

Polyethylene Glycol Priming 처리가 약용작물 케나프 종자 발아에 미치는 영향

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Effects of Polyethylene Glycol Priming on Seed Germination of the Medicinal Plant, Kenaf

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ABSTRACT

Background: The present study assessed the response of kenaf (*Hibiscus cannabinus* L., Jangdae) seed to NaCl and the effects of polyethylene glycol (PEG) on kenaf seed germination and vigor.

Methods and Results: Seed germination ranged from 11.3% to 58.8% after 24 hours of immersion in NaCl concentrations from 0% to 0.5%. The priming treatments had lower electrical conductivity (EC) values for the seeds than for the control and a deteriorated palisade layer. Priming in 10% PEG for 48 hours increased the germination upto 96.3% in H₂O solution and 98.8% in 0.3% NaCl solution compared to that of the control (78.8%). Germination synchronization, and shoot and root growth of the primed seeds were greater than those of the control. The T₅₀ of the control in H₂O and 0.3% NaCl solution was 22 and 28 times, respectively. After priming, nine times was sufficient to reach T₅₀ in both solution. The mean number of days to germination (MDG) decreased from 1.43 days for the control to 0.55 days for 0% PEG in H₂O solution and from 1.57 days for the control to 0.56 days for 0% PEG in 0.3% NaCl solution. The dry weight after the 10% PEG treatment was higher than that of the control.

Conclusions: Taken together, 10% PEG treatment for 24 hours is recommended for kenaf seed invigoration before planting.

Key Words: *Hibiscus cannabinus* L., Priming, Polyethylene Glycol, Germination Percentage

INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) from the family Malvaceae is a common warm season annual fiber plant native to India and Africa (Yazan *et al.*, 2011). Although kenaf is a tropical plant, today its cultivars are well adapted to a wide geographical and climatic range (Danalatos and Archontoulis, 2010).

Kenaf plants have been widely used for the production of paper, biocomposites, fiber boards and bioplastics and in the textile industry. It is an important cordage crop in many developing countries. In developed countries such as USA and Japan, it has been grown for fiber production

and forage. Also, various biologically active compounds have been reported in the kenaf seed, including omega-3 fatty acids, phenolic compounds, and sterols (Alexopoulou *et al.*, 2013; Ryu *et al.*, 2013). Phenylpropanoids abundant in the kenaf leaf are important for these beneficial health effects (Jin *et al.*, 2013; Ryu *et al.*, 2016).

Kenaf was introduced in Korea in the 60's but ever since, it has limited use in the country. In recent years, its value in Korea has been increasing as forage and biomass production for fuel. Kenaf can reach heights of 4 - 6 m depending on environmental conditions. It requires 50 - 140 days to complete maturity, so seed production is limited to frost-free areas for the late ripening variety. Its

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stalk is composed of two distinct fibers, bast and core, which comprise approximately 35% and 65% of the stalk mass, respectively (Columbus and Fuller, 1999).

Bast is characterized as a bark, containing long fibers, and the core being physically similar to balsawood, containing soft, short fibers. They sharply lose germination capacity after harvest because of the high oil content of its seeds. Under conditioned storage at 20°C and 10% humidity, kenaf remained viable for about 8 months (Carberry *et al.*, 1990).

However, under the hot and humid climates with average ambient temperature around 35°C and humidity above 60%, its viability loss is faster (Daniel *et al.*, 2012). There is a kenaf variety called ‘Jangdae’ released from KAERI (Korea Atomic Energy Research Institute). It has a low germination rate which is a major limitation to commercially use in Korea.

The reclaimed tidal land of Korea is 135,100 ha which is about 9% of cultivation acreage (Lee *et al.*, 2012). Various approaches have been carried out to increase the availability of land and collection of plants suitable for the reclaimed tidal land (Lee *et al.*, 2000; Oh *et al.*, 2015). From their results, there were some problems in plants containing a high C/N ratio posing nitrogen starvation which consequently leads to relatively low yield. However, kenaf has a relatively low C/N ratio of 30-60 and a higher yield of roughly 17-32 t/ha on the dry basis (Wang, 1994). Those are the advantages of kenaf over other plants.

