ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS Journal of Agronomy
ISSN 1812-5379
DOI: 10.3923/ja.2021.25.34

Research Article
Scarification of Seeds of *Capsicum chinense* Jacq. With Phytohormones and Physicochemical Treatments to Improve Seedling Quality

[1]Edmundo Gomez-Mendez, [1]Lucero Polanco-Arjona, [2]Rosa Ma. Salinas-Hernandez,
[1]Jose Manuel Salaya-Dminguez and [1]Hortensia Brito-Vega

[1]Educational Engineering Program in Agronomy,
Academic Division of Agricultural Sciences of the Juarez Autonomous University of Tabasco km 25 Villahermosa-Teapa Highway,
Central Municipality, Tabasco, 86000, Mexico
[2]Sensory Laboratory, Agricultural Sciences Research Center, Food Engineering Educational Program,
Academic Division of Agricultural Sciences of the Juarez Autonomous University of Tabasco km 25 Villahermosa-Teapa Highway,
Central Municipality, Tabasco, 86000, Mexico

Abstract
Background and Objective: Loss of viability is one of the main problems of habanero pepper seeds. After being in storage for more than three months, the speed and final percentage of germination of habanero pepper seeds decrease considerably. The aim of the study was proposed to evaluate hormonal, chemical and physical treatments in the scarification of seeds of habanero pepper *Capsicum chinense* Jacq. to determine the effect of dormancy on germination and seedling quality. **Materials and Methods:** The seven treatments were: T_1 (hot water at 50°C/5 min), T_2 (Biozyme TF 1.6% (v/v)/24 hrs), T_3 (Sodium chloride (NaCl) 0.5 M/24 hrs), T_4 (Gibberellic acid (AG_3)) at 400 ppm/20 hrs), T_5 (cold 4°C/48 hrs), T_6 (Potassium nitrate (KNO_3) 3%/24 hrs), T_7 (seeds without treatment). The agronomic parameters evaluated were (a) Germination (%), (b) Germination percentage, (c) Cumulative germination over time (%) and (d) Seedling quality, which was evaluated through the following parameters: seedling height, number of leaves, stem diameter and root length. **Results:** The data were subjected to analysis of variance. The statistical analysis showed no significant differences in germination percentage between the evaluated treatments ($\alpha \leq 0.05$). The treatments that showed the highest average values were hot water, Biozyme TF and Gibberellic acid, with germination percentages above 90%. **Conclusion:** Phytohormonal scarification with Biozyme TF stimulated seed germination and led to 90% of the seeds germinating on the same day, with high-quality seedlings of up to 80-90%.

Key words: Biozyme, gibberellic acid, genetic potential, quality seedlings, habanero pepper, capsicum, fungicide

Citation: Gomez-Mendez, E., L. Polanco-Arjona, R.M. Salinas-Hernandez, J.M. Salaya-Dominguez and H. Brito-Vega, 2021. Scarification of seeds of *Capsicum chinense* Jacq. with phytohormones and physicochemical treatments to improve seedling quality. J. Agron., 20: 25-34.

Corresponding Author: Hortensia Brito-Vega, Educational Engineering Program in Agronomy,
Academic Division of Agricultural Sciences of the Juarez Autonomous University of Tabasco km 25 Villahermosa-Teapa Highway,
Central Municipality, Tabasco, 86000, Mexico

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

In Mexico, the cultivation of chili peppers (*Capsicum* spp.), together with corn and beans, is part of a food production system that has sustained human life in Mesoamerica for thousands of years. The genus Capsicum has domesticated at least 5000 BC and its species have become the most consumed worldwide. Chili peppers were taken from America to Europe, Asia and Africa by the Spanish and Portuguese and became a crop consumed worldwide[1]. Habanero pepper (*Capsicum chinense*) is traditionally produced in the Yucatan Peninsula: Campeche and Quintana Roo. The traditional open field yields vary from10-40 t ha^{-1}. Quintana Roo has further developed the production technology of habanero pepper under greenhouse conditions using low and medium technology, specifically in the enterprise Hidroponia, which works with medium technology and has 40 ha of greenhouses, Yields per square meter vary from 7-12 kg in both production systems, the production is channelled to Mexico including Mexico City for fresh consumption and to prepare sauces and to the USA and Canada for industrialization[2]. The cultivation of habanero chili has spread to different states of the country, with an estimated production of 9351 t (worth 166.9 million pesos) in 2018-2019. The main producing states were Yucatan, Tabasco and Campeche. In Tabasco alone, 800 ha were cultivated with habanero chilli in 2019, producing 2671 t of this increasingly valuable crop product[3]. The production of a profitable crop require high-quality seeds, which have a greater probability of leading to the successful establishment of seedlings because they maintain greater viability during storage. Seed quality depends on genetic, phytosanitary, physical and physiological aspects, the latter of which include viability, germination capacity and vigour, which are affected by the growth conditions of the mother plant during seed development, the degree of maturity at the time of harvest and the harvesting method. In some species, the maturity of the seeds coincides with the maturity of the fruits, so that the early-harvested fruits provide poor quality seeds[4]. Loss of viability is one of the main problems of habanero pepper seeds. After being in storage for more than three months, the speed and final percentage of germination of habanero pepper seeds decrease considerably. Conditioning the seeds before sowing helps to reinvigorate, accelerate and standardize the germination process under optimal and adverse conditions, reducing the time between imbibition and seedling emergence[5]. One of the greatest challenges in the production of habanero peppers is to have healthy and vigorous seedlings of excellent quality at the time of transplantation[6], Several variables directly influence germination and natural conditions are often unfavourable for this process. In some species of the genus *Capsicum*, chemical, physical and hormonal treatments have been used for seed scarification due to the advantages they offer, such as ease of use and relatively low application costs. The objective of this present study, therefore, was to evaluate hormonal, chemical and physical treatments in the scarification of seeds of habanero pepper *Capsicum chinense* Jacq. to determine the effect of dormancy on germination and seedling quality.

