Effect of salinity and drought on the germination of *Lygeum spartum* L in the region of Saïda (Western Algerian Steppe)

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ABSTRACT

Albardine (*Lygeum spartum* L.) is one of the major native grass species of the semi-arid and arid regions of the Mediterranean basin. In Algeria, it is much more widespread on the high plateaus of southern Oranais. This species occupies an important place in the steppe region because it has many ecological, economic and fodder interests. The present work aims to study the tolerance of *Lygeum spartum* seeds to water and salt stress, two abiotic factors that affect the physiology of the plant during the germinal stage. The methodology adopted consists of using increasing concentrations under a controlled temperature (15°C) for 21 days of germination. The germination responses of the seeds to different degrees of salt stress induced by NaCl (2, 4, 6, 8, 10 g/l) and water stress induced by PEG (-2, -4, -6, -8, -10 bar), showed that the salt and water stresses retarded the germination rate of *Lygeum spartum* L seeds and also decreased their percentage during the time of the experiment. However, seeds soaked in distilled water (control) recorded a maximum germination rate of 80%. The results of this study show that *Lygeum spartum* seeds are moderately salt and drought tolerant with a depressive effect on germination rate at a salt concentration (10g/l) and an osmotic pressure of -10 bar.

Key words: *Lygeum spartum* L, germination, salt stress, water stress, steppe, Algeria.

INTRODUCTION

The Algerian steppe has become for some years a sign of an ecological and climatic imbalance. The intense degradation of this fragile environment is due to silting, wind erosion, overgrazing, land clearing, drought and salinization. These factors lead to desertification, which requires a better understanding of how to combat this scourge and adapt appropriate management (Haddouche et al. 2006; Nedjimi and Brahim, 2012). During the last decades, the steppe rangelands of the Algerian high plains have been marked by intense degradation affecting vegetation cover, biodiversity and alteration of soil quality (Borsali et al. 2018; Zouidi et al. 2018). At the beginning of this degradation, the most perceptible changes are those that affect certain dominant perennial plants ensuring the physiognomy of these rangelands, such as the four steppe formations (Alfa, Armoise, Sparte and Remth).

Lygeum is a monospecific genus of the Poaceae family Willis (1980), represented by the perennial species Lygeum spartum L. described for the first time by Battandier and Trabut (1895). In Algeria this species constitutes a dominant element of the Algerian steppe which occupies the second place after the Alfa (Quezel and Santa, 1962), with an extended area estimated at 3 million hectares. It grows on sandy soils and saline soils in arid and semi-arid bioclimatic stages (Le Houérou, 2001; Nedjimi and Beladel, 2015; Nedjimi, 2016). As such, it is an important element in the equilibrium of the environment and the fight against desertification (Barbero and Quézel, 1986; Le Houérou, 1995; Hourizi, 2017).

Seed germination and early growth of emerged plants represent the most fragile and vulnerable phases of the plant life cycle which are intimately connected and closely affected by various overlapping environmental factors such as temperature, water availability, salinity, light, seedling establishment requirements, germinated seed establishment requirements. All of these factors represent the bottleneck that should be established, whether for crop production or land restoration (Zhang et al. 2018; Paraskevopoulou et al. 2020).

Morphologically, germination is characterized by the emergence of the radicle, is in fact only a process of growth of the root meristematic cells, where turgidity constitutes the essential element of its triggering (Schiefelbein et al. 1997). Physiologically, water deficit greatly disrupts protein synthesis and consequently limits the remobilisation of carbohydrate reserves and energy substances stored as starch in the dried seeds (Bewley et al. 2013). The selection of parameters limiting the impact of water deficit on the progress of the different phases of germination constitutes an essential objective in any work to improve the aptitudes of tolerance to this type of stress.

Soil salinity is one of the main abiotic stresses that results in water deficits limiting germination and plant growth (Munns and Tester, 2008; Abdelly et al. 2008). Salinity risks are more important in arid and semi-arid areas characterized by low rainfall, high evapotranspiration and the use of highly mineralized irrigation water (Shannon, 1986; Benidire et al. 2015).