Rapid and uniform field emergences of seeds are two essential pre-requisites to increase yield, quality and ultimately profit in annual crops. Slow germination ability of some seeds results to smaller seedlings and consequently smaller plants. This also makes such seedlings more vulnerable to soil-born diseases (Bennett, 1998).

Uniform performance of seeds of cultivated plants is seldom achieved, where a seed represents an amalgam of individuals, each with different germination vigor (McDonald, 2000). For these reasons, seed priming has become a common treatment to increase the rate and uniformity of emergence in many vegetable and flower species, where it results in a more rapid and uniform germination when the seeds are re-imbibed (Gurusinghe *et al.*, 1999).

Seed priming has been used to accelerate germination, uniform seedling emergence and improve germination

performance under the temperature or drought stresses (Janmohammadi *et al.*, 2008; Jahangir *et al.*, 2009).

Seed osmopriming using either PEG had improved the germination potential of some herbaceous perennials (Finnerty *et al.*, 1992), pigeonpea (Nayyar and Malik, 1993), brassica (Rao and Phillips, 1993), and carrot (Duman and Esiyok, 1998). However, the secret to successful seed priming is ceasing the priming treatment at just the right time to allow re-drying, hence each species must be investigated for optimal priming treatments and treatment durations (Bradford, 1986).

Therefore, the objectives of this trial were to investigate the effects of PEG on kenaf seed (Jangdae) germination and vigour, and optimize the condition with PEG concentration.

MATERIALS AND METHODS

1. Seed and other materials preparation

The kenaf (*Hibiscus cannabinus* L.) variety was Jangdae released from KAERI (Korea Atomic Energy Research Institute). The experiment was conducted in the Laboratory of Agri-Food Processing, Agricultural Research and Extension Services, Iksan from February to April, 2017.

Seeds, 12 g for each treatment were sterilized by soaking in NaOCl solution for 10 min and were dried for 30 minutes. Containers, with brand name Twist pack (A) 400 (Twist pack 3, ACE Industry Inc., Norcross, GA, USA), were purchased at a store.

2. Measurement of seed water uptake and electrical conductivity value

To determine the water uptake, three replicates of 12 g seed samples were soaked at water (150 ml) and kept seeds in an incubator (HB-302S-4, Hanbaek Scientific Co., Bucheon, Korea) at 25°C. The moisture content was measured after 1, 3, 6, 12 and 24 hours.

To determine the electrical conductivity (EC) value, seeds were treated with various PEG concentration (0, 10, 20, 25, 30, 35, and 40%) for 24 hours at constant temperatures of 20°C in the dark in an incubator (HB-302S-4, Hanbaek Scientific Co., Bucheon, Korea), and its value was measured in 1, 3, 6, 12 and 24 hours using an EC measuring instrument (D-74G, HORIBA Jobin Yvon, Kyoto, Japan).

3. Germination tests to NaCl and PEG

To confirm RD_{50} , salt concentration causing 50% growth reduction, of kenaf seeds to salt, prepared seeds were inoculated in various NaCl solutions (0, 0.1, 0.2, 0.3, 0.4, and 0.5%) for 72 hours.

The solutions were used for seed germination and distilled water was used as the control. Three replicates with 20 seeds each were placed in covered Twist pack (A) 400 (Twist pack 3, ACE Industry Inc., Norcross, GA, USA) container with two filter paper soaked with 7 ml test solutions. Seeds were germinated at constant temperatures of 25°C with lights on an incubator (HB-302S-4, Hanbaek scientific Co., Bucheon, Korea).

Germination was scored at same time daily. A seed was considered to be germinated as seed coat ruptured, plumule and radicle came out and were >2 mm long. Plant, three replicates of 10 plants, was dried at constant temperatures of 60°C for 2 days and dry weight was scored.

In the conduct of PEG (poly ethylene glycol 6000, Sigma-Aldrich Co., St. Louis, MO, USA) test, which was used as osmopriming agent solution, seeds were primed with various PEG concentration (0, 10, 20, 25, 30, 35, and 40%) for 24 hours at constant temperatures of 20°C in the dark in an incubator (HB-302S-4, Hanbaek Scientific Technology Co., Ltd., Bucheon, Korea), three replicates with 20 seeds each were placed in Twist pack (A) 400 (Twist pack 3, ACE Industry Inc., Norcross, GA, USA) container with two filter paper soaked with 7 ml test solutions, and germinated for 72 hours at constant temperatures of 25°C with lights on a previous incubator.

