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RESEARCH ARTICLE

Genotypic Screening and Seed Treatment Studies for Improving Seed Germination and Vigor in Quinoa

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Abstract

Quinoa (*Chenopodium quinoa* Willd) - a potential pseudocereal native to the Andean region of South America is known as "mother grain" as it is rich source of high-quality proteins, lipids, minerals and vitamins. The germplasm lines of quinoa available with Punjab Agricultural University (PAU), Ludhiana, possessed a low germination percentage under laboratory and field conditions. The present study was aimed to screen 50 promising genotypes of quinoa for germination parameters, i.e., germination percentage, seedling vigor index (SVI) I and II, mean germination time and speed of germination using "between-paper" method under controlled conditions in the laboratory. One genotype, namely EC-896071, recorded the highest germination, i.e., 83.8%, followed by genotype EC-896076, which had 70.5% germination. Other genotypes which exhibited germination higher than 40% were EC-896063 (53.3%), EC-896081 (53%), EC-507739 (43.8%) and EC-896091 (42.5%). The above-mentioned six quinoa genotypes *viz.,* EC-507739, EC-896063, EC-896071, EC-896076, EC-896081 and EC-896091 were selected for seed treatment studies in order to enhance the germination and seedling vigor. Hydropriming for 2 hours recorded the highest improvement in mean germination time, speed of germination, germination percentage, SVI I and II and this time duration was standardized for other seed treatments also. Seeds were also primed with different chemicals *viz*., magnesium nitrate (0.5%), potassium nitrate (0.5%), potassium dihydrogen phosphate (0.5%), zinc sulfate (0.5%), kinetin (5ppm); and scarified with 5% H_2SO_4 for 10 minutes and hot water (35°C) for 15 minutes. A comparison of hydropriming with all other treatments revealed that hydropriming for 2 hours is the best treatment for improving germination and seedling vigor of quinoa genotypes.

Keywords: Germination, Quinoa, Seed priming , Seed scarification, Vigor.

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Introduction

Chenopodium quinoa Willd., commonly known as quinoa, is a tetraploid traditional crop domesticated by the Incas and Indian cultures in the Altiplano region of the Andes in South America, dating 5000 to 3000 BC. Throughout the history of the Inca civilization, quinoa was considered to be a sacred food. During the Incas (pre-Columbian America), armies were fed a mixture of quinoa and fat, which was known as "war balls" due to their high nutritional value (Graf *et al*., 2015). Quinoa is an annual herbaceous plant belonging to the Amaranthaceae family. It is a pseudocereal crop, not a true cereal grain, as it is a dicotyledonous plant, while cereals are monocotyledonous. In quinoa seeds, reserve food is stored in a large central perisperm, one to two-cell layered endosperm and peripheral embryo (Prego *et al*., 1998). Quinoa seeds have a high nutritive value than most cereal grains and contain high content of essential amino acids such as lysine and high-quality proteins along with fats, carbohydrates, minerals and vitamins, and are free of gluten (Bhargava *et al*., 2006; Melini and Melini, 2021). The production of gluten-free foods from pseudocereals holds significance for individuals with celiac disease, ensuring a nutrient-rich diet (Villaluenga *et al.,* 2020). Quinoa also gained importance

in agriculture because of its huge genetic variability and its ability to tolerate predominant adverse environmental factors *viz.* soil salinity, frost, drought, or marginal soils (Hinojosa *et al.,* 2018; Stoleru *et al.,* 2019).

According to the Food and Agricultural Organization (FAO) of the United Nations, quinoa has an ideal balance of amino acids than any other grain. Quinoa has been integrated into the diet of astronauts by the National Aeronautics and Space Administration (NASA). It has emerged as a new potential crop for NASA's Controlled Ecological Life Support System (CELSS) due to the balanced and unique amino acid composition of this miracle grain(Sharma *et al*., 2021). Apart from beneficial components, quinoa grains also contain some anti-nutritional factors such as saponins, tannins, phytic acid and trypsin inhibitors. The saponins that cause bitterness are present in the outer layer, i.e., the pericarp of the seed, which can be removed through de-hulling, polishing and washing of the seed (Melini and Melini, 2021).

Quinoa seeds have porosity in the integuments, which enables them to easily gain or lose moisture from the environment, leading to loss of viability. Storage of quinoa seeds for longer duration under ambient conditions has been reported to increase the deterioration of seeds (Strenske *et al*., 2017). Seed priming is a pre-sowing soaking treatment to fasten the imbibition of water and start pre-germinative metabolic processes, consequently reducing the mean germination time and improving the germination percentage (Lutts *et al*., 2016). Seed hydropriming refers to controlled hydration, leading seeds to a physiologically active state by activating their metabolic processes partially without initiating actual seed emergence. Hydropriming treatment gets the seed into the first germination phase, in which metabolic activities are initiated (Pill and Necker, 2001). Other priming treatments include halopriming, osmopriming, hormopriming, nutripriming, *etc.*

Chenopodium quinoa germplasm, available with the Department of Plant Breeding and Genetics, PAU, Ludhiana, was observed to possess a low germination percentage. Therefore, present study was undertaken to screen the quinoa genotypes to identify genotypes having higher germination and optimum seedling vigor. Selected genotypes were also subjected to hydropriming and other seed treatments for improving their germination and early seedling growth.

