Stimulation of Germination and Seedling Vigor in Dormant Seeds of African Juniper

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SUMMARY. Breaking of dormancy in african juniper (*Juniperus procera*) seeds is a challenge faced by nurseries attempting to grow large numbers of this plant for restoration projects. The purpose of this study was to develop a protocol for breaking dormancy and stimulating germination in african juniper. Seeds were presoaked in different concentrations (0, 1, 10, or 20 mg·L⁻¹) of gibberellic acid (GA₃), indole-3-butyric acid (IBA), and naphthalene acetic acid (NAA), and incubated under different air temperatures (10, 15, and 20 °C). The petri dishes were monitored daily for 84 days, to record germination percentage, rate, and uniformity, and the growth of shoots and roots, and biomass production. The highest germination percentages were obtained under 20 °C with a high concentration of NAA (20 mg·L⁻¹). The greatest seedling growth was under 20 °C with IBA. The greatest seedling length was under 20 °C with a low concentration of IBA (1 mg·L⁻¹). The greatest shoot fresh weight was under 20 °C with medium GA₃ concentration (1 mg·L⁻¹). Compared with the control, almost all growth regulator treatments stimulated higher germination percentages and vigor indices with increased temperatures.

Germination is a critical event in the life cycle of a plant, and its timing largely predetermines seedling survival (Chauhan et al., 2010). Both morphologically and physiologically, dormancy must be broken for germination to occur. Even under optimal conditions (e.g., temperature, light, oxygen, and moisture), some seeds do not germinate due to seed dormancy (Bewley et al., 2013; Poljak et al., 2015). Seed dormancy takes five different forms, namely morpho-physiological dormancy, morphological dormancy, physiological dormancy, physical dormancy, and a combination of physical

and physiological dormancy (Baskin and Baskin, 2004, 2014; Bonner, 2008). Seeds of juniper (*Juniperus*) species possess various dormancy characteristics, such as physiological dormancy in phoenician juniper (*J. phoenicea*) or morpho-physiological dormancy in persian juniper (*J. polycarpus*), which make sexual propagation difficult (Al-Ramamneh et al., 2012; Daneshvar et al., 2016). Under natural conditions, juniper seeds typically take 2 years or more to germinate, and low percentages and rates of germination are common. These problems result from a combination of chemical factors in the embryo, and physical factors, such as the thick, solid outer layer of the two-layered seedcoat (Bassett, 1987; Tilki, 2007; Tylkowski, 2009, 2010). Dealy (1990) indicated that the germination of many juniper species is delayed by embryo dormancy or solid seedcoats. Many plant species have evolved dormancy as a means of optimally timing germination to coincide with conditions favorable for

the growth and survival of the next generation (Leadem, 1997).

Temperature is an important factor influencing germination, and species survival. Temperature requirements of seeds from different populations of a species can vary, and the germination requirements of plants depend on interactions between genes and the environment, and on species-specific seed dormancy patterns (Baskin and Baskin, 2001; Nikolaeva, 1977). Seed germination also is affected by growth regulators and enzymatic activity. Evidence for the participation of growth regulators in seed germination comes from the correlation between hormone concentrations and specific development stages, effects of hormone treatments, and the relationship of hormones with metabolic activities. Occasionally, growth and/or differentiation are inhibited by hormones. This inhibition can be alleviated by treatment with growth regulators such as auxins and gibberellins (Chauhan et al., 2009).

The present study was conducted to examine 1) the efficacy of different temperatures in breaking dormancy; 2) the effects of applied plant growth regulators (PGRs), NAA, GA₃, and IBA, under different concentrations on dormancy release; and 3) whether dormancy release and germination of african juniper seeds are stimulated by applications involving a combination of temperature and PGRs.

