Effect of storage conditions and sodium hypochlorite treatment on germination of *Cucumis prophetarum* (Cucurbitaceae) seeds from arid Arabian deserts

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Research article

Keywords: Cucurbitaceae, *Cucumis prophetarum*, Germination requirements, NaOCl, orthodox seeds, sterilization, storage conditions

Posted Date: February 10th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-201765/v1>

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Abstract

Background

This is the first study on seed germination of *Cucumis prophetarum* in the Arabian Peninsula. Light and temperature as the main environmental factors and seed storage conditions greatly affect the germination of many Cucurbitaceae species. *C. prophetarum* is the perennial prostrate with woody rootstocks that grow throughout the year in the arid Arabian deserts. We examined the effects of seed storage conditions and sterilization by sodium hypochlorite (NaOCl) on germination of *C. prophetarum* seeds. Matured, fresh and field stored seeds were collected in March of 2016 and 2017 from a population in the United Arab Emirates. Fresh and the stored seeds (field, freeze, and room temperature) were germinated at three temperature regimes (15/25, 20/30 and 25/35°C) in both continuous darkness and alternating 12 h light/12 h darkness.

Results

The fresh and freeze stored seeds had higher germination percentage than the field and room temperature stored seeds. High germination was recorded in both lower and moderate temperatures (15/25 and 20/30°C) in light conditions. Sterilization of the seeds by NaOCl had a negative effect on the speed and germination percentage under all storage conditions, and it changes light and temperature requirements of seeds for germination.

Conclusions

Germination of *C. prophetarum* is sensitive to incubation light and temperature as well as to the seed storage conditions. The germination ability of stored seeds indicates that seed storage behaviour of *C. prophetarum* is orthodox. Light and temperature requirements for seed germination reflects a suitable place, habitat, and time for seedling emergence of *C. prophetarum*. The effect of NaOCl treatment on the germination may be associated with concentration and exposure periods of seeds. Therefore, we suggest that when using NaOCl for seed sterilization or to stimulate the germination, caution must be taken for using its concentration and exposure time, especially for species with thin and soft seed coats like *C. prophetarum*. Further studies on seed germination ecology would help to understand better the adaptive strategy of the *C. prophetarum* in the arid desert environments.

Background

Plant seeds usually experience varying environmental conditions during development and maturation in natural habitats, and their storage under different conditions can influence dormancy, germination, and seedling emergence [1, 2, 3, 4, 5, 6]. The seeds are generally categorized according to the post-shedding storage characteristics to orthodox, intermediate, and recalcitrant. The storage behavior is the capacity of

seeds to survive desiccation [7, 8, 9, 10]. Orthodoxy and recalcitrance are the extremes categories. Orthodox seeds are desiccation-tolerant and can survive low moisture content (ca., 5% or below). As such, seeds are not chilling sensitive, they can be stored over the long-term at -20°C and dry condition without significant viability loss. In contrast, recalcitrant seeds need water to survive (i.e., they are damaged by desiccation), are mostly short-lived and can be stored for a few months. Intermediate seeds lie between the previous categories that seeds can tolerate drying to about 7–11% moisture content and lose viability more rapidly at low temperature [11, 8, 9, 12].

The wild plant species have plasticity traits and strategies to respond to environmental variations and survive harsh conditions [13]. One important strategy is dormancy, that is the inability of a viable seed to complete its germination under favorable conditions in which non-dormant seeds germinate. Dormancy is critical for enabling seeds to delay their germination until the environment becomes favorable to seedling survival [14, 4]. Literature suggests that the mature seeds of the majority of wild species possess varying degrees of dormancy, which enables the distribution of germination over time and hence determines the survival of a species and its populations in variable environments [14, 15]. For example, in the desert regions with long, dry, and hot summers, the seed dormancy is an important survival strategy that prevents seed germination after seed maturation until the rainy season. In general, seed dormancy is controlled by some environmental factors, such as temperature, light, and seed storage conditions [16, 6].

Temperature and light are considered important environmental factors that regulate seed germination, ecological interaction and can influence species distribution [17, 6, 18]. Temperature is the main determinant in seed germination of many species and each species has an optimal temperature for its seed germination. Likewise, a light requirement of seed germination is variable as seeds of many species require light for germination. In contrast, others are insensitive to light, and in some species, the germination is inhibited by light [19, 20].

Storage conditions and duration are important factors affecting germination parameters. Bradychory or delayed dispersal is a mechanism through which plants retain their seeds within maternal plants until they are released [21, 22, 23]. Bradychory is described in many arid desert species where seed release from the mother plants is delayed until the occurrence of favorable conditions for seed germination and seedling establishment [24, 25, 26, 27]. Various environmental factors, such as temperature, light, and seed moisture contents, can control seed longevity under field storage conditions. Because of significant relationships between seed viability and the storage environment [28, 29], seeds stored under different conditions can produce a variety of seed germination patterns, ranging from zero to 100 percent germination [30, 20, 6]. Moreover, the longevity of seeds stored under laboratory conditions does not necessarily relate to their persistence in nature [31, 9], and therefore marked differences may occur.

The seed surface sterilization of many species is necessary to eliminate all microorganisms such as bacteria and fungi that can easily grow in vitro conditions during seed germination and may cause seed rot and reduction of germination percentage [32, 33, 34]. Sodium hypochlorite (NaOCl) is an effective seed disinfectant against a variety of microorganisms like bacteria, viruses, and fungi; hence it is widely

used as a sterilizing of seeds before germination experiments [35, 36, 34]. In general, to eliminate seed-borne fungi and bacteria, seeds are soaked for several minutes in 0.5-5% of NaOCl and then washed several times in distilled water [35].