Germination was scored at same time daily. Plant, three replicates with 10 plants each, was dried at constant temperatures of 60°C for 2 days and dry weight was scored.

4. Measurement of growth degree of shoot and root to salt

Shoot and root growth were evaluated for 5 days after germination. All seedlings were taken from each treatment and growth was observed using the naked eye. Root and shoot length were not measured due to severe distortion.

5. Germination performance measurements

At the end of experiment, germination rates, growth of

shoots and roots in NaCl solutions, T_{50} (times to reach 50% of the final germination rate), MDG (mean number of days to germination), and dry weight were recorded to evaluate germination performance. Dry weight was measured using a four digit balance and expressed in gram.

6. Scanning electron microscope image

The seeds were air-dried for 48 hours at 30°C. Each was then fastened using a nipper before cutting vertically to avoid mechanical injury for the vertical section filming. The specimen were air-dried for 20 hours at 80°C to shoot, then was placed on aluminum stub and plated with gold by a gold ion sputtering device (JFC-1100E, Fine Coat, Jeol Ltd., Tokyo, Japan) at 10 mA for 400 seconds.

A palisade layer of seeds plated with gold were observed using a scanning electron microscope (JSM-5410LV, Jeol Ltd., Tokyo, Japan) at condition of 15 kV.

7. Statistics

Results were analyzed for analysis of variance (ANOVA) using SAS Enterprise Guide 4.2 (Statistical Analysis System, 2009, SAS Institute Inc., Cary, NC, USA). Means were compared at 5% significance level using Duncan's Multiple Range Test (DMRT) comparison ($p < 0.05$ and 0.01).

RESULTS AND DISCUSSION

1. Response of kenaf to NaCl

The first aim of this study was to assess the response of kenaf (*Hibiscus cannabinus* L.) seed at various NaCl levels. In this part of the study, kenaf seeds was only exposed to 0% NaCl (NaCl-free, NF), and eventually to other NaCl concentrations (Curtis and Lauchli, 1986).

The germination percentage of seed ranged from 11.3 to 58.8 after 24 hours and from 66.3 to 86.3 after 72 hours, respectively (Fig. 1). There was a significant difference in germination percentage between seeds grown on solution with NF and 0.1% NaCl after 24 hours exposure. However, there was no difference between 0.4% NaCl treatment compared to NF after 72 hours. Only, a meaningful distinction in 72 hours was shown at 0.5% NaCl treatment (Fig. 1).

Bases on this observation, it is concluded that kenaf

was placed in the category of moderate salt tolerant non-halophytic crop under salinity. This result was in agreement with that of an earlier report (Mass and Hoffman, 1977). Previous study showed that its germination percentage declined with increasing salt concentration (Francois *et al.*, 1990). Curtis and Läuchli (1985) noticed that seed germination of kenaf cultivars were only slightly impaired by NaCl salinity upto 200 mM.

The results of kenaf shoots and roots growth difference are presented in Table 1. Its vegetative development decreased as the salt stress level increased. The RD₅₀, salt concentration of causing 50% growth reduction, for shoots and roots growth is observed at 0.2 - 0.3% NaCl. Curtis and Curtis and Läuchli (1986) reported a threshold of about 0.21% NaCl for significant growth reduction of kenaf due to salinity. We took up 0.3% of NaCl as selection concentration for subsequent experiment. Leaf growth rate declined linearly with increasing salt stress (Curtis and Läuchli, 1985).

Plant dry weight was approximately 0.2 g in all salt treatments after 5 days of seed inoculation (Fig. 2). Based on this result, a kenaf dry weight was not negatively impacted by NaCl concentration upto 0.5%. It is concluded that a dry weight is not suitable criteria to estimate salt tolerance of kenaf upto 5 days. So, a longer duration of the test is needed to be able to use this criteria to estimate salt tolerance of kenaf.

Francois *et al.* (1992) reported that the dry weight of stem was only reduced 11.6% in soil salinity above 8.1 ds/m, which is comparable to 0.42% NaCl. After comparing the results presented in Fig. 1 and 2, we concluded that germination was a more sensitive tool in measuring the effect of salinity to kenaf rather than dry weight.