Materials and methods

SEED COLLECTION, SURFACE STERILIZATION, AND GERMINATION TREATMENTS. At the end of Aug. 2017, ripe cones were collected from african juniper trees grown in the Riyadh Reserve, which is located in southwestern Saudi Arabia. Seeds were collected from 15 randomly selected trees from a natural 75-m² stand. Seeds were extracted from the cones by soaking cones in a solution of 1 g·L⁻¹ sodium hydroxide (NaOH) with warm water for 2 d to soften the outer

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.0929	ft ²	m ²	10.7639
2.54	inch(es)	cm	0.3937
28.3495	oz	g	0.0353
7.4892	oz/gal	g·L ⁻¹	0.1335
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

coating. Cones were rinsed with warm water. To separate the seeds from the pulp, seeds were rubbed on a screen. Seeds were air dried (Harrington, 1977). Moisture content of the seeds was 12% to 15%. After pre-washing the seeds with tap water for 1 h, they were surface sterilized in a laminar flow cabinet, by soaking them in 70% ethanol for 2 min and 1% sodium hypochlorite for 10 min. The seeds were rinsed three times (15 min each) with distilled water. The seeds were presoaked for 24 h at various concentrations (0, 1, 10, or 20 mg·L⁻¹) of PGR (GA₃, IBA, or NAA) (Caisson Laboratories, Smithfield, UT) at various temperatures (10, 15, and 20 °C). Seeds soaked in distilled water served as a control. The seeds were placed in petri dishes (ExtraGene, Taichung City, Taiwan) with wet filter paper (Whatman International, Maidstone, UK) and incubated in a seed germinator (KB 240-UL; Binder, Tuttingen, Germany) under a 16-h photoperiod provided by cool white fluorescent tubes and a light intensity of 34 μmol·m⁻²·s⁻¹ photosynthetic photon flux density. On daily monitoring, the mean germination percentages, growth of root and shoots, and increases in biomass were measured.

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS. The experimental layout was a split-split-plot in a complete randomized block design, with three replicates per treatment (Steel and Torrie, 1986). The three PGR treatments (GA₃, IBA, and NAA) were arranged in the subplots, and the four concentration treatments (0, 1, 10, and 20 mg·L⁻¹) were randomly allocated to the sub-subplots. Each plot had three petri dishes in each replicate. For the seed germination test, 20 seeds were planted in petri dishes on moistened filter paper. Regression analysis, analysis of variance, and comparison of correlation coefficients were conducted using SAS (version 9.2; SAS Institute, Cary, NC) software, and the means of the different treatments were compared using the least significant difference test at the 5% probability levels.

DATA COLLECTION. Seed germination was measured daily with a final count after 84 d. The shoot dry weights (SDW) and entire seedlings were measured after oven-drying the seedlings at 80 °C for 48 h. Ten seedlings were randomly selected from petri dishes and seedling length, and the lengths of shoots (SL) were

measured, in addition to shoot fresh weight (SFW).

To evaluate germination time and speed, and to calculate seed vigor, petri dishes were checked daily, and the number of germinated seeds was recorded. Mean time to germination (MTG) is an index of seed germination speed and velocity (Ellis and Roberts, 1981) and is calculated as follows:

$$MTG = \frac{\sum (n_i \times d_i)}{\sum n_i},$$

where n_i is number of seeds newly germinated at time d_i is the days from beginning of the germination test, and $\sum$ is the final number of germinated seeds.

Mean daily germination (MDG) is an index of daily germination speed and is calculated as follows:

$$MDG = \frac{FGP}{Tp},$$

where FGP is the final germination percentage and Tp is the test period.

Germination speed was calculated using the following formula (International Seed Testing Association, 1999):

$$\text{Germination rate} = \frac{\text{No. normal seedlings}}{\text{days to first count}} + \dots + \frac{\text{No. normal seedlings}}{\text{days to final count}},$$

Seedling weight and length vigor indices (SWVI and SLVI, respectively) were determined using the following formulae (Ashkan and Jalal, 2013):

$$SLVI = (\text{mean shoot length} + \text{mean root length}) \times FGP$$

$$SWVI = \text{mean seedling weight} \times FGP$$

Results

The results showed significant differences among temperature (main plots), growth regulator type (subplots), and growth regulator concentrations (sub-subplots), as well as their interaction across all studied parameters (Table 1).