The objective of this work is to study the effect of osmotic stress caused by polyethylene glycol (PEG_{6000}) and salt stress caused by NaCl on the germination capacity of *Lygeum spartum* seeds in order to determine the concentrations that inhibit germination. In this study, the seeds of *Lygeum spartum* were chosen because it is a predominant species in the Algerian steppes, especially in arid and semi-arid areas, and a species that fixes the soil against desertification.

2. MATERIALS AND METHODS

2.1. Plant materials and seed collection region

These are *Lygeum spartum* grains, at full maturity, harvested in June 2020 from the south-western area of Maamoura commune, located in the south-east of the province of Saïda (35° 49′ 43″ N longitude, 00° 50′ 18″ W latitude, and 1094 m elevation). The study area covers an area of 127,100 hectares (1/5 of the wilaya's surface area) and is part of the daïra of El Hassasna, which is one of the most important daïras of the wilaya in terms of agricultural, forestry and steppe potential. It is considered an agro-pastoral area (D.P.A.T, 2011).

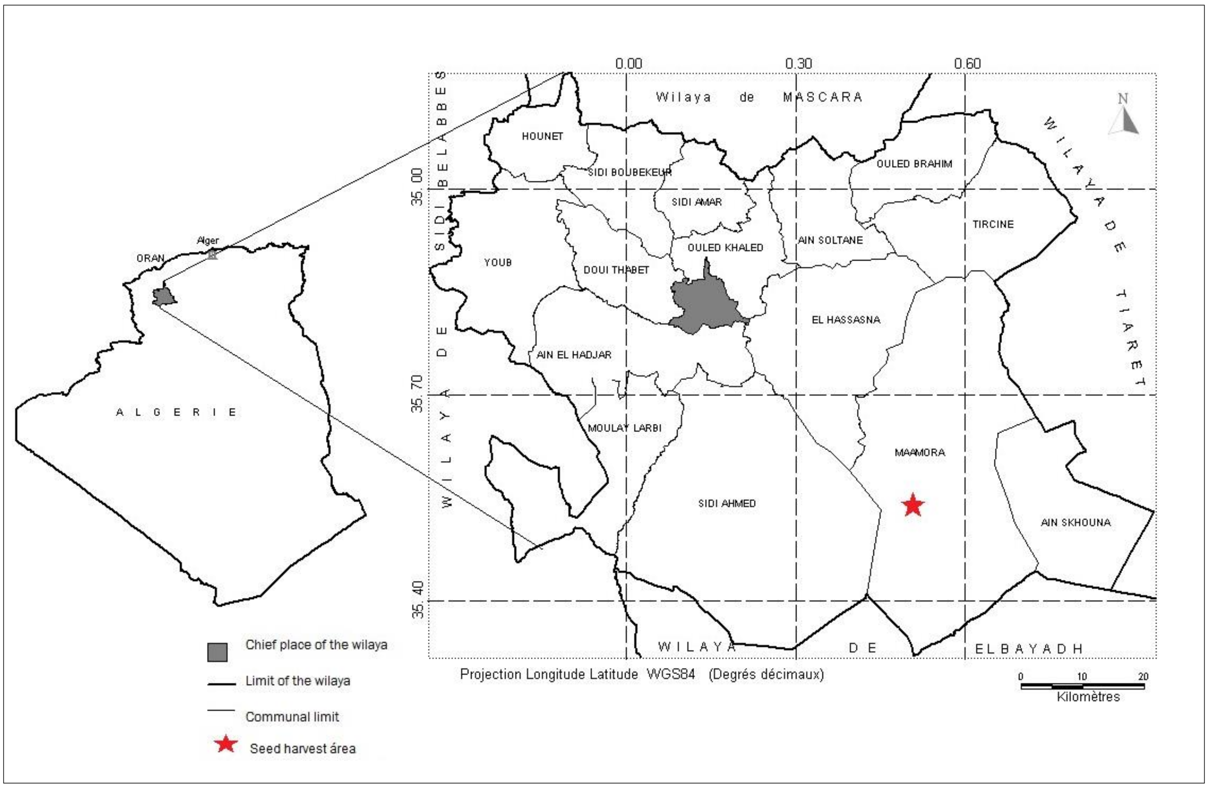

Figure 01. Location of the harvest area of *Lygeum spartum* seeds.

