REVIEW PAPER

Salinity in Cuba and pre-germination hydration-dehydration treatments of seeds

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ABSTRACT: Soil salinity is one of the main abiotic factors which affect the establishment and productivity of plants, effect that is increased at global scale. An easily implemented ecotechnology which has proven to be efficient to improve the germination, growth and productivity of cultivated and wild plants, in different stress scenarios (e.g. hydric, heat, acid and salinity), is the hydration-dehydration (HD) treatments of the seeds. This review reports about the salinity status of Cuban soils, the main effects of salinity on plants and different technologies that exist for the management of saline soils. The positive effects of the HD treatments on the performance of plants under salinity conditions are discussed, as well as theoretical and practical aspects related to the application of these physiological procedures to facilitate their introduction in agroforestry and silvopastoral practices.

Key words: seed priming, stress, soil management.

INTRODUCTION

Soil salinity constitutes one of the main factors of abiotic stress that cause crop productivity to decrease (Munns and Tester, 2008). It is estimated that there are more than 800 million hectares worldwide affected by salinity (FAO, 2014). In Cuba, according to data of the National Office of Statistics and Information (ONEI, 2013), 14,9 % of the agricultural surface and 9,1 % of the surface of the country are affected by salts.

Saline stressin plants limits water uptake by the roots, and causes similar changes as the ones that occur during hydric stress, such as the immediate reduction of the growth rate. In addition, it can induce ionic toxicity if excessive quantities of salts enter the plant (Munns, 2002), and, as a consequence of these primary effects (osmotic and ionic), it promotes the formation of oxygen reactive species; which causes a secondary stress, known as oxidative stress (Zhu, 2001).

Considerable efforts have been aimed at the knowledge of the physiological and biochemical changes that occur in the plants subject to salinity (Prisco and Gomes, 2010). The understanding of the complex mechanisms of tolerance to such stress (Zhu, 2002; Deinlein *et al*., 2014) constitutes the basis for the development of cultivars which economically produce under this condition (Prisco and Gomes, 2010). In addition to breeding, several technological methods and cultivation techniques are used in the management of the soils affected by salts, although some of them are not economically viable (Ruiz *et al*., 2007) and others can compromise the preservation of the environment, such as the application of chemical fertilizers for the irrigation water (Cuartero *et al*., 2006).

On the other hand, the hydration-dehydration (HD) treatments of the seeds constitute a known physiological procedure that improves the germination, establishment and productivity of plants under adverse environmental conditions (Sánchez *et al*., 2001a; Paparella*et al*., 2015). This ecotechnology is easily implemented, has low cost and risk; and it is a way to develop a more sustainable agriculture in poor or developing countries (Maiti and Pramanik, 2013). In Cuba, the effectiveness of these treatments has been tested in a large number of crops and native plants in diverse environmental scenarios, such as: hydric and heat stress, acidity, etc. (Sánchez *et al*., 2003a, 2007; Montejo and Sánchez, 2012). However, possibly due to their poor dissemination in rural areas, HD treatments have little application in the country, particularly to increase plant tolerance to salinity. A similar trend occurs in other underdeveloped regions of the world, especially in South America and African countries, but not in the Asian continent (Vanangamudi *et al*., 2006).

This review provides information about the salinity status of the soils in Cuba, the main effects of salinity on the plants and different alternatives that exist for the management of saline soils. Theoretical and practical aspects related to the application of HD treatments on the seeds are also discussed, in order to facilitate their extension to the productive practice under conditions of saline stress.

Salinity in Cuba

According to Ortega (1986), the main salt sources in Cuban soils are the saline sediments formed under continental conditions during the stages of Pleistocene aridity, followed by seawater intrusion in the karstic aquifers open to sea. The most important zones of continental accumulation of Pleistocene saline sediments are the Cauto-Guacanayabo depression, the Guantánamo Valley and the northern central provinces. However, this author states that the humid climate of Cuba favors the natural lixiviation of salts; for which the soils with primary or natural salinization are little extensive and are associated to coastal wetlands.

