

Full Length Research Paper

Effects of different osmotic solutions on onion seed emergence

Levent Arin, Serdar Polat, Murat Deveci* and Ahmet Salk

Department of Horticulture, Faculty of Agriculture, Namik Kemal University, Tekirdag, Turkey.

Accepted 09 October, 2019

This experiment was aimed at the optimisation of emergence with onion seeds. For this reason, onion seeds (*Allium cepa* L.) short-days cultivars (Aki and Alix) and long-days cultivars (Banko and Suluova) were primed with different concentrations of polyethylene glycol (PEG 6000) in inorganic salts (KNO_3 and KH_2PO_4) for different periods of time (3 and 6 days or until 1% radicle emergence) at 15°C. After the treatments, the effects of priming on seedling emergence were evaluated at optimal (20°C) and suboptimal (11°C) temperatures, under field conditions. Priming in all KNO_3 and KH_2PO_4 reduced the days to emergence without significant loss in emergence ratio. In contrast, seed priming with PEG was ineffective. In field experiments, which were conducted in different periods (at two week intervals in February and March for spring and in September and October for autumn), the emergences of primed seeds were not earlier than those of untreated seeds, except 'Alix'. In this variety, seeds primed with KNO_3 and KH_2PO_4 emerged approximately four days earlier than the control seeds, regardless of the sowing date.

Key words: *Allium cepa* L., polyethylene glycol, potassium salts, priming.

INTRODUCTION

Onion (*Allium cepa* L.) is a very important economic crop used in different ways and is well known for 5,000 years (Brewster, 1994). Turkey has an important place among the onion producing countries with 2,050,000 tonnes bulb production in 93,200 ha production area (FAO, 2008) in which the Trakya region has an important role in production. In the region, in which the production is generally performed by sets, agricultural inputs and the propagation material (mainly the seeds) have shown rapid increase in cost at the end of the 1980's. Although direct seeding is more economic than by sets, irregularities and delays in germination result in poor plant establishment and yield, especially by the reason of high or low temperatures. In plant species with small seeds and poor seed establishment, perhaps the most promising method of increasing the rate and uniformity of seedling establishment is seed priming that permits the

preliminary process of germination but not the final phase of radicle emergence (Heydecker and Coolbear, 1977; Heydecker and Gibbins, 1978). There are several chemicals that have been used for seed priming. Among these, potassium salts and polyethylene glycol (PEG) are the most widely used osmotica. In experiments with onions where only a single variety is used, osmotic potentials and treatment times have greatly differed (Peterson, 1976; Lippe and Skinner, 1979; Frutani et al., 1986; Haigh et al., 1986; Taylor et al., 1988; Bujalski et al., 1989; Suzuki et al., 1989; Ali et al., 1990; Gray et al., 1991; Arin, 1992; Duman, 2002). Heydecker and Coolbear (1977) and Bradford (1986) stated that treatment temperature, time and concentration are three important factors for success, and each must be determined for species, varieties and even for different seed lots. Concerning priming, Ok et al. (2000a) reported that the percentage of germination onion seeds was affected significantly by the seed treatment, priming duration and temperature. It was determined that the germination and vigor of onion seeds decreased as the

*Corresponding author. E-mail: muratdeveci@nku.edu.tr.

Table 1. Some properties of soil mixture.

N (ppm)	P ₂ O ₅ (ppm)	K ₂ O (ppm)	EC (μS.cm ⁻¹)	pH
100 to 300	100 to 300	150 to 400	350	4.4 to 5.9

Table 2. Soil properties of the experimental field.

Salt (%)	pH	CaCO ₃ (%)	P ₂ O ₅ (kg ha ⁻¹)	K ₂ O (kg ha ⁻¹)	Organic matter (%)	Texture
0.066	7.4	2.60	51.4	583.0	1.67	Clay-loam

osmotic potential increased from -1.0 to -1.4 MPa and the imbibition period from 24 to 96 h by Trigo et al. (1999a). In this experiment, the seeds of some important onion varieties, which are widely grown in Trakya region, were treated in different osmotic solutions at different times and different temperatures in the growth chamber for emergence tests to improve seedling establishment.