2.2. Seed germination experiment

Before their use in the germination tests, the healthy and intact seeds were sterilized on the surface with a hypochlorite solution (8% NaOCl) for 5 min and rinsed thoroughly with distilled water.

In order to assess the impact of drought on the germination of *Lygeum spartum* seeds, germination tests were carried out under different levels of water potentials through the use of polyethylene glycol (PEG6000), which forms a non-permeable, water-soluble, non-ionic and polymeric solution for the cells (Zouidi et al. 2019). PEG_{6000} is used to induce water deficiency by reducing water availability without causing physical damage to the plant (Romo et al. 2001). According to the equation established by Michel and Kaufmann (1973), Increasing concentrations of PEG_{6000} induce equally increasing water potentials (0. -2. -4. -6. -8 and -10 bar). This equation was used to induce the different levels of water stress tested.

The equation linking the different parameters is as follows:

$\Psi h = -(1.18\times10^{-2})\ C - (1.118\times10^{-4})\ C^2 + (2.67\times10^{-4})\ C\cdot T + (8.39\times10^{-7}) \times C^2\times T$ ……. (1)

where: Ψh – is water potential in bar; T– incubation temperature in °C; C– concentration of PEG $_{6000}$ in g/L.

To study the effects of salinity on germination, we conducted germination tests under salt stress using the optimal germination conditions determined in the experiments.

Five replicates of 20 seeds have been set to germinate, two folds of filter paper placed in plastic Petri dishes (9 cm diameter) are soaked daily with the solutions at different concentrations of NaCl (0, 2, 4, 6, 8, and 10g/l) and PEG 6000 (-0, -2, -4, -6, -8, and -10 bar). The seeds are then placed at an optimal germination temperature of 15°C; the duration of the test was determined by the germination period of 21 days. The germinated seeds were counted daily and removed from the Petri dishes.

The time taken for the percentage germination of all replicates to reach 50% was recorded as TG50.

2.3. The germination parameters measured

The germination rate (TG%) is a parameter that is the best way to identify the concentration of PEG and NaCl. It presents the physiological limit of seed germination. It is calculated by the ratio of the number of germinated seeds and the total number of seeds according to the formula described by AgroBio (2013):

TG (%)= (number of germinated seeds /total number of seeds) × 100

The germination speed allows expressing the germination energy responsible for the depletion of the seed reserves. The germination speed is estimated by the average time (T50) which corresponds to the germination of 50% of the seeds (Lang, 1965).

$$T50 = T1 + (0.5-G1/G2-G1) \times (T2-T1)$$

G1: Cumulative % of germinated seeds with a value closer to 50% (lower).

G2: Cumulative % of sprouted seeds with a value closer to 50% (higher).

2.4Statistical analysis

The results were subjected to analysis of variance (ANOVA) with a single factor of variation at 5 % probability level (P=0.05) after controlling normality distribution for comparing the averages of germination rates with stress. The post-hoc Fisher (LSD) test was applied for multiple comparisons of means. We used Minitab software package version 17.

