AMELIORATIVE EFFECTS OF SOME PRIMING TREATMENTS ON GERMINATION AND EMERGENCE OF LETTUCE SEEDS UNDER HIGH TEMPERATURE CONDITIONS

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Master Thesis

Department of Horticulture
Adviser: Assist. Prof. Dr. Nusret ÖZBAY

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This master's thesis was accepted by the following committee on 18.05.2017 with the vote unity.

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PREFACE

First, I thank God for my passion for science, for allowing me to rely on his strength and power, and for teaching me patience as I complete this journey. This has been one of the most challenging but rewarding experiences of my life.

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Midya Jaza MUHAMED

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LIST OF SYMBOLS AND ABBREVIATIONS

°C	: Celsius Degree
CaCl	: Calcium Chloride
Cm	: Centimetre
EBM	: endo-beta-mannanase
EI	: Emergence Index
FEP	: Final emergence percentage
FEP	: Final Emergence Percentage
FGP	: Final germination percentage
FGP	: Final Germination percentage
GA_3	: Gibberellic Acid
GI	: Germination Index
h	: hour
INO	: Synthetic sea water
KCl	: Potassium Chloride
KH_2PO_4	: Potassium Dihydrogen Phosphate
KNO_3	: Potassium Nitrate
L	: Litter
MDG	: Mean day germination
Mg	: Milligram
$MgCl_2$	: Magnesium Chloride
mM	: Millimole
Mn	: Manganese
MPa	: Mega Pascal
MTE	: Mean Time Emergence
MTG	: Mean time to germination
MTG	: Mean Time Germination
NaCl	: Sodium Chloride
$NaNO_3$	: Sodium Nitrate
NaOCl	: Sodium Hypochlorite
$NH_4H_2PO_4$	: Ammonium Dihydrogen Phosphate
P	: Phosphorus

PEG : Polyethylene glycol

Pro-Ca : Prohexadione Calcium

RH : Relative Humidity

RNA : Ribonucleic acid

T_{50} : The time to reach 50% germination

V : Volume

Zn : Zinc

$ZnSO_4$: Zinc Sulfat

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BAZI PRİMİNG UYGULAMALARININ MARUL TOHUMLARININ YÜKSEK SICAKLIKTA ÇİMLENME VE ÇIKIŞ PERFORMANSLARI ÜZERİNE ETKİLERİ

ÖZET

Marul (*Lactuca sativa* L.) tohumlarının çimlenmesi için maksimum sıcaklık aralığı 25-30 °C arasındadır. Optimum sıcaklık aralığının üzerindeki sıcaklıklar, marul tohumunun çimlenmesini engeller ve üniform olmayan bitkilerin meydana gelmesine neden olurlar. Su ile ıslatılan marul tohumlarının yüksek sıcaklık nedeniyle çimlenememesi olayı "termodormansi" olarak adlandırılır. Termodormansi ile başa çıkma metotlarından birisi de tohumların prime edilmesidir. Bu çalışmada priming çözeltilerine ilave edilen Prohexadione-Calcium (Pro-Ca) dozlarının marul tohumlarının 20, 30 ave 35 °C'de çimlenme ve fide çıkış performansları üzerine etkileri araştırılmıştır. Marul tohumları 0, 50, 100 ve 100 mgL^{-1} Pro-Ca içeren -1.50 MPa KNO_3 ve -1.50 MPa KH_2PO_4,solüsyonları içerisinde, karanlıkta 15 °C'de 20 saat süreyle prime edildi. Araştırma sonuçları priming uygulamalarının marul tohumlarında termodormansiyi azalttığı, çimlenme ve fide çıkış performanslarını artırdığını göstermiştir. Sonuçlar, Pro-Ca'nın priming solüsyonlarına eklenmesinin, termodormansiyi yenmek ve marul tohumlarının yüksek sıcaklıklarda çimlenme ve çıkış performanslarının iyileştirmek için etkili bir yöntem olarak kullanılabileceğini ortaya koymuştur.

Anahtar Kelimeler: Marul, priming, prohexadione-calcium, termodormansi.

AMELIORATIVE EFFECTS OF SOME PRIMING TREATMENTS ON GERMINATION AND EMERGENCE OF LETTUCE SEEDS UNDER HIGH TEMPERATURE CONDITIONS

ABSTRACT

The maximum temperature range for lettuce (*Lactuca sativa* L.) germination is 25° to 30°C. Temperatures above this optimum temperature range inhibit germination of imbibed lettuce seed and causes non-uniform stand establishment. The germination failure of completely imbibed lettuce seed due to the high temperature is termed 'thermodormancy'. One of the effective methods to overcome this dormancy is seed priming. The effects of incorporating Prohexadione-Calcium (Pro-Ca) into priming solutions on germination and emergence performances of lettuce seeds at 20, 30, and 35 °C were investigated. Priming was accomplished by imbibing lettuce seeds for 20 h at 15 °C in darkness in solutions of KNO_3 or KH_2PO_4, each at -1.50 MPa, containing 0, 50, 100, or 150 $mg.L^{-1}$ Pro-Ca. The priming treatments reduced thermodormancy and increased germination and emergence performances of lettuce seeds. The results indicated that inclusion of Pro-Ca into the priming solutions can be used as an effective method to overcome thermodormancy and improve germination and emergence performances of lettuce seeds at high temperatures.

Keywords: Lettuce, priming, prohexadione-calcium, thermodormancy.

1. INTRODUCTION

Farmers in Mediterranean basin have cultivated lettuce (*Lactuca sativa* L.) for many centuries. First forms of the plant were drawn on Egyptian tombs as having long stems, and evident short straight leaves (Ryder and Whitaker 1976; Harlan 1986). In addition in the time of ancient Greeks used leaves either fresh or cooked. Head types of lettuce did not show until 1543 in Europe (Helm 1954; Ryder and Whitaker 1976).

Lettuce leaves is used generally in many salad dish in many countries. Moreover, lettuce mainly is harvested in two ways. Firstly as a more convenient cut, washed and packaged – Secondly, as whole lettuce cuts used by consumer (Ryder 2002; Abbott 2010). Lettuce is one of the cool season crop that grow well between 15° to 24 °C day time and night time between 4° and 10 °C (Gray 1975; Ryder 1979). The best highest temperature range for lettuce seed germination is between 25 °C to 30 °C (Coons et al. 1988). Temperatures more than 30 ^{O}C will led to less germination or non-germination of imbibe lettuce seed is called Thermo-dormancy (Cantliffe et al. 2000).

In addition, operation leading to Thermo-dormancy thought to be linked to both morphological changes in the seed layers during seed formation, and the disturb effects of gas substitution at the time of seed absorption (Borthwick and Robbins 1928). Thermo-dormancy in lettuce seeds depends on the variety of the species; it might be encouraged when temperatures are more than 28 °C during germination (Borthwick and Robbins 1928).

Furthermore, when lettuce seeds were sown under high soil temperatures thermo-dormancy is a problem in incorporation of germination and seedling emergence. It can be overcome by seed priming (Cantliffe 1977; Guedesetal 1979; Cantlife and Guedes 1980; Cantliffe et al. 1981) The ingredient of priming must be standardized as much as viable for the execution to be successful commercially. Moreover, these ingredients include the kind of soak solution (osmoticum) and its osmotic potential, aeration,

temperature, light, soak duration, seed redrying method, seed storage, and seed quality (Cantliffe 1983). Many of these elements for lettuce have been done, followed by redrying the seeds at low temperature and relative humidity to delay radicle growth. In particular (Cantliffe et al. 1984; Perkins-Veazie and Cantliffe 1984) found that lettuce thermo-dormancy can be passed successfully by priming high-quality seeds, and that the priming was ineffective with aged or deteriorated seeds.

During imbibition of lettuce seed temperature above optimum range will lead to an event known as thermos-inhibition and thermo-dormancy, which cause to non-uniform germination and seedling emergence. In addition to avoid this trouble seed priming is account as a method. Priming can set water uptake by using an osmotic, which leads to hydrates the seed to a sufficient wetness grade, letting first stages of germination to happen before radicle emergence (Cantliffe 2005).

Seed priming is a technique to control the hydration level within seeds so that the metabolic activities necessary for germination can take place at relatively slow rate but radical emergence is prevented. The useful effects of priming have been related to different cellular, biochemical, and molecular processes including synthesis of RNA and proteins (Dell'Aquila and Bewley 1989).

Seed priming is a process before sowing seeds which include the controlled hydration of seeds that help pre- germinated metabolic events to take place but it is not enough to let radicle rupture the seed coat (Pill 1995).

In a research done by Guedes and Cantliffe (1980) and Cantliffe (1981) it was found that seed dormancy would overcome by seed priming method. Also, in a research done by Valdez et al. (1985), Cantliffe (1991), and Nascimento (2003) it was reported that thermo-dormancy could be broken in laboratory and field experiments. Gray (1977) and Nascimento (2003) found that very early stages of lettuce seed imbibition during germination are sensitive to high temperatures. Pill (1995) showed seed priming as a very helpful mechanism after completion of the phase I (hydration) and II (lag phase) of germination during this treatment and only require a favorable water potential gradient for water uptake in order to enhance radicle growth.

In addition, the step II of germination prolongs and radicle emergence are limiting by seed priming which basic metabolic events happen in this phase, and seeds get ready for step III and radicle protrusion (Bewley and Black 1994). For that reason extends step II in the time of priming encourage specific mechanism necessary for seed germination at high temperatures (Nascimento et al. 2001).