GERMINATION RESPONSES TO TEMPERATURE. The germination percentages were significantly greater for seeds incubated at a higher temperature (20 °C) and significantly lower for seeds incubated at a lower temperature

(10 °C). Increase in temperature to 20 °C resulted in an increase in germination rate, vegetative growth, MDG, SLVI, and SWVI. On the other hand, the MTG was reduced (Table 1).

GERMINATION RESPONSES TO PGR TYPE AND CONCENTRATIONS. PGR type and their concentrations significantly increased germination and growth of african juniper seeds, as compared with the control treatment. Except for SFW and SDW, all other parameters were significantly influenced by PGR type and their concentrations (Table 1). All PGR concentrations significantly enhanced the seed germination when compared with the control group, and for all incubation temperatures (Table 1). Among the PGRs tested, NAA showed overall higher seed germination (SG) as compared with IBA or GA₃. However, the highest seedling SL was observed with IBA.

GERMINATION RESPONSES TO COMBINATIONS OF TEMPERATURES AND PGRs. The maximum SG was observed in NAA-treated seeds at 20 °C, and SG of seeds soaked in NAA, IBA, and GA₃ were 83.89%, 75.56%, and 73.33%, respectively, whereas that in water was 66.67% at the end of the 84-d incubation period at 20 °C. The control at 10 °C showed the lowest germination (15.01%). Germination improved with increasing temperature for all three PGRs. For seedling vigor parameters, such as MDG and vigor index values, treatment with NAA at 20 °C produced maximum values (Table 1).

GERMINATION RESPONSES TO COMBINATIONS OF TEMPERATURES AND PGR CONCENTRATIONS AND COMBINATIONS OF PGR TYPE AND PGR CONCENTRATIONS. Germination improved with temperature for all PGR concentrations. Significant interaction effects were detected in seedling SL, SFW, and root fresh weight (RFW) between PGR type and PGR concentration. The interaction effects among PGR type and concentration of PGR on MTG, MDG, SLVI, and SWVI were significant (Table 1). Middle range concentrations of IBA and high concentrations of NAA produced large seedling SLs of 6.03 and 3.00 cm, respectively. Application of 10 mg·L⁻¹ IBA and 20 mg·L⁻¹ GA₃ stimulated elongation in seedling SL 6.03 cm, whereas application of 20 ppm NAA also increased weight (0.039 g) compared with the other treatments (Table 1).

Table 1. Seed germination (SG), seedling length (SL), shoot fresh weight (SFW), shoot dry weight (SDW), mean time to germination (MTG), mean daily germination (MDG), seedling length vigor index (SLVI), and seedling weight vigor index (SWVI) of african juniper in different temperatures and plant growth regulator (PGR) types and concentrations.