3. RESULTS

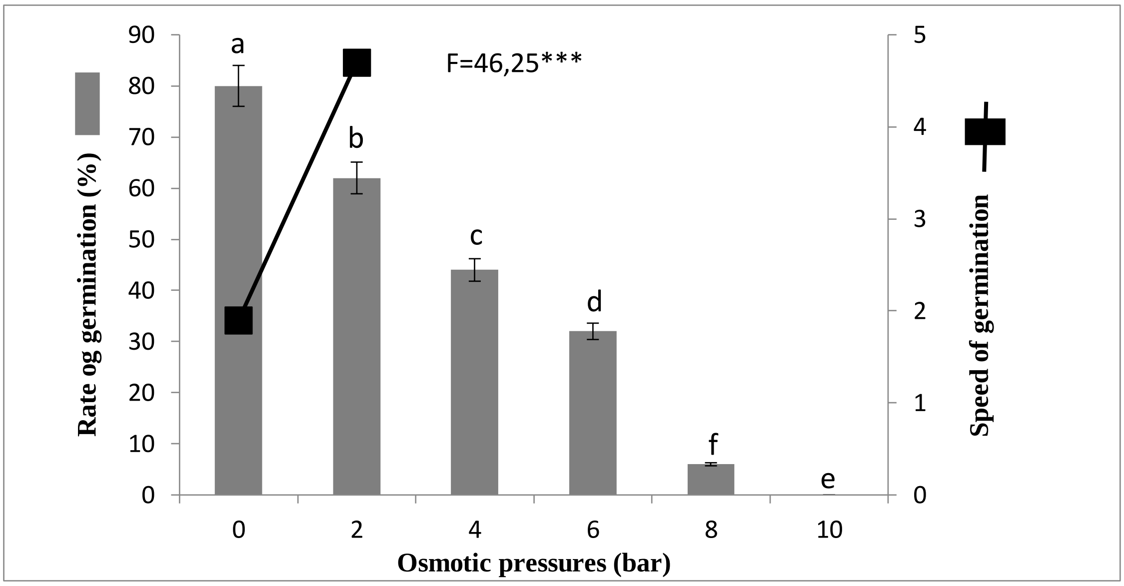

Figure 02 : Effect of different osmotic pressures on the rate and velocity of germination of *Lygeum spartum*. seeds.
Note: The bars and whiskers represent the mean ± standard deviation (n=5 repetitions).
Significance levels: * – P<0.05, ** – P<0.01, *** – P<0.001, NS – not significant.

The average germination capacity of the control treatment (0 bar) is 80%. According to the tests carried out at the level of our laboratory, the average rate of germination for Lygeum spartum is 37.33% that is due to the fragility of the seeds and the existence of parasitized and empty seeds, also from their low storage capacity. In general, the germination rate decreases considerably with increasing water stress of the substrate.

According to the results obtained in this study, the germination rate decreased on average 0% at -10 bar, -6% at -8 bar and 32% at -6 bar compared to the control treatment (0 bar).

Statistically, the above results are confirmed by the analysis of variance, which shows a highly significant effect (P < 0.001) of the different glycol concentrations (PEG 6000) on the germination rate (Figure 02).

The germination rate or average time to germination of 50% seeds is as follows: 2 days for seeds with osmotic pressure (0 bar) (soaked with distilled water) and 5 days for germination of seeds with the osmotic pressure of -2 bar.

Indeed, the more the concentrations of polyethylene glycol (PEG 6000) of the substrate increases, the more the germinal capacity decreases while slowing down the speed of germination.

