Germination Energy and Capacity of Maize Seeds Following Low-Temperature Short Storage

Marek Domin *, Franciszek Kluza *, Dariusz Góral, Sybilla Nazarewicz, Katarzyna Kozłowicz, Marek Szmigielski and Beata Ślaska-Grzywna

Department of Biological Bases of Food and Feed Technologies, University of Life Sciences in Lublin, Głęboka 28, 20612 Lublin, Poland
* Correspondence: marek.domin@up.lublin.pl (M.D.), franciszek.kluza@up.lublin.pl (F.K.)
Received: 31 October 2019; Accepted: 18 December 2019; Published: 19 December 2019

Abstract: The present research attempts to characterize the effect of low temperatures, and the moisture content of maize (Kosmo 230) meant for sowing on its energy and capacity to germinate. Seeds were moistened to varying degrees and stored under various conditions; then, their germination energy and capacity were assessed. Sowing material with 15% moisture content showed slightly declined germination ability when stored at −25—20 °C for over three days, while the storage of seeds with a 25 and 30% moisture content at −5–0 °C for 1–3 days had the effect of seed conditioning. Seedlings obtained from conditioned seeds showed sustainability characterized by faster growth, and demonstrated nearly twice the size as other plants. Warehousing and storage of maize grains with a 11.12% moisture content at temperatures up to −25 °C did not significantly affect seed germination capacity or energy, irrespective of storage time.

Keywords: corn; sprouting; storage suitability; storage conditions

1. Introduction

The cereals wheat, maize, rice, barley, and sorghum are grown on almost 700 million hectares, and collectively they provide approximately 40% of the energy and protein components of the human diet. Maize is one of the primary agricultural crops. After wheat, it ranks second in terms of cultivation area [1]. Maize is grown increasingly willingly by European farmers due to its advantages, which include versatility and high yield. Several years ago, a lack of suitable hybrids and the insufficient development of agricultural technology meant that, in areas such as Germany, Denmark, and Poland, maize was mainly grown for silage to feed cattle during winter [2]. However, today its cultivation for grain has become more popular [3].

Maize deserves special attention because of its composition. Its wealth in group B vitamins, valuable microelements (copper, manganese, and magnesium), the presence of constituents with antioxidant properties (carotene and xanthophyll), and unsaturated fatty acids (linoleic and oleic) enables the use of this plant in the daily diet and also in the prevention of many diseases. One of the distinguishing factors of maize, in comparison with other plant foods, is its high selenium content, which is an essential mineral nutrient for animal and human growth [4].

A challenging problem with maize is its storage. The germ, representing 12% of the whole seed, responds strongly to any changes in moisture content [5]. Whilst drying, the seed quickly loses water but equally promptly absorbs moisture from the environment. Under damp conditions, grain respiration raises its temperature, which, in turn, is conducive to mold growth and the proliferation of various types of pests, thus preventing further processing of the raw material. An inhibitory factor to these undesirable changes is lowering the grain temperature because, as grain is cooled, moisture is reduced and pest activity slowed down [6–8]. Keeping grain cool allows the minimization or even
elimination of environmentally harmful chemical treatments applied during storage. Besides, storage at low temperatures protects the grain from sugar losses. It has also been demonstrated that a subzero grain temperature ensures a reduction in losses during the unhusking of cobs [9]. Hence, lowering the temperature of moist grain immediately after harvesting and during storage offers a number of substantial benefits due to storage and ultimately affects its further sustainability.

An assessment of the seeds’ quality for sowing is made on the basis of their biological properties, such as viability, maturity, and age. Viability is defined by denoting the germination energy and capacity.

Germination capacity is the percentage of seeds that would normally germinate under optimal conditions for the species. The purpose of the germination evaluation tests is to determine the maximum germination potential of a particular batch of seeds. Seeds are planted under optimal conditions for to obtain variety. Test conditions and duration are different for each variety and are defined by rules [10]. Germination ability and germination energy are tested simultaneously. Germination energy is the number expressing the percentage of fast-germinating seeds. An assessment of the germination energy is carried out on day 4, and germination capacity on day 7 following planting the sample [10]. Plants grown from seeds with high germination energy and capacity show steady development that restricts competition from weeds and allows for the maximum use of land under cultivation [11–14].