In most of the soils affected in Cuba, salinity is secondary; among the causes that produce it are: deforestation of the highlands and coastal wetlands, use of salinized water from aquifers with marine intrusion, elevation of the salinized groundwater, as well as the use of low quality irrigation water (Ortega, 1986; González-Núñez *et al*., 2004). In addition, it is estimated that the increase of the sea level due to the climate change will compromise large extensions of land; which will have negative repercussions on the flora and fauna resources that maintain relation with the affected areas (Álvarez and Mercadet, 2012).

According to the information of the salinity map, which appears in the Nuevo Atlas Nacional de Cuba (New National Atlas of Cuba) (Obregón, 1989), it is known that one million hectares of agricultural soils are affected by salinity and more than one million have potential problems; and the eastern provinces are the most affected ones (González-Núñez *et al*., 2004). However, these values must be higher at present, although no new reports appear in scientific literature.

Effects of salinity on the plants

Soil salinity affects plant germination, growth and development. Its negative effect is mainly due to two components: the osmotic and the ionic one. The former is derived from the difficulty of plants to take water from a saline soil (due to the decrease of the hydric potential of the soil); while the latter lies in the ionic toxicity that can be caused by an excess of salts within the plant cell (Munns and Tester, 2008).

Plants have developed the capacity to detect the osmotic as well as the ionic component of salinity stress (Deinlein *et al*., 2014). The recognized stress activates transduction signals that transmit information among individual cells and throughout the plant. As a consequence, alterations of the gene expression at cell leveloccur, which influence the metabolism and development of the whole plant (Buchanan *et al*., 2000). Nevertheless, the resistance or sensitivity to a stress depends on the species, genotype and age of the plant; as well as on the characteristics of the stress: severity, duration, number of exposures and combination of stresses (Buchanan *et al*., 2000).

According to Munns and Tester (2008), there is a general division of plants according to their tolerance to salinity: halophytes (natural flora of highly saline soils) and glycophytes (salinity-sensitive plants); in this last group many edible species are included. The advances in molecular biology and especially the use of mutants of *Arabidopsis thaliana* (L.) Heynh. –species that constitutes an excellent experimental model for molecular studies in plants–, allow to understand better the tolerance mechanisms of plants to salinity from a physiological and biochemical point of view (Prisco and Gomes, 2010). A large list of genes and transcription factors has been identified in the search for resistant cultivars (Amudha and Balasubramani, 2011).

The osmotic component of salinity makes the response of plants to this type of stress very similar to the changes that occur in response to a hydric stress (Munns, 2002; Zhu, 2002). It is also stated that the ionic effect of salinity takes longer to cause alterations in plant metabolism than the increase of the osmotic pressure of the environment (Munns and Tester, 2008).

In response toa hydric stress, chemical signals from the roots are transported via the xylem to the leaves, which results in a decrease of the water loss by transpiration (stomatal closure) and a reduction of leaf growth (Schachtman and Goodger, 2008). Implied in this signaling are absicic acid (ABA), key regulator of stomatal conductance; as well as pH, cytokinins and malate (Schachtman and Goodger, 2008). Together with cell expansion and division,

photosynthesis is one of the first processes that are affected by a hydric or saline stress (Chaves *et al*., 2009); although the cause-effect relation between photosynthesis and growth rate can be difficult to clarify (Munns and Tester, 2008).

Probably detected as turgor changes, the osmotic stress regulates the biosynthesis of ABA and activates in plant cells many proteins-chinases and phospholipid systems that generate diverse molecular messengers (Zhu, 2002). Besides ABA, others plant growth regulators such as ethylene, jasmonic acid and salicylic acid are implied in the response of plants to salinity (Chávez *et al*., 2012).

One of the most relevant physiological mechanisms in the tolerance of plants to hydric deficit is the osmotic adjustment (Amudha and Balasubramani, 2011). It is defined as the increase of solutes per cell, independently from the changes that result from the loss of water, and is carried out due to the accumulation of ions in the vacuole or the synthesis of compatible solutes in the cytosol (Taíz and Zeiger, 2006). Among the compatible solutes (organic compounds that do not interfere in the cell metabolism) are proline and glycine betaine, which can also have protective functions (Amudha and Balasubramani, 2011).