2. Effect of various immersion times on seed water uptake

Kenaf is an upland-field crop. Thus, prolonged immersion of its seeds in water caused a decrease in vitality and shortens the seed's life, resulting to germination percentage reduction. It is important to determine the optimum immersion period for preventing water absorption by a balance of water potential.

Before priming treatment, seed moisture was about 10%. As the immersion times increases, seed moisture gently increased up to 1.93 times after 24 hours. Priming treated

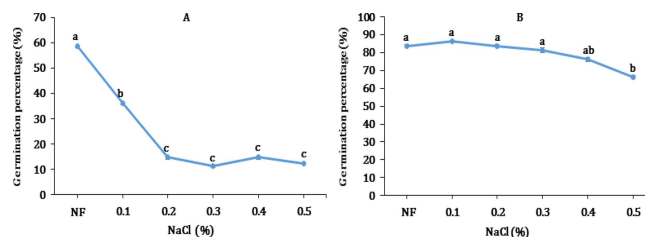


Fig. 1. Response in germination of kenaf seed at different NaCl concentration after 24 (A) and 72 (B) hours of immersion, respectively. Data represent the means ± S.E of three replicates. *Different letter for each treatment shows significant difference ($p < 0.01$) using Duncan's Multiple Range Test (DMRT) comparison. NF; NaCl-free, indicates seeds grown on solution without NaCl.

Table 1. Growth difference of kenaf shoots and roots at various NaCl concentrations after 5 days of germination.

Tissues	NaCl conc. (%)					
	NF	0.1	0.2	0.3	0.4	0.5
Shoot	+++++	++++	+++	++	+	+
Root	+++++	++++	+++	++	+	+

+++++; excellent, ++++; good, +++; medium, ++; poor, +; very poor, NF; NaCl-free, indicates seeds grown on solution without NaCl.

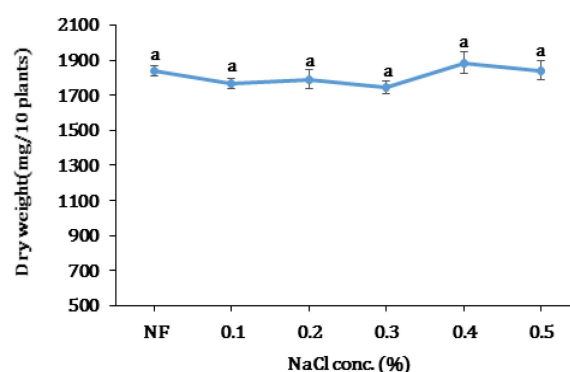


Fig. 2. Kenaf plant dry weight at various NaCl concentrations after 5 days of germination. Data represent the means ± SE of three replicates per replicate for each of the 10 plants. *The same letter for each treatment shows no significant difference using Duncan's Multiple Range Test (DMRT) comparison. NF; NaCl-free, indicates seeds grown on solution without NaCl.

seeds, particularly for 3 hours, had rapid water uptake at the early times of immersion. Beyond 12 hours, its content was statistically same. Thus, it implies that the critical point for soaking kenaf seed in water is 12 hours. After 12 hours, a part of the seeds broke seedcoat by coming out radicle (Fig. 3). Similar result was observed by Shekari *et al.* (2015).

3. Effect of various PEG and immersion times on ion leachate

In this part of the study, kenaf seeds were only exposed to 0% PEG and was expressed as HP (hydro-priming) (Table 2, Fig. 4).

As times went by, electrical conductivity (EC) value of HP increased consistently. In the presence of PEG (10-40%), the ion leakage concentration of the solution decreased sharply compared to HP (Table 2). HP treatment brought about higher palisade layer breakage than the PEG treatment. As a result, plenty of minerals were released through the impaired tissues, thus increasing the EC value. The EC increase signifies the degree of loss of solutes from the seeds, which reflects the extent of membrane deterioration resulting from seed aging (Roberts, 1989). By adding PEG, EC value decreased. Its value was observed to decrease starting from 10% PEG. It is clear that an alteration of EC value was affected by water rather than PEG. The priming treatments (hydro-priming