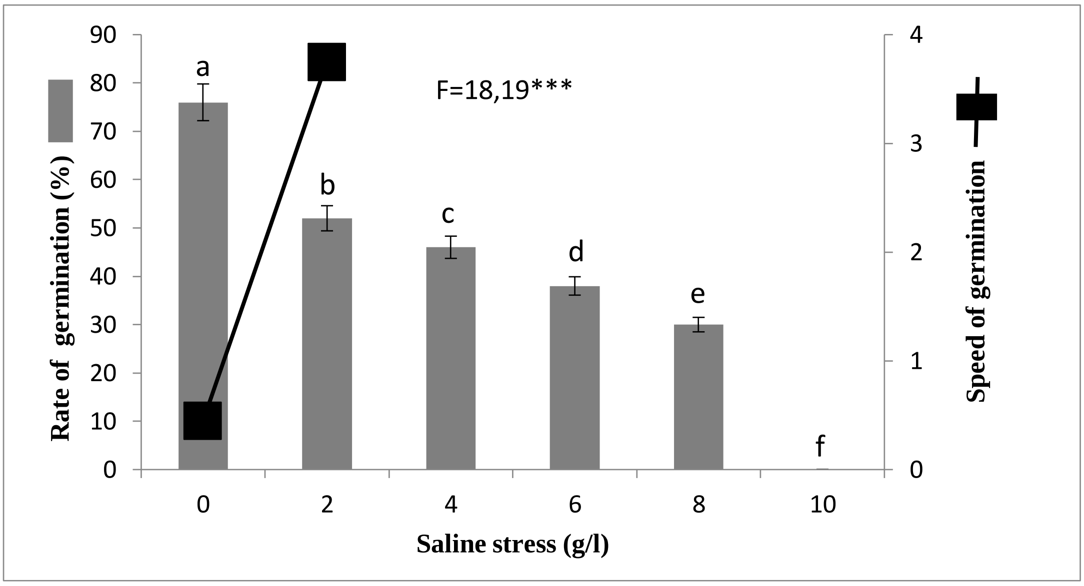

Figure 3. Effect of different saline stress on the rate and speed of germination of *Lygeum spartum*. seeds.
Note: The bars and whiskers represent the mean ± standard deviation (n=5 repetitions).
Significance levels: * – P<0.05, ** – P<0.01, *** – P<0.001, NS – not significant.

The results in Figure 3 indicate that the final germination rate is maximum (75%) for seeds not stressed by NaCl (controls). Then, this value begins to decrease with the increase in NaCl concentration to finally drop to 31% for the highest salt stress (8 g/l).

The concentration of 10 g/l completely inhibits the germination of *Lygeum spartum* grains. The results of the analysis of variance show that there is a significant difference in the germination rate of *Lygeum spartum* seeds ($P < 0.001$), soaked with different salt concentration solutions.

In general, the germination rate decreases considerably with increasing salt stress of the substrate.

3. DISCUSSION

Drought and salinity are the environmental constraints that cause the most damage to agro-pastoral production. Indeed, each year the lost surfaces caused by these two stresses are considerable. One billion hectares are threatened worldwide, including 3.2 million in Algeria (Toumi et al. 2014). This degradation of plant cover is especially valid for arid and semi-arid areas where climate change is becoming more and more restrictive for the growth and development of plants (Zouidi et al. 2019a), associated with significant evaporation favoring the accumulation of salts near the soil surface (Hkayet and Abdelly, 2004). Plant biotechnology techniques have proven to be effective on the one hand in understanding these adaptation mechanisms and on the other hand in creating plant material that is tolerant to different forms of environmental constraints (drought and salinity).

3.1. Effect of osmotic stress on the germination

The exceptional germinative capacity of Albardine compared to that of Alfa, gives it a role of colonizer of many spaces in semi-arid and arid zones. In North Africa, spartum is a mechanism to protect soils against erosion and also an economic source for traditional artisans. However, the combined actions of overgrazing associated with a prolonged cycle of aridity, the uprooting of tufts for baskets making and limited knowledge are often erroneous about this plant, thus causing a degradation of the steppes with *L. spartum* (Nedjimi , 2014; Nedjimi, 2016).

Water is an essential factor in germination and plant production. It has several functions within the plant. In particular, the importance of tissue constitutive water is the transport vector of all substances necessary for plant functioning (Heller et al. 2000; Zouidi et al. 2019b).

The results of this experiment show that the seeds of Albardine harvested in the steppe zone of western Algeria are moderately tolerant to water stress. This result confirms previous reports on the germination of other *Lygeum spartum* species, including those of Boudjada et al (2009) who studied variability in Albardine from seven provenances in Algeria. In the absence of sufficient moisture, the seed, even if correctly placed in the soil, does not develop, thus delaying the emergence of the crop and in case of persistent drought, the situation may result in no emergence (Feliachi et al. 2001). Drought is one of the main environmental factors that greatly affects the germination of species and reduces their survival during the early stages of development. Our results confirm the impact of water stress on the germination of Albardine. Moreover, the germination rate decreased considerably with increasing osmotic water stress of the substrate. Water scarcity is a determining factor for plant germination and growth, particularly in arid and semi-arid regions. It induces in stressed plants a decrease in mean water content, and a significant reduction in total biomass production (Albouchi et al. 2000).

According to Rollin (2017), the speed of germination can also be taken as a criterion. It can be quantified either by the time required to obtain the germination of 50% of the seeds, or by the value of the slope of the curve representing the percentage of germination as a function of time. Xerophilous species (C3) such as *L. spartum* have certain morphological and physiological adaptations to water stress, which are efficient in terms of water use and are therefore adapted to dry climates. After rain, *L. spartum* can react quickly to small variations in soil water content (Aidoud, 1989; Nedjimi, 2016).