There are three main ways of seed priming to develop seed quality. First one is hydro priming which soaks seeds in water. Second one is osmotic priming, in this way seeds soak in osmotic solution under low water scope to monitoring imbibition e.g. Poly ethylene glycol. Third one is halo priming that includes the use solutions of inorganic salts e.g. NaCl, KNO_3, $CaCl_2$ etc. Some of these salt solutions have direct or indirect effects for plant feeding (Di Girolamo and Barbanti 2012; Nawaz et al. 2013; Manonmani et al. 2014). For example, in the research done by Dorna et al. (2014) those seed priming techniques were compared for their effects on germination and vigor of pansy (*Viola* × *wittrockiana Gams*.) seeds at 20 °C, 30 °C and 35 °C. They reported that hydro priming the seeds negatively affected the speed of germination, the percentage of germinating seeds and germination capacity. In halo priming could speed up seed germination at all temperatures but did not affect the percentage of germinating seeds and germination capacity. Osmo-priming of seeds did not only enhance germination rates to the elevated range , but also raised percentage of germinating seeds at 30 °C and 35 °C maximum actively and fixedly affected seed germination capacity at 20 °C and 30 °C .

Cantliffe (1991) found that priming three cultivars of lettuce seeds in1% (w/v) $K_3P\ O_4$ for 20 h in the dark reduced thermo-dormancy. Germination was increased in petri dishes at 35 °C after addition of 100 mg 6-benzyladenine (BA)/liter to the above priming solution from (65%) non-primed seeds to (92%) for primed seeds in (Green Lakes), from (24%) for non-primed seeds to (86%) for primed seeds in (South Bay), respectively. Seedling emergence in (Green Lakes) and (Montello) was improved using soilless mix.

The objective of this study was to determine the effects of priming solutions on seed germination and seedling emergence for some thermo-sensitive lettuce genotypes at high temperature.

2. LITERATURE REVIEW

One of the most essential factors affecting growth and development of many plants is temperature stress. Seeds might enter into the condition of thermos-inhibition or thermo-dormancy at supra-optimal temperatures (Horowitz and Taylorson 1983). Germination of thermos-inhibited seeds fails at high temperatures, but germinates with reducing the temperature. However, the dormant state must be released by some form of dormancy-breaking treatment, even if the seeds are placed at their optimum germination temperature (Black et al. 2006; Vidaver and Hsiao 2011). Moreover, in both thermo-inhibited and thermo-dormant seeds, too high temperature maintained for an extended period could result in thermal death (Horowitz and Taylorson 1983). Block of lettuce seed germination at supra optimal temperatures (thermo-inhibition) leads to induction of a secondary dormancy (thermo-dormancy) (Khan et al 1980, 1981). Thermo-dormancy is an important problem in establishing stands of lettuce when seeds were sown under high soil temperatures. It can be circumvented by seed priming (Guedes and Cantliffe 1977; Guedes et al. 1979; 1980; Cantliffe et al. 1981).

Many researches and reports indicate that seed priming might be used for overcoming thermo-dormancy (Cantliffe et al. 1981; Valdes et al. 1985; Yoon et al. 1997; Cantliffe 1991; Carpenter and Boucher 1991; Weges et al. 1991; Parera and Cantliffe 1992). The best-known example is that of lettuce (Cantliffe et al. 1984; Szopińska and Tylkowska 2004; Schwember and Bradford 2005), leek (Parera and Cantliffe 1992) and tomato (Odell and Cantliffe 1986).

Cantliffe et al. (1984) found that lettuce thermo-dormancy can be by passed successfully by priming high-quality seeds, and that the priming was ineffective with aged or deteriorated seeds. The upper temperature limit that initiates the onset of thermo-dormancy varies among cultivars (Thompson et al. 1979). The cultivars differ in their temperature response were the affection is low above 30 °C, while others cultivars germinate at 33 °C. Little or no lettuce seed germination occurs above 35 °C. Thus this

variation in temperature sensitivity led to different success of priming to overcome thermo-dormancy.

Keys et al (1975) reported that the combination of gibberellic acid plus kinetin with ethylene plus carbon dioxide was most effective in overcoming thermo-dormancy in lettuce Great Lakes type seeds.

Researchers found that when 6 lettuce (*Lactuca sativa* L.) seed lots were placed in petri dishes at 35 °C, they failed to germinate. When primed in a 1% K_3PO_4 solution for 9 hours at 15 °C, the result was 56 to 94% germination occurred at 35 °C depending on the seed lot. When the seed lots were planted in soil at 35 °C in the laboratory, emergence was similar to the Petri dish germination test results, primed seeds emerged faster than non-primed seeds, at harvest, and plants from 2 out of 6 lots had earlier maturity due to seed priming (Guedes and Cantliffe 1979).

Atherton and Farooque (1983) reported seeds of spinach (*Spinacia oleracea* L.) were primed in osmotic solutions of polyethylene glycol 6000 (PEG) for 14 days at 10°C. Soaked seeds could be dried back and stored for at least 30 days at 5°C without losing their improved capacity for germination at high temperature improved subsequent germination at 30°C.

Cantliffe et al. (1984) found that lettuce seeds were primed in aerated solutions of 1% K_3PO_4 or water at 15 °C in the dark for various periods of time to determine the manner by which seed priming by passes thermo-dormancy. Lettuce seeds primed for 20 h in 1% K_3PO_4 or distilled water had up to 86% germination at 35 °C. Seed priming a pear to lead to the irreversible initiation of cell elongation, thus overcoming thermo-dormancy.

Barlow and Haigh (1987) reported that seeds of processing tomato variety UC 82B were primed in a solution of K_2HPO_4 and KNO_3 (-1.25 MPa) for 12 days at 15 °C then dried back before being sown, Seed priming resulted in a 35% decrease in the growing temperature during days above 10 °C necessary for the emergence of tomato plants. Primed seedlings emerged 4-5 days earlier than unprimed in early season sowing and 1-2 days earlier in mid-season sowings resulting in earlier flowering, fruiting and ripening.

Seed priming might to be offer a convenient method of both shortening the time to

establishment of early crops and given that greater flexibility in processing plant schedules.

In an earlier investigation, Pill et al. (1991) reported that tomato *(Lycopersicon esculentum* Mill.) and asparagus *(Asparagus officinalis* L.) seeds were primed in -0.8 MPa of polyethylene glycol 8000 (PEG) at 20 °C for 1 week at dark condition, synthetic sea water (INO), or $NaNO_3$. Increased FGP (final germination percentage) and resulted fewer days to 50% germination of both species, Seedling emergence from $NaNO_3$-primed seeds of both variety sown in a seedbed provided salty (- 0.39 MPa) irrigation was faster than from untreated dry-sown seeds. In the salty seedbed, priming improved final emergence percentage (FEP) from asparagus seeds provided they were not consequently dried, but had no result on the percentage emergence of tomato seeds. Fluid-drilling primed or germinated seeds of either varieties improved seedling establishment in the saline seedbed by reducing time to 50% emergence and/or increasing FEP comparative to primed, dried-back or untreated seeds.

Cantliffe and Elballa (1994) reported that three seed lots of carrot (*Daucus carota L. cv. Orlando Gold*) were primed in PEG (polyethylene glycol) was more effective to improve seed germination, and was highly effective at constant high temperature of 35 °C. The effect of priming action was reliant on seed lot quality. Germination at 25 °C and 35 °C of lot 2, which was judged to be of good value, was enhanced by all treatments regardless of prim duration, whereas that of lots 1 and 3 was only enhanced after 14 days of priming by some of the treatments The use of primed seed during the warm part of the growing season in Florida could effect in improved carrot stand establishment.

Han (1995) reported that priming pansy seeds with salt solutions ($CaCl_2$, KH_2PO_4 and $MgCl_2$). Priming with PEG (polyethylene glycol) improved germination, increased seedling emergence, reducing T50, and reducing the time of emergence in summer greenhouse studies.

Nascimento and Cantliffe (1998) presented data which indicates that the seeds one variety of thermo-sensitive lettuce genotype (Dark Green Boston-DGB and two thermos-tolerant lettuce varieties (Everglades –EVE and PI 251245 – p) were primed at 15 °C with constant light in aerated solutions of polyethylene glycol (PEG) at an osmotic

potential of -1.2 MPa or -1.3 for 1 to 5 days. Seeds were stored (10 ℃; 45% RH) for 12 months. At the beginning of storage, primed and nonprime seeds germinated 100% at 20 ℃; at 35 ℃, primed seeds germinated 100%, whereas nonprime seeds of DGB germinated only 4%. Nonprime seeds of thermo-tolerant (EVE and PI) genotypes germinated 100% at 35 ℃. Seed priming did not affect seed viability or seed vigor after storage in thermo-tolerant genotypes, but in thermosensitive DGB, feasibility of soaked seeds declined after 6 months of storage, but then remained regular through the next 6 months. Thus, seed priming successfully improved seed germination at supra-optimal temperature but storage conditions must be optimized order to prolong seed viability of primed seeds of certain genotypes.

Pill and Kilian (2000) reported that Curled' seeds of parsley (*Petroselinum crispum* L.) were primed osmotically in polyethylene glycol or matrically very well, exfoliated vermiculite at –0.5 MPa for 4 or 7 days at 20 ℃ or 30 ℃ with 0 or 1 mM GA_3. All priming treatments encouraged and hastened germination. Matric priming resulted in greater germination (89%) than osmotic priming (83%) when seeds were primed for 7 days at 30 ℃. Inclusion of 1 mM GA_3 during priming had little or no effect on germination. All matric priming actions (other than 4-day priming) were repeated to assess seedling emergence in a greenhouse (25 ℃ day/22℃ night). Priming improved the percentage, rate and synchrony of emergence, and increased hypocotyl extent at 3 weeks after planting. Priming at 30 ℃ with 1 mM GA_3 resulted in the highest emergence percentage, hypocotyl length, and shoot dry weight. They suggested that matric priming is a suitable choice to osmotic priming of parsley seeds.

