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PRIMING IMPROVES GERMINATION OF MONOGERM RED BEET (*BETA VULGARIS* L.) CLUSTERS

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ABSTRACT

Priming treatments have been widely used in a large number of species to improve germination characteristics. The objective of the study was to accomplish the quality of clusters of monogerm red beet breeding lines using osmopriming. The aim of the first experiment was to find an effective priming treatment, which improved the seed germination characteristics of two genotypes, AR79 and W411, primed for 6-120 h with -1.0 MPa KNO_3, $MgSO_4$, PEG 6000 and PEG 8000. Total treatments were 56, laid out in completely randomized design. The purpose of the second experiment was to see how storage for 6 and 12 months at 4 and 15°C affects the clusters germination of AR79, primed for 48 h with -1.0 MPa KNO_3 and PEG 6000. Total treatments were 8, laid out in completely randomized design. Priming improved all tested germination traits of both genotypes, such as the mean germination time, coefficient of uniformity of germination (CUG), coefficient of velocity, germination capacity and percentage (GC) of abnormal seedlings. Both lines presented the most optimal effects of germination after 48 h of priming with KNO_3 and PEG 6000. Cluster storage contributed to the deterioration of their germination. The type of priming solution had no effect on cluster germination after storage. Better results were obtained with clusters stored for 6 than those for 12 months only for the CUG and GC. The storage of clusters at 4°C was more advantageous for germination features than storage at 15°C.

Keywords: abnormal seedlings, COV, CUG, germination capacity, MGT, osmotic conditioning.

INTRODUCTION

Red beet (*Beta vulgaris* L.) is one of the major vegetables used in the kitchens of Europe, North America, the Middle East, and some regions of Asia. This species is appreciated mainly because of its nutritional and health benefits. In addition, its roots are a great source of betalain pigments commonly used in the food industry as a natural dye (Goldman and Navazio, 2008). In Poland, red beet production is one of the highest in Europe. In 2014, 358,000 tons of roots were harvested from the cultivated area of 11,000 ha (CSO, 2015).

The seeds of red beet, called a cluster, are botanically a multigerm fructification, which usually contain 2-5 embryos, occurring in up to five closely intertwined plants that require thinning by hand. Monogermity, having a recessive character, is the result of a mutation found in wild grown plants that was identified at the beginning of the 20th century. Initially, the monogerm gene was incorporated into the sugar beet, then to the red beet. Nowadays, most sugar beet cultivars are monogerms that permit clusters to be more accurately spaced in a precision sowing. In the case of red beet cultivars, multigerm genotypes still dominate (Goldman and Navazio, 2008). Currently, on the Polish National List of Vegetable Plant Varieties, there are 27 traditional multigerm seed cultivars, but only one is monogerm (PNLVPV, 2016). Additionally, in recent years, the open-pollinated red beet cultivars have been replaced by hybrids. Thus, the current red beet breeding program is aimed at selecting new parental lines favourable in terms of root yield and their nutritive quality. Today, red beet monogermity is also one of the major goals of red beet breeders that is needed in order to be able to perform precision seed sowing (Goldman and Navazio, 2008; Jagosz, 2015). On the other hand, the pericarp layer of monogerm beet fruits is much thicker than in the case of multigerm ones, which negatively influences seed germination, especially during moisture and temperature stress (Rochalska and Orzeszko-Rywka, 2008). Poor seed germination of red beet is determined by several factors such as immaturity or the underdevelopment of seeds, the chemical germination inhibitors in pericarp, physical impairment of germination by the pericarp tissue, seed hardness and impermeability to water and oxygen (Khazaei, 2001; Taylor *et al.,* 2003). Hence, extended cultivation of red beet is hindered by two factors: multigerm clusters and poor seed germination.