Temp (°C) ^z	PGR ^y	Rate (mg·L ⁻¹) ^z	SG (%)	SL (cm) ^z	SFW (g) ^z	SDW (g)	MTG (d)	MDG (%)	Vigor indices ^x	
									SLVI	SWVI
10	GA ₃	0	15.03 mf ^w	1.22 j	0.022 lm	0.0036 bcd	70.75 bc	0.17 lm	42.00 l	0.455 m
		1	26.66 klm	2.48 ij	0.023 klm	0.0030 d	69.53 bc	0.32 k	110.50 jkl	0.786 j-m
		10	26.68 klm	2.26 ij	0.030 e-l	0.0056 a	76.43 a	0.32 k	105.33 jkl	0.798 j-m
		20	35.01 i-m	4.48 fgh	0.027 h-m	0.0036 bcd	70.60 bc	0.40 jk	253.50 hij	1.286 hij
	IBA	0	14.89 m	1.25 j	0.022 klm	0.0035 cd	69.53 bc	0.16 m	45.12 kl	0.457 m
		1	33.30 i-m	3.93 gh	0.027 h-m	0.0046 ab	68.36 bc	0.40 jk	208.00 i-l	1.136 i-l
		10	31.65 i-m	3.97 gh	0.034 c-i	0.0036 bcd	69.10 bc	0.38 k	169.30 jkl	1.311 g-j
		20	23.33 lm	1.86 j	0.022 lm	0.0033 cd	76.07 a	0.28 klm	68.01 kl	0.616 klm
	NAA	0	15.12 m	1.20 j	0.02 lm	0.0036 bcd	70.23 bc	0.17 lm	44.03 kl	0.449 lm
		1	35.00 i-m	2.43 ij	0.026 i-m	0.0040 bcd	72.77 ab	0.42 ijk	139.83 jkl	1.158 ijk
		10	25.04 klm	1.77 j	0.02 lm	0.0033 cd	71.53 ab	0.30 kl	89.32 jkl	0.755 j-m
		20	30.01 j-m	3.96 gh	0.030 e-l	0.0046 ab	70.53 bc	0.38 k	143.29 jkl	1.123 i-l
15	GA ₃	0	48.28 e-k	6.80 a-d	0.038 a-f	0.0036 bcd	65.46 cd	0.58 fgh	446.66 d-g	2.151 ef
		1	43.32 g-l	6.77 a-d	0.037 a-g	0.0040 bcd	56.63 ef	0.52 hij	408.00 e-h	1.931 fg
		10	51.64 d-j	5.50 def	0.032 d-j	0.0037 bcd	60.47 de	0.61 e-h	421.33 efg	1.980 f
		20	45.02 f-l	4.46 fgh	0.031 e-k	0.0037 bcd	56.93 ef	0.54 ghi	333.50 ghi	1.736 f-i
	IBA	0	47.59 e-k	6.71 a-d	0.036 a-g	0.0037 bcd	64.45 cd	0.57 fgh	445.23 d-g	2.098 ef
		1	68.33 a-f	6.13 b-e	0.032 d-j	0.0040 bcd	55.80 ef	0.81 bcd	618.67 abc	2.761 de
		10	56.66 c-i	6.63 a-d	0.039 a-e	0.0047 ab	53.10 fg	0.52 hij	391.83 fgh	1.936 fg
		20	55.06 c-i	6.05 cde	0.030 e-l	0.0037 bcd	46.03 ij	0.56 ghi	432.66 efg	1.906 fgh
	NAA	0	48.11 e-k	6.62 a-d	0.035 b-h	0.0036 bcd	65.11 cd	0.57 fgh	444.02 d-g	2.144 ef
		1	71.70 a-e	6.17 b-e	0.032 d-j	0.0037 bcd	54.40 f	0.85 ab	622.50 abc	2.850 cd
		10	60.05 b-h	7.10 abc	0.042 abc	0.0036 bcd	55.10 f	0.71 b-f	515.65 c-f	2.873 cd
		20	66.64 b-g	3.43 hi	0.044 ab	0.0031 d	52.06 fgh	0.69 c-f	215.16 ijk	2.695 de
20	GA ₃	0	66.67 b-g	7.63 a	0.041 a-d	0.0036 bcd	48.03 ghi	0.67 d-g	543.17 b-f	2.941 cd
		1	73.33 a-d	7.57 a	0.046 a	0.0046 ab	47.33 hij	0.75 b-e	613.31 a-d	3.313 a-d
		10	71.65 a-e	7.00 abc	0.039 a-e	0.0033 cd	47.77 ghi	0.73 b-e	686.00 abc	2.973 cd
		20	75.06 a-d	7.73 a	0.041 a-d	0.0037 bcd	45.86 ij	0.83 bc	726.83 a	3.270 a-d
	IBA	0	65.23 b-g	7.52 ab	0.042 abc	0.0037 bcd	47.89 ghi	0.66 d-g	541.60 b-f	2.925 cd
		1	71.69 a-e	7.87 a	0.041 a-d	0.0043 bc	46.73 hij	0.73 b-e	702.00 ab	3.078 bcd
		10	81.64 ab	7.50 ab	0.043 ab	0.0033 cd	47.07 hij	0.85 ab	718.82 a	3.518 abc
		20	78.36 abc	7.66 a	0.044 ab	0.0040 bcd	48.30 ghi	0.73 b-e	629.35 abc	3.193 a-d
	NAA	0	67.21 b-g	7.50 ab	0.041 a-d	0.0037 bcd	48.12 ghi	0.68 c-f	546.00 b-f	2.896 cd
		1	78.29 abc	6.73 a-d	0.035 b-h	0.0040 bcd	42.06 jk	0.83 bc	686.00 abc	3.085 bcd
		10	81.68 ab	6.70 a-d	0.045 a	0.0037 bcd	42.83 ijk	0.85 ab	577.36 a-e	3.683 ab
		20	91.70 a	5.23 efg	0.046 a	0.0036 bcd	39.97 k	0.97 a	443.67 d-g	3.761 a