3.2. Effect of salinity on germination of *Lygeum spartum*

Algeria is among the countries at risk with 3.2 million ha affected by salinity (Belkhodja and Bidai, 2004) particularly in arid and semi-arid regions which are characterized by biotopes affected by salinization (Zouidi et al. 2018 Borsali et al. 2019). Indeed, this constraint constitutes a limiting factor for seed germination and productivity (Ashraf and Harris 2004; Abdel Latef, 2010), by causing osmotic, toxic or nutritional effects within the plant (Hanana et al. 2011). Thus, varietal selection requires knowledge of the mechanisms responsible for plant tolerance to salinity (Arbaoui et al. 2000). The study of the effects of different concentrations of a salt solution on the germination of *Lygeum spartum* seeds showed that the germination capacity is affected by increasing the salt concentration. The influence of salinity on the germination capacity of *Lygeum spartum* was manifested by a reduction in the rate of germination compared to controls, this reduction is more important as the concentration of salts is high.

The decrease in the final germination rate corresponds either to an increase in the external osmotic pressure which affects the absorption of water by the seeds; or an accumulation of Na^+ and Cl^- ions in the embryo (Groome et al. 1991). This toxic effect can lead to the alteration of the metabolic processes of germination and in the extreme case to the death of the embryo by excess ions. The emergence of the radicle would be controlled by the osmolarity of the environment (Bruggeman et al. 2002). According to Salama (2004), salinity also acts on germination by slowing down its speed, which exposes the seeds to greater risks of germination inhibition.

Nedjimi et al. (2010) classified this grass as a moderately salt-tolerant plant, able to tolerate also soil salinity levels equivalent to electrical conductivity (EC) values of 4–5 dS m^{-1}. At the germination stage, *L. spartum* seems to tolerate salinity at around temperature between 10–20°C (Nedjimi, 2013). The highest levels of around 10g/l proved to be inhibitory.

Under the highest saline conditions, seed survival rather than germination capacity may be an appropriate criterion for success, since resumption of germination occurs in seeds of *L. spartum* and other halophyte grasses when hypersaline conditions are attenuated. Dormancy reduces the risk of seedling mortality when moisture is limited and salinity is increased. This is most favourable under hypersaline conditions (Khan and Gulzar, 2003; Nedjimi, 2013).

CONCLUSION

The current situation of the Algerian steppe is alarming and is undergoing a process of degradation which requires appropriate development to protect the steppe formations, particularly the *Lygeum spartum* formations.

Water deficit is the main environmental factor responsible for low regeneration, yields and their irregularities in Legeum spartum. However, the impact of this abiotic stress on the productivity of this species is dependent on its intensity and time of persistence. The work carried out in this study focused on the adaptation of *Legeum spartum* sown to different levels of water stress by the addition of PEG.

The results reported in this study also show that *Legeum spartum* is a plant moderately sensitive to the action of NaCl. The germination capacity and the germination rate are indeed moderately affected and they decrease with the increase in the concentration of the added NaCl. The tests carried out during this experiment demonstrate that the adaptation of our species is closely dependent and favored by the different physiological, morphological and biochemical responses under stress conditions. All these factors influence the cultivation of this species, which could therefore be established in unproductive low-salt areas, thus providing a significant source of fodder. It is also likely to limit desertification in these arid zones characterized by great ecological fragility.

REFERENCES

Abdel Latef A. (2010). Changes of antioxidative enzymes in salinity tolerance among different wheat cultivars. Cereal research communications, 38(1) : 43-55.

Abdelly C, Ozturk M, Ashraf M, Grignon C. (2008). Bissaline Agriculture and High Salinity Tolerance. (Eds) Birkhausen Verlag/L Swizerland, 367 p.

Aidoud A. (1989). Contribution à l'étude des écosystèmes pâturés des hautes plaines Algéro-oranaises (Algérie) : fonctionnement, évaluation et évolution des ressources végétales. Thèse de Doctorat en sciences ; USTHB. Alger, 240p

Albouchi A, Sebei H, Mezni MY, El Aouni MH. (2000). Influence de la durée d'une alimentation hydrique déficiente sur la production de biomasse, la surface transpirante et la densité stomatique d'*Acacia cyanophylla* Lindl. Annales de l'INGRE, 4 : 139-161.