Priming is considered one of the best pre-sowing techniques of vegetable seeds to promote germination. The beneficial effects of sugar beet cluster priming on germination characteristics, plant health, and even their chemical composition have been confirmed by many researchers. Orzeszko-Rywka and Podlaski (2003, 2010), as well Rochalska and Orzeszko-Rywka (2008) compared several pre-sowing methods, such as rubbing, washing, priming and alternating magnetic field treatment, and found that seed priming had the best effect on the ability

and rate of germination. In the study by Sliwinska and Jedrzejczak (2002), improvement in seed quality was achieved after the process of their hydration and dehydration. Additionally, the effect of treatment was particularly visible in the case of seeds with low initial vigour. Sacala *et al.* (2016) noted the positive effect of cluster hydropriming on phosphatase activity, concentration of phosphate photosynthetic pigments in leaves, as well the nutrient status and root yield. Priming with water performed by Mukasa *et al.* (2003) shortened the germination period and seedling emergence in cool conditions. Habib (2010) also reported on the improvement of the percentage of germination, the rate of germination and the mean time of germination of clusters primed with hydrochloric acid. In turn, according to Jamil and Rha (2007), priming with gibberellic acid increased the final germination as well as germination rate under saline conditions. The clusters treated with potassium nitrate combined with acetyl salicylic acid improved final germination percentage, germination rate as well germination synchrony (Govahi *et al.,* 2007). Similarly, Dias *et al.* (2009) noted good results in seed vigour improvement and seedling protection against microorganisms following water, potassium nitrate and polyethylene glycol as well as fungicide treatments.

Presowing treatments has also been developed to improve the speed and the final germination of red beet clusters. The rubbing, leaching and soaking of monogerm clusters significantly influence the rise of germination parameters of seeds (Jagosz, 2017). Nirmala and Umarani (2008), using different priming methods to improve the seed vigour of red beet, selected hydropriming as the best technique. However, when comparing pre-sowing treatments, Costa and Villela (2006) concluded that cluster osmotic conditioning with polyethylene glycol and magnesium sulphate is one of the most promising in increasing the speed and uniformity of germination and emergence of the seedlings. At the same time, they admit that the pre-sowing treating method needs to be adjusted for the species, as well as to the different seed lots.

The beneficial effects of seed priming methods are widely documented in the literature. Pre-sowing treatments have been used in many species to improve speed, rate, uniformity and percentage of germination. In the case of pepper (Ozbay and Sosluoglu, 2016) or sorghum (Shehzad *et al.,* 2012) osmopriming improves also the seeds germination under unfavourable environmental conditions. To apply priming on a commercial scale, seeds must maintain the beneficial effects of such treatments after a storage period. However, the effects of storage of primed vegetable seeds on the germination are not as obvious, because there exist variable responses depending on the species, cultivar, age and lot of the seeds, the type of priming solution as well as the storage conditions (Pazdera, 2005; Toselli and Casenave, 2014). Govahi *et al.* (2008) noticed only a slight decrease in sugar beet seed quality after storage for one month. However, the literature is very poor regarding the storage of beet clusters.

The purpose of the study, composed of two experiments, was to find an effective and suitable way of cluster osmopriming that would improve the germination parameters, such as the mean germination time, coefficient of uniformity of germination, coefficient of velocity, germination capacity and percentage of abnormal seedling of new red beet monogerm breeding line AR79. Additionally, primed clusters should maintain the beneficial germination performance also after storage. The aim of the first experiment was to select the two kinds of priming solutions (inorganic salt and organic compound) and the priming duration that would have a favourable impact on the cluster germination of two monogerm breeding lines: AR79 and W411. The objective of the second experiment was to evaluate the effect of storage conditions, such as the period and the temperature, on the line AR79's cluster germination primed with two different solutions, selected on the basis of first experiment.

MATERIALS AND METHODS

The clusters of two monogerm seed red beet (*Beta vulgaris* L.) cytoplasmatic male sterile breeding lines, AR79 and W411, were used in the present study. The line W411 was bred in the University of Wisconsin – Madison (USA), while AR79 is a new breeding line selected in the Institute of Plant Biology and Biotechnology (IPBB) at the University of Agriculture in Krakow (Poland). The seed material was collected in September 2013 at the experimental field and the research was carried out in the Seed Science Laboratory of IPBB in April 2014.