Regarding the ionic compound of salinity, it is known that a high concentration of Na^+ in the environment interferes directly in the uptake of K^+ (essential macronutrient), besides inactivating enzymes and inhibiting synthesis of proteins (Buchanan *et al*., 2000). The excess of intracellular or extracellular Na^+ is detected by a sensorial mechanism which has not been identifiedyet. However, a signalization path based on genes highly sensitive to salinity or SOS (Salt Overly Sensitive) genes has been identified for the ionic aspect of salinity. Mediated by CA^{2+}, this signalization path results in the expression and changes in the activity of transporters of such ions as Na^+, K^+ and H^+. Thus, the influx of Na^+ is controlled by the membrane transporterHKT1. The excess of this ion can be excluded from the cell by SOS1 (Na^+/H^+antiport of plasmatic membrane); or sequestered in the vacuole by action of NHX (Na^+/H^+antiport of the tonoplast), according to Zhu (2003) and Deinlein *et al*. (2014).

In addition, salinity promotes the formation of reactive oxygen species (ROS), such as the superoxide anion (O_2), hydrogen peroxide (H_2O_2) and the hydroxyl radical (OH), which are capable of oxidizing membrane lipids, denaturalizing proteins and reacting with DNA, causing mutations (Prisco and Gomes, 2010). Nevertheless, plant cells produce ROS as molecular messengers in signal transduction cascades, in diverse processes such as the cell cycle, the programmed cell death; as well as in the defense against conditions of biotic and abiotic stress (Foyer and Noctor, 2005). These ROS are produced during reactions involved in normal metabolism, such as photosynthesis and respiration; but the stress conditions increase their formation from these and other sources like photo-respiration (Mittler, 2002).

Because ROS are toxic but also participate in signalization events, plant cells must regulate their concentrations (Mittler, 2002). For such reason, plants have developed defense systems which include antioxidant enzymes such as superoxide dismutase, ascorbate peroxidase and catalase; and non-enzymatic compounds such as ascorbate, glutathione and tocopherol (Foyer and Noctor, 2005).

There are, in general, three important and interconnected aspects which take place in salinity-tolerant plants. They are: growth control (cell division and expansion), which should be restarted, but with a reduced rate; the restoring of homoeostasis in the face of the new stress conditions, and the control and repair of damage or detoxification (Zhu, 2001). Many of the changes induced by saline stress in the plant cells can be considered as part of the detoxification signals. They include phospholipid hydrolysis, changes in the expression of genes that codify for LEA (late embryogenesis abundance) proteins, molecular chaperones, proteinases that eliminate de-naturalized proteins and activation of enzymes involved in the generation and elimination of ROS and other detoxifying proteins (Zhu, 2002).

According to Prisco and Gomes (2010), salinity initially alters water and nutrient absorption and membrane permeability. Such alterations have repercussions on the water and nutritional balance of the plant, and cause changes in the metabolism and hormonal balance, as well as in the production of ROS. All these changes compromise cell expansion and division and vegetative and reproductive growth, accelerate leaf senescence and result in an eventual death of the plant.

Management of saline soils

To make progress in the sustainable use and exploitation of saline soils, it is necessary to start from an adequate diagnosis. A set of indicators from the physical and chemical analyses of the soil samples are used, according to the purpose of the study, for the characterization and evaluation of the soils affected by salts (Otero *et al*., 2014).

Depending on these indicators there are several classification systems, but the most used is the one proposed by the United States Salinity Laboratory (Richards, 1954). This system is based on easily-obtained indicators, such as the electrical conductivity of the saturation extract (EC), the percentage of exchangeable sodium (PES) and pH, from which the salt-affected soils are divided into three groups (table 1): saline soils (showing high EC values), alkaline or sodic soils (with a high PES) and saline-sodic soils (combining an excess of soluble salts with a high PES).

Once the soils are evaluated, different alternatives can be applied for their management, among which the following stand out: hydrotechnical (soil washing), physical (tillage intensity, leveling, profile inversion), chemical (sodium exchange by calcium through the use of calcium salts or acids and biological methods (organic fertilizers, establishment of tolerant crops). Although the classifications of the methods vary, as well as the amelioration practices that they comprise, several authors coincide on the fact that the best results are obtained with their combined application (González *et al*., 2002a; Mesa, 2003).