Arbaoui M, Benkhelifa M, Belkhodja M. (2000). La réponse métabolique de la tomate industrielle (*Lycopersicum Esculuntum* Mill.) au choc salin, cultivée dans un sol sableux mélangé à la bentonite. Université de Sénia, Oran, Algérie. Séminaire 02, Ouargla 08-10 Novembre 1999 Agronomie et Hydraulique en zone aride et semi-aride.

Ashraf MP, Harris PJ. (2004). Potential biochemical indicators of salinity tolerance in plants. Plant science, 166(1): 3-16.

Benidire L, Daoui K, Fatemi ZA, Achouak W, Bouarab L, Oufdou K. (2015). Effet du stress salin sur la germination et le développement des plantules de Vicia faba L. (Effect of salt stress on germination and seedling of *Vicia faba* L.). Journal of Materials and Environmental Science, 6(3): 840-851.

Bensaadi N. (2011). Effet du stress salin sur l'activité des Alpha-amylases et la remobilisation des réserves des graines d'haricot (*Phaesolus vulgaris L.*) en germination (Doctoral dissertation, Université d'Oran1-Ahmed Ben Bella).98p.

Bewley JD, Bradford KJ, Hilhorst HWM, Nonogaki H. (2013). Germination. In: Seeds. Springer, New York, NY. https://doi.org/10.1007/978-1-4614-4693-4_4

Borsali AH, Hachem K, Zouidi M, Allam A. (2018). Effects of water and thermal stress on microbial respiratory activities in soils following a gradient of aridification. Bioscience Research, 15(1): 60-64.

Borsali AH, Hachem K, Zouidi M, Allam A. (2018). Effects of water and thermal stress on microbial respiratory activities in soils following a gradient of aridification. Bioscience Research 15 (1): 60-64.

Boudjada S, Salmi N, Boubetra K, Tagmount D, Makhlouf B (2009). Etude de la variabilité morphologique chez *lygeum spartum* L. en Algerie. Station de recherche forestiere. Baraki. Biocenoses, 1(3) :21-38.

Brueggeman R, Rostoks N, Kudrna D, Kilian A, Han F, Chen J, Druka A, Steffenson B, Kleinhofs A. (2002). The barley stem rust-resistance gene Rpg1 is a novel disease- resistance gene with homology to receptor kinases. Proc Natl Acad Sc USA, 99: 9328-9333.

Chaux C, Foury C. (1994). Maitrise des facteurs de production, qualité et traitement des semences, mise en culture par semis en place in Production légumière. Tome 1- Généralité. Tec et Doc. Lavoisier. pp 277-431-445.

Feliachi K, Amroune R, Khaldoune. (2001). Impact de la sécheresse sur la production des céréales cultivées dans le nord de l'Algérie : Céréaliculture N0 35.ED. ITGC. Algérie.

Groome MC, Axler S, Gfford DJ. (1991). Hydrolysis of lipid and protein reserves in lobolly pine seeds in relation to protein electrophoretic patterns following imbibition. Physiol. Plant, 83: 99-106.

Hanana M, Hamrouni L, Cagnac O, Blumwald E. (2011). Mécanismes et stratégies cellulaires de tolérance à la salinité (NaCl) chez les plantes. Environmental Reviews, 19(NA): 121-140.

Hayek T, Abdelly C. (2004). Effets de la salinité sur l'état hydrique foliaire, la conductance stomatique, la transpiration et le rendement en grains chez 3 populations de mil (*Pennisetum glaucum* L.). Revue des régions arides, 1 : 273-284.

Heler R, Esnault R. Lance C. (2000). Physiologie végétale et développement, Ed. Dunod, Paris. 366p.

Hourizi R. (2017). Suivi de la désertification des steppes à *Lygeum spartum* par l'utilisation de la télédétection et des SIG. Thèse de Doctorat en Sciences. Université des Sciences et de la Technologie Houari Boumediene. Algerie 159p.