In the first experiment, cluster samples (70 g) of both breeding lines were primed in a column bioreactor with 700 ml of -1.0 MPa solutions of potassium nitrate (KNO_3), magnesium sulphate ($MgSO_4$), polyethylene glycol – PEG 6000 and polyethylene glycol – PEG 8000 for 6, 12, 24, 48, 72, 96 and 120 hours, hence, experiment consisted of 56 treatments, laid out in completely randomized design. In the second experiment, 70 g samples of clusters of the line AR79 were conditioned with -1.0 MPa solutions of KNO_3 and PEG 6000 for 48 hours; hence, priming in the second experiment consisted of two treatments, laid out in completely randomized design. In both experiments, in order to stop microorganism progresses during the pre-sowing treatment, 0.1% thiram was added into each priming solution. The priming experiments were conducted in an incubator at 15ºC in darkness. Clusters primed in bioreactor columns were mixed and aerated using a pump. For each pre-germination treating, one sample of 400 clusters in the first experiment and five samples of

400 clusters in the second experiment, were removed from the priming solutions and rinsed three times in demineralized distilled water. Next, the cluster samples were dried for a week at room temperature in thin layers using an air flow at about 40% RH. Then, seed samples of the first experiment were germinated. In the second experiment, one sample was germinated directly after drying, and another four were hermetically packed and stored, two of them for 6 months and another two for 12 months, respectively, at 4 or 15°C, then the seeds were germinated. Finally, the second experiment consisted of 8 treatments, laid out in completely randomized design. As the control, non-primed clusters were used in the first experiment, and primed non-stored clusters were used in the second.

The germination tests of clusters were performed according to international standards for seed testing recommendations (ISTA, 2012). The following germination parameters were determined: mean germination time (MGT), coefficient of uniformity of germination (CUG), coefficient of velocity (COV), germination capacity (GC) and percentage of abnormal seedlings (AS). The germination tests were designed by using a completely randomized design with four replications, each consisting of 100 clusters taken at random. The clusters were uniformly placed in 120 × 210 mm plastic boxes on wet 110 × 20 mm 120 g m^{-2} pleated filter paper with 50 bellows (MUNKTELL) moistened by demineralized distilled water up to 55% of the total water capacity. These boxes were placed in the incubator with forced air at 20ºC circulation in darkness. The measurements of the GC (%) and AS (%) – as the final count – 14 days after planting, were performed using the ISTA Handbook for Seedling Evaluation Guidelines (Don, 2009). In order to account MGT (day), CUG and COV, the seedlings that had started germination (with a protruded radicle of 2 mm long) were counted daily, at the same time, from the moment of planting until the final count made 14 days after planting. MGT, CUG and COV were calculated according to the following formulas: $MGT = \Sigma (D \times N) / \Sigma N$; $COV = \Sigma N / \Sigma (D / N) \times 100$, and $CUG = \Sigma N / \Sigma (MGT - D)^2 \times N$, where N is the number of clusters which germinated on day D, and D is the number of days counted from the beginning of germination.

Data from both experiments were subjected to statistical analysis using the STATISTICA software (ver. 12). The results were subjected to a general analysis of variance (ANOVA). The comparison of means for the MGT, CUG, COV, GC and AS were carried out through the least significant difference (LSD) at $P \leq 0.05$ using the Duncan test.