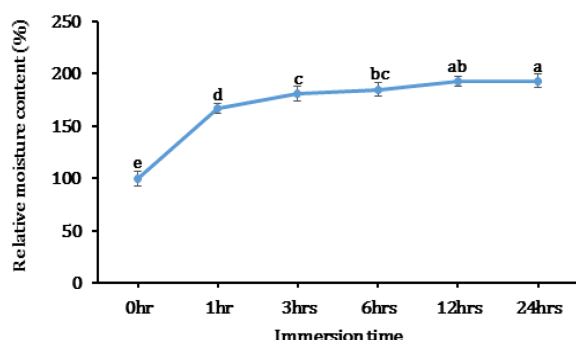


Fig. 3. Relative moisture content (%) of kenaf seeds at different soaking time to water. Data represent the means \pm SE of three replicates. *Different letter for each treatment shows significant difference using Duncan's Multiple Range Test (DMRT) comparison.

and PEG) deteriorated palisade layer (Fig. 4 B, C).

Kang and Choi (2006) who reported that the PEG priming treatment increased the leakage of inorganic compound such as Ca^{2+} and K^+ from hot pepper seed, which is in accordance with our result. Also, Kang *et al.* (2017) stated that the physicochemical properties of Sancho oil were changed according to purification process, which is caused by a deterioration of cell wall.

4. Effect of PEG on surging the germination percentage

Germination of Jangdae seed was generally poor in the control condition based on the kenaf seed maturity. So, it is necessary for kenaf seed to apply priming technique like PEG so as to surge germination uniformity and capability.

Table 3 illustrates the final germination against time, respectively. At the first 12 hours of treatment, the maximum germination rate was 78.8% in H_2O solution and 86.3% in 0.3% NaCl solution after 10% PEG treatment. However, control's (seed unprimed with HP and PEG) germination percentage showed 0% under both solutions. The highest germination was recorded between 24 and 48 hours under H_2O and 0.3% NaCl solutions.

At 72 hours, the earlier germinated seedlings died from fungal infection, resulting to a decrease of germination under both solutions. It is then concluded that 10% PEG was the critical concentration to surge germination. This method considerably reduced the time required to initiate seed germination.

Kim *et al.* (2006) reported that the pasture seed germination increased at 10 - 30% PEG treatment. These results are attributed to chemical effects of PEG causing cell wall looseness thus increasing water uptake of cells.

Table 2. EC value difference of kenaf seeds from 0 to 24 hours according to various PEG concentrations.

PEG (%)	EC value (mS/cm)					
	0 h	1 h	3 h	6 h	12 h	24 h
HP ¹⁾	0.54 \pm 0.02 ^a	2.16 \pm 0.1 ^a	3.73 \pm 0.14 ^a	5.14 \pm 0.17 ^a	6.54 \pm 0.20 ^a	9.17 \pm 0.21 ^a
10	0.50 \pm 0.01 ^b	1.49 \pm 0.1 ^b	2.49 \pm 0.03 ^b	3.26 \pm 0.14 ^b	4.08 \pm 0.14 ^b	6.02 \pm 0.21 ^b
20	0.48 \pm 0.01 ^b	0.95 \pm 0.1 ^c	1.39 \pm 0.03 ^c	1.82 \pm 0.05 ^c	2.33 \pm 0.17 ^c	3.20 \pm 0.10 ^c
25	0.44 \pm 0.01 ^c	0.75 \pm 0.1 ^d	1.08 \pm 0.01 ^d	1.38 \pm 0.01 ^d	1.70 \pm 0.02 ^d	2.31 \pm 0.02 ^d
30	0.41 \pm 0.01 ^d	0.58 \pm 0.1 ^e	0.76 \pm 0.01 ^e	1.16 \pm 0.07 ^e	1.18 \pm 0.02 ^e	1.52 \pm 0.02 ^e
35	0.35 \pm 0.01 ^e	0.47 \pm 0.1 ^f	0.58 \pm 0.01 ^f	0.69 \pm 0.01 ^f	0.85 \pm 0.04 ^f	1.05 \pm 0.06 ^f
40	0.30 \pm 0.01 ^f	0.38 \pm 0.1 ^g	0.45 \pm 0.01 ^g	0.52 \pm 0.01 ^g	0.59 \pm 0.01 ^g	0.73 \pm 0.03 ^g

Data represent the means \pm SD of three replicates. *Different letter for each column shows significant difference ($p < 0.05$) using Duncan's Multiple Range Test (DMRT) comparison. ¹⁾HP indicates seeds grown on solution without PEG was expressed as HP (hydro-priming).