Khan MA, Gulzar S. (2003). Germination responses of *Sporobolus ioclados*: a saline desert grass. Journal of Arid Environments, 53(3):387–394.

Le Houérou HN. (2001). Unconventional forage legumes for rehabilitation of arid and semiarid lands in world isoclimatic Mediterranean zones. Arid Land Research and Management, 15(3) : 185-202.

Michel BE, Kaufmann MR. (1973). The osmotic potential of polyethylene glycol 6000. Plant physiology, 51(5) : 914-916.

Munns R, Tester M. (2008). Mechanisms of salinity tolerance. Annual Review of Plant Biology. 59(1): 651–681.

Nedjimi B. (2013). Effect of salinity and temperature on germination of Lygeum spartum. Agricultural Research, 2(4) : 340-345.

Nedjimi B. (2014). Comportement physiologique du sparte (*Lygeum spartum* L.) en milieu salé. Nature & Technology, (11) : 30-33

Nedjimi B. (2016). *Lygeum spartum* L.: a review of a candidate for West Mediterranean arid rangeland rehabilitation. The Rangeland Journal, 38(5) : 493-499.

Nedjimi B, Beladel B. (2015). Chemical contents in *Lygeum spartum* L. using instrumental neutron activation analysis. Radiochimica Acta, 103(6) : 463-466.

Nedjimi B, Brahim GU. (2012). Les steppes algériennes : causes de déséquilibre. Algerian Journal of Arid Environment, AJAE, 2(2) : 12-24.

Paraskevopoulou AT, Kontodaimon Karantzi A, Liakopoulos G, Londra PA, Bertsouklis K. (2020). The effect of salinity on the growth of lavender species. Water, 12(3) : 618. https://doi.org/10.3390/w12030618

Quézel P, Santa S. (1962). Nouvelle flore de l'Algérie et des régions désertiques méridionales. Ed.CNRS. Paris. 2 vol. 1170p.

Rezgui M, Bizid E, Ben Mechlia N. (2004). Etude de la sensibilité au déficit hydrique chez quatre variétés de blé dur (*Triticum durum* Desf.) cultivées en conditions pluviales et irriguées en Tunisie. Revue des Régions Arides, 1 : 258-265.

Rollin P. (2017). Germination, © Encyclopædia Universalis France [URL http://www.universalis.fr/encyclopedie/germination/].

Romo S, Labrador E, Dopico, B. (2001). Water stress-regulated gene expression in Cicer arietinum seedlings and plants. Plant Physiology and Biochemistry, 39(11) : 1017-1026.

Schiefelbein JW, Masucci JD, Wang H. (1997). Building a root: the control of patterning and morphogenesis during root development. - Plant Cell 9: 1089-1098.

Shannon MC. (1986). New insights in plant breeding efforts for improved salt tolerance. Hort. Technol., 6 :96-99.

Slama F. (2004). La salinité et la production végétale. Centre de publication universitaire, Tunis.163P.

Toumi M, Barris S, Aid F. (2014). Effects of water and osmotic stress on the accumulation of proline and malondialdehyde (MDA) in two varieties of colza (*Brassica napus* L.). Bulletin de l'Institut Scientifique : Section Sciences de la Vie, 36 : 17-24.

Zhang H, Tian Y, Guan B, Zhou D, Sun Z, Baskin CC. (2018). The best salt solution parameter to describe seed/seedling responses to saline and sodic salts. Plant and Soil, 426(1) : 313-325.

Zouidi M, Borsali AH, Allam A, Gros R. (2018). Characterization of coniferous forest soils in the arid zone. Forestry Studies, 68(1) : 64-74.

Zouidi M, Borsali AH, Allam A, Gros R. (2019)a. Microbial activities and physicochemical properties of coniferous forest soilsin two forest areas (arid and semi-arid) of western Algeria. Bosque, 40(2): 163-171.

Zouidi M, Borsali AH, Kefifa A, Keddouri N, Gros R. (2019)b. Impact of the Aridity Gradient on the Physico-chemical Parameters of the Needles of *Pinus halepensis* Mill. in the Western Algeria. Indian Journal of Ecology, 46(1): 137-142.