RESULTS AND DISCUSSION

Nowadays, one of the most important directions of red beet breeding is monogermity, which enables precision sowing and allows skipping the thinning young plants. At the same time, monogerm clusters should have favourable germination parameters, such as rapid, synchronized and high percentage of germination. Modern vegetable breeding programs prefer hybrid cultivars, which are created on the basis of homozygous lines obtained in the process of inbreeding that causes a reduction in plant vigour. The new monogerm red beet line AR79, tested in this study, is also characterized by low germination parameters. In the first experiment, the line W411, selected for the experiment for comparative purpose, showed much higher germination capacity (83%) than the line AR79 (65%) (Table 1). Costa and Villela (2006) suggested that the pre-sowing treating method needs to be adjusted not only for the species, but also to the different seed lots. However, in the present research, priming treatments improved all measured germination parameters for both studied genotypes, compared to the control (non-primed clusters); the exception was CUG for AR79, where the difference between primed and non-primed clusters was not significant. In comparison with the control, all of the tested priming solutions visibly improved the germination parameters of the treated clusters. Additionally, the solutions of KNO_3 and PEG 6000 gave more favourable results for all of the tested germination characteristics than the $MgSO_4$ and PEG 8000 solutions. However, it is known that the different chemicals used in priming solutions may have beneficial or toxic effect on the seed germination of different species. Costa and Villele (2006) recommend solutions of $MgSO_4$ and PEG 6000 as beneficial for priming treatments of red beet clusters. Other researchers have obtained favourable results of sugar beet cluster germination using pre-sowing priming KNO_3 (Govahi *et al.,* 2007; Dias *et al.,* 2009) and PEG 8000 solutions (Capron *et al.,* 2000). In the present study, priming performed for 12 to 96 hours positively affected all of the tested germination characteristics, as compared to the non-primed clusters. With an increase in priming duration from 6 to 48 hours the MGT shortened, but further extension of priming time did not affect the additional improvement of MGT. Clusters primed for 48 hours presented the most beneficial values of the CUG and COV. After 24 and 48 hours of pre-sowing treatment, the GC increased by 12% compared to the control. Finally, treating for 24-120 hours significantly decreased the percentage of AS. In summary, priming for 48 hours was the most optimal for the highest number of the studied germination traits. Costa and Villela (2006) treated red beet clusters with -1.2 MPa PEG 6000 for 24-72 hours; they usually noted better results of germination for clusters treated for 72 hours. However, they suggested

that the results were more dependent on the seed lot and priming solutions rather than the priming duration. The interaction between priming treatments was significant for all germination characteristics tested in the present experiment (Table 2). The clusters of both tested lines presented favourable germination results, regardless of the type of priming solution. Also, treatment for 48 hours provided the most advantageous effects of germination for both genotypes. In addition, it was noted that treatment in both KNO_3 and PEG 6000 for 48 hours positively affected the clusters' germination.