The aim of this study is to characterize the effect of low temperature on the germination energy and capacity of stored maize meant for planting. The scope of the research includes the determination of optimal storage conditions, i.e., the temperature and moisture of the stored seed that does not impair its germination energy or capacity.

2. Materials and Methods

2.1. Materials

The study used the Kosmo variety of maize (Zea mays var. Kosmo 230) [15]. It is a commercial F1 hybrid (cross product of parental constituents) and belongs to the group of medium early varieties. According to the FAO rating, its earliness is denoted as 240 (the number of days of a plant’s full life cycle from planting to maturity). The corn seeds used in the experiment came from three suppliers. Compared to other varieties, they were characterized by resistance to stem and root lodging, as well as high resistance to corn smut (on stalks and cobs) [16]. The data from the registration testing showed that the total yield of dry matter was higher than the benchmark. Besides, it had over 50% of dry ear weight in the total yield of dry matter. This cultivar was registered in 2003. The grain supplied by the producer was sorted for planting. Its germination capacity reached 98%, and its thousand seed weight was 368.0g. The grains displayed the shape, color, and gloss appropriate for the given variety. The seeds were not treated.

2.2. Testing Methods

Determination of moisture content. Moisture content was determined using the dryer method as per ICC standard [17]. For this purpose, the material was crushed, and a 50 g sample was weighed to an accuracy of ±0.01 g and placed in a laboratory oven at 130 °C for 38 h. The seed moisture was calculated from the following formula:

\[ w = \frac{a - b}{a - c} \times 100\% \]  

(1)

where:
- \( a \) — weight of the container with the sample before drying [g]
- \( b \) — weight of the container with the sample after drying [g]
- \( c \) — weight of the container [g]

Moisture content determination was performed five times with the final result being the average.
**Determination of thousand kernal weight (TKW).** The weight of 1000 seeds gives an indication of the seed size and serves to calculate the sowing rate. This 1000 seed weight should be determined for each batch of seeds.

In order to determine this weight, 1000 seeds were weighed to an accuracy of ±0.01 g. The TKW determination was performed five times, with the final result being the average.

**Germination trials.** The zero test was performed, with all the ISTA (2006) germination requirements being satisfied, on the fourth day after the seeds were delivered by the producer. The seeds were moistened to 15, 20, 25, or 30% by placing 500 g samples in sealed containers with a specific amount of water. The precise absorption of water by the seeds necessitated their gradual addition followed by regular mixing throughout the whole sample volume.

The amount of water to be added was determined by the following formula:

\[
m_w = \frac{x_2 - x_1}{100 - x_2} \cdot m_z
\]

where
- \(x_1\) — initial moisture content [%]
- \(x_2\) — desired moisture content [%]
- \(m_z\) — weight of seeds [g]
- \(m_w\) — weight of water [g]

Appropriately moistened seeds were placed for 1, 3, 5, or 10 days at temperatures of 0, −5, −10, −15, −20, or −25 °C. Each determination included 400 seeds. Germination was conducted in eight batches (50 germinating seeds per batch) according to the ISTA (2006) standard. Two adjacent batches (2×50 units) were evaluated simultaneously. Seeds were planted directly after being stored at the preset temperature. The samples were set on plastic trays filled with a 2 cm thick sand layer. The seeds were placed so that they did not touch each other or the walls. They were covered with a 0.5 cm layer of sand without compacting to ensure adequate air supply. Before planting, the bedding was sterilized for 1 hour at 200 °C. The sand was moistened with distilled water. Thus prepared, the samples were put in a room at a temperature ranging between 20 °C and 30 °C. The tests concerning the examination of seeds for planting, carried out as per ISTA (2006), did not indicate any statistically significant effect of light on germination.

The germination energy and capacity were evaluated according to the ISTA (2006) standard. The seeds that sprouted were counted twice, i.e., four and seven days following planting. For each batch of 100 seeds, the seeds that germinated normally were counted, taking into account the initial and final counts. If the results of the germination capacity for particular batches did not exceed the standard deviation, batches were considered to be comparable. The result was the arithmetic mean of the determinations to within ±1% accuracy. The germination energy was determined on the basis of results of the first count, whilst the germinating capacity was determined on the basis of the second one.