The most used method for the recovery of saline soils is the washing or lixiviation of the soluble salts with low-salinity water. This method basically consists in applying a large lamina of water to dissolve the salts and remove them from the root zone of the crop; although to wash a saline soil it is essential that it is permeable and that it has adequate drainage conditions (Serrato *et al*., 2002).

The recovery of sodic soils has been done mainly changing the sodium in the colloidal complex by another cation; for such purpose sulfuric acid (H_2SO_4) and agricultural gypsum ($CaSO_4$ 2 H_2O) are applied; it has also been done mechanically, by mixing the surface layer with a plow, and through the use of halotolerant plants (Sánchez and Arguello, 2006; Ruiz *et al*., 2007). However, it is not easy or economical to eliminate or decrease the sodium concentrations in the soil. Chemical methods are costly for large extensions, due to the quantity of material that is used as well as to their application, because in some cases specialized equipment is required (Ruiz *et al*., 2007).

Zúñiga *et al*. (2011) evaluated a series of non-conventional technologies for the recovery of salt-degraded soils in the Cauca Valley, Colombia; for such purpose they applied three alternative treatments: biofertilizers, biopolymers and electromagnetism, compared with conventional chemical amendment (gypsum-sulfur) and an absolute control (drainage alone). According to the agronomic response of a corn (*Zea mays* L.) crop, the treatments based on the use of microorganisms (biofertilizers and electromagnetism) were the most effective ones. The use of bioremediation with halophyte bacteria capable of capturing sodium (Sánchez and Arguello, 2006), as well as the native isolations and the commercial rhizobium strains (López *et al*., 2011) are also alternatives that have been studied.

Another alternative for the amelioration and utilization of saline soils is the cultivation of forage pastures with salt-excreting properties, because they reduce salinity, and also their plant cover can be utilized. In that sense Ruiz *et al*. (2007) obtained positive results with three pasture species: *Sorghum sudanense* (Piper) Stapf, *Lolium perenne* L. and *Cynodon dactylon* (L.) Pers.In Argentina, just like in many countries, there are plantations of salinity-tolerant shrubs such as *Jatropha curcas* L., which produce oils of industrial use and constitute another example of the productive incorporation of plants in lands affected by salinity (Taleisnik and López, 2011). However, it should be taken into consideration that the incorporation of salinity-tolerant plants in affected soils can increase the accumulation of salts in the higher strata. This occurs if the plants use the saline underground water to cover their water requirements, as has been reported in plantations of *Eucalyptus*, *Acacia* and *Prosopis* (Taleisnik and López, 2011).

On the other hand, breeding contributes to the increase of the recovery of underused areas, as well as of the yield of those zones where salinity is a limiting factor of agricultural production

Table 1.Classification of the soils affected by salts.

Classification	EC (dS/m)	PES	pH
Saline	> 4	< 15	< 8,5
Sodic	< 4	> 15	> 8,5
Saline-sodic	> 4	> 15	< 8,5

Source: Richards (1954).

(Lamz and González, 2013); although it is a method that involves a large quantity of resources and considerable time (Argentel *et al*., 2010). In spite of the knowledge about the salinity tolerance mechanisms, the achievement of resistant plants is limited due to the large number of genes involved and because their effect depends on other genes, on the level and composition of salinity, as well as on other environmental factors (Cuartero *et al*., 2006). Another limitation is that the cultivars developed should be salinity-tolerant and, in turn, productive (Turan *et al*., 2012).

In addition to obtaining salinity-tolerant genotypes, Cuartero *et al*. (2006) emphasized three cultivation techniques that could increase plant productivity in saline soils: 1) increase of relative humidity around the plants; 2) use of grafts in the roots, capable of reducing the effect of salinity, so that desired traits can be combined; and 3) the use of pretreatments such as the exposure of the seeds and seedlings to saline or hydric stress conditions before planting.

Among the main technologies applied in Cuba to fight salinity are: soil washing, through the establishment of adequate irrigation-drainage systems; the application of organic matter and chemical amendments; the use of salinity-tolerant cultivars; and the intensive cultivation of rice, so that year after year, in the soils dedicated to this crop the salt concentration decreases, and afterwards they can be used for other crops or in rotation systems (González-Núñez *et al*., 2004).