Material and Method

Laboratory experiments were conducted in the Seed Physiology Laboratory, Office of Director (Seeds), Punjab Agricultural University, Ludhiana, Punjab, during 2022-2023. Fresh seeds of 50 genotypes acquired by Punjab Agricultural University, Ludhiana, from Regional Research Station, NBPGR, Shimla, were used in present study and their origin is given in Table 1. The seeds were stored at 4°C before evaluating them for seed quality parameters. These 50 quinoa genotypes were screened for germination parameters, *i.e.,* germination percentage, seedling length (cm), fresh weight of seedlings (g), seedling vigor index (SVI) I and seedling vigor index II. One hundred seeds of each genotype per replication were evaluated for germination using the between-paper method at a constant temperature of 20°C in a BOD incubator. On 7^{th} day, the final count was recorded and seedling length (root and shoot length) was measured using a centimeter scale. Fresh weight of 10 seedlings was measured using an electronic balance. Six best-performing genotypes were subjected to hydropriming for different durations for the selection of best hydropriming duration. The seeds were also primed with different chemicals *viz.*, magnesium nitrate (0.5%), potassium nitrate (0.5%), potassium dihydrogen phosphate (0.5%), zinc sulphate (0.5%), kinetin (5ppm); and scarified with 5% H_2SO_4 for 10 minutes and hot water (35°C) for 15 minutes in order to improve their germination (%), SVI I and II. Data on the following observations were recorded:

Germination (%)= The seeds germinated during the germination period were counted and the total number of seeds germinated was divided by the total number of seeds sown and the result was expressed in percentage.

SVI I was calculated by using the following formula proposed by Abdul-Baki and Anderson (1973):

SVI I = Germination (%) x average seedling length (cm)

SVI II was calculated using the following formula proposed by Huang *et al*.(2018):

SVI II = germination (%) x fresh weight of 10 seedlings (g)

Mean germination time (MGT) of the quinoa genotypes was calculated using the following equation suggested by Ellis and Roberts (1981):

$$MGT= \Sigma(D\times N)/\Sigma N$$

Where N is the number of seeds germinating on that particular day, counted from the beginning of germination and represented by D.

The summation of the ratios resulted by dividing the daily count of the seeds germinated to the number of days to germinate was used to calculate the speed of germination (AOSA,1983):

Speed of germination = (g1/d1) +(g2/d2) +…+ (gn/dn)

Where g1, g2….gn are the number of newly germinated seeds on 1, 2… nth day respectively. d1, d2…dn refer to 1, 2… nth day respectively.

Alpha(α)-amylase activity of the quinoa seeds was measured following the 3,5-dinitro-salicylic acid method (Murata *et al*., 1968). Quinoa seeds (0.1 g) were mixed with

2 mL of phosphate buffer and left at 4°C for 1-hour. After homogenization using mortar and pestle, contents were centrifuged at 10000 rpm for 15 minutes. The supernatant was taken and used for estimation of α-amylase activity. The supernatant (0.1 mL) was taken into the test tube. 0.5 mL of 1% starch was added into a test tube and incubated at room temperature for 15 min. After that, added 1-mL of DNS reagent to each test tube and kept in a water bath for 5 min at 100°C. The reaction was stopped by adding 0.5 mL of 40% potassium-sodium tartrate solution. Cooled the test tubes and then added 2.5 mL of distilled water. Absorbance was noted at 560nm using a spectrophotometer (Systronics UV-VIS Spectrophotometer 117).

Statistical analysis

The experiment was laid out in a completely randomized design (CRD) with four replications per genotype and critical difference values were calculated by analysis of variance (ANOVA) and Tukey's b test was applied to further analyze the differences using Minitab Software version 17

Result and Discussion

Germination and SVI

The performance of 50 genotypes based on germination percentage is summarised in Figure 1. There were significant differences in germination percentage among various quinoa genotypes. There was only one genotype namely EC-896071 which exhibited germination higher than 80%. Likewise, there was only one genotype EC 896076, which exhibited germination higher than 70%. Four genotypes, namely EC-896063, EC-896081, EC-507739, EC-896091 had germination in the range of 40 to 60%. Most of the genotypes (32) exhibited germination in the range of 20-40% and 12 genotypes had germination lesser than 20%. SVI I of quinoa genotypes varied widely between 116 and 1239.8 (Figure 2). EC-896071 genotype exhibited SVI I higher than 1200 followed by the genotype EC-896076, which had SVI I higher than 900, which may be attributed to their higher germination percentage (83.8 and 70.5%, respectively) and longer seedlings (14.8 cm). Four genotypes, namely EC-896063, EC-896081, EC-507739 and EC-896110, had SVI 1 between 600 and 900. Likewise, both of the above-mentioned genotypes, EC-896071 (20.36) and EC-896076 (15.24) exhibited higher values of SVI II in the range of 15-25 (Figure 3). Five genotypes, namely EC-896063, EC-896091, EC-896081, EC-507739 and EC-896089, had seedling vigor index II in the range of 10-15. Chaganti and Ganjegunte (2022) observed that germination varied among the tested quinoa genotypes from 72.2 to 94.4%. Manugade *et al*. (2023) observed that SVI I varied among the tested quinoa genotypes from 634.14 to 1088.