The results in the form of percentage shares were subjected to regression analysis and graphic interpretation using CurveExpert (Hyams Development, Madison, WI, USA) software for nonlinear regression analysis (curve fitting) and smoothing of data. The proposed regression models together with their fit factors are summarized in the charts.

3. Results

In seeds with a 11.12% moisture content, no reduction in germination capacity (98%—the nominal level) was noted, regardless of the storage duration and temperature before planting. The germination energy remained at a very high level (89–93%) (Figure 1).
Those seeds moistened up to 15% retained equally high germination capacity, after being stored at temperatures of 0 °C and −5 °C for all the storage periods, at −10 °C for 1 and 3 days, and at −15 °C for 1 day. After a prolonged storage period of 10 days at −10 °C, seeds moistened to 15% showed a germination capacity decline to 97%, which was also reported for seeds stored at −20 °C. Lowering the storage temperature to −25 °C for seeds stored for 10 days caused their germination capacity to drop to 95% (Figure 2).

Seeds containing 20% moisture and kept at a temperature of 0 °C and −5 °C were found to maintain their ability to germinate at the nominal level. However, storing them at −10 °C for 10 days lowered their germination capacity to 95%. Only after storage at −20 °C and −25 °C did the germination ability significantly drop to values between 73 and 76% after only 1 day, and between 67 and 68% after 10 days of storage (Figures 3 and 4).
Seeds containing 25% moisture retained the capacity to germinate at the nominal level whilst being stored for up to 3 days at 0 °C. Lowering the temperature to –10 °C resulted in a drop in germination. 94% of the seeds kept at this temperature for 1 day germinated, whereas only 84% did so after 10 days. In the case of seeds stored at –15 °C, germination declined to 31–50%. The lowest germination ability was observed for seeds stored at temperatures of –20 °C and –25 °C for 5 and 10 days (7–12% germinating) (Figures 5 and 6).
Figure 6. Germination energy and ability of maize seeds with 25% moisture content stored at −25 °C before sowing.

Seeds containing 30% moisture, after being stored for 3 days at 0 °C and −5 °C, did not display any significant downward trend in germination (94%). Importantly, after 10 days, only 56–68% of the seeds were found to germinate. The greatest decline in germination capacity, to nearly its total disappearance, was noted in seeds stored for 10 days at −15 °C (only 6 seeds germinated) and at −20 °C and −25 °C for all the storage periods (1–11 seeds germinated) (Figure 7).

Figure 7. Germination energy and ability of maize seeds with 30% moisture content stored at −25 °C before sowing.

Germination energy remained at the 79–84% level for seeds stored for 3 days at 0 °C, −5 °C, and −10 °C. With prolonged storage, at temperatures not lower than −5 °C, reduction in germination energy from 51% to 64% was reported and down to 31%, for temperatures not lower than −10 °C. The lowest germination energy was observed for seeds stored at temperatures ranging from −15 °C to −25 °C (1–19%).

Among the seeds stored at −20 °C, 98% germination ability was maintained by seeds with a moisture content of 11.12% (for all storage durations). Seeds with 15% moisture content displayed a slight drop in germination capacity (97%) after 10 days of storage. Seeds with a 20% moisture content germinated at the 68–76% level. The lowest germination ability was recorded for seeds containing 25% moisture (10–30%) and 30% moisture (2–11%).
Figure 8. Germination energy and ability of maize seeds stored before sowing for 10 days at −25 °C.

Among the seeds stored at −25 °C for 10 days, the germination capacity remained at 98% for seeds with a moisture content of 11.12% (for all storage periods). Seeds with a 15% moisture content showed a slight downward trend in germination ability (96%). Seeds with a 20% moisture content germinated at the 67–73% level. The lowest germination (1–17%) was found for seeds containing 25–30% moisture (Figure 8).

4. Discussion

Immediately after harvest, grain moisture content can exceed 25% [18,19]. Moist grains respire at a high rate, which results in breakdown of the reserves, especially starch, into monosaccharides, carbon dioxide and water with concurrent release of heat. Consequently, grain weight loss and development of microorganisms, bacteria, and molds are observed [20].