MATERIALS AND METHODS

Seeds of two short day ['Aki' (Tat seeds) and 'Alix' (Novartis)] and two long day ['Banko' (May seeds) and 'Suluova' (Agromar)] onion varieties were used for the experiments. Sterile glass containers (30x30x3 cm), with each having a sterile germination paper, were used for the treatments. Seeds were kept in osmotic conditioners containing KNO₃, KH₂PO₄ and polyethylene glycol (PEG 6000) with different concentrations (2% KNO₃, 4% KNO₃, 2% KH₂PO₄, 4% KH₂PO₄, 2% KNO₃+ KH₂PO₄, 4% KNO₃+ KH₂PO₄, -5 bar PEG 6000, -10 bar PEG 6000 and -15 bar PEG 6000) at 15°C for three different times (3 days, 6 days and until 1% radicle emergence). Treatment temperature, concentrations and treatment duration were referred to the results of different investigators (Wiebe and Tiessen, 1979; Furutani et al., 1986; Haigh et al., 1986; Bujalski et al., 1989; Suzuki et al., 1989; Gray et al., 1991; Arin, 1992). Osmotic solutions were replaced every day by new solution to minimize changes in viscosity and prevent toxicity. Time to 1% radicle emergence ranged between 7 and 14 days depending on the variety and concentration of solutions. After priming, the seeds were removed from glass containers and rinsed thoroughly in tap and distilled water in sieve, to remove solutions and dried until they reached their initial moisture content (Brocklehurst et al., 1984; Muhyaddin and Wiebe, 1989). Then, the seeds were treated with 80% thiram tetramethylthiuram disulphide (0.3 kg/100 kg seeds) to prevent fungal growth and stored hermetically in sealed polyethylene bags at 5±1°C during 8 months. Every 2 months, to evaluate the effects of priming on germination during the storage period, four replicates of 100 seeds each from each lot were tested for germination at 20°C (ISTA, 2003). Seeds from each treatment and unprimed seeds were tested for emergence at two different temperatures (20°C optimal and 11°C suboptimal) with four replications. Emergence tests, which were partly followed in growth chambers, were done in 72x19x4 cm plastic containers, having the soil mixture from Rito Seed Company-Antalya, Turkey. Properties of this compost are given in Table 1. Each container had equal amount of compost. The compost were thoroughly moistened and then weighed. The amount of vaporized water from the compost was added each day.

During the emergence tests, every container was checked each

day and the number of seedlings emerged from the compost having vertical cotyledon were recorded and pulled out (Harrington, 1962; Bierhuizen and Wagenvoort, 1974). Ratio of emergence and days to emergence were calculated according to Alvarado and Bradford (1988) [Days to emergence = $T_i X_i / T_i$, where X_i is the number of newly germinated seeds at time T_i]. For each variety, three suitable combinations were determined based on these results (solution and time). In deciding these combinations, special attention was given to the results of 20°C for autumn sown short day varieties ('Aki' and 'Alix') and the results of 11°C for spring sown long day varieties ('Banko' and 'Suluova'), because soil temperature in autumn are much higher than early spring.

Soil emergence tests were performed in field conditions. In autumn tests, the seeds of 'Aki' and 'Alix' were sown to the field by two-week intervals at September 5, September 19, October 3 and October 17, and for spring tests, the seeds of 'Banko' and 'Suluova' were sown at February 15, February 28, March 14 and March 29 by fortnight intervals. Meteorological and other ecological conditions were considered effectively in deciding these dates. The experimental layout was the split plot, while the experimental design was the time main plot. Seeds were sown by 25 cm distances between rows and 2 cm distances in rows. Soil properties are shown in Table 2, and air and soil temperatures are shown in Figure 1.

In both seasons, every parcel was visited three times in a week and the seedlings, with erect cotyledons, were recorded and the ratio of emergence (%) and days to emergence were calculated. Data dealing with the emergence ratio were transformed to arc sin before statistical analysis, but they were presented as real values in tables. The data were analysed by analysis of variance (ANOVA), while the means were separated by least significant difference test (LSD).

RESULTS AND DISCUSSION

The variations in the germination percentage during the storage period were not statistically important for all varieties and treatments, that is, they were not significantly different from the starting value after 8 months of storage.