Mean germination time (MGT) of various quinoa genotypes ranged between 1.04 and 2.52. EC-896276

Table 1: Origin of 50 quinoa genotypes used in the study

S. No	*Genotype*	*Origin*
1	IC-411824	Jammu & Kashmir, India
2	IC-411825	Jammu & Kashmir, India
3	EC-507738	United States of America (USA)
4	EC-507739	United States of America (USA)
5	EC-507741	United States of America (USA)
6	EC-507742	United States of America (USA)
7	EC-507743	United States of America (USA)
8	EC-507744	United States of America (USA)
9	EC-507746	United States of America (USA)
10	EC-507747	United States of America (USA)
11	EC-507748	United States of America (USA)
12	EC-507749	United States of America (USA)
13	EC-507767	United States of America (USA)
14	EC-896060	United States of America (USA)
15	EC-896061	United States of America (USA)
16	EC-896062	United States of America (USA)
17	EC-896063	United States of America (USA)
18	EC-896064	United States of America (USA)
19	EC-896069	United States of America (USA)
20	EC-896071	United States of America (USA)
21	EC-896072	United States of America (USA)
22	EC-896076	United States of America (USA)
23	EC-896077	United States of America (USA)
24	EC-896078	United States of America (USA)
25	EC-896079	United States of America (USA)
26	EC-896081	United States of America (USA)
27	EC-896085	United States of America (USA)
28	EC-896088	United States of America (USA)
29	EC-896089	United States of America (USA)
30	EC-896091	United States of America (USA)
31	EC-896094	United States of America (USA)
32	EC-896095	United States of America (USA)
33	EC-896097	United States of America (USA)
34	EC-896098	United States of America (USA)
35	EC-896099	United States of America (USA)
36	EC-896105	United States of America (USA)
37	EC-896109	United States of America (USA)
38	EC-896110	United States of America (USA)
39	EC-896111	United States of America (USA)
40	EC-896114	United States of America (USA)
41	EC-896115	United States of America (USA)
42	EC-896201	United States of America (USA)
43	EC-896203	United States of America (USA)
44	EC-896208	United States of America (USA)

45	EC-896210	United States of America (USA)
46	EC-896211	United States of America (USA)
47	EC-896213	United States of America (USA)
48	EC-896246	United States of America (USA)
49	EC-896275	United States of America (USA)
50	EC-896276	United States of America (USA)

genotype recorded the lowest mean germination time followed by genotypes EC-896071 and EC-896203, respectively (Figure 4). The germination speed of various quinoa genotypes ranged between 3.33 and 24.17. EC-896071 genotype had the fastest speed of germination followed by genotypes EC-896201 and EC-896203, respectively (Figure 5). Parsons (2012) reported that seed germination in the Amaranthaceae family starts in less than 24 hours; the majority of seeds start germinating in less than 2 hours after imbibition in quinoa. Another study reported that seeds germinate rapidly, leading to radicle protrusion in 6 to 10 hours after the imbibition in quinoa (Makinen *et al*., 2014).

Seed Treatments

Based on germination parameters, six quinoa genotypes, namely, EC-507739, EC-896063, EC-896071, EC-896076, EC-896081 and EC-896091, were selected for undertaking hydropriming and other seed treatment studies. Mean germination time of quinoa genotypes recorded the lowest value when hydroprimed for 2 hours. Quinoa genotypes also recorded the highest germination speed when hydro primed for 2 hours. The interaction effect between genotypes and priming treatments was non-significant with reference to mean germination time and speed of germination (Table 2). In five quinoa genotypes *viz*., EC-507739, EC-896063, EC-896076, EC-896081 and EC-896091, hydropriming for 2 hours resulted in the highest enhancement in germination percentage. Only in one genotype, namely EC-896071, the highest enhancement in germination percentage was recorded due to 8h hydropriming, which was, however, statistically at par to control, 2 and 4 hours hydropriming. Like germination, SVI I and SVI II of the tested six genotypes recorded the highest increment due to 2 h hydropriming (Table 3). From this study, 2 h soaking of seed was kept as the standardized duration for other seed treatment studies *viz*., magnesium nitrate (0.5%), potassium nitrate (0.5%), potassium dihydrogen phosphate (0.5%), zinc sulphate (0.5%) and kinetin (5 ppm). The seeds were also scarified with 5% H_2SO_4 for 10 min and hot water (35°C) for 15 minutes.

A comparison of hydropriming with different seed treatments revealed that hydropriming for 2 h recorded the highest germination percentage followed by seed priming with 5ppm kinetin (Table 4). The interaction effect between genotypes and treatment was significant. In