Compared to the control (primed, but non-stored clusters), the storage of primed clusters significantly decreased most of the studied germination features; the exception was AS percentage, which were similar for clusters stored at 4°C and for the control (Table 3). Unfortunately, the priming mostly accelerated seed ageing during storage, so the primed seeds usually deteriorated faster than non-primed ones (Hill *et al.,* 2007). According to Pazdera (2005), too-long durations of priming negatively influence the storability of vegetable seeds. In the current study, clusters primed with both KNO_3 and PEG 6000 presented similar values of germination traits after storage. However, the influence of the type of priming solution was reported by Toselli and Casenave (2014), who noted the more beneficial effects of osmo- than hygro-priming for the germination of treated and stored cotton seeds. Govahi *et al.* (2008) suggested better results of sugar beet germination after storage when acetyl salicylic acid rather than methyl jasmonate was incorporated into the PEG 6000. In the present study, the MGT, COV and AS were at a similar level in the case of clusters stored after priming for 6 and 12 months. Tajbakhsh *et al.* (2004) indicated a very strong influence of all pre-sowing treatments to reduce the percentage of abnormal seedlings of onion. On the other hand, Maude *et al.* (1994) reported significant increases in the incidence of leek abnormal seedlings with an increase in the duration of primed seed storage. In the current study, only the values of CUG and GC for clusters stored for 6 months were more favourable, compared to the clusters stored for 12 months. Usually, the extension of the seed storage period causes a decrease in their quality, which was noted by Tiryaki (2006) for amaranth seeds that were stored at room temperature for 4 months and still presented the beneficial effects of priming, but extensions of the storage period to 8 months resulted in a reduction of germination parameters. In the case of the primed clusters of the line AR79, storage at 4°C was much more favourable than storage at 15°C on all of the tested germination characteristics. According to Pazdera (2005), the storage of primed vegetable seeds at room temperature was less preferred for germination than at -18°C. But short storage for one month at 4°C and 20°C did not negatively influence the germination of primed lettuce seeds (Korkmaz and Pill, 2003). In the case of primed rice seeds stored for 7 months at -4°C and 25°C, only the higher temperature reduced the germination and growth attributes compared to the control (Hussain *et al.,* 2015). On the other hand, the storage of sugar beet clusters for 1 month at 4°C affected the differences of germination traits according to the priming substances used (Govahi *et al.,* 2008). As compared to the control, the storage of primed clusters generally worsens germination traits regardless of the priming solution, storage period or storage temperature (Table 4). The exception was AS, which was similar in the case of clusters primed with PEG 6000 and stored at 4°C. Treating of clusters with PEG 6000 and storage for 6 months raise AS compared to the control, but not significantly. There were also no differences noted in the percentage of AS and GC between clusters those were not stored and those stored for 6 months at 4°C. Regardless of the kind of priming solution, clusters stored at 4°C presented more favourable germination features than clusters stored at 15°C. It was also noted that the MGT and GC of clusters primed with PEG 6000 and stored at 15°C were much better than after treatment with KNO_3. Clusters primed with KNO_3 and stored for 6 months presented more preferred values of MGT and COV than clusters stored for 12 months, as well as the clusters stored for 6 and 12 months after treatment with PEG 6000. The CUG decreased after 12 months of cluster storage regardless of the type of priming solution. The GC of clusters primed with PEG 6000 after storage, both for 6 and 12 months, was 3% higher than in the case of clusters treated with KNO_3. The MGT and COV of clusters stored at 4°C tested after 6 and 12 months were similar. The values of CUG, GC and AS of primed clusters after 6 months of storage were better than after 12 months. The storage of primed clusters at 15°C for 6 months more favourably influenced the MGT, COV and GC than storage for 12 months. However, in the case of CUG and AS the storage period at 15°C was not important.

Rapid, synchronized and high germination percentage is required for commercial red beet clusters, which is especially difficult to obtain in the case of seed production of hybrid cultivars. The priming carried out in the present study significantly improved the germination performance of monogerm clusters of the new breeding line AR79. Although, implementing priming in commercial practice is limited by the reduction of longevity of treated clusters during storage. Nevertheless, in the current research, conditioned clusters after storage maintain the beneficial effects resulting from priming.

Table 1. The mean germination time (MGT), coefficient of uniformity of germination (CUG), coefficient of velocity (COV), germination capacity (GC) and percentage of abnormal seedling (AS) of monogerm red beet breeding lines AR79 and W411 clusters primed with KNO_3, $MgSO_4$, PEG 6000 and PEG 8000 for 6 to 120 hours

Cluster treatment	MGT (day)	CUG	COV	GC (%)	AS (%)
Genotype					
AR79	2.93^{a}	0.672^{ab}	37.00^{a}	76^{c}	5.51^{a}
W411	2.55^{a}	0.750^{a}	41.61^{a}	88^{a}	4.66^{a}
Control for AR79	4.67^{b}	0.442^{bc}	21.42^{b}	65^{d}	15.50^{b}
Control for W411	4.05^{b}	0.372^{c}	24.69^{b}	83^{b}	12.50^{b}
Priming solution					
KNO_3	2.44^{a}	0.740^{a}	42.86^{a}	85^{a}	3.00^{a}
$MgSO_4$	2.94^{b}	0.608^{b}	36.45^{b}	78^{bc}	7.13^{b}
PEG 6000	2.60^{a}	0.856^{a}	41.59^{a}	85^{a}	4.00^{a}
PEG 8000	2.97^{b}	0.641^{b}	36.31^{b}	80^{b}	6.21^{b}
Control	4.36^{c}	0.407^{c}	23.05^{c}	74^{c}	14.00^{c}
Priming duration					
6 h	4.20^{d}	0.459^{cd}	24.16^{e}	80^{bc}	8.63^{c}
12 h	3.50^{c}	0.542^{c}	29.22^{d}	85^{ab}	7.03^{b}
24 h	2.62^{b}	0.781^{b}	39.06^{c}	86^{a}	4.38^{a}
48 h	2.10^{a}	1.008^{a}	47.97^{a}	86^{a}	3.38^{a}
72 h	2.22^{a}	0.789^{b}	45.31^{b}	82^{abc}	3.81^{a}
96 h	2.26^{a}	0.687^{b}	44.71^{b}	79^{c}	3.84^{a}
120 h	2.26^{a}	0.712^{b}	44.69^{b}	77^{cd}	4.53^{a}
Control	4.36^{d}	0.407^{d}	23.05^{e}	74^{d}	14.00^{d}