Emergence at 20°C

According to the data obtained (Table 3), variety, time, osmotic solutions and interactions between variety and osmotic solutions affected the emergence ratio. 'Alix' has

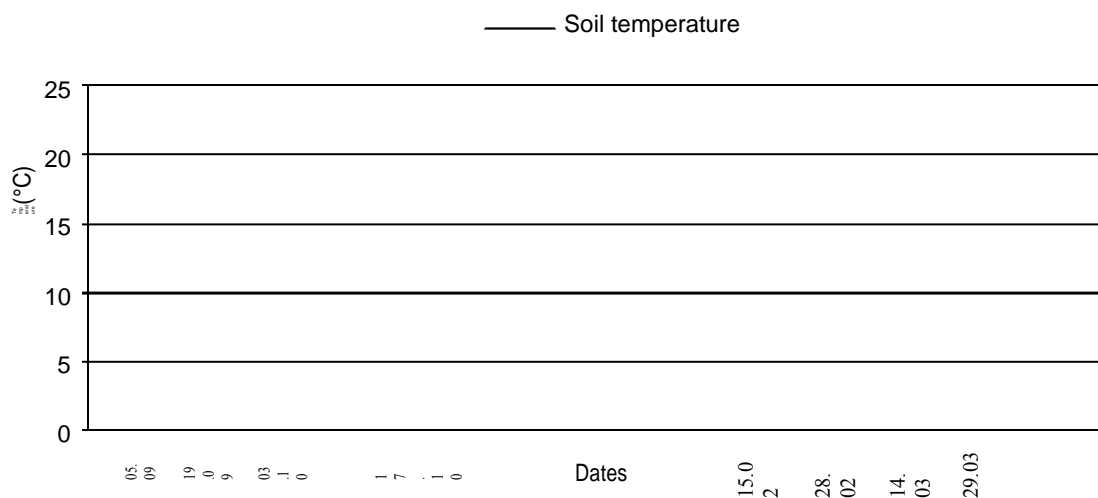


Figure 1. Mean air and soil temperatures at emergence period (5 cm).

Table 3. Emergence ratio at 20°C (%).

Osmotic solution	Variety				Priming time			Main effect
	Aki	Alix	Banko	Suluova	3 day	6 day	1% radicle	
2% KNO ₃	88.3 abcd	79.6 cdef	84.6 bcde	82.5 bcde	86.9	85.0	79.4	83.8 bcd
4% KNO ₃	84.2 bcde	78.8 cdef	81.7 bcde	77.9 cdef	81.6	79.4	80.9	80.6 cde
2% KH ₂ PO ₄	87.5 abcd	82.1 bcde	88.8 abcd	83.3 bcde	91.6	81.3	83.4	85.4 bc
4% KH ₂ PO ₄	81.7 bcde	83.3 bcde	83.8 bcde	82.9 bcde	85.0	83.4	80.3	82.9 bcd
2%KNO ₃ +KH ₂ PO ₄	80.0 cdef	85.4 bcde	90.8 abc	87.9 abcd	84.1	89.4	84.7	86.0 b
4%KNO ₃ +KH ₂ PO ₄	80.8 cdef	77.9 cdef	83.3 bcde	80.0 cdef	81.6	81.9	78.2	80.5 cde
-5 bar PEG ₆₀₀₀	79.6 cdef	73.3 efg	79.2 cdef	75.8 def	83.4	74.1	73.4	77.0 e
-10 bar PEG ₆₀₀₀	83.3 bcde	67.9 fg	84.6 bcde	83.8 bcde	86.9	75.3	77.5	79.9 de
-15 bar PEG ₆₀₀₀	84.2 bcde	60.8 g	80.0 cdef	84.2 bcde	82.2	77.8	71.9	77.3 e
Control	88.8 abcd	100.0a	88.8 abcd	95.0 ab	93.1	93.1	93.1	93.1 a
Main effect	83.8 a	78.9 b	84.5 a	83.3 a	85.6 a	82.1 b	80.3 b	

shown less emergence ratio (78.9%) than other varieties. Priming for three days increased the emergence ratio (85.6%). However, unprimed seeds gave the higher ratio (93.1%) in comparison to other seeds primed in osmotic solutions; PEG₆₀₀₀ being the lowest. On the other hand, concerning the variety × solution (including different concentrations) interaction, unprimed seeds of 'Alix' had 100% emergence, but -15 bar PEG₆₀₀₀ primed seeds of same variety had 60.8% emergence, being the lowest.