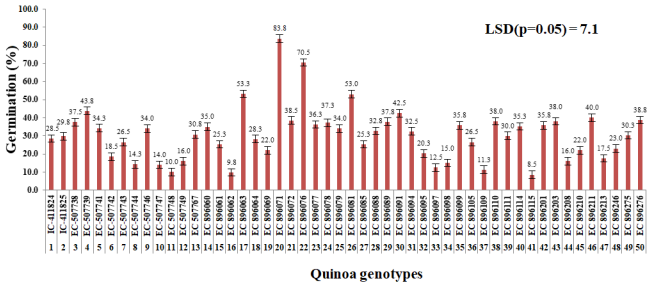

Figure 1: Germination percentage of 50 quinoa genotypes

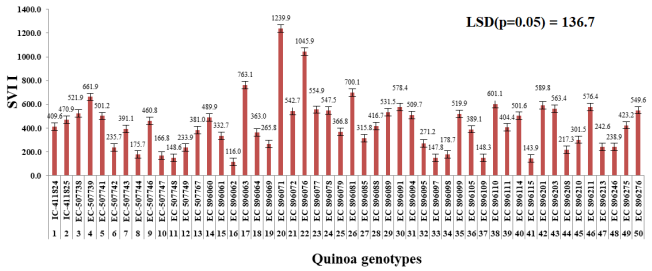

Figure 2: Seedling vigor index I (SVI I) of 50 quinoa genotypes

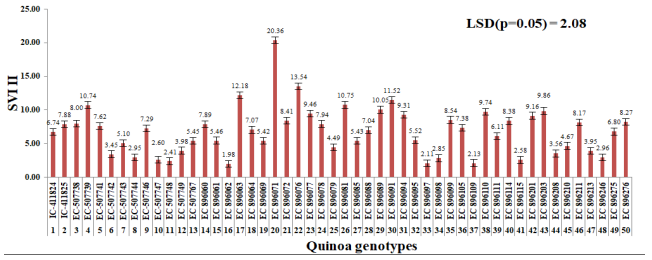

Figure 3: Seedling vigor index II (SVI II) of 50 quinoa genotypes

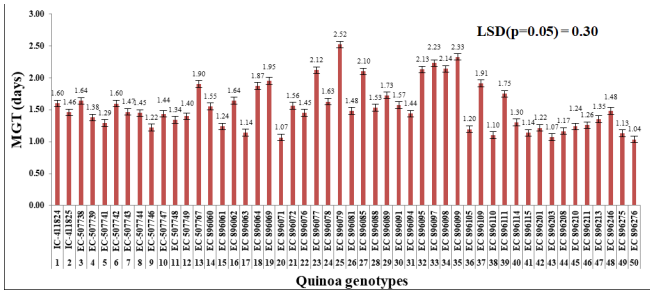

Figure 4: Mean germination time of 50 quinoa genotypes

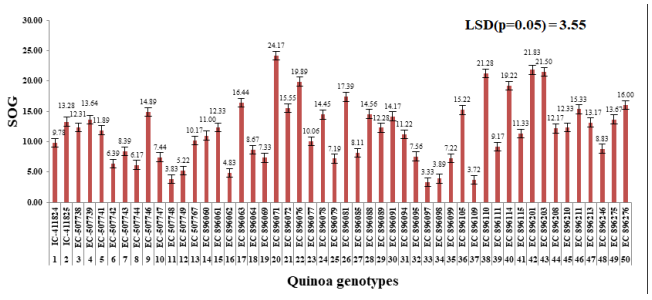

Figure 5: Speed of germination (SOG) of 50 quinoa genotypes

Table 2: Effect of hydropriming for different durations on mean germination time and speed of germination in selected quinoa genotypes

		Duration of hydropriming			
Genotypes	*Control (non-primed)*	*2 h*	*4 h*	*8 h*	*Mean*
Mean germination time (days)					
EC-507739	$1.26^{a} \pm 0.04$	$1.05^{a} \pm 0.03$	$1.15^{a} \pm 0.03$	$1.20^{a} \pm 0.05$	1.16^{a}
EC-896063	$1.21^{a} \pm 0.03$	$1.08^{a} \pm 0.02$	$1.16^{a} \pm 0.02$	$1.24^{a} \pm 0.06$	1.17^{a}
EC-896071	$1.10^{a} \pm 0.05$	$1.06^{a} \pm 0.01$	$1.08^{a} \pm 0.03$	$1.13^{a} \pm 0.02$	1.09^{a}
EC-896076	$1.14^{a} \pm 0.02$	$1.11^{a} \pm 0.03$	$1.13^{a} \pm 0.04$	$1.15^{a} \pm 0.03$	1.13^{a}
EC-896081	$1.28^{a} \pm 0.15$	$1.16^{a} \pm 0.06$	$1.16^{a} \pm 0.03$	$1.25^{a} \pm 0.13$	1.21^{a}
EC-896091	$1.26^{a} \pm 0.10$	$1.19^{a} \pm 0.04$	$1.21^{a} \pm 0.12$	$1.22^{a} \pm 0.04$	1.22^{a}
Mean	1.21^{a}	1.11^{a}	1.15^{a}	1.20^{a}	
Speed of germination					
EC-507739	$16.7^{e-i} \pm 0.61$	$20.2^{a-f} \pm 1.74$	$16.7^{e-i} \pm 16.6^{i}$	$16.6^{e-i} \pm 0.31$	17.5^{ab}
EC-896063	$16.9^{c-i} \pm 0.34$	$17.0^{c-i} \pm 0.29$	$16.8^{d-i} \pm 15.3$	$15.3^{f-i} \pm 0.83$	16.5^{b}
EC-896071	$21.7^{a-d} \pm 0.78$	$22.3^{a} \pm 0.17$	$20.5^{a-e} \pm 20.3$	$20.3^{a-e} \pm 1.17$	21.2^{a}
EC-896076	$19.7^{a-g} \pm 1.02$	$22.1^{ab} \pm 0.61$	$21.8^{abc} \pm 19.8$	$19.8^{a-f} \pm 1.53$	20.9^{a}
EC-896081	$16.3^{e-i} \pm 0.55$	$17.6^{a-i} \pm 1.25$	$17.3^{b-i} \pm 17$	$17.0^{c-i} \pm 0.76$	17.0^{b}
EC-896091	$14.1^{hi} \pm 1.39$	$18.8^{a-h} \pm 0.97$	$14.8^{ghi} \pm 13$	$13.0^{i} \pm 0.58$	15.1^{b}
Mean	17.6^{a}	19.7^{a}	18.0^{a}	17.0^{a}	

Values with different superscripts vary significantly (p <0.05).