An experiment was conducted by Yeon-Ok et al. (2000) to determine the effect of priming duration and temperature on germination of vegetable seeds. Priming solutions were -0.50 MPa PEG 8000 for carrot, 50 mM K_3PO_4 for lettuce, 200 mM KH_2PO_4 for onion, and 100 mM $Ca(NO_3)_2$ for Welsh onion seeds. The priming temperatures varied from 10℃ to 25℃ and priming duration varied from 12 hours to 5 days depending on tested vegetable crops. The results of the experiment showed that germination percentage of carrot seeds was significantly affected by the seed treatment and priming temperature. Priming at 20℃ for 3 days was most effective in reducing number of days to attain 50% of the final germination percentage (T50) and mean number of days to germination (MDG). Priming lettuce seeds at 20℃ for 2 days increased percent germination and

shortened T50 and MDG without radicle protrusion. Priming at either 10℃ or 15℃ for 3, 4, or 5 days did not affect percent germination of onion seeds, but was effective in reducing T50 and MDG.

In the research conducted by (Pazdera and Hosnedl 2002), nine seed lots of lettuce were treated by pre-hydration (for 3, 6, 12 and 24 hours) and by osmo-priming in polyethylene glycol 6000 solution (for 24, 72 and 144 hours) with osmotic potential –1.5 MPa. The effect of hydration treatment depends on seed lot attributes. A possible complementary parameter can be the mean time of germination (MTG) with high association between untreated and treated seed lots. The osmo-priming is a more suitable technique for lettuce seed than pre-hydration. Generally, a shorter time of hydration (till 6 hours at pre-hydration and till 72 hours at priming) proved more successful on the parameters of lettuce seed lots after treatment.

In a research conducted by Korkmaz and Pill (2003), two lettuce (*Lactuca sativa* L.) cultivars ‘Cortina’ and ‘Green lakes’ were subjected to different priming treatments and storage conditions. Seeds were osmotically primed in K_3PO_4, KH_2PO_4 or $NH_4H_2PO_4$ and PEG 8000, having water impending of –0.49 or -1.5 MPa for 10 or 20 hours at 15 °C in darkness. Following priming, the seeds were subjected to germination tests at 20 °C as of which FGP, G50, and G10–90 values were calculated. Only priming with KH_2PO_4 (-1.5 MPa) for 20 hours enhanced the germination synchrony of low vigor cultivar, ‘Green lakes’ and therefore KH_2PO_4 was chosen to be the priming agent for subsequent experiments. Primed (-1.5 MPa KH_2PO_4, for 20 hours) ‘Cortina’ and ‘Green lakes’ then they were stored at 4 °C (refrigerator) or 20 °C (incubator) for one month. Following storage, germination tests were performed and it was seen that storing the soaked seeds of both cultivars for one month had little or no effect on the capability (FGP) and germination rate (G50), but slightly reduced the germination synchrony (G10–90).

Lucio et al. (2004) found that the osmotic conditioning in PEG was the most suitable treatment to improve the performance of asparagus seeds. Priming improved germination in seeds with low physiological quality only. The major effect of priming was on seedling emergence rate and growth, in competition of seed physiological quality.

Bonina (2005) reported that the lettuce seeds were primed in an aerated polyethylene

glycol 8000 (PEG) solution at 15 °C in constant light, and were sampled at 24 h, 48 h, and 72 h. A particular-seed gel assay for endo-beta-mannase was used to determine enzyme action in each lot at each priming period. At 36 °C, germination of primed seeds was over 90% while non-primed seeds germinated at 40%. Priming improved germination rate up to 40% as compared to non-primed seeds at both 20 °C and 36°C under either light or dark conditions. 48 h was determined as the optimal hydrothermal priming time. EBM activity was observed in 25% of all lots at 48 h prime period. Thus it was proposed if at least 25% of seeds exhibit EBM activity, optimal hydro thermal time is achieved. Formative priming time with the EBM test, gives the seed industry a method to better optimize the priming process for endospermic seeds such as lettuce.

Mavi et al. (2006) reported that primed two tomato rootstocks seeds primed in 2% KNO_3 significantly reduced mean emergence time, T50 time to 50% emergence, T1.5 time to reach 1.5 mm hypocotyl thickness and increased fresh and dry weights. Although all treated once had remarkably effective but the greatest reduction in coefficient of variation (CV) in KNO_3 treated seeds indicated that treatment furthermore reduced plant to plant variation among the seedlings. Results indicated that priming is relatively effective through reducing germination time than subsequent relative growth rate and a valuable device to develop seedling quality in turn obtaining thicker and well-developed seedlings in rootstocks tomato seedling production.

Abdulrahmani et al. (2007) reported that nutrient priming in P solutions was superior, compared to other priming techniques in Barley (*Hordeum volgare L.*) seeds. This priming media improved root and shoot dry weight 12.5% over untreated seeds, respectively. P solutions were applied on seeds which then sown in the field. Priming treatments had significant effects on mean transplant emergence percentage and rate in the field. Maximum seedling emergence percentage and rate were achieved with 100 mM P and 10 mM Zn + 100 mM P priming, respectively. Therefore, these priming techniques could be used to improve seedling establishments of barley in the field.

Effect of osmo-priming on lettuce seeds germination at supra optimal temperature (35 °C) was investigated. With KNO_3 (0.25, 0.5, and 1%), $CaCl_2$ (15, 25, and 50 mM) and PEG 8000 (0.1, 0.2 and 0.3g/H_2O) alleviated thermo-dormancy and improved lettuce seeds vigor. Moreover, priming extensively improved final germination percentage, force

of germination, germination index, shoot length, root length, vigor index and condensed mean germination time and time taken to 50% germination, when compared to control under supra-optimal germination environments. It can be accomplished that osmo-priming can act as effective tool to invigorate lettuce seeds at supra optimal temperature (Jahangir et al. 2009).

Dursun and Ekinci, (2010) reported that percentage of germination in parsley seeds at different temperatures was significantly affected by priming treatments. Hydro-priming (12h, 24h and 36 h) and mannitol 0.60 mol/L for 2 days usually had the highest germination percentages. In general, the highest germination percentage with priming was resolute at 10 °C. It may be said that seed priming treatments increased seed germination percentage at stressful temperatures. The highest germination percentages were observed in both hydro priming and mannitol treatments while compared with PEG and KNO3 treatments. The PEG and KNO3 (2 and 4 days) treatments were higher than unprimed treatment in all of the temperatures.

Chen and Arora (2011) reported that spinach seeds (*Spinacia oleracea* L. cv. Bloomsdale) were primed with −0.6 MPa PEG at 15 °C for 8 d, and dried at room temperature for 2 d, then subjected to germination test. Results showed that osmo-priming strengthens the anti-oxidant system and improved seed germination potential, resulting in an increased stress tolerance in germinating seeds. Osmo-priming-mediated promotive result on stress tolerance, however, may diminish in relatively older (5-week) seedlings.

Nasri et al (2011) showed that germination percentage, root and shoot length and seedling fresh weight of primed seeds of lettuce were higher than non-primed seeds in saline environment. Priming also increased acid phosphatase and phytase activities in the roots, shoots and cotyledons under saline stress.

Asgharipour and Rafiei (2011) reported that priming increased tomato emergence, emergence rate, and plumule length. No significant differences were found on plumule dry weight and radicle length. Priming with PEG negatively affected the rate and growth of emerged seedling. Among the assessed priming impending; water potential of -4 for 24 h had the most effective impact on emergence and seedling growth.

Sadeghi et al. (2011) reported that soybean (*Glycine max* L.) seeds were primed with six levels of Polyethylene glycol (PEG6000) as priming medium (distilled water as control, -0.4, -0.8, -1.2, -1.6 and-2 MPa) for 6, 12, 24 and 48 hours at 25 °C. Outcome of variance analysis made clear that different osmotic potential and priming duration had significant effect on percentage of germination, germination index, and mean germination time, the time to get 50% germination, seed vigor and electrical conductivity of seeds. Besides -1.2 MPa osmotic potential increased germination percentages, germination index and seed vigor mean although decreased mean germination time, the time to get 50% germination and electrical conductivity of seeds. Also it was observed that 12 h priming period had most effect on studied traits as-1.2 MPa osmotic potential treatment. Generally primed seeds showed better state than control treatment.

Vuozie (2012) reported that priming Bambara ground nut **(***Vigna subterranean* L. Verdc.**)** Seed in water for 24 h before sowing significantly improved final emergence, seedling establishment, growth and yield compared to the control (0 hour prime). Furthermore, the primed Bambara ground nut genotypes flowered much earlier and produced greater dry matter, pod and grain yield at Wa than at Kumasi. The interactive result of the landraces and the priming also revealed increased plant growth and grain yield in Kumasi more than Wa. This study offers useful information to improve Bambara ground nut seed germination, plant stand and grain yield in the Guinea Savanna agro- ecological zone with more stressful environmental conditions. Finally, all the yield parameters were enhanced following seed priming, and 24 hours of soaking seeds in water is suggested since it appeared to be the best in most yield parameters.

In an earlier the study conducted by Muhammad Imran (2012), two independent field experiments were conducted under conditions of suboptimal temperatures for the period of germination and early growth revealed an increase in grain yield of 10 – 15 % for plants derived from Zn+Mn and Fe primed seeds *(Zea mays* L. and *Glycine max* L). This finding demonstrates long-lasting determination of priming effects.

Elouaer and Hannachi (2012) reported that safflower (*Carthamus tinctorius*) seeds were primed in solution of 5 g/L NaCl and KCl with five levels of salinity (0, 5, 10, 15 and 20 g/L). NaCl (5 g/L for 12 h) and KCl (5 g/L for 24 h) at 20 °C and then exposed to germination tests in petri dishes. Priming treatments improved germination parameters

(germination percentage, mean germination time, germination index and coefficient of velocity) and seedling development parameters (radicle and seedling length, seedling fresh and dry weight and vigor index of safflower under saline condition. The researchers suggested that NaCl and KCl priming could be used as a method to improve safflower seed germination under saline condition.