Days to emergence were found to be statistically different, except the interactions of variety × time, variety × time × solutions and solution main effect (Table 4). As in the percentage of emergence, 'Alix' had the longest period for emergence in comparison to other varieties, but three days of priming resulted in the shortest period for emergence. Priming the seeds with PEG₆₀₀₀ has resulted in the longest period for emergence compared to

other solutions, and same results have been obtained with the different times and concentration of the same solution.

Emergence at 11°C

Time and osmotic solution main effects were found to be important with respect to emergence ratio (Table 5). All solutions have resulted in a higher percentage than the unprimed seeds (except for PEG₆₀₀₀ treatments and 4% KNO₃); meanwhile, the longer the time for treatment, the lower the percentage of emergence.

Concerning the days to emergence, variety and solution (including different concentrations) main effects and interactions of solutions × time has given different results, which were found to be statistically important.

Table 4. Days to emergence at 20°C (Days).

Osmotic solution	Variety				Priming time			Main effect
	Aki	Alix	Banko	Suluova	3 day	6 day	1% radicle	
2% KNO ₃	9.9 h	9.8 h	9.8 h	9.6 h	10.0 cd	9.5 cd	9.8 cd	9.8
4% KNO ₃	10.2 h	10.1 h	10.2 h	9.9 h	10.0 cd	10.0 cd	10.3 c	10.1
2% KH ₂ PO ₄	9.4 h	9.5 h	9.6 h	9.8 h	9.8 cd	9.6 cd	9.3 d	9.6
4% KH ₂ PO ₄	9.6 h	10.2 h	9.9 h	9.8 h	10.1 cd	9.7 cd	9.7 cd	9.8
2%KNO ₃ +KH ₂ PO ₄	9.8 h	10.1 h	9.9 h	9.8 h	10.1 cd	10.0 cd	9.6 cd	9.9
4%KNO ₃ +KH ₂ PO ₄	9.8 h	10.1 h	9.9 h	9.9 h	10.1 cd	10.2 cd	9.4 cd	9.9
-5 bar PEG ₆₀₀₀	12.0 fg	15.6 a	13.1 cde	12.4 efg	12.4 b	13.6 a	13.8 a	13.2
-10 bar PEG ₆₀₀₀	12.5 defg	15.1 a	13.4 d	12.1 efg	12.1 b	13.8 a	14.0 a	13.3
-15 bar PEG ₆₀₀₀	13.0 cdef	14.6 ab	13.7 bc	11.8 g	11.8 b	14.0 a	14.0 a	13.3
Control	9.7 h	9.8 h	9.9 h	9.7 h	9.8 cd	9.8 cd	9.8 cd	9.8
Main effect	10.6 c	11.5 a	10.9 b	10.5 c	10.6 b	11.0 a	11.0 a	

Table 5. Emergence ratio and days to emergence at 11°C (%).

Osmotic solution	Emergence ratio	Days to emergence			Main effect
		Priming time			
		3 days	6 days	1% radicle	
2% KNO ₃	87.8 a	32.4 cdefg	31.2 efghi	29.9 i	31.2 cd
4% KNO ₃	71.2 cd	33.1 cdef	31.1 efghi	31.8 cdefghi	32.0 bcd
2% KH ₂ PO ₄	88.0 a	30.9 fgh	29.8 i	31.9 cdefghi	30.9 cd
4% KH ₂ PO ₄	85.1 ab	31.4 defghi	31.1 efghi	30.2 ghi	30.9 cd
2%KNO ₃ +KH ₂ PO ₄	85.3 ab	31.8 cdefghi	30.3 ghi	30.1 hi	30.7 d
4%KNO ₃ +KH ₂ PO ₄	82.6 abc	32.4 cdefghi	32.5 cdefg	31.6 cdefghi	32.2 bc
-5 bar PEG ₆₀₀₀	72.8 d	31.9 cdefghi	33.7 abc	33.4 bcde	33.0 ab
10 bar PEG ₆₀₀₀	72.2 d	33.0 cdef	33.4 bcde	35.9 a	34.1 a
15 bar PEG ₆₀₀₀	76.2 bcd	33.3 bcde	33.7 abcd	35.6 ab	34.2 a
Control	77.8 bcd	32.0 cdefghi	32.0 cdefghi	32.0 cdefghi	32.0 bcd
Priming time			Variety		
3 days	82.8 a		Aki	30.4 d	
6 days	81.8 a		Alix	31.3 c	
1% radicle	77.2 b		Banko	32.6 b	
			Suluova	34.3 a	

'Suluova' has taken 34.3 days to emerge, while 'Aki' has taken 30.4 days to emerge. The longest days to emergence, which were more than 34 days, have been obtained from the PEG₆₀₀₀ solutions with -10 and -15 bar potentials. Unprimed seed emerged in 32.0 days and the earliest emergence of seedlings was observed in 2% KNO₃+ KH₂PO₄ with 30.7 days.