Table 3: Effect of hydropriming for different durations on germination percentage, seedling vigor index I and seedling vigor index II in selected quinoa genotypes

		Duration of hydropriming			
Genotypes	*Control (non-primed)*	*2 h*	*4 h*	*8 h*	*Mean*
Germination (%)					
EC-507739	$42.7^{hij} \pm 2.3$	$46.3^{f-j} \pm 1.2$	$44.3^{g-j} \pm 0.9$	$39.3^{j} \pm 0.7$	43.2^{e}
EC-896063	$54.0^{d-g} \pm 2.6$	$61.3^{cde} \pm 0.7$	$57.3^{def} \pm 0.7$	$58.7^{de} \pm 1.8$	57.8^{c}
EC-896071	$84.0^{a} \pm 1.0$	$82.7^{a} \pm 1.8$	$82.3^{a} \pm 1.9$	$85.7^{a} \pm 3.2$	83.7^{a}
EC-896076	$70.7^{bc} \pm 4.7$	$80.0^{ab} \pm 2.9$	$63.3^{cd} \pm 2.6$	$60.3^{cde} \pm 2.7$	68.6^{b}
EC-896081	$53.7^{d-h} \pm 1.3$	$60.7^{cde} \pm 0.7$	$51.7^{e-i} \pm 0.9$	$43.7^{g-j} \pm 1.2$	52.4^{cd}
EC-896091	$42.3^{ij} \pm 1.5$	$51.3^{e-i} \pm 0.7$	$43.7^{g-j} \pm 3.0$	$41.3^{ij} \pm 1.3$	44.7^{de}
Mean	57.9^{ab}	63.7^{a}	57.1^{ab}	54.8^{b}	
SVI I					
EC-507739	$577.1^{ij} \pm 37.4$	$665.5^{ghi} \pm 9.8$	$595.0^{ij} \pm 9.4$	$495.5^{j} \pm 11.8$	583.3^{d}
EC-896063	$776.3^{fgh} \pm 23.7$	$862.2^{ef} \pm 43.1$	$777.8^{fgh} \pm 25.7$	$777.9^{fgh} \pm 23.4$	798.5^{bc}
EC-896071	$1204.8^{ab} \pm 6.1$	$1340.2^{a} \pm 8.7$	$1184.8^{bc} \pm 10.3$	$1254.1^{ab} \pm 24.7$	1246.0^{a}
EC-896076	$953.3^{de} \pm 54.1$	$1042.9^{cd} \pm 48.4$	$857.8^{ef} \pm 38.6$	$796.5^{fg} \pm 29.6$	912.6^{b}
EC-896081	$679.6^{ghi} \pm 8.2$	$883.9^{ef} \pm 20.9$	$629.5^{hij} \pm 35.8$	$533.8^{ij} \pm 5.0$	681.7^{cd}
EC-896091	$588.1^{ij} \pm 35.4$	$677.8^{ghi} \pm 8.9$	$542.8^{ij} \pm 39.6$	$498.2^{j} \pm 13.3$	576.7^{d}
Mean	796.5^{b}	912.1^{a}	764.6^{b}	726.0^{b}	
SVI II					
EC-507739	$11.26^{efg} \pm 1.06$	$12.36^{d-g} \pm 0.66$	$10.53^{efg} \pm 0.38$	$8.29^{g} \pm 0.19$	10.61^{d}
EC-896063	$14.60^{cde} \pm 0.71$	$16.93^{bc} \pm 1.18$	$13.78^{c-f} \pm 0.23$	$13.96^{c-f} \pm 1.34$	14.82^{bc}
EC-896071	$22.54^{a} \pm 0.21$	$24.32^{a} \pm 0.2$	$21.72^{a} \pm 0.77$	$23.63^{a} \pm 1.6$	23.05^{a}
EC-896076	$16.67^{bc} \pm 0.86$	$20.4^{ab} \pm 0.31$	$16.42^{bcd} \pm 0.67$	$13.05^{c-f} \pm 0.72$	16.63^{b}
EC-896081	$13.06^{c-f} \pm 0.29$	$15.98^{cd} \pm 0.59$	$11.69^{efg} \pm 0.66$	$10.09^{fg} \pm 0.03$	12.70^{cd}
EC-896091	$11.6^{efg} \pm 1.59$	$14.13^{c-f} \pm 0.09$	$11.45^{efg} \pm 0.42$	$10.6^{efg} \pm 0.24$	11.94^{cd}
Mean	14.95^{ab}	17.35^{a}	14.26^{b}	13.27^{b}	

Values with different superscripts vary significantly (p<0.05).