MATERIALS AND METHODS

Description of the study area: The study was carried out in the nursery and greenhouse area of the Academic Division of Agricultural Sciences and in the Plant Health Laboratory of DACA-UJAT, located on the Villahermosa-Teapa road, km 25 Ra^{-1}, La Huasteca 2nd. Section, Municipality of Centro, Tabasco, Mexico. The study was carried out at the soil and plant chemical and physical analysis laboratory, Agricultural Sciences Research Center and also for the preparation of trays, sowing, germination, growth and development of *Capsicum chinense* was carried out in the area greenhouses of the Academic Division of Agricultural Sciences, Villahermosa-Tabasco from January-December, 2019.

Genetic material: Seeds from the orange variety of Habanero pepper *Capsicum chinense* Jacq. were used. The seeds were obtained from healthy, ripe fruits of uniform size, freshly harvested from plants grown hydroponically in the greenhouses of the Academic Division of Agricultural Sciences.

Description of the treatments: (1) Hot water has proved to be a simple and practical, low-cost and effective alternative for seed sanitary control in germination tests[7], (2) Biozyme TF is a growth regulator based on plant extracts and biologically active phytohormones[8], such as gibberellic acid, auxins and cytokinins. It acts at the cellular level, stimulating cell division and elongation[9], (3) Sodium chloride (NaCl)[10]. Physiologically, salinity is expressed as salt concentration in millimolar units (Mm), (4) Gibberellic acid (AG_3) is a natural compound that acts as plant growth and development regulator. Gibberellins are directly involved in the control and promotion of seed germination[11], (5) Refrigeration is used when the seeds need to be affected by low temperatures to germinate[12], (6) Potassium nitrate is a chemical used to promote seed germination. The use of nitrate solutions has been effective in increasing seed germination[13] and (7) In the control treatment, no chemical or physical products were applied to the seeds.

Table 1: Scarification treatments evaluated in seeds of habanero *Capsicum chinense* Jacq

Treatments	Description	Time
T_1	Hot water 50°C	5 min
T_2	Biozyme TF1.6% (v/v)	24 hrs
T_3	Sodium chloride (NaCl) 0.5 Molar	24 hrs
T_4	Gibberellic acid (GA_3)at 400 ppm	20 hrs
T_5	Refrigeration 4°C	48 hrs
T_6	Potassium nitrate (KNO_3) 3%	24 hrs
T_7	Control (seeds without treatment)	-------

Experimental design: The treatments were distributed in a completely randomized experimental design in an area of 2×2 m^2 covered with shade mesh (Table 1). There were seven treatments with four repetitions. Each experimental unit consisted of a tray of 200 wells containing peat moss substrate and 25 seeds per repetition for a total of 700 seeds.

Seed extraction: The seeds were selected from freshly harvested mature fruits of uniform size and good phytosanitary appearance, with an average weight of 10.21 g, an average diameter of 2.9 cm and an average length of 4.6 cm. The selected fruits were taken to the laboratory to extract the seeds from fruit using gloves and a scalpel. Impurities (pericarp remains) were then removed to obtain clean seeds.

Cleaning and selection of seeds: After extracting the seeds, they were cleaned using the float in water, while viable seeds are denser and sink[14], which consists of immersing the seeds in water for 24 hrs. Full seeds stay at the bottom of the glass, while empty seeds and other impurities float to the surface. In this way, 700 seeds were selected and counted. These were then divided into groups of 100 to subject them to the respective treatments.

Experiment: The seed treatments were applied as follows: T_1 Hot water. Distilled water was poured into a 500 mL beaker and heated in an electric stove at 50°C. The temperature was measured with a thermometer. Once the water reached 50°C, the seeds were submerged for 5 min. T_2 Biozyme TF. 8 mL of Biozyme TF were measured in a 50 mL test tube, which was then added to a 500 mL beaker containing distilled water and mixed. The seeds were then immersed in this solution and kept there for 24 hrs. T_3 Sodium chloride (NaCl): 14.6 g of sodium chloride were weighed on an analytical balance. They were then dissolved in 500 mL of distilled water contained in a beaker, where the seeds were immersed for 24 hrs. T_4 Gibberellic acid (AG_3): 2.4 g of gibberellic acid were weighed on an analytical balance and were later dissolved in a beaker containing 500 mL of distilled water, where the seeds were immersed for 20 hrs. T_5 Refrigeration: The seeds were kept for 48 hrs in a laboratory refrigerator (MABE)set at 4°C. T_6 Potassium Nitrate (KNO_3): 15 g of potassium nitrate (reagent grade) were weighed on an analytical balance and dissolved in a beaker containing 500 mL of distilled water, where the seeds remained submerged for 24 hrs. T_7 Control seeds were not given any treatment.

Sowing: The seeds were sown in polyethylene trays with 200 wells, each of which was filled up to ¾ of its volume with peat moss substrate. One seed was placed in each well and then covered with a thin layer of substrate. All wells were labelled for identification. After sowing, each well was watered and then covered with black plastic to maintain humidity and temperature. The plastic was removed on the third day.

Seedling management: After the first watering, no more watering applied during the first three days. After the 3rd day, watering was done manually using an atomizer. After the emergence of the cotyledon leaves, watering was applied daily in the mornings and evenings using Steiner solution at 25%, taking care not to saturate the substrate with too much moisture. Foliar fertilizer (Bayfolan Forte) was applied every seven days at a dose of 1 mL for each litre of water. Fifteen days after the start of germination, fungicide (Captan) was applied at a concentration of 1 g L^{-1} of water to prevent problems caused by fungi.