Hamidi and Anosheh (2013) reported that sunflower seeds were primed in polyethylene glycol (PEG), urea and potassium nitrate (KNO_3). The results of the study revealed that priming of sunflower seeds with urea and KNO_3 had no helpful and significant effect on germination percentage, while significantly increased radicle and shoot length. Also PEG in both experiments notably decreased germination percentage but increased seedling growth. Increasing effect of urea and KNO_3 on seed priming on seedling growth was more than PEG. The researchers concluded that this increasing effect of urea and KNO_3 priming could be due to their nutritive effect on the seeds.

Comparing different types of priming methods, researchers found that hydro priming of Pansy (*Viola × wittrockiana Gams.*) seeds negatively affected the speed of germination, the percentage of germination and germination capacity. Halopriming hastened seed germination at 20 °C, 30 °C and 35 °C but did not influence the percentage of germinating seeds and germination ability. Osmo-priming of seeds in PEG solution of osmotic potential –1.0 MPa at 20 °C not only enhanced germination rates at 20 °C, 30 °C, and 35 °C to the highest extent, but also increased percentage of germinating seeds at 30 °C and 35 °C most successfully and positively affected seed germination capacity at 20 °C and 30 °C (Dorna et al. 2014).

Toklu (2015) reported that primed lentil (*Lens culinaris Medik.*) seeds with. GA_3 treatment increased shoot length. Distilled water, ZnSO4 and control treatments improved germination rate and percentage. GA3 treatment increased plant height and seedling emergence rate, whereas KCl treatment enhanced the number of nodules, as well as root and shoot dry weight when compared to the non-primed seeds. $ZnSO_4$ treatment increased yield components and grain yield in field conditions.

3. MATERIALS AND METHODS

This study was conducted during 2016 at the Vegetable Physiology Laboratory, Department of Horticulture, Faculty of Agriculture, and University of Bingöl, Turkey.

3.1. Plant Material

Lettuce (*Lactuca sativa*) seeds of 'Carioca' and 'Riccia Lollo' cultivars (Franchi Seed Company, Milano, Italy) were used in the experiments. The initial seed moisture was 7 % (dry weight basis). Moisture contents were determined according to the standardized laboratory test for moisture content is the oven method (ISTA 1996). The standard germination test was conducted on the seeds and their initial germination percentage was determined as 90% and 94%, ('Carioca' and 'Riccia Lollo', respectively). The Seeds were stored in a sealed container at 10 °C and 45% relative humidity until used.

Figure 3.1. 'Carioca' lettuce variety

Lettuce 'Carioca'

Carioca produces vigorous plant with horned head, good sized, round, red, tender and

crunchy margins. It is an early variety. The seeds of the variety can be sown from February to September. Harvest time is from May to November. It is also suitable for winter cultivation.

Figure 3.2. ‘Riccia Lollo’ lettuce variety

Lettuce ‘Riccia Lollo’

A loose leaf 'picking lettuce', Riccia produces an abundant pale green leaves to add to salads and sandwiches, or used as a garnish. Lettuce is very suitable for inter-cropping between taller, long-standing vegetables, such as beans, tomatoes, peppers, etc. Lettuces require rich, moisture retentive soil free of weeds.

3.2. Growing Media

The mixture of peat moss and perlite [4:1 (v/v)] was used in the experiments. Peat moss is the most commonly used soilless medium. It is widely available and relatively inexpensive (Kueper 2010).

Peat Moss **Perlite**

Figure 3.3. Two growing media used in the experiments

Peat moss is formed from sphagnum mosses in very acid bog conditions which preserve most of the plant fiber structure. It is lightweight, relatively pathogen free, and has a high water holding capacity (Meche 2017). Perlite is a volcanic rock that is heated and expanded to become a lightweight material. Because it is heated to 760-1090 °C, it is sterile. Perlite improves drainage and aeration by creating tiny air tunnels that allow water and air to flow freely to the roots. Perlite can hold 3-4 times its weight in water, yet will not become soggy (Kueper 2010; Meche 2017). All growing media materials were purchased from E-Tartes Company (İzmir, Turkey). No pre-plant fertilization was included in the media.

3.3. Priming Treatments

Based on results of the preliminary experiments, KNO_3 and KH_2PO_4 were chosen as priming agents. The priming agents were supplemented with 0, 50, 100, or 150 $mg.L^{-1}$ Prohexadione Calcium (Regalis, BASF 125 10W containing 10% Prohexadione-Ca as the active ingredient). For all the treatments, the seeds were surface disinfested in 1% (active ingredient) sodium hypochlorite (NaOCl) for 5 min to eliminate seed-borne microorganisms. After disinfestation, they were washed under running tap water and surface moisture was removed by placing them between sterile paper towels for 30 min at

room temperature.

Figure 3.4. The boxes used during priming process

Priming was accomplished by imbibing lettuce seeds for 20 h at 15 °C in darkness in solutions of KNO_3 or KH_2PO_4, each at -1.50 MPa, containing 0, 50, 100, or 150 $mg.L^{-1}$ Pro-Ca. The lettuce seeds were placed in covered plastic germination boxes (10 × 10 × 4 cm) on double layers of filter paper (Whatman #1) saturated with 8 mL priming solution (Figure 3.4). Following priming, the seeds from each box were washed in a sieve and rinsed under running tap water to remove priming chemicals and left to surface dry on drying papers placed in petri dishes under room conditions (20 °C and 45% relative humidity) for 24 h. Untreated dry seeds were taken as control.

3.4. Germination and Emergence Tests

Germination and emergence tests were carried out in a growth chamber (Model ICE 256, Memmert, Germany) at 20, 30 and 35°C. Lettuce seeds were placed on two layers of filter paper moistened with 2 mL of distilled water in sterile 60 x 50 mm petri plates (Figure 3.5). Treatments were arranged in a completely randomized design with four replications of 50 seeds (Figure 3.5). The filter papers were moistened with distilled

water as needed.

Figure 3.5. Visible radicle protrusion through the seed coat and pericarp

Germination throughout the paper is defined as visible radicle protrusion through the seed coat and pericarp (Figure 3.5). The numbers of the germinated seeds were recorded daily until no further germination occurred (18 d). From the total number of seeds germinated, final germination percentage (FGP) and its angular transformation (arcsine√FGP), mean time to germination (MTG), and germination index (GI) were calculated (Ellis and Roberts 1981).

For emergence test, seeds were primed as described above and 50 seeds from each treatment were planted into 1.5 cm depth in 7 × 5 cm (diameter × height) round plastic cups filled with growth medium consisting of peat and perlite in the ratio of 4:1 (Figure 3.6.).

The cups were watered and placed in the same growth chamber used in germination test. The cups were moistened with distilled water as needed. Seedling emergence was recorded daily for 18 days. The seedlings were counted as emerged when the hypocotyls appeared above the surface of the growing media. Final emergence percentage (FEP) and its angular transformation (arcsine√FEP), mean time to emergence (MTE), and emergence index (EI) were calculated.

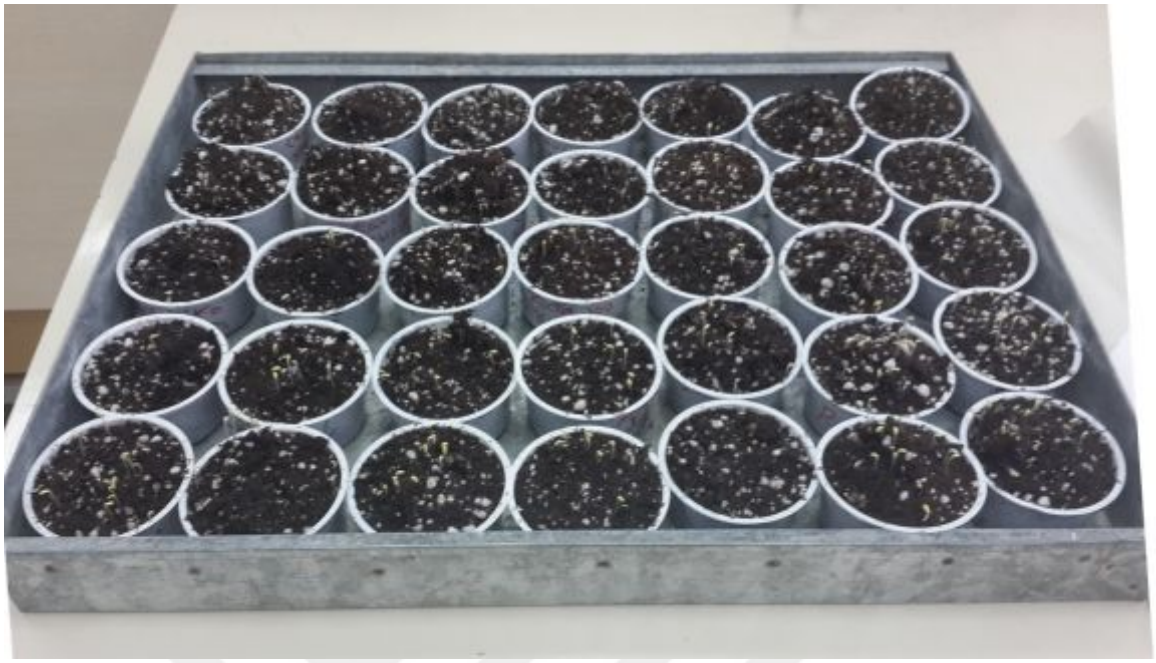

Figure 3.6. Round plastic cups used in the emergence tests

3.5. Germination and Emergence Parameters

3.5.1. Final Germination Percentage [FGP (%)]: It was calculated according to the germination count taken after 18 days and expressed as percentage according to the following equation described by Ellis and Roberts (1981) and Ruan et al. (2002).

$$FGP = \frac{\text{Number of germinated seeds after 18 days}}{\text{Total number of seeds tested}} \text{ X } 100$$

3.5.2. Mean Time to Germination (MTG): It was calculated to the following equation of Ellis and Roberts (1981).

$$MGT = \frac{\sum Dn}{\sum n}$$

Where n is the number of seeds, which were germinated on day D, and D is number of days counted from the beginning of germination.