Significance

Temperature (T)	**	**	**	NS	**	**	**	**
PGR	*	**	NS	NS	**	**	*	**
Concentration (C)	**	*	NS	NS	**	**	**	**
T × PGR	*	NS	**	NS	*	**	*	*
T × C	*	**	NS	NS	**	**	**	*
PGR × C	NS	**	**	NS	*	**	**	*
T × PGR × C	*	**	*	**	**	**	*	*

^z(°C × 1.8) + 32 = °F, 1 mg·L⁻¹ = 1 ppm, 1 cm = 0.3937 inch, 1 g = 0.0353 oz.

^yGA₃ = gibberellic acid, IBA = indole-3-butyric acid, NAA = naphthalene acetic acid.

^xSLVI = (mean shoot length + mean root length) × FGP, SWVI = mean seedling weight × FGP (Ashkan and Jalal, 2013).

^wMeans followed by similar letters in each column are not significantly different at $P \leq 0.05$ level, according to least significant difference test.

NS, *Nonsignificant or significant at $P \leq 0.05$, respectively.

INTERACTION EFFECTS OF TEMPERATURE, PGR TYPE, AND PGR CONCENTRATIONS. The highest percentage of germination (91.70%) was recorded for seeds incubated at 20 °C, treated with 20 mg·L⁻¹ NAA, followed by those incubated at 20 °C, treated with 10 mg·L⁻¹ NAA (81.68%) and

those incubated at 20 °C, treated with 10 mg·L⁻¹ IBA (81.64%). The lowest germination percentages, of 14.89% and 15.03%, were observed for seeds incubated at 10 °C with control treatments of IBA and GA₃, respectively (Table 1). The greatest shoot elongation (7.87 cm) was observed for seeds

incubated at 20 °C with 1 mg·L⁻¹ IBA, and the lowest elongation values (1.22, 1.25, and 1.20 cm) were observed for the control group under a low temperature of 10 °C.

Regarding biomass, the greatest SFW (0.046 g) was recorded for seeds incubated under a high temperature

of 20 °C with either 1 mg·L⁻¹ GA₃ or 20 mg·L⁻¹ NAA, followed by the SFW for seeds incubated at 20 °C with 10 mg·L⁻¹ NAA (0.045 g); the lowest SFW (0.021–0.022 g) was recorded for the control group incubated under a low temperature of 10 °C (Table 1). The greatest SDW (0.0056 g) was recorded for seeds incubated at 10 °C with 10 mg·L⁻¹ GA₃, and the lowest SDW was recorded for seeds incubated under a low temperature of 10 °C with 1 mg·L⁻¹ GA₃.