Field emergence

In field trials, emergence was affected by the sowing time and it showed difference in 'Aki' and 'Alix' varieties.

Seeds, which were sown in autumn, tend to emerge at a high percentage, but the highest ratio was obtained from the seeds sown at October 17, which later tended to have higher sowing percentage. Same results were obtained for days to emergence and in both periods, more rapid emergence occurred at October 3 sowings in all the varieties (Table 6).

Osmotic solutions and interactions were ineffective for this trial in all the varieties except 'Alix' (Table 6). The seed primed with all solutions completed emergence earlier than unprimed seeds, which emerged at 23.3 days. Days to emergence in field reached 33.5 days for unprimed seeds with September 5th sown seeds.

Table 6. Effect of sowing date and osmotic solution on the days to emergence of 'Alix' in the field (Days).

Sowing date	Osmotic solution				Main effect
	B ₁	C ₃	C ₅	Control	
05 September	22.7 b	21.9 b	22.2 b	33.5 a	25.1 a
19 September	23.6 b	21.4 bc	20.5 bcd	21.9 b	21.9 a
03 October	15.1 de	15.4 de	13.3 e	16.4 cde	15.0 b
17 October	21.8 b	22.8 b	22.5 b	21.3 bc	22.1 a
Main effect	20.8 ab	20.4 b	19.6 b	23.3 a	

* B₁: 6 days, 2% KNO₃; C₃: 1% radicle, 2% KH₂PO₄; C₅: 1% radicle, 2% KNO₃+KH₂PO₄.

However, the shortest period was obtained from the seeds, which were sown on October 3rd, primed in 2% KNO₃+ KH₂PO₄ solution until 1% radicle emergence.

The increase in duration results in a somewhat earlier emergence under controlled temperature emergence tests. PEG treatments showed no substantial benefit of priming to onion emergence. Emergence ratio and days to emergence at 20 and 11°C were negatively affected by PEG solutions. The seeds primed in PEG 6000 solutions have less and later emergence than unprimed seeds. According to the results of some previous research, aeration of treatment solution is important (Peterson, 1976), in that PEG treatment delays and lowers the ratio of germination (Furutani et al., 1986) and aeration increases the germination ratio (Bujalski et al., 1989). In all vegetable seeds in general, there is a benefit of low temperature (15°C) priming in various PEG polymers which enhances germination, whereas in onions, germination ratio decreases with PEG priming, although the time-spread of germination is same with untreated seeds (Gray et al., 1991). Same results of this present research led us to think about the aeration problem again, although the solutions were freshly prepared and changed every day. According to Mexal et al. (1975), O₂ exchange capacity of PEG is 90% lesser than water and in some seeds, lower O₂ levels promotes anaerobic respiration and probably results in ethanol levels to increase toxic concentrations (Mayer and Poljakoff-Mayber, 1982). Yuri (1988) has also mentioned the toxic effects of same PEG polymers. Duman (2002) stated that KNO₃ treatment with bubble-column improved germination and emergence rates faster than both PEG and Petri dishes treatments. Benefits in earlier emergence of seeds primed in different concentrations of potassium salts at 20°C are not enough when compared to unprimed seeds. Time to emergence has only been enhanced in seeds primed at 2% KH₂PO₄ (Table 4). At the suboptimal emergence temperature (11°C) tests done in all salt solutions, the ratio of emergence did not increase, but in PEG solutions, the ratio of emergence increased and the time to emergence decreased, except in 4% KNO₃+ KH₂PO₄ and 4%KNO₃. Experimental data