3.5.3. Germination Index (GI): It was calculated as described in the Association of Official Seed Analysts (AOSA, 1983) by following formula:

$$GI = \sum(\frac{GT}{Tt})$$

Where GI is the germination index, G is the number of seeds, which were germinated on day T, t is number of days counted from the beginning of germination.

3.5.4. Final Emergence Percentage (FEP): It was calculated according to the emergence count taken after 18 days and expressed as percentage according to the following equation described by Ellis and Roberts (1981) and Ruan et al. (2002).

$$FEP = \frac{\text{Number of emerged seeds after 18 days}}{\text{Total number of seeds tested}} \text{ X } 100$$

3.5.5. Mean Time to Emergence (MTE): It was calculated to the following equation of Ellis and Roberts (1981).

$$MET = \frac{\sum(Dn)}{\sum n}$$

Where n is the number of seeds, which were emerged on day D, and D is number of days counted from the beginning of emergence.

3.5.6. Emergence Index (EI): It was calculated as described in the Association of Official Seed Analysts (AOSA, 1983) by following formula:

$$EI = \sum(\frac{ET}{Tt})$$

Where EI is the emergence index, E is the number of seeds, which were emerged on day T, t is number of days counted from the beginning of emergence.

3.6. Experimental Design and Statistical Analysis

The experiments were arranged according to completely randomized design with four replicates, each replicate having 50 seeds. The experiments were repeated twice. Mean values of the germination and emergence parameters were statistically analyzed by SAS ANOVA procedure to evaluate the significant effects of the priming and Pro-Ca doses. Means were separated by using Duncan's Multiple Range Test (DMRT) at a significance level of $P \leq 0.05$.

4. RESULTS

4.1. 'Carioca' Results

4.1.1. Final Germination Percentage (FGP, %)

Data related to the effects of priming treatments on final germination percentage (FGP) of 'Carioca' lettuce seeds at 20, 30 and 35 °C are given in Table 4.1. There were significant differences among the priming treatments in terms of FGP of lettuce seeds (Table 4.1).

Table 4.1. Effects of priming treatments on final germination percentage [FGP] and angular transformation (in brackets)] of 'Carioca' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**FGP (%)**		
Priming Agent	**Pro-Ca (mg L^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	85.55 [67.66] B	98.65 [83.33] A	62.66 [52.33] CD
	50	86.76 [68.66] B	93.54 [75.33] AB	61.52 [51.66] CD
	100	83.88 [66.33] B	97.73 [81.33] A	76.50 [61.00] AB
	150	83.88 [66.33] B	95.19 [77.33] A	68.18 [55.66] BC
KH_2PO_4	0	87.54 [69.33] B	98.65 [83.33] A	81.24 [64.33] A
	50	88.30 [70.00] B	94.68 [76.66] A	77.95 [62.00] A
	100	84.74 [67.00] B	85.55 [67.33] BC	61.52 [51.66] CD
	150	84.31 [66.66] B	83.88 [66.33] C	55.80 [48.33] D
Non-primed seeds		94.68 [76.66] A	93.59 [75.33] AB	30.19 [33.33] E
Significance		**	**	***

** significant at P≤0.01, *** significant at P≤0.001Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

According to the Table 4.1, FGP values of 'Carioca' lettuce seeds at 20°C ranged from 83.88 to 94.68%. The results showed that, at temperature 20°C, non-primed seeds had the highest FGP (94.68%) and it was significantly different from other treatments. The priming treatments decreased the FGP in lettuce seeds at 20°C compared to the non-primed seeds. However, there were no significant differences among the priming treatments in terms of FGP (Table 4.1).

FGP values of 'Carioca' lettuce seeds at 30°C ranged from 83.88 to 98.65%. KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca gave the lowest FGP values (83.88 and 85.55%, respectively). Rest of the priming treatments and non-primed seeds gave the similar FGPs and there were statistically in the same group.

At temperature of 35°C, FGP values of 'Carioca' lettuce seeds ranged from 30.19 to 81.24%. All priming treatments significantly improved lettuce seed germination at 35°C compared to non-primed seeds which had an FGP of 30.19% (Table 4.1). KNO_3 supplemented with 100 mg L^{-1} Pro-Ca and KH_2PO_4 supplemented with 0 and 50 mg L^{-1} Pro-Ca gave the highest FGP values (76.50, and 81.24 and 77.95%, respectively).

4.1.2. Mean Time to Germination (MTG, days)

Data of mean time to germination [MTG] of 'Carioca' lettuce seeds at 20, 30 and 35 °C is shown in Table 4.2**.** There were significant differences among the priming treatments in terms of MTG of lettuce seeds (Table 4.2). According to the Table 4.2, MTG values of 'Carioca' lettuce seeds at 20°C ranged from 2.25 to 2.59 days. The results showed that, at temperature 20°C, non-primed seeds had the lowest MTG (2.25 days) and it was significantly different from other treatments. The priming treatments increased the MTG in lettuce seeds at 20°C compared to the non-primed seeds.

Table 4.2. Effects of priming treatments on mean time to germination [MTG] of 'Carioca' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**MTG (Days)**		
Priming Agent	**Pro-Ca (mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	2.42 C	2.36 CD	4.68 BC
	50	2.50 ABC	2.32 D	4.84 BC
	100	2.40 C	2.37 CD	4.69 BC
	150	2.47 ABC	2.47 CD	4.48 C
KH_2PO_4	0	2.52 ABC	2.29 D	4.25 C
	50	2.46 BC	2.35 CD	5.02 BC
	100	2.56 AB	3.15 A	5.59 B
	150	2.59 A	2.87 AB	6.84 A
Non-primed seeds		2.25 D	2.76 AB	5.54 B
Significance		***	***	**

** Significant at P≤0.01, *** significant at P≤0.001, Means followed by the same letter are not

significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

MTG values of 'Carioca' lettuce seeds at 30°C ranged from 2.32 to 2.87 days (Table 4.2). KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca and non-primed treatment gave the highest MTG values (3.15, 2.87 and 2.76 days, respectively). Rest of the priming treatments and non-primed seeds gave the similar MTGs and there were statistically in the same group. Especially, KNO_3 supplemented with 50 mg L^{-1} Pro-Ca and KH_2PO_4 supplemented with 0 mg L^{-1} Pro-Ca gave the lowest MTG values (2.32 and 2.29 days respectively). In other words, they shortened the mean germination time compared to the control (non-primed seeds).

At temperature of 35°C, MTG values of 'Carioca' lettuce seeds ranged from 4.25 to 6.84 days. KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca gave the highest MTG value (6.84 day), which means that it took longer time to germinate. On the other hand, KNO_3 supplemented with 50 mg L^{-1} Pro-Ca and KH_2PO_4 supplemented with 0 mg L^{-1} Pro-Ca gave the lower FGP values (4.48 and 4.25 days, respectively) compared to the control. In other words, they shortened the mean germination time compared to the control (non-primed seeds).

4.1.3. Germination Index [GINDEX]

Data of germination index [GINDEX] of 'Carioca' lettuce seeds at 20, 30 and 35 °C is shown in Table 4.3**.** There were significant differences among the priming treatments in terms of GINDEX of lettuce seeds (Table 4.3).

According to the Table 4.3, GINDEX values of 'Carioca' lettuce seeds at 20°C ranged from 17.66 to 21.80. The results showed that, at temperature 20°C, non-primed seeds had the highest GINDEX (21.80%) and it was significantly different from other treatments. The priming treatments decreased the GINDX in lettuce seeds at 20°C compared to the non-primed seeds. However, there were no significant differences among the priming treatments in terms of GINDEX (Table 4.3).

GINDEX values of 'Carioca' lettuce seeds at 30°C ranged from 18.47 to 26.46. KH_2PO_4 supplemented with 50 mg L^{-1} Pro-Ca gave the highest GINDEX value (26.46). Non-primed seeds and KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca gave the lowest GINDEX values (18.47 and 18.20, respectively). Rest of the priming treatments and non-

primed seeds gave the similar GINDEXs and there were statistically in the same group.

Table 4.3. Effects of priming treatments on germination index [GINDEX] of 'Carioca' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**GINDEX**		
Priming Agent	**Pro-Ca (mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	18.72 B	21.70 BC	5.06 BC
	50	18.50 B	21.05 CD	5.13 BC
	100	19.25 B	21.46 BCD	6.24 AB
	150	18.08 B	20.96 CD	5.34 B
KH_2PO_4	0	18.82 B	23.14 B	7.79 A
	50	19.22 B	26.46 A	6.02 B
	100	17.77 B	19.51 DE	5.07 BC
	150	17.66 B	18.20 E	3.18 D
Non-primed seeds		21.80 A	18.47 E	3.28 D
Significance		***	***	***

*** Significant at P≤0.001, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

At temperature of 35°C, GINDEX values of 'Carioca' lettuce seeds ranged from 3.18 to 7.79 (Table 4.3). All priming treatments (except for KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca) significantly improved lettuce seed germination index at 35°C compared to non-primed seeds. The 'Carioca' lettuce seeds primed KNO_3 supplemented with 100 mg L^{-1} Pro-Ca and KH_2PO_4 alone gave the highest GINDEX values (6.24 and 7.79, respectively) while KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca and non-primed control gave the lowest GINDEX values (3.18 and 3.28, respectively).

4.1.4. Final Emergence Percentage (FEP, %)

Data of final emergence percentage (FEP) of 'Carioca' lettuce seeds at 20, 30 and 35 °C is shown in Table 4.4**.** There were significant differences among the priming treatments in terms of FEP values of lettuce seeds in all treatments at 30 and 35 °C (Table 4.4). With respect to FEP at 20 °C, no significant differences were observed among the treatments (Table 4.4).