The SFW, MDG, and seedling vigor index (SVI) increased as temperature increased, particularly at the highest concentration (20 mg·L⁻¹) of NAA, IBA, and GA₃, compared with the control group. The SVI of the control group at 10 °C were the lowest observed, whereas the greatest SLVI was observed for seeds incubated at 20 °C with 20 mg·L⁻¹ GA₃ (726.83), and the greatest SWVI was observed for seeds incubated at 20 °C with 20 mg·L⁻¹ NAA (3.761). MTG decreased when the temperature was increased from 10 to 20 °C, and the greatest MTG was observed for the seeds incubated at 10 °C with 10 mg·L⁻¹ GA₃ (76.43) (Table 1).

TIME CHANGE IN GERMINATION PERCENTAGE. Our results on germination percentages over the 84 d of observation showed the following: at 10 °C and 20 mg·L⁻¹ germination (35.01%) occurred only for GA₃. However, NAA and IBA at concentrations of 1 mg·L⁻¹ at 10 °C gave germination rates of 35% and 33.30%, respectively (Fig. 1A–C). At 15 °C and 10 mg·L⁻¹ a germination of 51.64% was obtained with GA₃. SG also occurs with NAA and IBA (1 mg·L⁻¹) treatments of 71.70% and 68.33%, respectively (Fig. 1D–F). The greatest seed germination was observed for the seeds incubated at 20 °C with 20 mg·L⁻¹ GA₃ and NAA (75.06% and 91.70%, respectively), and SGs of 81.64% and 81.68%, respectively, for 20 °C with 10 mg·L⁻¹ IBA and NAA were also obtained (Fig. 1G–I).

Discussion

Physical seedcoat dormancy happens in junipers (Schmidt, 2000). Fordham and Spraker (1977) reported that juniper seeds are prohibited from germinating by impervious seedcoats that delay the admission of water, in addition to undeveloped embryos. Seeds are said

to be doubly dormant, because two circumstances must be overwhelmed before germination can take place. In wildlife, these seeds require 2 years or more to germinate. Slow and low germination percentages, with germination from time to time being delayed more than 2 years in juniper, are not uncommon. These issues result from a combination of chemical factors in the physical and embryo factors, such as the thick solid outer layer of the two-layered seedcoat (Bassett, 1987; Djavanshir and Fechner, 1976). Broome (2003) specified that juniper trees can be difficult to propagate from seed because they are slow growing and vulnerable to browsing.

Our study investigated the influences of three different PGRs and temperatures on the morphology and germination of african juniper seeds, including comparison of vigor of seedlings. Temperature affects both germination percentage and speed by influencing water uptake, thereby influencing the physiological processes and biochemical reactions that determine germination (Oliveira et al., 2013; Taiz and Zeiger, 2010). Several investigators have noted that germination percentage improved with increase in temperature (Baskin and Baskin, 2004; Gimenez et al., 2005; Labbafi et al., 2018). It is well known that temperature still plays a very important role in the germination of seeds for many plant species because temperature is an environmental signal. Temperature influences both germination ability and the rate at which germination occurs (Bewley and Black, 1994).

Our results under low and medium temperatures are similar to those of Bewley and Black (1994). The embryos of juniper seeds are morphologically immature and require a period of additional growth before they are able to germinate. However, in some plant species with morphologically immature embryos, the developmental period is followed by a period of embryo dormancy, which is ended by low temperature. The hydrated seeds of many woody and herbaceous species are released from dormancy when exposed to temperatures of 5 to 15 °C. Plant species respond differently to the most effective temperatures range (Brandel and Schutz, 2003). On the other hand, Baskin and Baskin (2004) and Daneshvar et al. (2016) indicated that cold stratification at 1 °C up to 16