similar to our results are those of, for example, Bradford (1986) who mentioned that the KH₂PO₄ solution hastened the seedling emergence, and Haigh et al. (1986) working with tomatoes, carrots and onions who found the benefits of priming with KNO₃+ KH₂PO₄ at 15°C by 14 days. Trigo et al. (2000) stated that onion seeds osmoconditioned in aerated KNO₃ exhibited a better performance compared to seeds in PEG 6000. Ok et al. (2000b) working with osmotic priming chemicals [including KNO₃, KH₂PO₄, K₃PO₄, NaOH, Ca(NO₃)₂ and PEG 8000] and their concentration to improve the germination of carrot, lettuce, onion and Welsh onion seeds, found that among the chemicals with no influence on percentage germination, 200 mM KH₂PO₄ significantly reduced both 50% of the final germination percentage and the mean number of days to germination. Also, Suzuki et al. (1989) indicated that the priming of some vegetable seeds, including onions in -10 bar K₃PO₄ solution, have given better results than Na and Mg salt solutions. Additional data about the different effects of mineral salts come from Haigh et al. (1986) who found the advantageous effects of K salts in comparison to other minerals, and PO₄ ion gives an additional extra benefit to these K salts because it is imbibed by the seed itself (Suzuki et al., 1989). Mauromicale and Cavallaro (1997) also pointed out that the embryo and endosperm K⁺ content of tomato seeds primed in KNO₃ + KH₂PO₄ was increased by 65 and 33% of the control value, respectively, and by this reason, higher water absorption in seed primed with potassium salt was observed during osmopriming. On the other hand, priming at lower temperatures, has been proved to give more acceptable results than higher temperatures (Szafirowska et al., 1981; Pill and Finch-Savage, 1988).

In this experiment, all the varieties were affected from the sowing date. The emergence at a shortest period was obtained from the third sowing time for all varieties. However, in field emergence tests, priming shortened the time of emergence in only 'Alix' variety. Also, Trigo et al. (1999b) reported that under stress conditions, seed priming with KNO₃ improved radicle length and germination rate in only 'Petrolini' variety. This result can easily be explained by the additional factors affecting field

emergence and different inherent characteristics of these varieties.

Ultimately, being an extraction from this experiment, onion seed priming in KNO_3 and KH_2PO_4 solutions for six days or until 1% radicle emergence, has benefits for seedling emergence at low temperatures. Since only the emergence of 'Alix' variety was promoted following priming with KNO_3 and KH_2PO_4 under field conditions, additional precise tests are required for varietal needs.

ACKNOWLEDGEMENT

This work was supported by Trakya University Research Fund (Project TUBAP- 317), which aided the study in overcoming its financial problems.