Evaluated variables: The agronomic parameters evaluated were (a) days of germination and (b) percentage of germination. The latter was determined from the ratio between total seeds sown and total seeds germinated, using the formula[15,16]:

$$\text{Germination (\%)} = \frac{\text{TG} \times 100}{\text{TS}}$$

Where:

TG = Total seeds germinated

TS = Total seeds sown

Cumulative germination over time (%): This variable was determined based on the total number of seeds sown and the number of seeds germinated at different time intervals (days). A total of nine observations were made. The evaluation period started nine days after sowing (when germination started) and ended 33 days after the start of germination.

Seedling quality: A single evaluation was made 53 days after germination, for which several seedlings were sacrificed. Twelve seedlings from each treatment were randomly selected to measure the following characteristics: Seedling height, measured from the collar to the apex of the seedling using a 20 (cm) ruler. The number of leaves, the number of leaves of each seedling was counted, considering those that were fully developed. Stem diameter: the stem diameter was measured in Millimeters (mm) using a digital vernier at a height of one centimeters from the collar of the seedling. Root length, the length of the root was measured in Centimeters (cm) using a tape measure, from the collar to the tip of the root.

Analysis of data: The data obtained were subjected to analysis of variance and Tukey's tests for comparison of means (α = 0.05). All statistical tests were carried out using the statistical package SAS[17]. The values were transformed before the arcsine (%)/100 to normalize distribution and subsequently, transformed to their original value.

RESULTS AND DISCUSSION

Germination (%): The analysis of variance of this variable showed no significant differences between the evaluated treatments ($\alpha \leq 0.05$) as observed in Table 2. This indicates that the seeds had a good germination capacity of the seeds even without the scarification treatment, with a germination rate higher than 80%. Found that storing habanero pepper seeds for 6 months at 26°C guaranteed a higher germination rate in the H-228 and H-259 varieties[18]. Point out that newly harvested seeds of certain chili pepper cultivars can exhibit dormancy or a reduced germination rate. In the present study, although the seeds were sown a week after being extracted, they did not show signs of immaturity[19]. On the contrary, they showed a good germination rate (greater than 70%) and can thus be considered of "high quality"[20]. The treatments that showed the highest average germination rate was T_2 (Biozyme) and T_1 (Hot water), with germination percentages above 90%, higher than the rest, although not significantly. It is thus possible to suggest that Biozyme TF stimulates seed germination of the seeds, allowing them to express their genetic potential. After immersing the seeds of Amashito pepper (*Capsicum annuum* L. var. *Glabriusculum*) for 12 hrs in a Biozyme solution, obtained a germination rate greater than 50% 8 days after sowing[21]. That immersion time allows the active compounds of Biozyme TF to penetrate through the hard and waxy epicuticular outer layer and deactivate the

Table 2: Comparison of means of the germination percentage in seeds of *Capsicum chinense* Jacq

Germination(%)	
Treatments	Mean
T_1	90^{a*}
T_2	96^{a}
T_3	86^{a}
T_4	80^{a}
T_5	82^{a}
T_6	86^{a}
T_7	86^{a}

*Means with the same letters are statistically equal (Tukey, $\alpha \leq 0.05$)

possible natural inhibitors of germination. That hot water is a simple and practical low-cost alternative for the effective sanitary control of seeds, including chili pepper seeds but it is rarely used as a promoter of germination[22]. The present study obtained satisfactory results with it, with a germination rate of 90% but this could be due to the very particular characteristics of the seeds under study.

It should be mentioned that the T_4 treatment (gibberellic acid (AG_3)) was expected to show similar germination percentages to treatments T_2 (Biozyme) and T_1 (Hot water), given that different authors have reported a positive response of germination to this phytohormone. However, in the present study, the T_4 treatment showed the lowest germination percentage, probably due to the low concentration used. A similar response was reported[23] in a study on habanero pepper seeds. In that study, the treatments associated with the highest percentage of germination recovery were those with Polyethylene glycol (0.5 ppm) and KNO_3 at 3%. The percentage values were 92 and 91%, respectively. The lowest value was associated with the use of AG_3at a concentration of 400 mg L^{-1}. Other authors have reported a variety of responses to different concentrations of AG_3, from 250-5000 mg L^{-1}. A germination percentage of 66% wild chili peppers using 5000 mg L^{-1} of AG_3[24], while germination percentages of 46 and 43% using 250 and 500 mg L^{-1} of AG_3[25], respectively. Immersed pequin pepper seeds in an aqueous solution of AG_3 at a concentration of 5000 mg L^{-1} for 24 hrs and managed to increase their germination percentage from 8-82% in two wild populations of pequin chili pepper from the central region of Tamaulipas[26]. These results suggest that AG_3 should be used in high concentrations. Immersed seeds of simojovel chili pepper *Capsicum annuum* L. for 24 hrs in sodium chloride (NaCl, 0.5 M) and gibberellic acid AG_3 at different concentrations (0, 100, 350, 400 450 and 500 mg L^{-1})[27]. The combination of treatments, with previous exposure to NaCl, yielded a germination percentage of up to 91.57% when

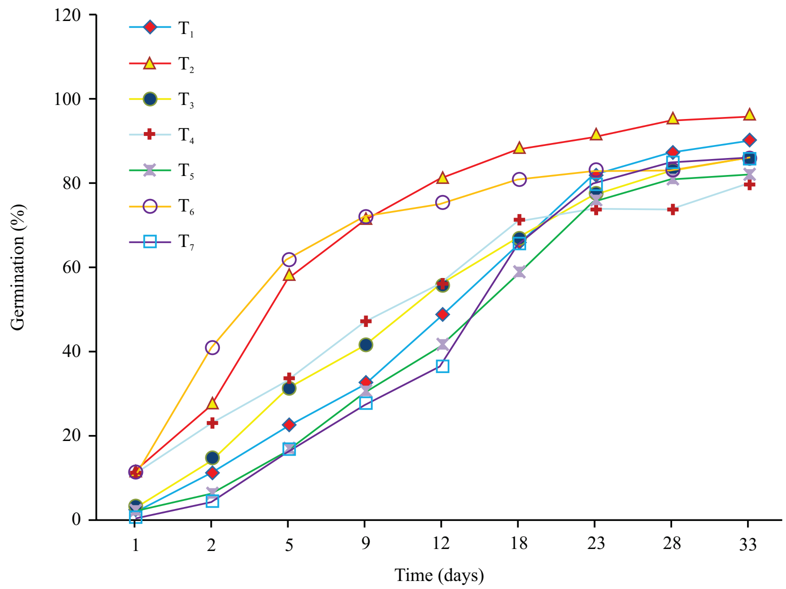

Fig. 1: Cumulative germination in seeds of habanero pepper *Capsicum chinense* Jacq. after the start of germination