weeks was not effective to completely break dormancy of juniper seeds, and that application of GA₃ was more effective at releasing dormancy than a combined treatment of cold stratification and PGR. Morpho-physiological dormancy is the most common dormancy type in juniper seeds. Seeds may have simple morpho-physiological dormancy, which might be an adaptive instrument for comparatively warmer autumn temperature throughout seed maturation and the following cold winter temperature under natural circumstances. Yavuz and Yilmaz (2017) reported that the highest germination percentage of syrian juniper (*J. drupacea*) seeds was obtained after warm and cold stratifications. Moreover, seeds prechilled for 8 weeks and soaked in 500 ppm GA₃ also demonstrated high germination percentages. However, GA₃ without any pretreatments did not have a significant effect on the germination of syrian juniper seeds, indicating that juniper seeds have morpho-physiological dormancy. Due to seed lot variability, germination percentages and dormancy behavior can also be traced to environmental and genetic effects during seed growth (Daneshvar et al., 2016; Mazer and Lowry, 2003). We are aware that african juniper seeds we used were collected from randomly selected trees in a natural area, and that natural variation may have accounted for some of the differences we observed in germination and dormancy behavior. However, temperature was an important influence on dormancy release. Although dormancy release generally occurs in the region of 5 °C, in some cases it may occur between 12 and 15 °C (Baskin and Baskin, 2001).

By stimulating enzyme activity, seed hormones improve and promote seed vigor and germination (Ding, 2004; Fan et al., 2012). Auxin has been reported to promote cell division and SG, initiate growth of dormant buds, and promote development of lateral roots (Boerjan et al., 1995; Muday and Haworth, 1994). Jiang and Chen (1997) reported that vigor index, germination rate, and catalase and peroxidase activity could be enhanced by soaking the seeds in a sufficiently concentrated solution of NAA. Song et al. (2009) reported that meeting the environmental requirements of seeds by pretreating them

Fig. 1. (A–I) Time-course changes in germination percentage for african juniper seeds in different temperature (10, 15, and 20 °C) treatments and plant growth regulators [gibberellic acid (GA_3), indole-3-butyric acid (IBA), naphthalene acetic acid (NAA)] and their concentrations (0, 1, 10, and 20 $\text{mg}\cdot\text{L}^{-1}$); 1 $\text{mg}\cdot\text{L}^{-1}$ = 1 ppm, ($^{\circ}\text{C} \times 1.8$) + 32 = $^{\circ}\text{F}$.

with different PGRs promoted the germination of crape myrtle (*Lagerstoeemia subcostata*).

The role of PGR in breaking dormancy of tree seeds is well-known (Daneshvar, et al., 2016). The applications of GA_3 have been typically used to break physiological dormancy of solid seedcoat species (Daneshvar, et al., 2016; Yao et al., 2015). An interesting feature of our trial was the effectiveness of GA_3 in enhancing SG, irrespective of temperature. The treatment of seeds with high temperature and NAA appears to increase germination. The role of PGR in overcoming the harmful effects on growth may be due to the change in endogenous growth substances that they initiate (Hoque and Haque, 2002; Yoshida and Hirasawa, 1996). Although SG, and root and shoot elongation varied in response to different treatments, presoaking the seeds in PGR clearly improved germination and seedling establishment, as previously reported by Ahmad et al. (1998) and Harris et al. (1999). Penfield (2017) reported that GA_3 is the most

extensively used PGR for improving SG percentage in different plant species. The 24-h soaking period increased total water uptake, which likely increased the imbibition rate, initiating the biochemical changes required for SG.

Conclusions

In an effort to break dormancy and stimulate germination of african juniper seeds, we tested the effects of different, combined temperature and hormone treatments. We drew the following conclusions from our results: 1) an increased temperature of 20 °C up to 12 weeks is effective to break dormancy; 2) exogenous applications of NAA, IBA, and GA_3 play a minor role in dormancy release compared with the control, but combined treatments are effective in breaking dormancy; 3) incubating african juniper seeds at 20 °C with 20 $\text{mg}\cdot\text{L}^{-1}$ NAA at 12 weeks induces germination of 91.70%, and is a simple, economically viable alternative to the application of costly plant growth substances; and 4) the study suggests that morpho-physiological dormancy is the most probable dormancy type in african juniper seeds.

This mode of dormancy may be an adaptation to arid environments, and african juniper's rapid seedling growth makes it a useful species for desert reclamation and the sustainable development of arid zones.

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