Table 4: Effect of different priming and scarification treatments on germination percentage, SVI I and SVI II in selected quinoa genotypes

Genotypes	*Control (non-primed)*	*Hydropriming*	*$Mg(NO_3)_2$*	*KNO_3*	*KH_2PO_4*	*$ZnSO_4$*	*Kinetin*	*5% sulphuric acid treatment*	*Hot water treatment (15 minutes)*	*Mean*
		2 h	*0.5%*	*0.5%*	*0.5%*	*0.5%*	*5ppm*	*10min*	*35°C*	
Germination (%)										
EC-507739	$39.7^{tu} \pm 0.3$	$46.3^{p-u} \pm 1.2$	$37.3^{u} \pm 0.7$	$40.3^{stu} \pm 1.2$	$46.3^{p-u} \pm 0.9$	$52.7^{k-r} \pm 0.7$	$49.5^{o-t} \pm 0.3$	$50.0^{n-t} \pm 0.6$	$49.7^{o-t} \pm 2.3$	45.8^{d}
EC-896063	$50.3^{m-t} \pm 0.9$	$61.3^{h-l} \pm 0.7$	$60.3^{i-o} \pm 1.2$	$63.3^{g-k} \pm 1.8$	$55.7^{j-p} \pm 1.2$	$45.3^{p-u} \pm 0.7$	$61.0^{h-m} \pm 0.6$	$45.0^{p-u} \pm 1.5$	$53.7^{k-q} \pm 1.2$	55.1^{c}
EC-896071	$80.7^{abc} \pm 1.5$	$82.7^{ab} \pm 1.8$	$84.3^{a} \pm 1.2$	$77.3^{a-e} \pm 0.7$	$75.7^{a-f} \pm 2.0$	$73.0^{b-g} \pm 2.1$	$83.0^{ab} \pm 0.6$	$77.3^{a-e} \pm 3.7$	$78.7^{a-d} \pm 0.3$	79.2^{a}
EC-896076	$65.3^{f-j} \pm 1.8$	$80.0^{abc} \pm 2.9$	$68.0^{d-i} \pm 2.3$	$71.3^{c-h} \pm 0.7$	$71.3^{c-h} \pm 0.7$	$66.3^{f-j} \pm 3.0$	$73.0^{b-g} \pm 1.7$	$75.3^{a-f} \pm 1.8$	$66.7^{e-i} \pm 1.8$	70.8^{b}
EC-896081	$51.3^{l-r} \pm 0.3$	$60.7^{h-n} \pm 0.7$	$54.3^{k-q} \pm 1.2$	$55.7^{j-p} \pm 1.9$	$54.3^{k-q} \pm 4.1$	$50.7^{l-s} \pm 4.7$	$48.0^{p-u} \pm 0$	$53.7^{k-q} \pm 1.9$	$60.7^{h-n} \pm 2.9$	54.4^{c}
EC-896091	$42.7^{r-u} \pm 1.8$	$51.3^{l-r} \pm 0.7$	$44.7^{q-u} \pm 1.3$	$43.7^{q-u} \pm 0.3$	$42.7^{r-u} \pm 1.8$	$46.8^{p-u} \pm 2.6$	$50.0^{n-t} \pm 4.6$	$49.3^{p-t} \pm 1.8$	$38.0^{u} \pm 1.2$	45.5^{d}
Mean	55.0^{b}	63.7^{a}	58.2^{ab}	58.6^{ab}	57.7^{ab}	55.8^{ab}	60.8^{ab}	58.4^{ab}	57.9^{ab}	
SVI I										
EC-507739	$505.0^{u} \pm 14.2$	$665.5^{n-u} \pm 9.8$	$497.4^{u} \pm 10.4$	$576.5^{q-u} \pm 8.6$	$604.7^{p-u} \pm 17.9$	$840.2^{g-n} \pm 6.8$	$598.7^{q-u} \pm 19.5$	$734.9^{k-s} \pm 26.6$	$734.0^{k-s} \pm 51.9$	631.7^{cd}
EC-896063	$704.8^{l-t} \pm 13.3$	$862.2^{f-m} \pm 43.1$	$796.8^{h-o} \pm 4.9$	$839.7^{g-n} \pm 21.5$	$761.0^{l-q} \pm 11.7$	$704.1^{l-t} \pm 16.6$	$759.1^{i-r} \pm 17.6$	$626.6^{o-u} \pm 18.4$	$747.9^{j-r} \pm 25.0$	749.7^{cd}
EC-896071	$1170.0^{abc} \pm 22.2$	$1340.2^{a} \pm 8.7$	$1163.3^{abc} \pm 29.1$	$1115.6^{bcd} \pm 15.6$	$1097.1^{bcd} \pm 35.3$	$1167.5^{abc} \pm 33.5$	$1099.7^{bcd} \pm 32.0$	$1166.8^{abc} \pm 70.6$	$1238.2^{ab} \pm 4.1$	1189.5^{a}