REFERENCES

- Ali A, Machado VS, Hamil AS (1990). Osmoconditioning of tomato and onion seeds. *Sci. Hort. (Amst)*, 43: 213-224.
- Alvarado AD, Bradford KJ (1988). Priming and storage of tomato (*Lycopersicon lycopersicum*) seeds. I. Effects of storage temperature on germination rate and viability. *Seed Sci. Technol.*, 16: 601-612.
- Arin L (1992). Cikisin iyileştirilmesinde soğan (*Allium cepa* L.) tohumunun PEG (polietilen glikol) ile muamelesi [Effects of seed treatment with PEG on onion seedling emergence]. Türkiye I. Ulusal Bahçe Bitkileri Kongresi, İzmir, pp. 73-76.
- Bierhuizen JF, Wagenvoort WA (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. *Sci. Hort. (Amst)*, 2: 213-219.
- Bradford KJ (1986). Manipulation of seed water relations via osmotic priming to improve germination under stress conditions. *Hort. Sci.*, 21: 1105-1112.
- Brewster JL (1994). Onions and Other Vegetable Alliums. Cambridge University Press, Cambridge.
- Brocklehurst PA, Dearman J, Drew RLK (1984). Effects of osmotic priming on seed germination and seedling growth in leek. *Sci. Hort. (Amst)*, 24: 201-210.
- Bujalski W, Nienow AW Gray D (1989). Establishing the large scale osmotic priming of onion seeds by using enriched air. *Ann. Appl. Biol.*, 115: 171-176.
- Duman I (2002). Comparison of different osmotic treatment methods to enhance the germination in onion (*Allium cepa* L.) seeds. *Ege Üniversitesi Ziraat Fakültesi Dergisi*, 39(2): 1-8.
- FAO (2008). Statistics database. On internet <http://faostat.fao.org/site/339/default.aspx>.
- Furutani SC, Zandstra BH Price HC (1986). The effects of osmotic solute composition and duration and temperature of priming on onion seed germination. *Seed Sci. Technol.*, 14: 545-551.
- Gray D, Drew RLK, Bujalski W Nienow AW (1991). Comparison of polyethylene glycol polymers, betaine and L. proline for priming vegetable seeds. *Seed Sci. Technol.*, 19: 581-590.
- Haigh AM, Barlow EWR, Milthorpe FL (1986). Field emergence of tomato, carrot and onion seeds primed in an aerated salt solution. *J. Am. Soc. Hort. Sci.*, 111: 660-665.
- Harrington JF (1962). The effect of temperature on the germination of several kinds of vegetable seeds. XVI Intern. Hort. Cong., Brussels II, 435-441.
- Heydecker W, Coolbear P (1977). Seed treatments for improved performance: Survey and attempted prognosis. *Seed Sci. Technol.*, 5: 353-425.
- Heydecker W, Gibbins BM (1978). The priming of seeds. *Acta Hort.*, 83: 213-223.
- ISTA (2003). International Seed Testing Association. International rules for seed testing. Intl. seed testing assn., Zurich, Switzerland.
- Lippe WN, Skinner JA (1979). Effect of sowing pre-germinated onion seeds in cold soil on time of emergence, maturity and yield. *Hort. Sci.*, 14: 238-239.
- Mauromicale G, Cavallaro V (1997). A comparative study of the effects of different compounds on priming of tomato seed germination under suboptimal temperatures. *Seed Sci. Technol.*, 25(3):399-408.
- Mayer AM, Poljakoff-Mayber A (1982). The Germination of Seeds. Pergamon Press, Inc., London.
- Mexal J, Fisher JT, Osteryoung J, Reid CPP (1975). Oxygen availability in polyethylene glycol solution and its implication in plant-water relations. *Plant Physiol.*, 55: 20-24.
- Muhyaddin T, Wiebe HJ (1989). Effect of seed treatment with polyethylenglycol (PEG) on emergence of vegetable crops. *Seed Sci. Technol.*, 17: 49-56.
- Ok JY, Cheal KJ, Lai CJ (2000a). Effect of priming duration and temperature on the germinability of carrot, lettuce, onion and Welsh onion seeds. *Korean J. Hort. Sci. Technol.*, 18(3): 327-333.
- Ok JY, Cheal KJ, Lai CJ (2000b). Germination of carrot, lettuce, onion and Welsh onion seeds as affected by priming chemicals at various concentrations. *Korean J. Hort. Sci. Technol.*, 18(2): 93-97.
- Peterson JR (1976). Osmotic priming of onion seeds -The possibility of a commercial-scale treatments. *Sci. Hort. (Amst)*, 5: 207-214.
- Pill WG, Finch-Savage WE (1988). Effects of combining priming and plant growth regulator treatments on the synchronization of carrot seed germination. *Ann. Appl. Biol.*, 113: 383-389.
- Suzuki H, Obayashi S, Luo H (1989). Effects of salt solutions on the priming of several vegetable seeds. *J. Jpn. Soc. Hort. Sci.*, 58: 131-138.
- Szafirowska A, Khan AA, Peck NH (1981). Osmo-conditioning of carrot seeds to improve seedling establishment and yield in cold soil. *Agron. J.*, 73: 845-848.
- Taylor AG, Klein DE, Whitlow TH (1988). SPM: Solid matrix priming of seeds. *Sci. Hort. (Amst)*, 37: 1-12.
- Trigo MFOO, Nedel JL, Lopes NF, Trigo LFN (1999a). Onion (*Allium cepa* L.) seeds osmoconditioning with polyethylene glycol solutions. *Revista Brasileira de Sementes*, 21(1): 145-150.
- Trigo MFOO, Nedel JL, Garcia A, Trigo LFN (1999b). Osmoconditioning effects with aerated potassium nitrate solutions on onion seeds performance. *Revista Brasileira de Sementes*, 21(1): 139-144.
- Trigo MFOO, Nedel JL, Garcia A, Trigo LFN (2000). Osmotic conditioning in onion seeds: vigor effects. *Revista Científica Rural*, 5(2): 1-11.
- Wiebe HJ, Tiessen H (1979). Effects of different seed treatments on embryo growth and emergence of carrot seeds. *Gartenbauwissenschaft*, 44: 280-284.
- Yuri JA (1988). Anwendung von polyethylen-glycol und mannitol bei studien zum wasserstreß. *Gartenbauwissenschaft*, 53: 270-273.