Bhattacharya and Raha (2002) report that the total amount of carbohydrate in maize grains with 14% moisture content decreases from 74.7% to 69.8% after four months of storage. Similarly, maize grain germinability, which initially reached 89%, fell to 72% after four months of storage. This was caused by development of storage fungi that damaged grains. Commonly, grain is stored dried to less than 14% moisture; however, even such a moisture level does not prevent fungal growth or a decline of germinability [21–24]. Lowering of moisture content and temperature of the stored grain mass limits the risk of mold development and, thus, the occurrence of mycotoxins in the stored mass. Besides, grain freezing makes the vital life processes cease. The respiratory activity of grain stops so the reserves are not degraded. A number of earlier papers have highlighted that freezing results in irreversible damage to maize seed grains [25,26]. The present paper has shown that high values of germinability and germination energy of maize grain with 11.12% moisture after storage under different conditions were consistent with those published by other authors studying germination of maize seeds [27–29]. The experimentally obtained results of germinability and germination energy correlated with a moisture content of sowing seed grains have confirmed the appropriacy of the NDSU Extension Service guidelines, which recommend long-term storage of maize seeds under 15% moisture at a temperature range of between −1 °C and 10 °C (30–50F), while grains of 22–30% moisture need drying or can be used as fodder [30].

With the aim of enhancing maize germinability and germination energy, grain is soaked in water before sowing to a 35–40% moisture level. This treatment is applied in countries with a warm climate, as increased germinability and germination energy of maize grains with above 20% moisture is observed at germination temperatures above 15 °C. The results of the present studies confirmed the negative effect of temperatures under 10°C on the maintenance of the germination ability of maize grains with 20–35% moisture. A decline in germination ability was determined for maize with ca. 90% at 15–40 °C to less than 30% at 7 °C temperature [31,32].

A severe decline in germinability and germination energy of grain with a high moisture level noted as early as after the first storage day at temperatures under 0 °C can be attributed to injury to
the germ whose susceptibility to low-temperature damage increases proportionally to the moisture content of seeds sown. Grain with a high moisture level shows a great degree of germ enzymatic activity. Lowering the temperature of seeds with high moisture reduces the enzymatic activity rate, which disturbs the normal development of germ and, then, of a seedling [33,34].

Cooling of seeds with a moisture level above 20% to temperatures below their cryoscopic temperature contributed to ice crystal formation in both the germ and maize grain endosperm. The higher the moisture content of cooled grains, the more extensive were the ice structures formed. Crystallization of water contained in cooled grain with an above 20% moisture level proved to be the agent causing germ abilities to develop to nearly zero.

5. Conclusions

1. Germination energy and capacity for maize with a moisture content below 15% do not decline, even after a 10-day storage period in temperatures down to –25 °C. Seeds with above 15% moisture content showed a slight drop in germination energy and ability when stored in temperatures between –20 °C and –25 °C for more than 3 days. This characteristic can be used to eliminate pests from seeds.

2. Storing grain with moisture contents of 25% and 30%, in temperatures between 0 °C and –5 °C and for 1 to 3 days has the effect of conditioning the sowing material. Seedlings obtained from thus-conditioned grain grow faster, being nearly twice their size in comparison to other samples. The reduction in the germination ability is low, at 1–4%.

3. During storage, an increase in the moisture of grain for sowing significantly affects germination energy and capacity. Grain with a 25% moisture content, stored at –15°C, shows approximately a 50% decrease in germination ability, whereas at 30% humidity and –15 °C temperature, germination capacity virtually disappears.

4. Storing maize with a 11.12% moisture content, even at a temperature of –25 °C, has no significant influence on its energy and ability to germinate, irrespective of storage duration. This implies that a reduction in the grains’ moisture content before storage can greatly conserve its germination energy and ability during storage at low temperatures, in comparison with grain of higher moisture content.