Table 3: Comparison of means of the accumulated germination of *Capsicum chinense* Jacq. seeds after 33 days

Treatments	Seeds germinated	Media (%)
T_1	12.19	48.77^{bc*}
T_2	17.16	68.66^{a}
T_3	12.72	50.88^{bc}
T_4	13.02	52.11^{b}
T_5	10.88	43.55^{c}
T_6	16.47	65.88^{a}
T_7	11.08	44.33^{bc}

*Means with the same letters are statistically equal (Tukey, $\alpha\leq 0.05$)

using 350 mg L^{-1} of AG_3 while preconditioning with NaCl without applying AG_3 yielded a germination percentage of only 43.25%, still an 86% increase in the germination percentage compared to untreated seeds. Determined the effect of salinity in the germination and growth processes of paprika pepper *Capsicum annuum* L. var. *Papri* king[28]. Using NaCl at 200 mM, yielded a significant increase ($\alpha\leq 0.05$) in the germination percentage to 71%, which was, however, 15% lower than the value found (86%) in the present study. In general, all treatments used in the present study were associated with germination percentages higher than 80%, including the control treatment, which indicates the good quality of the seeds used. This suggests that any treatment can yield high germination percentages when the seeds used are healthy and viable.

Cumulative germination over time (%): The analysis of variance of this variable showed significant differences ($\alpha\leq 0.05$) between the evaluated treatments. The highest values were associated with treatments T_2 (Biozyme) and T_6 (KNO_3), with mean values of 68.66 and 65.88%, respectively, followed by treatment T_4 (AG3) with 52.11%. The lowest values were associated with treatments T_5 (Refrigeration) and T_7 (Control), with 43.55 and 44.33% (Table 3).

The result of Fig. 1 shows that 5 days after starting germination, only two treatments yielded germination values higher than 50%: Biozyme (57%) and KNO_3 (62%), while treatment T_7 (Control) yielded only 16% during the same period. This suggests that the treatments associated with the highest germination values in the shortest time tend to standardize seed emergence and consequently, seedling growth, which is of great importance for the production process. Treatment T_2 (Biozyme), which was associated with the highest average germination values in the shortest time, seems to be the best treatment to promote germination, with a percentage of germinated seeds higher than 80% 12 days after germination started. In contrast, treatment T_7 (Control) had only 36% of germinated seeds. T_6 (KNO_3) yielded an average total germination value of 86% but only 72% of germinated seeds 12 days after germination started, surpassing the rest of the treatments except for T_2 (Biozyme). Assessed the effect of Biozyme on the induction of germination of the pequin chili pepper (*Capsicum annuum* L. var. *Glabriusculum*)[29]. They found that immersing the seeds of this pepper with Biozyme at 1.6% (v/v) during 24 hrs was associated with a seed germination percentage of 86% 12 days after sowing. Their results were similar to those obtained in the present study. Regarding the effect of potassium nitrate (KNO_3). Suggest that it promotes metabolic tissue repair and increased respiration, thereby improving growth and germination percentage[30]. In the present study, treatment T_1 (Hot Water) was associated with one of the highest germination percentages (90.9%) but not with rapid germination, yielding only 48.48% germination 12 days after sowing. In contrast, treatments T_2 (Biozyme) and T_6 (KNO_3), yielded germination percentages above 70% in the same period. Treatment T_1 (Hot Water) was thus associated with high percentages of total germination but also with irregular seed emergence, yielding a mean accumulated germination of 44.33%. In contrast, treatment T_2 (Biozyme) yielded a mean accumulated germination of 68.66%. This is why works by other authors combine hydrothermal treatment with AG_3 or KNO_3, which accelerate the germination process. For example, assessed the percentage and speed of germination of wild chili peppers in response to pre-germinative treatments[31]. The combination of hydrothermia with 5000 mg L^{-1} of AG_3 at 50°C for 5 min yielded the highest germination percentage (92%). The germination percentage of four sets of pequin chili pepper (*Capsicum annuum* L. var. *Aviculare*) and achieved germination after 17 days using a combination of 5000 mg L^{-1} of AG_3 and hot water at 50°C for 6 min[32]. In the present study, treatment T_4 (AG_3) was associated with one of the lowest germination percentages (80%), even lower than treatment T_7 (Control, 86%) but the accumulated germination percentage (52.11%) was exceeded only by treatments T_2 (Biozyme) and T_6 (KNO_3), with values of 68.66 and 65.88%, respectively. This suggests that treatment with AG_3 leads to uniform seed emergence, with 56% of the seeds germinated 12 days after the germination started. By that time, only 36% of the seeds had germinated with treatment T_7 (Control). The germination in seeds of chiltepin chilli pepper (*Capsicum annuum* L. var. *glabriusculum*) and found that GA_3 is efficient as a promoter of germination, of the seeds germinated 3 weeks after sowing and that treating seeds with 1.6% of Biozyme TF® for 24 hrs immersion is achieved up to 86% of seeds germinated at 12 days after planting[29].