Work has also been conducted in breeding programs and there are in Cuba two salinity-tolerant rice varieties (IACUBA-25 and INCA LP-7), released to production (González *et al*., 2002b). Nevertheless, the release of varieties with good productive performance under field conditions with salinity problems has not been fruitful (Lamz and González, 2013). Taking into consideration that the selection of salinity-tolerant plants is a long process, in Cuba work is conducted in the search for efficient indicators for the early selection of genotypes with better agronomic performance (Lamz and González, 2013; Lamz *et al*., 2013). Other alternative and promising physiological ways have been little explored, such as the HD treatments of the seeds, aspect that is discussed below.

Hydration-dehydration (HD) treatments of the seeds

The pre-germination HD treatments of the seeds have been efficient to accelerate and uniform germination, re-invigorate aged seeds, and increase the crop yield under optimum and adverse ecological conditions. Such techniques are mainly known as seed priming, seed reinvigoration and seed hardening (Khan, 1992; Taylor *et al*., 1998; Welbaum *et al*., 1998a; McDonald, 2000; Sánchez *et al*., 2001a); although the most used term in the scientific literature is seed priming, independently from the objectives pursued.

The common characteristic is that all these techniques imply controlled water absorption (Varier *et al*., 2010). It can be defined as the water uptake that starts the early events of germination, but not enough so as to allow the radicle emergence, followed by dehydration (McDonald, 2000). The seeds can be hydrated in osmotic solutions, in water or in solid particles (Taylor *et al*., 1998). The water uptake is controlled depending on the balance of chemical potentials (Heydecker *et al*., 1973), limitation of the quantity of added water (Henckel, 1982), or depending on the time of immersion in water (Orta *et al*., 1998).

In all the fresh non-dormant seeds, water absorption shows a triphasic pattern: a fast initial absorption due to the low hydric potential of the seeds (phase I), followed by a period of variable length in which the water content increases very little (phase II) and, finally, the increase in the water uptake re-starts, because of the emergence of the radicle (phase III) (Bewley and Black, 1994). During this process different biophysical, physiological and biochemical events occur (Bewley, 1997; Obroucheva and Antipova, 1997; Welbaum*et al*., 1998b). The time in which each phase is completed can vary from hours to weeks, depending on the species, the characteristics of the seeds and the germination conditions (Bewley, 1997). The aged and/or dormant seeds possibly might not surpass phase I or phase II of such pattern; because they have low germination vigor, are dead, or because dormancy imposes restrictions on the water uptake and on the metabolic development of the embryo (Bewley and Black, 1994; Sánchez *et al*., 2004).

In priming, the seeds progress through phases I and II, without arriving at phase III (fig 1). However, in the hardening treatments developed by Henckel (1982), the seeds are hydrated until the incipient emergence of the embryo; while to re-invigorate aged seeds, short hydration periods (without reaching phase II) have proven to be sufficient (Sánchez *et al*., 2004, 2005). The usefulness of each treatment will depend on the changes caused on the seeds by the level of hydration reached (Sánchez *et al*., 2001a). Thus, for the effect of the treatment to be homogeneous, all the seeds must reach the same moisture level. When osmotic solutions are used, the water absorption barrier is established based on the balance of hydric potentials (solution-seeds);