Author Contributions: Conceptualization, M.D.; formal analysis, F.K.; investigation, M.D. and K.K.; methodology, M.D. and B.-Ś.-G.; project administration, M.D.; software, S.N.; supervision, F.K.; visualization, M.S.; writing — original draft, M.D.; writing — review and editing, D.G. and M. S. All authors read and approved the final manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Dunwell, J.M. Transgenic cereals: Current status and future prospects. J. Cereal Sci. 2014, 59, 419–434.
2. Odgaard, M.V.; Bocher, P.K.; Dalgaard, T.; Svenning, J.C. Climatic and non-climatic drivers of spatiotemporal maize-area dynamics across the northern limit for maize production-A case study from Denmark. Agric. Ecosyst. Environ. 2011, 142, 291–302.
3. Tillie, P.; Dillen, K.; Rodríguez-Cerezo, E. Modelling ex-ante the economic and environmental impacts of Genetically Modified Herbicide Tolerant maize cultivation in Europe. Agric. Syst. 2014, 127, 150–160.
4. Wang, J.; Wang, Z.; Mao, H.; Zhao, H.; Huang, D. Increasing Se concentration in maize grain with soil- or foliar-applied selenite on the Loess Plateau in China. Field Crops Res. 2013, 150, 83–90.
5. Rooney, L.W.; Suhendro, E.L. Food quality of corn. In Snack Foods Processing; Lusas, E.W., Rooney, L.W., Eds.; CRC Press: Boca Raton, FL USA, 2001.
6. Warrick, C. Aerating Stored Grain Cooling or Drying for Quality Control C Grains Industry Guide; GRDC Grain Storage Extension Project: Kingston, Australia, 2013. Available online: www.grdc.com.au (accessed on 31 July 2013).
7. Reed, C.R. Managing Stored Grain to Preserve Quality and Value; American Association of Cereal Chemists International Press: St. Paul, MN, USA, 2006.
8. Domin, M.; Kluza F. Method for Preparing Corn Cobs for Threshing. Patent PL 212,131 B1, 22 August 2012.
9. Domin, M.; Kluza F. Decreasing the temperature of popping corn cobs as a process reducing the losses of mechanical seeding. Electron. J. Pol. Agric. Univ. 2005, 4, 8. Available online: www.ejpau.media.pl/volume8/issue4/art-09.html (accessed on 14 October 2005).
10. ISTA. ISTA Handbook on Seedling Evaluation. International Seed Testing Association; ISTA: Bassersdorf, Switzerland, 2006.
11. Bhattacharya, S.; Puri, S.; Jamwal, A.; Sharma, S. Studies on seed germination and seedling growth in Kalmegh (Andrographis paniculata wall. Ex nees) Under abiotic stress conditions. Int. J. Sci. Environ. Technol. 2012, I, 197–204.
12. Tang, D.S.; Hamayun, M.; Khan, A.L.; Shinwari, Z.K.; Kim, Y.H.; Kang, S.M.; Lee, J.H.; Na, C.I.; Nawaz, Y.; Kang, K.K.; et al. Germination of some important weeds influenced by red light and nitrogenous compounds. Pak. J. Bot. 2010, 42, 3739–3745.
13. Windauer, L.B.; Martinez, J.; Rapoport, D.; Wassner, D.; Benech-Arnold, R. Germination responses to temperature and water potential in Jatropha curcas seeds: A hydrotim model explains the difference between dormancy expression and dormancy induction at different incubation temperatures. Ann. Bot. 2012, 109, 265–273.
14. Sandhu, K.S.; Singh, N.; Malhi, N.S. Some properties of corn grains and their flours I: Physicochemical, functional and chapati-making properties of flours. Food Chem. 2007, 101, 938–946.
15. Anonym. Common Catalogue of Varieties of Agricultural Plant Species, 32nd ed.; Official Journal of the European Union: Brussels, Belgium, 2013; pp.1–22; C 379 A/01.
16. Adamczyk, J.; Rogacki, J.; Cygert, H. The Progress in Maize Breeding in Poland. Acta Sci. Pol. Agric. 2010, 9, 85–91.