Even though there were no significant differences among the treatments in terms of FEP

at 20°C, the best FEP value (77.96%) was obtained from the treatment of KH_2PO_4 supplemented with 50 mg1^{-1} Pro-Ca (Table 4.4).

The FEP values of 'Carioca' lettuce seeds at 30°C ranged from 50.58 to 83.46%. KNO_3 supplemented with 0 and 100 mg L^{-1} Pro-Ca and KH_2PO_4 supplemented with 0 and 50 mg L^{-1} Pro-Ca gave the highest FEP values (69.80, 80.32, 81.68 and 83.46%, respectively). KNO_3 supplemented with 50 mg L^{-1} Pro-Ca followed above group in terms of FEP. The lowest FEP value (50.58%) was obtained from the KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca (Table 4.4).

Table 4.4. Effects of priming treatments on final emergence percentage (FEP) and angular transformation (in brackets)] of 'Carioca' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**FEP (%)**		
Priming Agent	**Pro-Ca (mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	71.92 [58.00]	69.80 [56.66] A	20.14 [26.66] BC
	50	74.49 [59.66]	70.86 [57.33] B	20.14 [26.66] BC
	100	71.92 [58.00]	80.32 [63.66] A	22.52 [28.33] B
	150	71.92 [58.00]	58.37 [50.00] C	18.31 [25.33] D
KH_2PO_4	0	67.64 [55.33]	81.68 [64.66] A	39.61 [39.00] A
	50	77.96 [62.00]	83.46 [66.00] A	24.49 [29.66] B
	100	73.48 [59.00]	59.25 [50.33] C	12.85 [21.00] DE
	150	72.44 [58.33]	50.58 [45.33] D	9.55 [18.00] E
Non-primed seeds		68.18 [55.66]	59.82 [50.66] C	12.45 [20.66] DE
Significance		NS	***	***

*** Significant at P≤0.001, ^{NS} non-significant, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

At temperature of 35°C, FEP values of 'Carioca' lettuce seeds ranged from 9.55 to 39.61% (Table 4.4). KH_2PO_4 alone gave the highest FEP value which is 39.61%) while KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca and non-primed control treatments gave the lowest FEP values (12.85, 9.55, and 12.45%, respectively).

4.1.5. Mean Time to Emergence (MTE, days)

Data related to the effects of priming treatments on mean time to emergence (MTE) of 'Carioca' lettuce seeds at 20, 30 and 35 °C are given in Table 4.5. There were significant differences among the priming treatments in terms of MTE of lettuce seeds (Table 4.5).

According to the Table 4.5, MTE values of 'Carioca' lettuce seeds at 20°C ranged from 4.23 to 6.39 days. The results showed that, at temperature 20°C, non-primed seeds had the highest MTE (6.39 days) and it was significantly different from other treatments. All priming treatments increased the MTE in lettuce seeds at 20°C compared to the non-primed seeds (Table 4.5).

Table 4.5. Effects of priming treatments on mean time to emergence (MTE) of 'Carioca' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**MTE (Days)**		
Priming Agent	**Pro-Ca (mg.l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	4.77 B	3.96 ABC	4.79 BC
	50	4.70 BC	3.45 C	5.46 B
	100	4.73 BC	3.39 C	5.12 B
	150	4.23 D	4.58 A	4.68 BC
KH_2PO_4	0	4.71 BC	3.54 BC	4.33 C
	50	4.60 BCD	3.45 C	5.24 B
	100	4.54 BCD	4.22 ABC	6.25 A
	150	4.30 CD	4.38 AB	6.89 A
Non-primed seeds		6.39 A	3.49 C	5.44 B
Significance		***	*	***

* Significant at P≤0.05, *** significant at P≤0.001, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

MTE values of 'Carioca' lettuce seeds at 30°C ranged from 4.33 to 4.58 days (Table 4.5). Priming treatments (except for KNO_3 supplemented with 150 mg L^{-1} Pro-Ca) did not have any significant positive effect on MTE compared to the non-prime control, even some treatments (KNO_3 supplemented with 150 mg L^{-1} Pro-Ca and KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca increased the MTE. In other words, they extended the mean emergence time compared to the control (non-primed seeds).

At temperature of 35°C, MTE values of 'Carioca' lettuce seeds ranged from 4.33 to 6.89 days. KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca gave the highest MTE value (6.24 and 6.89 days, respectively), which means that those treatments took longer time to emergence. On the other hand, KH_2PO_4 supplemented with 0 mg L^{-1} Pro-Ca gave the lower MTE value (4.33 days) compared to the control. In other words, they shortened the mean emergence time compared to the control (non-primed seeds).

4.1.6. Emergence Index [EINDEX]

Data of emergence index [EINDEX] of 'Carioca' lettuce seeds at 20, 30 and 35 °C is shown in Table 4.6**.** There were significant differences among the priming treatments in terms of EINDEX of lettuce seeds (Table 4.6).

Table 4.6. Effects of priming treatments on emergence index (EINDEX) of 'Carioca' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**EINDEX**		
Priming Agent	**Pro-Ca (mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	7.82 AB	11.04 A	1.53 B
	50	8.30 AB	10.96 A	1.30 BC
	100	7.94 AB	12.25 A	1.42 B
	150	8.71 AB	6.53 B	1.27 BC
KH_2PO_4	0	7.60 B	11.96 A	3.17 A
	50	8.88 A	12.35 A	1.59 B
	100	8.49 AB	7.19 B	0.66 CD
	150	8.66 AB	5.48 B	0.44 D
Non-primed seeds		5.62 C	10.34 A	1.52 B
Significance		***	***	***

** Significant at P≤0.01, *** significant at P≤0.001, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT)

According to the Table 4.6, EINDEX values of 'Carioca' lettuce seeds at 20°C ranged from 5.62 to 8.88. All priming treatments increased the EINDEX compared to the non-primed control. The results showed that, at temperature 20°C, non-primed seeds had the lowest EINDEX (5.62) and it was significantly different from other treatments. However, there were no significant differences among the priming treatments in terms of EINDEX (Table 4.6).

EINDEX values of 'Carioca' lettuce seeds at 30°C ranged from 5.48 to 12.35 (Table 4.6). Priming treatments did not have any significant positive effect on EINDEX compared to the non-prime control, even some treatments (KNO_3 supplemented with 150 mg L^{-1} Pro-Ca and KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca reduced EINDEX. Rest of the priming treatments and non-primed seeds gave the similar EINDEXs and there were statistically in the same group (Table 4.6). At temperature of 35°C, EINDEX values of 'Carioca' lettuce seeds ranged from 0.44 to 3.17 (Table 4.6). The highest EINDEX

value (3.17) was obtained from the treatment of KH_2PO_4 alone while the lowest EINDEX value (0.44) was obtained from KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca. Rest of the priming treatments and non-primed seeds gave the similar EINDEXs and there were statistically in the same group (Table 4.6).

4.2. 'Riccia Lollo' Results

4.2.1. Final Germination Percentage (FGP, %)

Data related to the effects of priming treatments on final germination percentage (FGP) of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C are given in Table 4.7. There were significant differences among the priming treatments in terms of FGP of lettuce seeds (Table 4.7).

Table 4.7. Effects of priming treatments on final germination percentage [FGP and angular transformation (in brackets)] of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**FGP (%)**		
Priming Agent	**Pro-Ca (mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	72.58 [58.00] E	65.45 [54.00] C	30.72 [33.66] B
	50	78.00 [62.67] CDE	75.99 [60.66] B	43.62 [41.33] A
	100	75.33 [60.33] DE	73.98 [59.33] BC	29.76 [33.00] BC
	150	74.00 [59.33] DE	66.54 [54.66] C	24.49 [29.66] DC
KH_2PO_4	0	89.33 [71.33] AB	79.39 [63.00] B	39.61 [39.00] A
	50	91.33 [73.33] A	92.41 [74.00] A	33.44 [35.33] B
	100	85.33 [67.67] ABCD	56.37 [48.66] D	21.55 [27.66] D
	150	82.00 [64.67] BCDE	50.00 [45.00] D	11.70 [20.00] E
Non-primed seeds		87.33 [69.67] ABC	67.10 [55.00] C	14.44 [22.33] E
Significance		**	***	***

** Significant at P≤0.01, *** significant at P≤0.001, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

According to the Table 4.7, FGP values of 'Riccia Lollo' lettuce seeds at 20°C ranged from 72.58 to 91.33%. The results showed that, at temperature 20°C, KH_2PO_4 supplemented with 0, 50 and 100 mg L^{-1} Pro-Ca, and non-primed seeds had the highest FGP (89.33, 91.33, 85. 33and 87.33%, respectively). All treatments of KH_2PO_4 supplemented Pro-Ca gave statistically higher FGP values compared to the KNO_3 + Pro-

Ca treatments (Table 4.7).

FGP values of 'Riccia Lollo' lettuce seeds at 30°C ranged from 50.00 to 92.41% (Table 7). KH_2PO_4 supplemented with 50 mg L^{-1} Pro-Ca gave the highest FGP value (92.41%). KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca gave the lowest FGP values (56.37 and 50.00%, respectively). Rest of the priming treatments and non-primed seeds gave the similar FGPs and there were statistically in the same group.

At temperature of 35°C, FGP values of 'Riccia Lollo' lettuce seeds ranged from 11.70 to 43.62% (Table 4.7). All priming treatments (except for KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca) significantly improved lettuce seed germination at 35°C compared to non-primed seeds which had an FGP of 14.4% (Table 4.7). KNO_3 supplemented with 50 mg L^{-1} Pro-Ca and KH_2PO_4 alone gave the highest FGP values (43.62, and 39.61%, respectively).