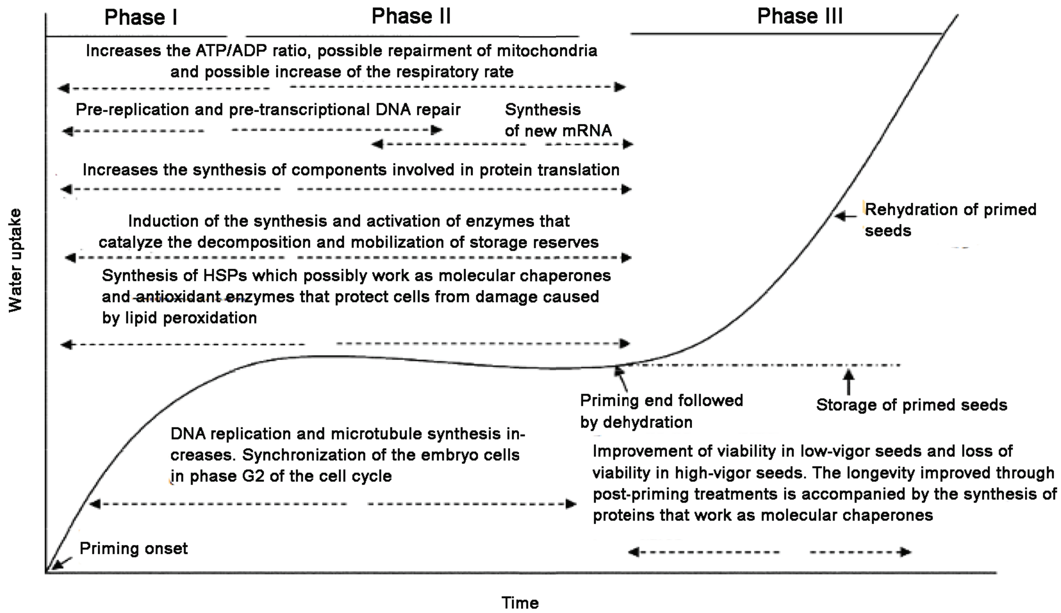

Figure 1. Triphasic pattern of water absorption and metabolic events during seed priming. Source: Varier *et al.* (2010)

in the techniques in which hydration occurs in water, homogeneity can be achieved subjecting the seeds to two or more cycles of partial hydration-dehydration (Orta *et al*., 1998).

Priming treatments, besides producing the general activation of the metabolic apparatus related to the pre-germination stage, restore cell integrity (enzymatic self-repairing of the membranes) through the synthesis of lipids, proteins, RNA and DNA (Bewley and Black, 1994; Bewley, 1997); can eliminate or reduce dormancy in the seeds and cause the adaptation of plants to environmental stress conditions to be phenotypically expressed (Sánchez *et al*., 2001a; Paparella *et al*., 2015).

Varier *et al.* (2010) summarized the metabolic events that occur in the seeds during priming (fig. 1), among which the following stand out: 1) synchronization of all the embryo cells in the phase G2 of the cell cycle, so that after re-imbibition, cell division proceeds uniformly; 2) repair of the damaged DNA, ensuring the availability of a template free from errors for the replication and transcription; and 3) induction of the synthesis and activation of enzymes that catalyze the decomposition and the mobilization of the storage reserves, antioxidant enzymes such as catalase and superoxide dismutase, as well as heat shock proteins (HSPs), which work as molecular chaperones.

The beneficial effects of priming are preserved even after drying the seeds; however, dehydration is a crucial stage (Mc Donald, 2000). It has been stated that many seeds are tolerant to desiccation during phases I and II, but they frequently become intolerant in phase III (Taylor *et al*., 1998). A fast dehydration after priming can damage the seeds, which results in an irreversible loss of the advantages obtained during hydration (Welbaum *et al*., 1998a). On the other hand, priming can reduce the longevity of seeds with high vigor (Varier *et al*., 2010).

The success or failure of the treatments are influenced by a complex interaction of factors, which include: the plant species, the substances used, the hydric potential of the solution, light, oxygen, temperature, duration of hydration, seed vigor, dehydration, as well as the storage conditions and time after the treatment (Parera and Cantliffe, 1994). The seed lots vary in their response to priming, even within the same cultivar. Due to this variability, the optimum conditions to carry out priming should be determined for each seed lot (McDonald, 2000).

There are predictive models to establish the optimum conditions in which the treatments should be carried out, taking into consideration mainly three variables: the hydric potential of the seed, the temperature and duration of the treatment (Gummerson, 1986; Bradford and Haigh, 1994; Bradford, 1995); but these models cannot be generalized to all the species (Sánchez *et al*., 2001a). As general rule, the best temperature for priming is close to the optimum germination temperature for a particular species (Bradford, 1986). Thus, determining the optimum germination temperature and the water absorption dynamics for the species (or seed lot) under

study constitutes a useful step before implementing an HD treatment.