Seedling height: The analysis of variance showed significant differences ($\alpha \leq 0.05$) in this variable. The mean comparison test showed that the treatments that yielded the best seedling height results were the T_2 treatment (Biozyme) with 4.96 cm and the T_5 treatment (Refrigeration) with 4.84 cm. The treatments that yielded the lowest height seedling results were treatments T_4 (AG_3) with 3.86 cm and treatment T_7 (Control) with 3.05 cm (Fig. 2). It is worth mentioning that the latter treatment was also associated with low germination speed. Means with the same letters are statistically equal (Tukey, $\alpha \leq 0.05$). Reported positive effects on seedling height (with values of up to 7.93 cm) when using gibberellin and auxin growth regulators with seeds of pequin chili pepper (*Capsicum annuum* var. *Aviculare*)[33]. Evaluated the effect of subjecting seeds of wild chiltepin chilli pepper (*Capsicum annuum* var. *Glabriusculum*) to two different temperatures, 2 and 5°C[34]. The results showed negative effects (slow and deficient growth) on the growth of seedlings. The height of chili seedlings (*Capsicum annuum* L.) grown in polystyrene trays under greenhouse conditions[35]. They applied fertilizer to the seedlings every three days starting at 17 days after emergence. The fertilizer consisted of 16N-40P-13K dissolved in water and applied with irrigation at a concentration of 1 g L^{-1}. As a result, 60 and 74 days after sowing the seedlings reached 12.8-10.7 cm in height[36]. It is

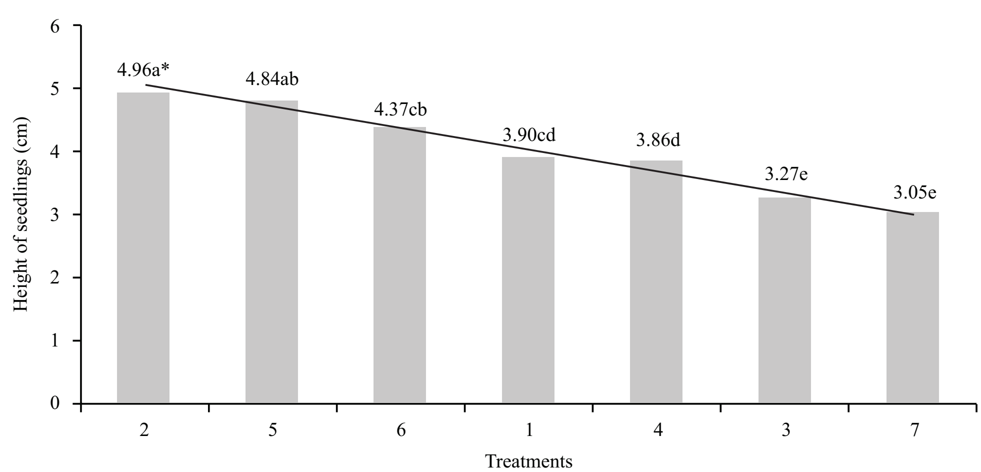

Fig. 2: Height of *Capsicum chinense* Jacq. seedlings in each of the evaluated treatments

*Means with the same letters are statistically equal (Tukey, $\alpha \leq 0.05$)

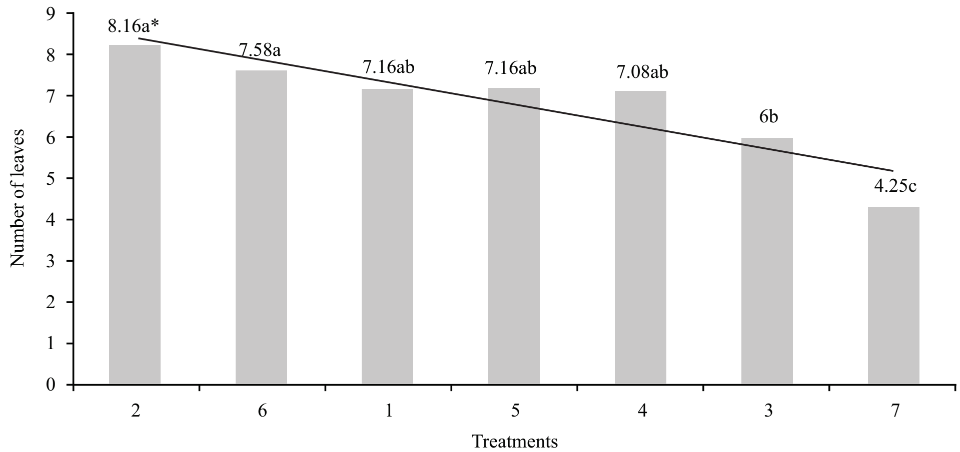

Fig. 3: Number of leaves in *Capsicum chinense* Jacq seedlings. for each of the evaluated treatments
*Means with the same letters are statistically equal (Tukey, α ≤ 0.05)

worth mentioning that these results were higher than those obtained in the present study, where the highest seedlings measured only 4.96 cm 53 days after germination.

A number of leaves: There were significant differences (α≤0.05) between the evaluated treatments in the number of leaves of the seedlings. The highest means (8.16 leaves) were associated with treatment T_2 (Biozyme), followed by treatment T_6 (KNO_3) with 7.58 leaves (Fig. 3). As can be seen in Fig. 3, these treatments had a greater number of leaves than the rest of the treatments. The treatments with the lowest number of leaves were treatment T_3 (NaCl) and T_7 (Control) with 6 and 4.25, leaves, respectively (Fig. 3). That even though the quality standards for seedlings are usually defined by each producer according to their preferences, a quality seedling, ready for transplantation, is widely considered to be a seedling with 3-4 pairs of true leaves, which is usually achieved between 40 and 50 days after sowing[37].