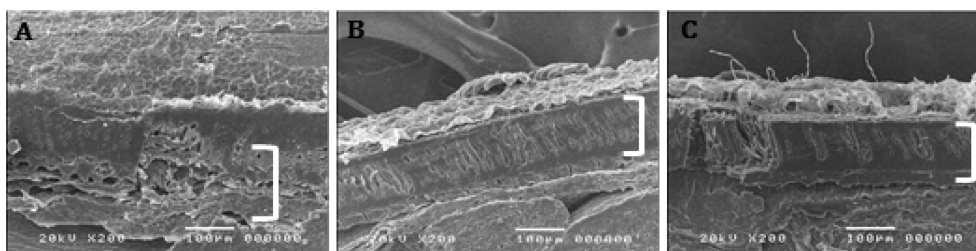


Fig. 4. Scanning electron microscope image of cross section of kenaf seed coat after PEG priming treatment for 24 hours. A; control indicates seeds untreated with priming, B; HP indicates seeds grown on solution without PEG was expressed as HP (hydro-priming), C; 10% PEG treatment. A white parenthesis indicates palisade layer.

The most probable mechanism for PEG enhancement of germination is the intensification of mass transfer and easier access of the water to the interior of the cell wall structure.

As to findings at 72 hours, it was represented with a survival seedlings. Significant difference in survival rate of seedlings also occurred among treatments for both solutions. In H₂O solution, the survival rate of 90% at 20 and 25% PEG treatment were significantly greater than that of the other treatments.

Also, the survival rate of 95% at 10% PEG treatment was significantly greater than that of the other treatments under 0.3% NaCl solution. The results can be contributed to a lower EC value caused by minimal tissue damage (Table 2). A high EC value in the solution indicates high minerals leakage from the seeds thus affected the survival rate at 72 hours.

Ismail *et al.* (2006) stated that a higher germination

percentage was obtained with PEG treatment compared to the control. PEG would be the preferred osmoticum because it is inert and the embryo can not take up its large molecular size (McDonald, 2000). PEG's molecular hinder too much water absorption by seed. Excessive water absorption by the seeds hampers seed germination.

Also, Davison and Bray (1991) suggested that PEG treatment induced various proteins synthesis related with germination. The earlier germinated seedlings after priming treatment such as HP and 10% PEG showed earlier dead. Previous studies on cotton and kenaf have shown a strong association between rapid germination and seedcoat susceptibility to mold growth, seed rot and diseased seedling roots (Bird, 1982; Cook *et al.*, 1992).

Germination synchronization, shoot length, and leaf unfolding of primed seed were greater than those of the control. Also, main root or hair root appeared faster in the treated seeds and grew abundantly compared to the

Table 3. Response of kenaf seed germination at various PEG concentrations at different immersion time.

Solutions	Hours	PEG (%)							
		Control ¹⁾	HP ²⁾	10	20	25	30	35	40
H ₂ O	12	0.0±0.0 ^d	83.8±1.5 ^a	78.8±2.9 ^{ab}	65.0±4.2 ^b	21.3±1.7 ^c	0.0±0.0 ^d	0.0±0.0 ^d	0.0±0.0 ^d
	24	48.8±2.1 ^b	90.0±1.6 ^a	96.3±0.5 ^a	93.8±1.9 ^a	83.8±1.7 ^a	56.3±1.3 ^b	57.5±1.9 ^b	57.5±2.1 ^b
	48	85.0±1.4 ^b	91.3±1.7 ^{ab}	96.3±0.5 ^a	95.0±1.4 ^a	91.3±1.5 ^{ab}	83.8±1.3 ^b	90.0±0.8 ^{ab}	91.3±0.5 ^{ab}
	72 ³⁾	72.5±1.3 ^c	77.5±1.0 ^{bc}	86.3±0.5 ^{ab}	90.0±2.0 ^a	90.0±1.4 ^a	80.0±0.8 ^{abc}	88.8±1.0 ^a	83.8±1.3 ^{ab}
0.3% NaCl	12	0.0±0.0 ^d	78.8±2.8 ^a	86.3±1.3 ^a	48.8±2.6 ^b	13.8±1.5 ^c	0.0±0.0 ^d	0.0±0.0 ^d	0.0±0.0 ^d
	24	33.8±2.9 ^e	88.8±2.2 ^{ab}	97.5±0.6 ^a	81.3±0.5 ^{bc}	72.5±3.0 ^c	53.8±2.8 ^d	42.5±1.3 ^{de}	35.0±1.2 ^e
	48	78.8±3.3 ^b	88.8±2.2 ^{ab}	98.8±0.5 ^a	88.8±1.7 ^{ab}	91.3±1.7 ^{ab}	92.5±1.9 ^{ab}	90.0±1.4 ^{ab}	87.5±1.3 ^{ab}
	72 ³⁾	71.3±2.2 ^{cd}	58.8±2.5 ^d	95.0±1.2 ^a	80.0±1.2 ^{bc}	90.0±1.8 ^{ab}	85.0±2.4 ^{abc}	78.8±1.5 ^{bc}	76.3±1.7 ^{bc}