4.2.2. Mean Time to Germination (MTG, days)

Data of mean time to germination (MTG) of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C is shown in Table 4.8**.** There were significant differences among the priming treatments in terms of MTG of lettuce seeds (Table 4.8).

According to the Table 4.8, MTG values of 'Riccia Lollo' lettuce seeds at 20°C ranged from 1.75 to 2.79 days. KH_2PO_4 alone gave the lowest MTG value (1.75 days) compared to the other priming treatments and control. KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca and non-primed treatment gave the highest MTG value (2.79 and 2.34 days). Rest of the priming treatments and non-primed seeds gave the similar MTGs and there were statistically in the same group (Table 4.8).

MTG values of 'Riccia Lollo' lettuce seeds at 30°C ranged from 1.71 to 5.09 days (Table 4.8). KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca and non-primed treatment gave the highest MTG value (5.09 days). This treatment was followed by KH_2PO_4 supplemented with 100 mg L^{-1} Pro-Ca treatment which had a MTG of 4.08. KH_2PO_4 supplemented with 0 and 50 mg L^{-1} Pro-Ca gave the lowest MTG values (2.17 and 1.71 days respectively). In other words, they shortened the mean germination time compared to the control (non-primed seeds). Rest of the priming treatments and non-primed seeds gave the similar

MTGs and there were statistically in the same group (Table 4.8).

Table 4.8. Effects of priming treatments on mean time to germination (MTG) of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**MTG (Days)**		
Priming Agent	**Pro-Ca (mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	2.20 B	3.20 CD	5.50 BC
	50	2.30 B	3.19 CD	6.19 AB
	100	2.23 B	2.98 CD	6.03 AB
	150	2.13 B	3.35 C	5.98 AB
KH_2PO_4	0	1.75 C	2.17 EF	4.34 C
	50	2.19 B	1.71 F	5.59 BC
	100	2.23 B	4.08 B	5.53 BC
	150	2.79 A	5.09 A	6.83 AB
Non-primed seeds		2.34 B	2.92 CD	6.99 A
Significance		***	***	*

* Significant at P≤0.05, *** significant at P≤0.001, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

At temperature of 35°C, MTG values of 'Riccia Lollo' lettuce seeds ranged from 4.34 to 6.99 days (Table 4.8). KNO_3 supplemented with 50, 100 and 150 mg L^{-1} Pro-Ca and KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca and also non-primed control treatment gave the highest MTG values (6.19, 6.03, 5.98, 6.83 and 6.99 days, respectively), which means that it took longer time to germinate. On the other hand, especially KH_2PO_4 alone gave the lowest MTG value (4.34 days) compared to the control. In other words, they shortened the mean germination time compared to the control (non-primed seeds).

4.2.3. Germination Index [GINDEX]

Data of germination index [GINDEX] of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C is shown in Table 4.9**.** There were significant differences among the priming treatments in terms of GINDEX of lettuce seeds (Table 4.9).

Table. 4.9. Effects of priming treatments on germination index (GINDEX) of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**GINDEX**		
Priming Agent	**Pro-Ca (mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	18.44 C	12.29 DE	4.03 B
	50	20.32 C	14.31 CD	4.77 B
	100	19.05 C	14.82 CD	3.66 B
	150	20.75 C	12.79 D	3.48 B
KH_2PO_4	0	31.65 A	24.18 B	9.15 A
	50	27.05 B	32.80 A	4.82 B
	100	21.91 C	9.07 EF	3.17 BC
	150	17.59 C	6.75 F	0.99 D
Non-primed seeds		20.16 C	17.55 C	1.07 D
Significance		***	***	***

*** Significant at P≤0.001, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

According to the Table 4.9, GINDEX values of 'Riccia Lollo' lettuce seeds at 20°C ranged from 17.59 to 31.65. The results showed that, at temperature 20°C, KH_2PO_4 alone treatment had the highest GINDEX (31.65%) and it was significantly different from other treatments. This treatment was followed by KH_2PO_4 supplemented with 50 mg L^{-1} Pro-Ca treatment which had a GINDEX of 27.05. Rest of the priming treatments and non-primed seeds gave the similar GINDEXs and there were statistically in the same group (Table 4.9).

GINDEX values of 'Riccia Lollo' lettuce seeds at 30°C ranged from 6.75 to 32.80 (Table 4.9). KH_2PO_4 supplemented with 50 mg L^{-1} Pro-Ca gave the highest GINDEX value (32.80), which means that the treatment increased seed vigor. This treatment was followed by KH_2PO_4 alone treatment which had a GINDEX of 24.18. KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca gave the lowest GINDEX values (9.07 and 6.75, respectively). Rest of the priming treatments and non-primed seeds gave the similar GINDEXs and there were statistically in the same group (Table 4.9).

At temperature of 35°C, GINDEX values of 'Riccia Lollo' lettuce seeds ranged from 0.99 to 9.15 (Table 4.9). Priming treatments (except for KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca) significantly improved lettuce seed germination index at 35°C compared to non-primed seeds. The 'Riccia Lollo' lettuce seeds primed in KH_2PO_4 alone gave the

highest GINDEX value (9.15) while KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca and non-primed control gave the lowest GINDEX values (0.99 and 1.07, respectively).

4.2.4. Final Emergence Percentage (FEP, %)

Data of final emergence percentage (FEP) of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C is shown in Table 4.10**.** There were significant differences among the priming treatments in terms of FEP values of lettuce seeds in all treatments at 30 and 35 °C (Table 4.10). With respect to FEP at 20 °C, no significant differences were observed among the treatments (Table 4.10). Even though there were no significant differences among the treatments in terms of FEP at 20°C, the best FEP value (77.33%) was obtained from the treatment of KH_2PO_4 supplemented with 50 mg1^{-1} Pro-Ca (Table 4.10).

Table 4.10. Effects of priming treatments on final emergence percentage (FEP) and angular transformation (in brackets)] of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**FEP (%)**		
Priming Agent	**Pro-Ca(mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	67.33 [55.00]	62.66 [52.36] A	32.35 [34.66] A
	50	71.33 [58.00]	54.67 [47.69] BC	33.99 [35.66] A
	100	68.00 [56.00]	50.00 [45.00] BC	21.08 [27.33] B
	150	68.00 [55.66]	48.00 [43.85] BC	18.76 [25.66] B
KH_2PO_4	0	76.00 [60.66]	66.67 [54.77] A	22.04 [28.00] B
	50	77.33 [62.00]	55.33 [48.07] B	11.70 [20.00] C
	100	73.33 [59.00]	47.28 [43.44] C	8.22 [16.66] D
	150	58.00 [49.66]	40.00 [39.23] D	4.33 [12.00] E
Non-primed seeds		60.67 [51.33]	54.00 [47.30] BC	4.81 [12.66] E
Significance		NS	**	***

** Significant at P≤0.01, *** significant at P≤0.001, ^{NS} non-significant, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

The FEP values of 'Riccia Lollo' lettuce seeds at 30°C ranged from 40.00 to 66.67% (Table 4.10). KNO_3 alone and KH_2PO_4 alone treatments gave the highest FEP values (62.66 and 66.67%, respectively). The lowest FEP value (40.00%) was obtained from the KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca (Table 4.10).

At temperature of 35°C, FEP values of 'Riccia Lollo' lettuce seeds ranged from 4.81 to

33.99% (Table 4.10). KNO_3 alone and KNO_3 supplemented with 50 mg L^{-1} Pro-Ca treatments gave the highest FEP values (32.35 and 33.99%, respectively) while KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca and non-primed control treatments gave the lowest FEP values (4.33 and 4.81%, respectively).

4.2.5. Mean Time to Emergence (MTE, days)

Data related to the effects of priming treatments on mean time to emergence (MTE) of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C are given in Table 4.11. There were significant differences among the priming treatments in terms of MTE of lettuce seeds (Table 4.11).

Table 4.11. Effects of priming treatments on mean time to emergence (MTE) of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**MTE (Days)**		
Priming Agent	**Pro-Ca (mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	3.75 C	3.91 CD	5.04
	50	4.11 C	4.24 BCD	5.84
	100	4.14 C	4.41 BC	5.20
	150	3.68 C	4.82 B	5.12
KH_2PO_4	0	3.54 C	3.01 E	5.39
	50	3.59 C	3.09 E	6.14
	100	4.03 C	5.63 A	5.81
	150	5.14 B	6.07 A	5.50
Non primed seeds		6.41 A	3.69 D	5.77
Significance		***	***	NS

*** Significant at P≤0.001, ^{NS} non-significant, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

According to the Table 4.11, MTE values of 'Riccia Lollo' lettuce seeds at 20°C ranged from 3.54 to 6.41 days. The results showed that, at temperature 20°C, non-primed seeds had the highest MTE (6.41 days) and it was significantly different from other treatments. All priming treatments increased the MTE in lettuce seeds at 20°C compared to the non-primed seeds (Table 4.11).

MTE values of 'Riccia Lollo' lettuce seeds at 30°C ranged from 3.01 to 6.07 days (Table

4.11). The lowest MTE values (3.01 and 3.09 days, respectively) were obtained from the treatment of KH_2PO_4 supplemented with 0 and 50 mg L^{-1} Pro-Ca which means that they shortened the mean emergence time compared to the control (non-primed seeds). Priming treatments (except for KNO_3 supplemented with 0 and 150 mg L^{-1} Pro-Ca) did not have any significant positive effect on MTE compared to the non-prime control, even some treatments (KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca and KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca increased the MTE. In other words, they extended the mean emergence time compared to the control (non-primed seeds).

With respect to MTE at 35°C, no significant differences were observed among the treatments (Table 4.11). Even though there were no significant differences among the treatments in terms of MTE at 35°C, the best MTE value (5.04 days) was obtained from the treatment of KNO_3 alone (Table 4.11).