Stem diameter: The analysis of variance showed that there were no significant differences (α≤0.05) in stem diameter between treatments. The means comparison test showed that all treatments were statistically equal, all with a stem diameter of 1 mm as can be seen in Table 4. This could be because, at this stage, stem thickness is not yet fully developed. Evaluated the effect of a commercial product Formax-F® (a hormonal compound consisting of a complex of cytokinins derived from adenine at a concentration of 14,000 mg L^{-1}) on the stem thickness of seedlings of black habanero pepper (*Capsicum chinense* Jacq.) at the beginning of flowering[38]. The authors

Table 4: Comparison of means of stem diameter in *Capsicum chinense* Jacq. for each of the evaluated treatments

Stem diameter (Mm)	
Treatments	Mean
T_1	1^{a*}
T_2	1^a
T_3	1^a
T_4	1^a
T_5	1^a
T_6	1^a
T_7	1^a

*Means with the same letters are statistically equal (Tukey, α≤0.05)

reported significant differences between the treated seedlings and the control seedlings (16.1 vs 13.4 mm, respectively), with treated seedling stems growing 20% thicker. It is worth mentioning that stem thickness was measured 53 days after germination.

Root length: The analysis of variance showed significant differences (α≤0.05) in root length between the evaluated treatments (Fig. 4). The highest means (6.29 cm) were associated with treatment T_5 (Refrigeration), followed by treatment T_2 (Biozyme) and T_4 (AG_3), both with 5.75 cm. The lowest means were associated with treatment T_1 (Hot water) and treatment T_7 (Control), with 3.33 and 2.47 cm, respectively. Applied the growth regulator Biozyme to pepper seeds (*Capsicum annuum* L.) at a dose of 1 mL dissolved in distilled water and compared the effect to a control treatment consisting of distilled water. The seeds were sown after being immersed in the biozyme solution[39]. There were significant differences in root length between the biozyme treatment and the control treatment. The seedlings treated with biozyme showed root length values of 3.58 and 3.30 cm, compared to

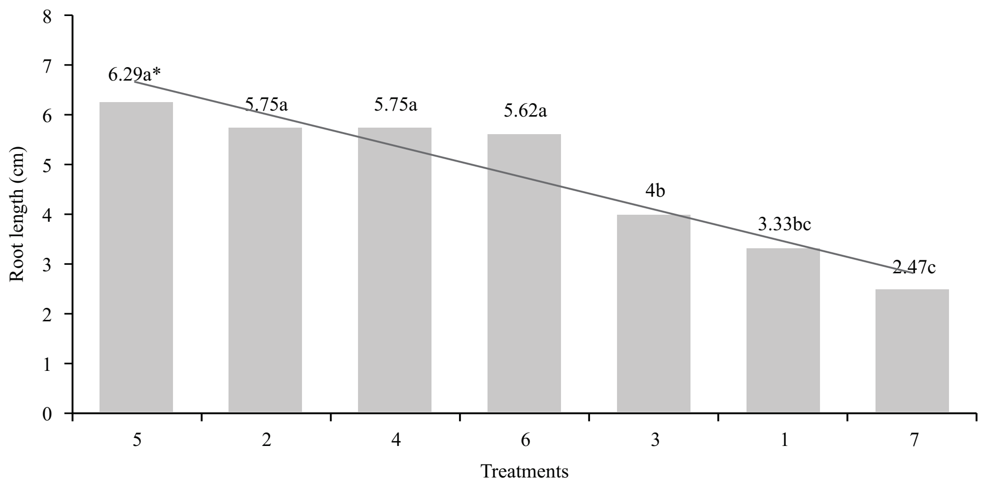

Fig. 4: Root length of *Capsicum chinense* Jacq. in each of the evaluated treatments

*Means with the same letters are statistically equal (Tukey, $\alpha \leq 0.05$)

the control seedlings, with 1.25 and 1 cm. It is important to emphasize that, in the present study, treatments T_2, T_5 and T_4 showed root length values of 6.29 and 5.75 cm, surpassing the other treatments. Reported that subjecting seeds of habanero pepper (*Capsicum chinense* Jacq.) of the "Jaguar" variety to a desiccation treatment for 72 hrs at $70\pm35°C$ resulted in seedlings with root lengths of up to 7.50 and 7.21 cm[40].

CONCLUSION

Hormonal treatment Biozyme TF was associated with the best response in terms of germination percentage over a shorter time as well as in terms of seedling quality, (height, number of leaves, root length) surpassing the rest of the treatments. Regarding stem diameter, all treatments yielded the same values, which could be because at this stage seedlings have not yet fully developed. The hot water was associated with a high germination percentage but over a longer time, which resulted in plants with heterogeneous growth. The AG_3 was associated with fast and homogeneous germination but a low germination percentage, probably due to the low concentration of AG_3 used.

SIGNIFICANCE STATEMENT

The loss of viability of the habanero pepper seeds is one of the main problems because after storing the seeds for more than 12 months, the speed and the final percentage of germination decrease considerably. One of the biggest challenges in the production of the habanero pepper is to have 99% germination, growth and development, which leads to healthy seedlings in trays, at the time of transplantation. Chemical, physical and hormonal treatments have been used in the scarification of the seeds but it has not yet been defined which method is the most appropriate to shorten the days and increase the germination percentage to 99% of non-commercial seeds, at the same time. lower costs when buying commercial seeds.

ACKNOWLEDGMENTS

The authors wish to thank the Academic Division of Agricultural Sciences of the Universidad Juarez Autonoma de Tabasco and CA Sustainable Tropical Agriculture for the support provided in the realization of this project thesis: "Scarification of seeds and quality of seedlings of *Capsicum chinense* Jacq., In Tabasco, Mexico".