Seed priming has gained a lot of popularity in the induction of salinity tolerance in relatively little tolerant plants (Iqbal and Ashraf, 2013). Although its bases are still studied, the beneficial effects go from the germination and establishment stages, to productivity increases of the harvests (table 2). Different solutions can be used in the hydration stage; however, the imbibition of seeds in distilled water and the later dehydration constitute a fast and simple method to improve the functioning of germination under saline conditions (Rehman *et al*., 1998a), as it has been suggested for other stress conditions (Sánchez *et al*., 2001a; Vanangamudi *et al*., 2006).

In addition, HD treatments have been applied combined with heat shock (Sánchez *et al*., 2001b, 2006) and acid shock (Sánchez *et al.,* 2007), and significant increases were achieved in germination and seedling vigor under heat stress and acidity conditions of the environment, respectively. According to Henckel (1982), a brief exposure of the seeds to sub-lethal germination conditions can induce the subsequent resistance of plants to lethal conditions. The phenotypical expression of this genotype-environment relation is translated into deep biochemical and physiological changes, which will remain latent under ideal environmental conditions (Henckel, 1982; Heydecker, 1982). In this sense, HD treatments in combination with salt shocks could also be implemented.

In Cuba the effect of the HD treatments of the seeds has been studied in a large number of agricultural species, in silvopastoral systems and in tropical pioneer trees (Orta *et al*., 1998; Sánchez *et al*., 1999a, 1999b, 2001a, 2001b, 2003a, 2003b, 2005, 2006, 2007; Montejo *et al*., 2002, 2004, 2005; González *et al*., 2005, 2008, 2009a, 2009b). With such treatments the germination and seedling establishment under different abiotic stress conditions could be achieved. For example, in seeds of tropical pioneer trees (table 3) the

Table 2. Hydration-dehydration treatments with possitive results to saline stress.

Species	Imbibition solutions	Results	References
Acacia coriaceae DC. *Acacia tortilis* (Forsk.)	Water	Increases and accelerates germination	Rehman *et al*. (1998a) Rehman *et al*. (1998b)
Acacia nilotica Willd. Ex Del. *Acacia tumida* F. Muell. Ex Benth. *Acacia salicina* Lindl. *Acacia senegal* (L.) Willd.	Water	Increases and accelerates germination Accelerates germination Accelerates germination Accelerates germination	Rehman *et al*. (1998b)
Aeluropus macrostachyus Hack	NaCl, $CaCl_2$ KCl	Increase germination percentage and rate, and seedling growth	Askari (2013)
Agropyron elongatum (Host) P. Beauv	PEG 6000 Water	Increase germination, mean germination time, germination rate and the seed vigor index	Abbasi *et al*. (2013)
Brassica napus L.	NaCl	Improves germination and seedling vigor	Kandil *et al*. (2012)
Brassica napus	Gibberellic acid	Improves the seedling growth of the tolerant cultivar	Benincasa *et al*. (2013)
Bromus inermis Leyss *Bromus tomentellus* Boiss	PEG 6000 Water	Increase and accelerate germination	Tavili *et al*. (2011)
Coriandrums ativum L.	NaCl	Increases and accelerates germination, improves seedling growth and mineral balance, increases the content of proline, sugars and soluble proteins	Ben Fredj *et al*. (2013) Ben Fredj *et al*. (2014)
Cucurbita pepo L.	Ascorbic acid Salicylic acid	Increase the fresh weight of the seedlings, the protein content and the nitrate-reductase activity	Rafique *et al*. (2011)
Species	Imbibition solutions	Results	References

Table 2. (*Continuation*)