17. Cauvain, S.P.; Young, L.S. The ICC Handbook of Cereals, Flour, Dough & Product Testing: Methods and Applications; DEStech Publications Inc.: Lancaster, PA, USA, 2009.
18. Magan, N.; Aldred, D. Post-harvest control strategies: Minimizing mycotoxins in the food chain. Int. J. Food Microbiol. 2007, 119, 131–139.
19. Gonçalves, A.; Gkrillas, A.; Dorne, J. L.; Dall’Asta, C.; Palumbo, R.; Lima, N.; Battilani, P.; Venâncio, A.; Giorni, P. Pre- and Postharvest Strategies to Minimize Mycotoxin Contamination in the Rice Food Chain. Compr. Rev. Food Sci. Food Saf. 2019, 18, 441–454.
20. Jian, F.; Jayas, D.S. The Ecosystem Approach to Grain Storage. Agric. Res. 2012, 1, 148–156.
21. Bhattacharya, K.; Raha, S. Deteriorative changes of maize, groundnut and soybean seeds by fungi in storage. Mycopathologia 2002, 155, 135–141.
22. Ding, N.; Xing, F.; Liu, X.; Selvaraj, J.N.; Wang, L.; Zhao, Y.; Wang, Y.; Guo, W.; Dai, X.; Liu, Y. Variation in fungal microbiome (mycobiome) and aflatoxin in stored in-shell peanuts at four different areas of China. Front. Microbiol. 2015, 6, 1055.
23. Chulze, S.N. Strategies to reduce mycotoxin levels in maize during storage: A review. Food Addit. Contam. 2010, 27, 651–657.
24. Suleiman, R.A.; Rosentrater, K.A.; Bern, C.J. Effects of Deterioration Parameters on Storage of Maize. J. Nat. Sci. Res. 2013, 3, 147–165.
25. Rossman, E.C. Freezing injury of maize seeds. Plant Physiol. 1949, 24, 629–656.
26. Neetoo, H.; Chen, H. Influence of Growth Temperatures of Salmonella and Storage Temperatures of Alfalfa Seeds on Heat Inactivation of the Pathogen during Heat Treatment. J. Food Process. Preserv. 2015, 39, 1992–2000.
27. Dragicevic, V.; Spasic, M.; Simic, M.; Dumanovic, Z.; Nikolic, B. Stimulative influence of germination and growth of maize seedlings originating from aged seeds by 2,4-D potencies. Homeopathy 2013, 102, 179–186.
28. Ortiz, J.; Suarez, D.; Puentes, A.; Velasquez, P.; Santos, Navarro, A. Comparison of the effects in the germination and growth of corn seeds (Zea mays L.) by exposure to magnetic, electrical and electromagnetic fields. Chem. Eng. Trans. 2015, 43, 169–174.
29. Enayatgholizadeh, M.R.; Gharineh, M.H.; Bakhshandeh, A.M.; Alami-Saeid, K.H.; Siatat, S.A. Response of the seedling characters of new hybrid seeds of corn in laboratory conditions using standard germination test. Adv. Environ. Biol. 2013, 7, 141–146.
30. Hellevang, K. Corn Drying and Storage Tips for 2011. NDSU Extension Service. 2011. Available online: https://www.google.com/search?q=Corn+Drying+and+Storage+Tips+for+2011&ie=utf-8&oe=utf-8&aq=t&rls=org.mozilla:pl:official&client=firefox-a&channel=np&source=hp (accessed on 20 September 2011).

31. Finch-Savage, W.E.; Dent, K.C.; Clark, L.J. Soak conditions and temperature following sowing influence the response of maize (Zea mays L.) seeds to on-farm priming (pre-sowing seed soak). Field Crops Res. 2004, 90, 361–374.

32. Nadeem, M.K.; Qaswar, M.; Ahmed, N.; Rabnawaz; Rasool, S.J. Effect of Seed Soaking Time on Germination of Maize (Zea mays L.). PSM Biol. Res. 2017, 2, 46–50.

33. Guan, Y-J.; Hu, J.; Wang, X-J.; Shao, C-X. Seed priming with chitosan improves maize germination and seedling growth in relation to physiological changes under low temperature stress. J. Zhejiang Univ. Sci. B 2009, 10, 427–433.

34. Cao, Q.; Li, G.; Cui, Z.; Yang, F.; Jiang, X.; Diallo, L.; Kong, F. Seed Priming with Melatonin Improves the Seed Germination of Waxy Maize under Chilling Stress via Promoting the Antioxidant System and Starch Metabolism. Sci. Rep. 2019, 9, 15044.