REFERENCES

1. Glodjinon, N.M., P.A. Noumavo, K. Adéot, K. Garba and H.S. Sonangnon *et al*., 2019. The technical production, storage and conservation routes of chilli peppers (*Capsicum* spp.) produced in Benin and constraints impeding the development of the sector. J. Anim. Plant Sci., 42: 7279-7295.
2. Rodríguez, H.M., J.A.M. Villalobos, M.A.V. Valle, M.D.P. Talavera and M.M.V. Castorena, 2013. Habanero pepper: Growing description in the *Yucatan peninsula*. Rev. Chapingo Serie Zonas Áridas, 12: 37-43.
3. López, R.L., M.A. Inzunza-Ibarra, A. Fierro-Álvarez and D.J. Palma-López, 2018. Dates of transplantation and productivity of habanero pepper with drip irrigation. Rev. Mexicana de Cienc. Agrícolas, Vol. 9. 10.29312/remexca.v9i1.847.

4. Meneses-Lazo, R.E. and R. Garruña, 2020. The habanero pepper (*Capsicum chinense* JACQ.) as a study plant model in Mexico. Trop. Subtropical Agroecosyst., Vol. 23.
5. Rajan, M.S.A., R. Thriunavukkarasu, J. Joseph and W. Aruni, 2020. Effect of seaweed on seed germination and biochemical constituents of *Capsicum annuum*. Biocatalysis Agric. Biotechnol., Vol. 29. 10.1016/j.bcab.2020.101761.
6. García-Ruiz, R.F., S.L. Castañeda-Garzón and E.F. Valdéz-Hernández, 2018. Quality of rocoto pepper (*Capsicum pubescens* Ruiz & Pav.) Seeds in relation to extraction timing. Acta Agronómica, Vol. 67. 10.15446/acag.v67n2.59057.
7. Alcalá-Rico, J.S.G.J., A. López-Benítez, M.E. Vázquez-Badillo, D. Sánchez-Aspeytia and S.A. Rodríguez-Herrera *et al*., 2019. Seed physiological potential of capsicum annuum var. *Glabriusculum genotypes* and their answers to pre-germination treatments. Agronomy, Vol. 9. 10.3390/agronomy9060325.
8. El-Sayed, S.F., 1995. Response of three sweet pepper cultivars to biozyme under unheated plastic house conditions. Sci. Horti., 61: 285-290.
9. Pérez-Pastrana, J., I. Islas-Flores, I. Bárány, D. Álvarez-López and A. Canto-Flick *et al*., 2018. Development of the ovule and seed of habanero chili pepper (*Capsicum chinense* Jacq.): Anatomical characterization and immunocytochemical patterns of pectin methyl-esterification. J. Plant Physiol., 230: 1-12.
10. Gantait, S., S. Kundu, L. Yeasmin and M.N. Ali, 2017. Impact of differential levels of sodium alginate, calcium chloride and basal media on germination frequency of genetically true artificial seeds of *Rauvolfia serpentina* (L.) Benth. ex Kurz. J. Appl. Res. Med. Aromat. Plants, 4: 75-81.
11. Panigrahi, J., B. Gheewala, M. Patel, N. Patel and S. Gantait, 2017. Gibberellic acid coating: A novel approach to expand the shelf-life in green chilli (*Capsicum annuum* L.). Sci. Hortic., 225: 581-588.
12. Hernández-Flores, E., A.R. Quero-Carrillo, B.M.T. Joaquín, A. Hernández-Garay and F.J. Hernández-Guzmán, 2016. Scarification and germination methods on *Brachiaria brizantha* cv. Insurgent. Revista Mexicana Ciencias Agrícolas, 7: 173-184.
13. Ruttanaruangboworn, A., W. Chanprasert, P. Tobunluepop and D. Onwimol, 2017. Effect of seed priming with different concentrations of potassium nitrate on the pattern of seed imbibition and germination of rice (*Oryza sativa* L.). J. Integr. Agric., 16: 605-613.
14. Daneshvar, A., M. Tigabu, A. Karimidoost and P.C. Odén, 2017. Flotation techniques to improve viability of *Juniperus polycarpos* seed lots. J. For. Res., 28: 231-239.
15. BaskinJerry, C.C. and J.M. Baskin, 1998. Germination Ecology of Plants with Specialized Life Cycles and/or Habitats. In: Seeds Ecology, Biogeography and Evolution of Dormancy and Germination, BaskinJerry, C.C. and J.M. Baskin (Eds.)., Academic Press, Cambridge, Massachusetts, pp: 459-557.
16. Sanjuan-Martínez, J., Y.D. Ortiz-Hernández, T. Aquino-Bolaños and S. Cruz-Izquierdo, 2020. Seed and seedling quality of three chilis (*Capsicum annuum* L.) native to Oaxaca, Mexico. Ciência Rural, Vol. 50. 10.1590/0103-8478cr20190921.
17. Spilke, J., H.P. Piepho and X. Hu, 2005. Analysis of unbalanced data by mixed linear models using the mixed procedure of the SAS system. J. Agron. Crop Sci., 191: 47-54.
18. Andureza-Noh, R.H., L. Latournier-Moreno, N. Moran-Vázquez, F. Cervantes-Ortiz, M. Mendoza-Elos and J.A. Rangel-Lucio, 2017. Habanero pepper (*Capsicum chinense* Jacq.) physiological seed response to storage. Acta Universitaria, 27: 22-29.
19. Ureche, M.A.L., M.M. Pérez-Rodriguez, R. Ortiz, R.P. Monasterio and A.C. Cohen, 2021. Rhizobacteria improve the germination and modify the phenolic compound profile of pepper (*Capsicum annum* L.). Rhizosphere, Vol. 18. 10.1016/j.rhisph.2021.100334.
20. Melese, K., 2015. Seed multiplication and dry pod yield performance evaluation of improved hot pepper varieties in northern Ethiopia, in case of central Tigray. Int. J. Afr. Asian Stud., 16: 46-48.
21. González-Pereyra, J., V. Yáñez-Morales, A. Santiago-Santiago and A. Montero-Pineda, 2004. Fungi biodiversity on pepper wilt, and some related factors, in Tlacotepec de José Manzo, El Verde, Puebla. Agrociencia, 38: 653-661.
22. Miller, S.A. and M.L.L. Ivey, 2021. Hot Water and Chlorine Treatment of Vegetable Seeds to Eradicate Bacterial Plant Pathogens. Plant Pathology. Coffey Road, Columbus, Ohio 43210.
23. Garruña-Hernández, R., L. Latournerie-Moreno, O. Ayala-Garay, J.M. Santamaría and L. Pinzón-López, 2014. Pre-sowing treatments: an option to increase germination of habanero pepper seeds (*Capsicum chinense* Jacq.). Agrociencia, 48: 413-423.
24. Sivachandiran, L. and A. Khacef, 2017. Enhanced seed germination and plant growth by atmospheric pressure cold air plasma: combined effect of seed and water treatment. RSC Adv., 7: 1822-1832.
25. Samarah, N.H., N.A. AL-Quraan, R.S. Massad and G.E. Welbaum, 2020. Treatment of bell pepper (*Capsicum annuum* L.) seeds with chitosan increases chitinase and glucanase activities and enhances emergence in a standard cold test. Sci. Horti., Vol. 269. 10.1016/j.scienta.2020.109393.
26. Wijesinghe, R.E., S.Y. Lee, P. Kim, H.Y. Jung, M. Jeon and J. Kim, 2017. Optical sensing method to analyze germination rate of *Capsicum annum* seeds treated with growth-promoting chemical compounds using optical coherence tomography. J. Biomed. Optics, Vol. 22. 10.1117/1.jbo.22.9.091502.
27. Hernández-Verdugo, S., R.G. López-España, F. Porras, S. Parra-Terraza, M. Villarreal-Romero and T. Osuna-Enciso, 2010. Variation in germination among populations and plants of wild chili pepper. Agrociencia, 44: 667-677.