EC-896076	$932.1^{d-j} \pm 30.8$	$1042.9^{c-f} \pm 48.4$	$901.8^{e-k} \pm 57.1$	$990.1^{c-g} \pm 16.4$	$985.7^{c-g} \pm 6.0$	$1076.5^{b-e} \pm 39.0$	$938.1^{d-i} \pm 6.8$	$1102.9^{bcd} \pm 21.0$	$983.4^{c-h} \pm 7.5$	1010.2^{b}
EC-896081	$695.2^{m-t} \pm 18.8$	$883.9^{f-l} \pm 20.9$	$787.4^{i-p} \pm 25.7$	$762.5^{i-q} \pm 12.3$	$706.0^{l-t} \pm 63.5$	$730.3^{k-s} \pm 92.1$	$601.6^{p-u} \pm 2.1$	$737.7^{k-s} \pm 11.6$	$853.3^{g-n} \pm 63.1$	759.6^{c}
EC-896091	$555.7^{stu} \pm 18.2$	$677.8^{m-u} \pm 8.9$	$595.4^{q-u} \pm 24.7$	$571.4^{r-u} \pm 5.9$	$557.2^{stu} \pm 33.8$	$673.1^{n-u} \pm 45.4$	$638.6^{o-u} \pm 65.9$	$636.3^{o-u} \pm 18.6$	$521.5^{tu} \pm 14.6$	624.6^{d}
Mean	760.5^{b}	912.1^{a}	790.4^{ab}	809.3^{ab}	785.3^{ab}	865.3^{ab}	772.6^{ab}	834.2^{ab}	846.4^{ab}	
SVI II										
EC-507739	$9.03^{r} \pm 0.15$	$12.36^{j-r} \pm 0.66$	$10.64^{o-r} \pm 0.26$	$10.22^{pqr} \pm 0.40$	$11.8^{k-r} \pm 0.09$	$14.83^{g-n} \pm 0.82$	$11.27^{m-r} \pm 0.33$	$13.23^{i-q} \pm 0.18$	$13.50^{i-p} \pm 1.03$	11.67^{c}
EC-896063	$11.84^{k-r} \pm 0.70$	$16.93^{e-i} \pm 1.18$	$15.37^{g-m} \pm 0.59$	$14.38^{g-o} \pm 0.57$	$13.4^{i-p} \pm 0.79$	$13.37^{i-p} \pm 0.29$	$15.10^{g-n} \pm 0.86$	$11.05^{n-r} \pm 1.18$	$13.03^{i-r} \pm 0.51$	13.72^{c}
EC-896071	$21.55^{a-d} \pm 0.67$	$24.32^{ab} \pm 0.2$	$24.88^{a} \pm 0.18$	$22.09^{a-d} \pm 1.41$	$19.7^{c-f} \pm 1.05$	$21.28^{a-d} \pm 0.88$	$21.73^{a-d} \pm 0.21$	$20.25^{b-e} \pm 0.52$	$22.44^{abc} \pm 0.20$	22.16^{a}
EC-896076	$14.87^{g-n} \pm 0.11$	$20.4^{b-e} \pm 0.31$	$16.68^{e-i} \pm 0.35$	$15.69^{f-k} \pm 0.68$	$16.7^{e-i} \pm 0.63$	$20.78^{a-e} \pm 0.72$	$16.83^{e-i} \pm 0.70$	$18.44^{c-g} \pm 0.14$	$17.98^{d-h} \pm 0.18$	17.43^{b}
EC-896081	$12.01^{j-r} \pm 0.30$	$15.98^{f-j} \pm 0.59$	$14.24^{h-p} \pm 0.53$	$13.20^{i-q} \pm 0.58$	$12.4^{j-r} \pm 1.21$	$14.07^{h-p} \pm 2.00$	$11.73^{k-r} \pm 0.32$	$13.08^{i-r} \pm 0.11$	$15.44^{g-l} \pm 1.39$	13.54^{c}
EC-896091	$10.13^{pqr} \pm 0.76$	$14.13^{h-p} \pm 0.09$	$13.3^{i-q} \pm 0.25$	$11.08^{n-r} \pm 0.39$	$11.4^{l-r} \pm 0.39$	$13.41^{i-p} \pm 0.59$	$13.30^{i-q} \pm 1.26$	$13.66^{i-p} \pm 0.12$	$9.20^{qr} \pm 0.26$	12.08^{c}
Mean	13.24^{b}	17.35^{a}	15.85^{ab}	14.44^{ab}	14.27^{ab}	16.29^{ab}	14.99^{ab}	14.95^{ab}	15.27^{ab}	

