.
15. Rines HW, Stuthman DD, Briggle LW, Youngs VL, Jedlinski H, Smith DH, et al. Collection and evaluation of *Avena fatua* for use in oat improvement. Crop Sci. 1980;20:65–68. http://dx.doi.org/10.2135/cropsci1980.0011183X002000010015x
16. Luby JJ, Stuthman DD. Evaluation of *Avena sativa* L. / *A. fatua* L. progenies for agronomic and grain quality characters. Crop Sci. 1983;23:1047–1052. http://dx.doi.org/10.2135/cropsci1983.0011183X002300060007x
17. Milach SC, Rines HW, Phillips RL, Stuthman DD, Morikawa T. Inheritance of a new dwarfing gene in oat. Crop Sci. 1997;38:356–360. http://dx.doi.org/10.2135/cropsci1998.0011183X003800020013x
18. Cavan G, Biss P, Moss SR. Herbicide resistance and gene flow in wild-oats (*Avena fatua* and *Avena sterilis* ssp. *ludoviciana*). Ann Appl Biol. 1998;133:207–217. http://dx.doi.org/10.1111/j.1744-7348.1998.tb05821.x
19. Morikawa T, Sumiya M, Kuriyama S. Transfer of new dwarfing genes from the weed species *Avena fatua* into cultivated oat *A. byzantine*. Plant Breed. 2007;126(1):30–35. http://dx.doi.org/10.1111/j.1439-0523.2007.01309.x
20. Li R, Wang S, Duan L, Li Z, Christoffers MJ, Mengistu LW. Genetic diversity of wild oat (*Avena fatua*) populations from China and the United States. Weed Sci. 2007;55(2):95–101. http://dx.doi.org/10.1614/WS-06-108.1

Wpływ różnych warunków przechowywania na zdolność kiełkowania nasion *Avena fatua* L.

Streszczenie
Warunki przechowywania w zmiennej temperaturze i wilgotności istotnie obniżały zdolność kiełkowania nasion *Avena fatua*. Nasiona przechowywane w niskiej, ale stałej temperaturze zachowały zdolność kiełkowania przez 5 lat. W warunkach szklarniowych ziarniaki *A. fatua* kiełkowały i dojrzewały

szybciej niż na polu, lecz rozwijające się osobniki były mniej bujne i wytwarzały mniej nasion. Wyższa temperatura w szklarni przyśpieszała rozwój roślin i dojrzewanie nasion. Wschody polowe były zróżnicowane i zależne od warunków przechowywania nasion, od obiektu, od kolejnej reprodukcji i warunków pogodowych. Stwierdzono, że poszczególne osobniki *A. fatua* były zdolne do wytworzenia dorodnych nasion o wysokiej masie tysiąca nasion (MTN) niezależnie od pojawienia się chorób grzybowych. Znajomość biologii *A. fatua* jest bardzo ważna z powodu statusu tej rośliny jako chwastu zastrzeżonego w kwalifikowanym materiale siewnym wszystkich roślin uprawnych.