Data represent the means ± SD of three replicates. *Different letter for each row shows significant difference ($p < 0.05$) using Duncan's Multiple Range Test (DMRT) comparison, ¹⁾Control indicates seed unprimed with HP and PEG, ²⁾HP indicates seed primed with hydro-priming, ³⁾72 hours means a survival rate of seedlings.

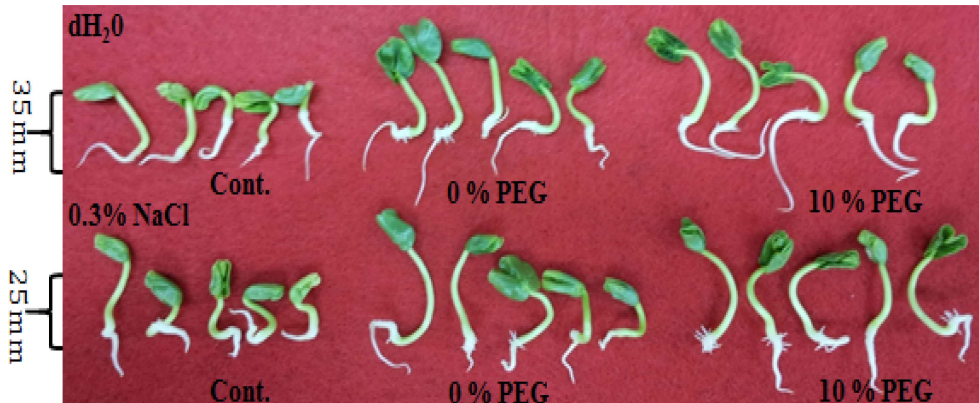


Fig. 5. Comparison of seedlings at various PEG concentrations after 3 days of germination under H₂O and 0.3% NaCl. Cont indicates unprimed seeds, 0% PEG indicates seed primed with HP (hydro-priming).

control (Fig. 5). Enhanced effect, which hasten germination rate and growth progress was greatest at HP and 10% PEG under both solutions compared to the control. (Fig. 5).

5. Effect of PEG on surging both T₅₀ and MDG

The findings of T₅₀ (times to reach 50% of the final germination rate) and MDG (mean number of days to germination) after PEG treatment is as follows.

The T₅₀ of the control under H₂O and 0.3% NaCl solution was 22 and 28 times, respectively. At HP and 10% PEG treatment, 9 times was sufficient to reach T₅₀. It is over 2-3 times higher than that of control in H₂O and 0.3% NaCl solutions (Table 4). T₅₀ of the PEG treatments were higher than that of the control. MDG decreased from 1.43 days being maximum for the control, to 0.55 days being minimum for HP in H₂O solution and from 1.57 days being maximum for the control to 0.56 days being minimum for HP in 0.3% NaCl solution (Table 4).

The analysis of the resulting data indicates that the T₅₀ and MDG were significantly affected by the PEG priming during the germination. A previous study demonstrated that an increase in germination rate and MDG in primed barley seeds may be due to initiating metabolic events in primed seeds (Yaldagard *et al.*, 2008).