Values with different superscripts vary significantly ($p<0.05$).

Table 5: Effect of different priming and scarification treatments on α-amylase activity (mg maltose min^{-1} g^{-1}) in selected quinoa genotypes

Genotypes	*Control*	*Hydropriming*	*$Mg(NO_3)_2$*	*KNO_3*	*KH_2PO_4*	*$ZnSO_4$*	*Kinetin*	*5% sulphuric acid*	*Hot water*	*Mean*
		2 h	*0.50%*	*0.50%*	*0.50%*	*0.50%*	*5ppm*	*10min*	*35°C*	
EC-507739	$9.23^{m-o} \pm 0.23$	$9.46^{l-o} \pm 0.19$	$9.70^{k-o} \pm 0.24$	$9.45^{l-o} \pm 0.07$	$10.45^{i-m} \pm 0.13$	$9.76^{k-o} \pm 0.17$	$9.51^{k-o} \pm 0.08$	$9.66^{k-o} \pm 0.18$	$9.99^{k-o} \pm 0.13$	9.69^{c}
EC-896063	$10.18^{i-o} \pm 0.11$	$10.57^{i-l} \pm 0.1$	$11.29^{g-j} \pm 0.24$	$10.56^{i-l} \pm 0.18$	$10.74^{h-k} \pm 0.33$	$10.27^{i-n} \pm 0.08$	$9.87^{k-o} \pm 0.27$	$10.00^{k-o} \pm 0.32$	$10.28^{i-n} \pm 0.08$	10.42^{c}
EC-896071	$14.13^{ab} \pm 0.26$	$14.84^{a} \pm 0.23$	$14.30^{ab} \pm 0.25$	$14.08^{ab} \pm 0.28$	$13.53^{bcd} \pm 0.31$	$13.99^{ab} \pm 0.14$	$14.33^{ab} \pm 0.11$	$14.36^{ab} \pm 0.24$	$14.06^{ab} \pm 0.27$	14.18^{a}
EC-896076	$13.76^{abc} \pm 0.30$	$14.02^{ab} \pm 0.38$	$13.83^{ab} \pm 0.15$	$14.31^{ab} \pm 0.35$	$13.38^{b-e} \pm 0.23$	$13.87^{ab} \pm 0.17$	$13.64^{abc} \pm 0.18$	$13.70^{abc} \pm 0.12$	$13.47^{b-e} \pm 0.22$	13.78^{a}
EC-896081	$12.21^{efg} \pm 0.25$	$12.54^{c-g} \pm 0.2$	$12.38^{d-g} \pm 0.03$	$12.56^{c-f} \pm 0.31$	$11.48^{f-i} \pm 0.14$	$11.99^{fgh} \pm 0.11$	$12.02^{fg} \pm 0.13$	$12.04^{fg} \pm 0.13$	$11.95^{fgh} \pm 0.16$	12.13^{b}
EC-896091	$8.99^{o} \pm 0.20$	$9.67^{k-o} \pm 0.12$	$10.27^{i-n} \pm 0.01$	$9.18^{no} \pm 0.39$	$9.13^{no} \pm 0.34$	$9.58^{k-o} \pm 0.16$	$9.70^{k-o} \pm 0.07$	$9.65^{k-o} \pm 0.32$	$9.73^{k-o} \pm 0.14$	9.55^{c}
Mean	11.42^{a}	11.85^{a}	11.96^{a}	11.69^{a}	11.45^{a}	11.58^{a}	11.52^{a}	11.57^{a}	11.58^{a}	

Values with different superscripts vary significantly ($p<0.05$).

three genotypes *viz*., EC-896076, EC-896081 and EC-896091, hydropriming for 2 h recorded the highest germination; while in genotype EC-896071, seed priming with 0.5% magnesium nitrate recorded the highest germination. In genotype EC-896063, 0.5% potassium nitrate recorded the highest germination; however, in genotype EC-507739, 0.5% zinc sulphate recorded the highest germination.

Hydropriming for 2 h also recorded the highest SVI I and II. The interaction effect between genotypes and treatments was significant for both the vigor indices (Table 4). In genotypes EC-896063, EC-896081 and EC-896091, hydropriming for 2 h recorded the highest SVI I and II. Genotype EC-507739 recorded the highest SVI II when primed with 0.5% zinc sulphate closely followed by scarification with 5% sulphuric acid and hot water at 35°C. In genotypes EC-896071 and EC-896076, SVI II recorded the highest value when primed with 0.5% magnesium nitrate and 0.5% zinc sulphate, respectively which were closely followed by hydropriming for 2 h.

Alpha- amylase activity recorded the highest value when seeds were treated with 0.5% magnesium nitrate which was statistically at par to 2 h hydropriming (Table 5). The interaction effect between genotypes and treatments was significant w.r.t. α- amylase activity. In genotype EC-896071, hydropriming for 2 h recorded the highest enhancement in α-amylase activity which could be responsible for higher germination and vigor indices of this quinoa genotype (Table 4). In genotype EC-896091, priming with 0.5 % magnesium nitrate recorded the highest α-amylase activity which was, however, statistically at par to 2 h hydropriming. Priming with 0.5 % potassium nitrate recorded the highest enhancement in α-amylase activity in genotypes EC-896081 and EC-896076 which was statistically at par to 2 h hydropriming. Seed priming activates α-amylase which hydrolyses the starch reserves, giving rise to α-maltose and α-glucose sugars that provide energy to the developing embryo during early seedling growth (Pujadas and Palau, 2001; Pawar and Laware, 2018). Hydropriming has been reported to enhance α-amylase activity in many cereals, including wheat and maize (Wattanakulpakin *et al*., 2012; Chakraborty and Bose, 2020).

Gayathri and Reddy (2018) observed that seed priming with 1% KH_2PO_4 and hydropriming for 6 h increased germination percentage in quinoa variety IC-411724, while in present study, the highest improvement in germination percentage was achieved by hydropriming for 2 h. Musa *et al*.(2014) reported that hydropriming of amaranth seeds for 2 hours resulted in a significant enhancement of germination. Hydropriming for 12 h and priming with 1% potassium nitrate has been reported to be the optimum priming technologies in beetroot and spinach, respectively, which are also the members of family Amaranthaceae (Nirmala and Umarani, 2008; Kulsumbi *et al*., 2020).

Conclusion

Germination varied widely between 8.5 and 83.8% among the tested quinoa genotypes; only one genotype, EC-896071, exhibited germination higher than 80% and another genotype EC-896076 exhibited germination higher than 70%. These identified quinoa genotypes also possessed higher values of SVI I and II as compared to other tested genotypes. Thus, genotypes EC-896071 and EC 896076 can be utilized in the breeding programs for the development of varieties possessing higher germination and early seedling vigor. Quinoa seeds may also be hydro primed for 2 hours to achieve enhancement in germination and vigor indices.

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