Means in each treatment group followed by the same letters are not significantly different at $P \leq 0.05$.

Table 2. Interaction of genotype, priming solution and priming duration of monogerm clusters of red beet breeding lines AR79 and W411 on their germination traits

Cluster treatment		MGT (day)	CUG	COV	GC (%)	AS (%)
Genotype × priming solution						
	KNO_3	2.55^{ab}	0.636^{b}	41.44^{ab}	81^{cd}	3.1^{a}
	$MgSO_4$	3.18^{b}	0.584^{bc}	33.59^{c}	72^{e}	7.9^{c}
AR79	PEG 6000	2.81^{ab}	0.883^{a}	39.00^{abc}	78^{d}	4.8^{ab}
	PEG 8000	3.16^{b}	0.585^{bc}	33.95^{bc}	72^{e}	6.2^{bc}
	control for AR79	4.67^{d}	0.442^{cd}	21.42^{d}	65^{f}	15.5^{e}
	KNO_3	2.34^{a}	0.843^{a}	44.27^{a}	90^{ab}	2.9^{a}
	$MgSO_4$	2.69^{ab}	0.632^{b}	39.32^{abc}	84^{c}	6.4^{bc}
W411	PEG 6000	2.40^{a}	0.829^{a}	44.17^{a}	92^{a}	3.2^{a}
	PEG 8000	2.78^{ab}	0.697^{ab}	38.67^{abc}	87^{b}	6.2^{bc}
	control for W411	4.05^{c}	0.372^{d}	24.69^{d}	83^{c}	12.5^{d}
Genotype × priming duration						
	6 h	4.54^{f}	0.403^{g}	22.21^{gh}	75^{fgh}	9.6^{e}
	12 h	3.82^{e}	0.476^{fg}	26.46^{f}	80de	7.3^{cd}
	24 h	2.90^{c}	0.679^{cd}	35.29^{d}	77^{efg}	5.3^{abc}
AR79	48 h	2.18^{ab}	0.994^{a}	46.20^{b}	78^{efg}	3.8^{a}
	72 h	2.28^{b}	0.782^{bc}	44.08^{bc}	74^{gh}	3.9^{a}
	96 h	2.40^{b}	0.651^{cde}	42.12^{c}	73^{h}	4.1^{a}
	120 h	2.38^{b}	0.722^{bcd}	42.61^{c}	72^{h}	4.7^{ab}
	control for AR79	4.67^{f}	0.442^{g}	21.42^{h}	65^{i}	15.5^{g}
	6 h	3.87^{e}	0.515^{efg}	26.10^{f}	86^{c}	7.6^{de}
	12 h	3.18^{d}	0.609^{def}	31.97^{e}	89^{b}	6.8^{bcd}
W411	24 h	2.35^{b}	0.884^{ab}	42.82^{c}	93^{a}	3.5^{a}
	48 h	2.02^{a}	1.023^{a}	49.74^{a}	93^{a}	3.0^{a}