28. Demir, I. and K. Mavi, 2008. Effect of salt and osmotic stresses on the germination of pepper seeds of different maturation stages. Braz. Arch. Biol. Technol., 51: 897-902.
29. González-Cortés, N., R.J. Vera, E.C.G. Baños, H.S. Espino and E.P. de la Cruz, 2015. Germination of amashito Chili (*Capsicum annuum* L. var. Glabriusculum) in Southeastern Mexico. Rev. Mex. Cienc. Agrícolas, 6: 2211-2218.
30. Prado-Urbina, G., L. Lagunes-Espinoza, E. García-López, C. Bautista-Muñoz, W. Camacho-Chiu, G.F. Mirafuentes and V.H. Aguilar-Rincón, 2015. Seed germination of wild chili peppers in response to pre-germination treatment. Ecosistemas Recursos Agropecuarios, 2: 139-149.
31. Shim, S.I., J.C. Moon, C.S. Jang, P. Raymer and W. Kim, 2008. Effect of potassium nitrate priming on seed germination of seashore Paspalum. Hort. Sci., 43: 2259-2262.
32. Sandoval-Rangel, A., A.T. González, M. Cabrera-De la Fuente, J.A.G. Fuentes and A. Benavides-Mendoza, 2018. Age, benefit and gibberellic acid affect the germination and production of piquín pepper plant. Rev. Mex. Cienc. Agríc., 9: 4199-4209.
33. Rueda-Puente, E.O., B. Murillo-Amador, T. Castellanos-Cervantes, J.L. García-Hernández, M.A. Tarazòn-Herrera, S.M. Medina and L.E.G. Barrera, 2010. Effects of plant growth promoting bacteria and mycorrhizal on *Capsicum annuum* L. var. *aviculare* ([Dierbach] D'arcy and Eshbaugh) germination under stressing abiotic conditions. Plant Physiol. Biochem., 48: 724-730.
34. Quintero, C.M.F., O. Guillen-Castillo, P. Delgado-Sánchez, J. Marín-Sánchez, A.I. Guzmán, A. Sánchez and J.M. Guzmán, 2018. Relieving dormancy and improving germination of piquín chili pepper (*Capsicum annuum* var. glabriusculum) by priming techniques. Cogent Food Agric., Vol. 4. 10.1080/23311932.2018.1550275.
35. Gómez-González, A., J.G. Reyes-Contreras, E.J. García-Herrera, J. Pimentel-López and H. Silos-Espino, 2019. Effect of orientation and container shape on the growth and development of chile ancho pepper cultivated in greenhouse. Rev. Mexicana de Cienc. Agrícolas, 22: 43-51.
36. Ruiz, M.B. and C.A. Parera, 2017. Effect of harvesting time on seed quality of two bell pepper cultivars (*Capsicum annuum*). Rev. Facultad Cienc. Agrar., 49: 67-77.
37. Hernández-López, A., E.G. Beltrán-Peña, A.E.A. Oliveira, O.N. Gaona and A.X. Avila-Alejandre, 2018. Water preconditioning on germination and emergence of *Capsicum chinense* Jacq. Rev. Mex. Cienc. Agrícolas, 9: 1703-1714.
38. Vinković, T., O. Novák, M. Strnad, W. Goessler, D.D. Jurašin, N. Parađiković and I.V. Vrček, 2017. Cytokinin response in pepper plants (*Capsicum annuum* L.) exposed to silver nanoparticles. Environ. Res., 156: 10-18.
39. Montalvo, J.E.O., K. Morozova, G. Ferrentino, M.O.R. Sucre, I.M.R. Buenfil and M. Scampicchio, 2021. Effects of local environmental factors on the spiciness of habanero chili peppers (*Capsicum chinense* Jacq.) by coulometric electronic tongue. Eur. Food Res. Technol., 247: 101-110.
40. Sosa-Moguel, O., J.A. Pino, G. Ayora-Talavera, E. Sauri-Duch and L. Cuevas-Glory, 2017. Biological activities of volatile extracts from two varieties of habanero pepper (*Capsicum chinense* Jacq.). Int. J. Food Properties, 20: S3042-S3051.