Li *et al.* (1999) reported that the seed primed with PEG showed a fast MDG, resulting to improved germination rate rather than an increase in germination percentage. It appeared that PEG treatment might induce various proteins synthesis related with germination (Davison and Bray, 1991).

6. Effect of PEG on the dry weight

Results indicated an effect of priming on dry weight at 3 days after initiating germination (Fig. 6). In H₂O solution, the dry weight was similar in all test treatments (1,867 - 1,943 mg/10 plants) except at 10% PEG with 2,088 mg/10 plants which was noticeably higher. There was no significant difference on dry weight observed between the control and primed seeds exposed to abiotic stress of 0.3% NaCl.

However, the dry weight measurement after the PEG priming treatment showed to be higher compared to the control. According to Ismail *et al.* (2005), the dry weight of tomato after PEG treatment soared. Our results concur with their findings. It seemed that there is a close connection between PEG treatment and dry weight.

In conclusion, the study performed on kenaf suggested that its seeds can be primed with both hydropriming (water) and osmopriming (PEG) to boost germination. Osmopriming with 10% PEG for 24 hours could significantly improve results rather than non-priming and hydropriming regardless of abiotic stress based on the germination rate, T₅₀, and MDG. Finally, we are recommending this technique to improve the economic yield of kenaf.

We primed kenaf seeds for 24 hours following the methodology in Daniel *et al.* (2012). However, further research is needed to reduce durations of the priming treatment to decrease the operation costs.

Table 4. Difference of T₅₀ and MGD kenaf seed at various PEG concentration in 48 hours.

Solutions	PEG (%)	GP ¹⁾	T ₅₀ ²⁾	MDC ³⁾
H ₂ O	Control ⁴⁾	85.0±1.4 ^b	22	1.43
	HP ⁵⁾	91.3±1.7 ^{ab}	9	0.55
	10	96.3±0.5 ^a	9	0.59
	20	95.0±1.4 ^a	10	0.67
	25	91.3±1.5 ^{ab}	14	0.97
	30	83.8±1.3 ^b	21	1.33
	35	90.0±0.8 ^{ab}	21	1.36
	40	91.3±0.5 ^{ab}	21	1.37
0.3% NaCl	Control	78.8±3.3 ^b	28	1.57
	HP	88.8±2.2 ^{ab}	9	0.56
	10	98.8±0.5 ^a	9	0.58
	20	88.8±1.7 ^{ab}	12	0.81
	25	91.3±1.7 ^{ab}	15	1.13
	30	92.5±1.9 ^{ab}	22	1.42
	35	90.0±1.4 ^{ab}	24	1.53
	40	87.5±1.3 ^{ab}	27	1.60

Data represent the means ± SD of three replicates. *Different letter for each column shows significant difference ($p < 0.05$) using Duncan's Multiple Range Test (DMRT) comparison. ¹⁾GP; germination percentage in 48 hours, ²⁾T₅₀; times to reach 50% of the final germination rate, ³⁾MDC; mean number of days to germination, ⁴⁾Control indicates seed unprimed with HP and PEG, ⁵⁾HP indicates seed primed with hydro-priming.

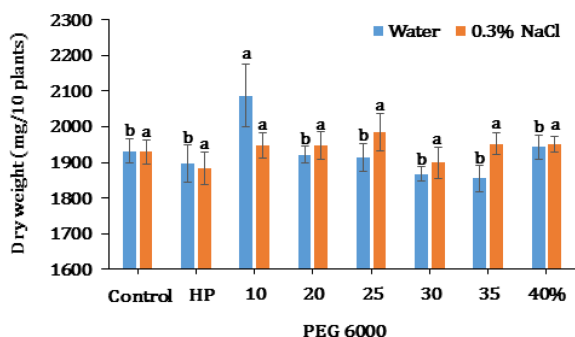


Fig. 6. Dry weight of seedling at various PEG concentrations after 3 days of germination under H₂O and 0.3% NaCl. Data represent the means ± S.E of three replicates per replicate for each of the 10 plants. *Different letter for each solution shows significant difference ($p < 0.05$) using Duncan's Multiple Range Test (DMRT) comparison. Control indicates seed unprimed with HP and PEG. HP indicates seed primed with hydro-priming.

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