	72 h	2.16^{ab}	0.797^{bc}	46.54^{ab}	89^{b}	3.8^{a}
	96 h	2.13^{ab}	0.724^{bcd}	47.31^{ab}	85^{c}	3.6^{a}
	120 h	2.15^{ab}	0.702^{cd}	46.78^{ab}	83^{cd}	4.4^{a}
	control for W411	4.05^{e}	0.372^{g}	24.69^{fg}	83^{cd}	12.5^{f}
Priming solution × priming duration						
	6 h	3.64^{gh}	0.586^{ijk}	27.67^{jk}	84^{a-g}	6.3^{fgh}
	12 h	2.92^{f}	0.692^{g-i}	34.62^{i}	91^{a}	4.0^{b-f}
	24 h	2.20^{abc}	0.838^{c-g}	45.57^{de}	89^{abc}	1.6^{a}
KNO_3	48 h	1.94^{a}	1.037^{ab}	51.52^{a}	86^{a-f}	1.5^{a}
	72 h	2.08^{ab}	0.756^{e-h}	48.08^{bcd}	84^{a-g}	2.0^{ab}
	96 h	2.17^{abc}	0.633^{hij}	46.11^{cde}	83^{a-i}	2.5^{abc}
	120 h	2.16^{abc}	0.636^{hij}	46.44^{cde}	81^{c-j}	3.1^{a-e}
	6 h	4.48^{j}	0.430^{kl}	22.48^{lm}	76^{g-j}	11.0^{k}
	12 h	3.75^{h}	0.503^{jkl}	27.01^{jk}	79^{d-j}	9.5^{jk}
	24 h	2.81^{ef}	0.690^{ghi}	36.30^{i}	83^{a-h}	7.0^{ghi}
$MgSO_4$	48 h	2.24^{abc}	0.856^{c-f}	44.68^{def}	80^{c-j}	5.4^{e-h}
	72 h	2.40^{cd}	0.681^{g-i}	41.66^{fgh}	78^{f-j}	5.6^{fgh}
	96 h	2.45^{cd}	0.525^{i-l}	41.16^{gh}	75^{hij}	5.8^{fgh}
	120 h	2.42^{cd}	0.572^{ijk}	41.87^{fgh}	73^{j}	5.6^{fgh}
	6 h	4.10^{i}	0.426^{kl}	24.70^{klm}	83^{b-i}	7.5^{hij}
	12 h	3.43^{g}	0.581^{ijk}	29.49^{j}	87^{a-e}	5.6^{fgh}
	24 h	2.58^{de}	0.906^{b-e}	39.55^{h}	87^{a-d}	2.6^{a-d}
PEG 6000	48 h	1.99^{ab}	1.144^{a}	50.23^{ab}	91^{ab}	2.3^{abc}
	72 h	2.09^{ab}	0.944^{bc}	47.80^{bcd}	86^{a-f}	3.1^{a-e}
	96 h	2.01^{ab}	0.924^{bcd}	49.99^{ab}	81^{c-j}	2.0^{ab}
	120 h	2.03^{ab}	1.066^{ab}	49.36^{abc}	79^{d-j}	4.9^{d-g}
	6 h	4.61^{j}	0.393^{l}	21.77^{m}	78^{e-j}	9.8^{k}
	12 h	3.90^{hi}	0.393^{l}	25.76^{kl}	81^{c-j}	9.0^{ijk}
	24 h	2.92^{f}	0.692^{ghi}	34.80^{i}	83^{b-i}	6.3^{fgh}
	48 h	2.21^{abc}	0.996^{abc}	45.44^{de}	85^{a-f}	4.4^{c-f}
PEG 8000	72 h	2.30^{bcd}	0.776^{d-h}	43.71^{efg}	79^{d-j}	4.5^{c-f}
	96 h	2.42^{cd}	0.667^{hij}	41.61^{fgh}	77^{f-j}	5.1^{efg}
	120 h	2.44^{cd}	0.573^{ijk}	41.11^{gh}	75^{hij}	4.5^{c-f}
	control	4.36^{j}	0.407^{l}	23.05^{lm}	74^{ij}	14.0^{l}

Explanations: see Table 1.