4.2.6. Emergence Index [EINDEX]

Data of emergence index [EINDEX] of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C is shown in Table 4.12**.** There were significant differences among the priming treatments in terms of EINDEX of lettuce seeds (Table 4.12).

Table 4.12. Effects of priming treatments on emergence index [EINDEX] of 'Riccia Lollo' lettuce seeds at 20, 30 and 35 °C

Priming treatments		**EINDEX**		
Priming Agent	**Pro-Ca (mg l^{-1})**	**20°C**	**30°C**	**35°C**
KNO_3	0	9.12 B	9.26 BC	3.55 A
	50	8.05 B	7.61 CD	3.50 A
	100	8.64 B	6.65 D	2.34 B
	150	9.22 B	6.45 D	2.02 B
KH_2PO_4	0	11.32 A	11.91 A	2.34 B
	50	11.35 A	9.82 B	1.04 C
	100	10.15 AB	3.98 E	0.88 CD
	150	6.49 C	3.72 E	0.39 D
Non-primed seeds		5.12 C	9.40 BC	0.47 D
Significance		***	***	***

*** Significant at P≤0.001, Means followed by the same letter are not significantly different at the 0.05 level, using Duncan's Multiple Range Test (DMRT).

According to the Table 4.12, EINDEX values of 'Riccia Lollo' lettuce seeds at 20°C

ranged from 5.12 to 11.35. All priming treatments (except for KH_2PO_4 supplemented with and 150 mg L^{-1} Pro-Ca) increased the EINDEX compared to the non-primed control. KH_2PO_4 supplemented with 0, 50 and 100 mg L^{-1} Pro-Ca had the highest EINDEX values (11.32, 11.35 and 10.15, respectively). The results showed that, at temperature 20°C, non-primed seeds and KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca had the lowest EINDEX values (5.12 and 6.49, respectively) and they were significantly different from other treatments (Table 12).

EINDEX values of 'Riccia Lollo' lettuce seeds at 30°C ranged from 3.72 to 11.91 (Table 4.12). KH_2PO_4 alone had the highest EINDEX value (11.91). Both KNO_3 and KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca reduced EINDEX compared to the control treatment (Table 4.12). The lowest EINDEX values (3.98 and 3.72, respectively) were obtained from the treatments of KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca.

At temperature of 35°C, EINDEX values of 'Riccia Lollo' lettuce seeds ranged from 0.39 to 3.55 (Table 4.12). The highest EINDEX values (3.55 and 3.50) were obtained from the treatments of KNO_3 supplemented with 0 and 50 mg L^{-1} Pro-Ca. In general priming treatments increased the EINDEX compared to the non-primed control (Table 4.12). The lowest EINDEX values (0.39 and 0.47) were obtained from the treatments of KH_2PO_4 supplemented with 150 mg L^{-1} Pro-Ca and the control treatment, respectively.

5. DISCUSSION

In general, the priming treatments improved germination performances of both lettuce varieties at high temperatures conditions especially at 35C in the current study. Our results are in agreement with Cantliffe (1981) who indicates that seed priming effectively overcomes thermo-dormancy in lettuce both in the laboratory and the field. Perkins-Veazie and Cantliffe (1984) found that lettuce thermo-dormancy can be bypassed successfully by priming high-quality seeds. Coons et al. (1990) reported that lettuce cultivars osmo-primed with different concentration of NaCl increased the germination percentage at 20, 25, 30 and 35 °C. Jahangir et al. (2009) reported that osmo-priming on lettuce seeds at supra temperature 35°C improved FGP when seeds primed with KNO_3, $CaCl_2$ and PEG. On the contrary, Korkmaz and Pill (2013) reported that priming and storing the primed seeds of lettuce cultivars for one month had little or no effect on the FGP and rate (G50), but slightly reduced the germination synchrony (G10-90). Combining the advantages of both seed priming and plant growth regulators by adding growth regulators to the priming solution might result in additional enhancement of seed germination. In our study, addition of Pro-Ca to KNO_3 resulted in more improvement in seed germination compared to the KNO_3 treatment alone, their addition helped improve germination compared to the non-primed control. A number of processes stimulating germination are activated by seed priming and persist following the re-desiccation of the seed (Asgedom and Becker, 2001). Therefore, upon sowing, the primed seeds can rapidly imbibe and restore the seed metabolism, resulting in an increased germination rate, decreased physiological germination heterogeneity and better seedling development (Rowse, 1995).

At temperature of 35°C, KNO_3 supplemented with 50 mg L^{-1} Pro-Ca and KH_2PO_4 supplemented with 0 mg L^{-1} Pro-Ca gave the lower FGP values (4.48 and 4.25 days, respectively) compared to the control. In other words, they shortened the mean germination time compared to the control (non-primed seeds).

Kester et al. (1997) who reported that Priming with KNO_3 decreased the MTG in tomato seeds. Han (1995) reported that priming reduced MTG in pansy seeds with salt solutions of $CaCl_2$, KH_2PO_4, $MgCl_2$ and PEG. Korkmaz (2006) reported that priming lettuce seeds in the presence or absence of plant growth regulators in general improved germination rate (G50) and germination synchrony (G10-90) at 35°C compared to non-primed seeds which had a G50 of 3.13 days and G10-90 of 2.92 days. Huns and sung (1997) reported that seed priming resulted in an increase in anti-oxidant as glutathione and ascorbate in seed. These enzymes make germination more speed via reduction of lipid peroxidation activity. It has been declared that priming had been resulted in more germination speed especially in drought stress, saline stress and low temperatures in sorghum, sunflower and melon (Foti et al. 2002; Sivritepe et al. 2003; Demirkaya et al. 2006). In the other study, Kaya (2008) reported that priming, the mean germination time of pepper plants was decreased with priming application at 35 °C. Elouaer and Hannachi (2012) reported that priming improved MGT in safflower seeds when primed in solution of 5 g/L NaCl and KCl at stressful conditions affected to decrease mean time to germination.

Priming treatments increased the GINDEX of the lettuce seeds. KH_2PO_4 supplemented with 50 mg L^{-1} Pro-Ca gave the highest GINDEX value (26.46). The results of current study are in agreement with Sadeghi et al (2011) who reported that priming increased germination index in Soybean (*Glycine max* L.). Baque et al. (2016) reported that that seed priming enhanced germination percentage, vigor index and germination index (GI) of wheat seed.

There were significant differences among the priming treatments in terms of FEP values of lettuce seeds in all treatments at 30 and 35 °C (Table 4.4). At 35 °C, KH_2PO_4 alone gave the highest FEP value which is 39.61%) while KH_2PO_4 supplemented with 100 and 150 mg L^{-1} Pro-Ca and non-primed control treatments gave the lowest FEP values (12.85, 9.55, and 12.45%, respectively). The present result is in agreement with Cantliffe (1991) when Primed of three cultivars of lettuce (*Lactuca sativa* L.) seeds in the dark reduced thermodormaney. Seedling emergence was improved in lots of 'Green Lakes' and 'Montello' using soilless mix at 35°C. These results suggest that priming applications may have effects on FEP at high temperatures (35 °C. These results are also in line of Korkmaz (2006) who reported that priming treatments improved FEP of lettuce seedlings at high temperature compared to non-primed seeds which had an FEP of 14%. The

researcher also reported that inclusion of growth regulators into the priming solution enhanced high temperature emergence of lettuce seedlings further compared to seeds primed in KH_2PO_4 only (41%) except that inclusion of 3 mM putrescine (47%) gave similar FEP as seeds primed in KH_2PO_4 only. Vuozie (2012) reported that priming improved FEP and seedling establishment in Bambara ground nut seeds when primed with water for 24 h before sowing compared to the non-primed seeds. Priming might have triggered some physiological factors affecting seed germination, and consequently increased the rate of seed emergence.

At temperature of 35°C, KNO3 supplemented with 0 mg L-1 Pro-Ca gave the lower MTE value (4.25 days) compared to the control in 'Carioca' lettuce seeds. In other words, they shortened the MTE compared to the control (non-primed seeds). The results of current study are in agreement with Barlow and Haigh (1987) who reported that priming decreased MET and resulted in earlier seedlings in tomato seeds primed in KH2PO4 and KNO3 (-1.25 MPa) for 12 days at 15°C. Korkmaz (2006) who reported that priming improved emergence rate of lettuce seedlings at high temperature compared to non-primed seeds. Our results are also in agreement with Mavi et al. (2006) who showed that priming improved MTE when primed tow tomato root stocks seeds primed in 2% KNO3 significantly reduced mean emergence time. Farooq et al (2007) reported that osmo-priming with 1% KNO3 and 2% CaCl2 increased emergence index but priming with (2%, 3%) of KNO3 and (1%, 3%) CaCl2 treatments decreased emergence index compared to non-primed seeds.

6. CONCLUSION

High temperature stress is one of the most important factors affecting seed germination and emergence of many vegetable crops such as lettuce. At supra-optimal temperatures lettuce seeds may enter into the state of thermo-dormancy. This phenomenon can be overcome by some pre-sowing seeds treatments. Priming is one of the most popular pre-sowing seeds treatments. Still, great deal of priming techniques have been found to be beneficial seed treatments that increase the speed and percentage of germination and seedling emergence, as well as improve the tolerance of the seeds to field stress conditions such as adverse temperatures.

In view of the many benefits of seed priming and growth regulators on enhancing seed germination, combining the advantages of both treatments by adding growth regulators to the priming solution might result in additional enhancement of seed germination. The results of present experiment showed that the improvement of the percentage of germination and emergency of lettuce seeds at the higher temperatures, especially 35°C, was related with priming treatments. Incorporation of Pro-Ca into the priming agents further increased the percentage of germinating and emerging lettuce seeds at 30 and 35°C. Priming with the addition of this plant growth regulator may be an effective way to increase the speed of seedling emergence and stand establishment in lettuce at high temperatures.

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RESUME

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