Glycine max (L.) Merr.	Water, Auxin, Gibberellin	Improve emergence and grain productivity	Bejandi *et al*. (2009)
Hordeum vulgare L.	Water	Increases harvest productivity	Rashid *et al*. (2006)
Moringa oleifera Lam.	Water	Increases the germination percentage and rate, dry matter and length of the seedlings	Ferreira *et al*. (2011)
Physalis peruviana L.	PEG 6000	Increases germination percentage, rate and uniformity; increases dry matter of the seedlings	Mascarenhas *et al*. (2014)
Silybum marianum (L.) Gaertn.	Gibberellic acid Mannitol NaCl Water	Improve germination and seedling establishment	Sedghi *et al*. (2010)
Triticum aestivum L.	Kinetin Prostart	Improve emergence and seedling growth	Afzal *et al*. (2005)
Triticum aestivum	NaCl Manitol, Plant extract, Water	Improve germination and seedling growth	Amoghein *et al*. (2013)
Triticum aestivum	Indoleacetic acid Indolebutyric acid, Tryptophan Water	Increase CO_2 assimilation and grain productivity; decrease the concentrations of endogenous ABA	Iqbaland Ashraf (2013)
Triticum secale Witm.	KH_2PO_4 Water	Increase the germination percentage and seedling growth	Yagmur y Kaydan (2008)
Zea mays L.	Water, NaCl, KCl, $CaCl_2*2H_2O$	Increase the dry and fresh matter of plumules and radicles	Ashraf and Rauf (2001)
Zea mays	28-Homobras-si-nolide	Increases the content of antioxidant enzymes; decreases lipid peroxidation	Arora *et al*. (2008)
Zea mays	Water	Improves germination and seedling growth	Janmohammadi *et al*. (2008)
Zea mays	NaCl	Induces biochemical and physiological changes which improve response to stress	Bakht *et al*. (2011)

PEG: Polietilenglicol

hardening treatments significantly increased germination under extreme drought conditions (hydric and heat stress) with regards to the control treatment (Sánchez *et al*., 2011). Although the results are positive, it is a technique little applied in the country.

To the best of the authors' knowledge there are no studies in Cuba about the role of these techniques in the improvement of plant response to saline stress conditions. This could be an important research line, not only due to its theoretical interest, but because of the practical significance their application could have in agricultural and forestry repopulation systems under adverse or changing ecological conditions, as it is proposed in the possible environmental scenarios induced by climate change.

FINAL CONSIDERATIONS

The soil salinity affects the productivity of crops throughout the planet and also compromises the permanence of vegetation in natural ecosystems, aspects that will have a larger impact according to the environmental scenarios proposed by the climate change. In this sense, in this contribution it was proven that the germination HD pre-germination

Table 3.Effect of hydration-dehydration treatments on the final germination of pioneer trees under stress conditions.

	Germination under hydric stress (%)			
Species/treatment	-0,49 MPa	-0,97 MPa	-1,46 MPa	Total mean
Cecropias chreberiana				
Control	15,0	0,0	0,0	5,0
Treatment	29,0	17,6	0,0	15,6
Trichospermum mexicanum				
Control	21,3	7,0	0,0	9,5
Treatment	44,1	19,0	10,0	24,3
Hibiscus elatus				
Control	4,6	0,0	0,0	1,5
Treatment	25,3	11,5	0,0	12,2
Guazuma ulmifolia				
Control	40,0	15,0	3,0	19,3
Treatment	68,0	40,0	19,5	42,5
	Germination under heat stress (%)			
	25/40 ºC	25/45ºC	25/50 ºC	Total mean
Cecropia schreberiana				
Control	70,2	25,0	0,0	31,7
Treatment	92,6	52,0	35,0	59,8
Trichospermum mexicanum				
Control	80,0	24,0	0,0	34,6
Treatment	94,0	56,0	40,4	63,4
Hibiscus elatus				
Control	34,4	0,0	0,0	11,4
Treatment	67,6	30,2	20,5	39,4
Guazuma ulmifolia				
Control	73,3	24,0	0,0	32,4
Treatment	95,3	57,3	33,2	61,9

Source: Sánchez *et al*. (2011) MPa - megapascals

treatments constitute an adequate ecotechnology to increase plant tolerance to salinity and to other abiotic stress conditions (including the combination of stresses). Thus, such physiological treatment could be a promising tool to mitigate the adverse effects of salinity on plant germination, establishment and yield. Also starting from the principle that plants under natural conditions are subject to multiple stress conditions, it would be adequate to apply the seed HD pre-germination treatments combined with other hardening physiological treatments (e.g. heat, acid or saline shock) to improve the reproductive performance of plants under adverse ecological conditions, and, as experimental model, to know the adaptive capacity of plants under changing environmental conditions.

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