Table 3. The mean germination time (MGT), coefficient of uniformity of germination (CUG), coefficient of velocity (COV), germination capacity (GC) and percentage of abnormal seedling (AS) of monogerm red beet breeding line AR79 clusters primed with KNO_3 and PEG 6000 and stored for 6 and 12 months at 4 and 15°C

Cluster treatment	MGT (day)	CUG	COV	GC (%)	AS (%)
Priming solution					
KNO_3	2.58^{b}	0.673^{b}	39.30^{b}	72^{b}	6.81^{b}
PEG 6000	2.73^{b}	0.752^{b}	37.12^{b}	75^{b}	5.38^{b}
Control for KNO_3	2.04^{a}	1.005^{a}	48.98^{a}	80^{a}	2.25^{a}
Control for PEG 6000	2.12^{a}	1.175^{a}	47.28^{a}	82^{a}	3.50^{a}
Storage period					
6 months	2.58^{b}	0.624^{b}	39.32^{b}	75^{b}	5.06^{b}
12 months	2.73^{b}	0.467^{c}	37.11^{b}	72^{c}	7.13^{b}
Control	2.08^{a}	1.090^{a}	48.13^{a}	81^{a}	2.88^{a}
Storage temperature					
Storage at 4ºC	2.37^{b}	0.679^{b}	42.29^{b}	77^{b}	4.31^{a}
Storage at 15ºC	2.94^{c}	0.413^{c}	34.14^{c}	70^{c}	7.88^{b}
Control	2.08^{a}	1.090^{a}	48.13^{a}	81^{a}	2.88^{a}

Explanations: see Table 1.

Table 4. Interaction of priming solution, storage period and storage temperature of primed clusters on the germination traits of monogerm red beet breeding line AR79

Cluster treatment		MGT (day)	CUG	COV	GC (%)	AS (%)
Priming solution × storage temperature						
KNO_3	storage at 4ºC	2.32^{b}	0.621^{b}	43.26^{b}	76^{b}	5.63^{b}
	storage at 15ºC	2.85^{c}	0.364^{c}	35.35^{c}	68^{d}	8.00^{c}
PEG 6000	storage at 4ºC	2.42^{b}	0.737^{b}	41.31^{b}	78^{b}	3.00^{a}
	storage at 15ºC	3.04^{d}	0.461^{c}	32.94^{c}	72^{c}	7.75^{c}
	Control	2.08^{a}	1.090^{a}	48.13^{a}	81^{a}	2.88^{a}
Storage period × priming solution						
6 months	KNO_3	2.42^{b}	0.576^{bc}	41.66^{b}	74^{bc}	5.75^{bc}
	PEG 6000	2.74^{c}	0.673^{b}	36.98^{c}	77^{b}	4.38^{ab}
12 months	KNO_3	2.74^{c}	0.409^{c}	36.95^{c}	70^{d}	7.88^{c}
	PEG 6000	2.72^{c}	0.526^{bc}	37.27^{c}	73^{cd}	6.38^{bc}
	Control	2.08^{a}	1.090^{a}	48.13^{a}	81^{a}	2.88^{a}
Storage temperature × storage period						
Storage at 4ºC	6 months	2.32^{b}	0.799^{b}	43.22^{b}	79^{a}	3.25^{a}
	12 months	2.42^{b}	0.558^{c}	41.35^{b}	75^{b}	5.38^{b}
Storage at 15ºC	6 months	2.84^{c}	0.449^{cd}	35.42^{c}	72^{c}	6.88^{bc}
	12 months	3.04^{d}	0.376^{d}	32.87^{d}	68^{d}	8.88^{c}
	control	2.08^{a}	1.090^{a}	48.13^{a}	81^{a}	2.88^{a}

Explanations: see Table 1.

Conclusions: Current research is one of the few published so far, which tested the priming techniques for monogerm red beet genotypes. The results revealed beneficial effect of applied osmopriming treatments on the seed germination characteristics of the studied breeding lines. The fact is that, the storage of primed clusters contributed to the deterioration of their quality. Although, the treated and stored seeds presented still more favourable values of the germination than untreated clusters.

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