It has been documented that pretreatment of seeds by NaOCl can influence the seed germination and dormancy of many species. NaOCl can enhance germination for some species, such as *Amaranthus powellii* S. Wats [37], *Polygonum convolvulus* L. and *Saponaria vaccaria* L. [38], *Stipa viridula* Trin. [39], *Angelica glauca* Endgew. and *Aconitum heterophyllum* Wall. [40]. NaOCl, also inhibited seed germination of some species like *Brassica chinensis* L. [41], while it had no effect on germination of other species such as *Setaria faberi* R.A.W.Herm. and *Abutilon theophrasti* Medik. [37, 42].

The Cucurbitaceae family comprises approximately 1000 species, including numerous fruit crops and vegetables worldwide, and has significant economic importance [43]. Wild species of Cucurbitaceae have rich genetic diversity, which can help them adapt to different environmental conditions. Species of this family are mainly distributed in tropical and subtropical areas [44, 45, 46].

Cucumis prophetarum L (Cucurbitaceae) is a perennial desert plant with woody rootstocks and prostrate hairy stems that can reach up to 200 cm in length. Green with soft spines are immature fruits, while the mature ones are yellow. This species has many medicinal benefits against different ailments, including diabetes and diarrhoeic diseases, and used in traditional Indian medicine [47, 48]. In the United Arab Emirates (UAE), *C. prophetarum* is uncommon and distributed mostly in mountain and wadi beds habitats. The flowering period of this plant is February to July [49, 50]. *C. prophetarum* is bradychoric that can retain the mature seeds within the maternal canopy for varying periods [23]. Its diaspore unit is the seed (ca., 0.4 cm) with ballistic dispersal mode as the seeds are forcefully ejected by explosive dehiscence of the fruit [51, 52, 23].

Several studies have reported the role of light and temperature during the germination process of many Cucurbitaceae species. For the light condition, darkness is the main requirement for seed germination of many species such as *Citrullus colocynthis* (L.) Schrad. [4] *Citrullus lanatus* (Thunb.) Matsum. & Nakai [53]. Seed germination of several species is sensitive to the temperature; for example, melon germination declined from almost 100% to zero when the temperatures were below the optimum (ca., 14 to 45°C) [54]. *C. colocynthis* seeds had good germination in moderate and high temperatures (20/30 and 25/35°C), but no germination happened at 15/25°C in the light [4].

In general, few studies dealt with *C. prophetarum* germination traits. As per our review of available literature, no studies exist about seed germination of *C. prophetarum* in the Arabian Peninsula. Keeping this in view, the aim of this study was to investigate the effects of storage conditions (e.g., fresh seeds, room temperature, freezing, and field conditions) and sterilization of seeds by NaOCl on germination of *C. prophetarum* under different combinations of temperature and light conditions.

Methods

Study area

The United Arab Emirates lies in the south-eastern Arabian Peninsula between latitudes 22° 40' and 26° 00' north and longitudes 51° 00' and 56° 00' east. The climate of the country is hyper-arid, hot with two main seasons. A short rainy season from November to March, with mild temperatures around 20°C and a long dry, hot season with a mean temperature range between 35–40°C that can reach 47°C and humidity levels reaching more than 90%. The rainfall is very scarce and erratic and concentrated from November to February [81, 82, 83].

Seed collection and storage treatments

In March 2016, the yellow fruits of *C. prophetarum*, which had freshly mature seeds, were collected from a wild population in Al Shuwaib area (E: 24.781625, N: 55.817591, alt: 241m above sea level) of Abu Dhabi emirate, UAE. Identification of the plant was made by Hatem A. Shabana, Tamer Mahmoud, Sanjay Gairola at the SSBH and confirmed by using the relevant regional flora. The voucher specimens (SSBH 1237 & SSBH 1255) were deposited in the herbarium of SSBH, Sharjah, UAE. In this study, all seeds were collected under international standard seed bank guidelines for scientific research and did not involve endangered or protected species. The permission was not needed to collect such samples for research purposes.

Generally, the yellow color is an indicator of fruit ripening in this species. The fruits were randomly collected from 20–25 individuals to diminish the effect of genetic variation within the population and the middle of the population to avoid the edge effect. These individuals were tagged permanently for future fruit/seed collection. Also, old fruits from these tagged plants were removed to ensure that the seed age was around one year at the next collection in March 2017. To assess the effect of field storage of seeds on germination, old fruits from the tagged individuals were collected after 12 months in March 2017.

Immediately after collection, the fruits were transported to the laboratory and seeds were extracted manually from the fruits, washed with water, and dried on a laboratory bench. The fresh seeds of March 2016 collection were divided into three parts; one part was germinated immediately after collection (hereafter referred to as fresh seeds), the second part was stored in brown paper bags at room temperatures (20 ± 2 °C, hereafter referred as room temperature storage) and the third part was dried to 5–8% moisture content at 15 °C and 15% relative humidity followed by storage at -18 °C (hereafter referred as freezing storage). Both second and third parts were stored for one year until their germination in March 2017. Seeds of March 2017 collection that remained in the field for about one year in the range of temperature between 16 °C to 46 °C (hereafter referred to as field storage) were immediately subjected to germination after collection.

Seed sterilization and germination experiment

Seeds of different storage conditions were divided into two groups prior to the starting of the germination experiment. The first group of seeds were disinfected with 50% Clorox solution (commercial bleach)

containing 5.25% Sodium hypochlorite for two minutes and rinsed several times in distilled water, while the second group was kept without sterilization.

Fresh (March 2016) and stored seeds (room temperature, freezing, field storage March 2017) were germinated in three programmed incubators set at daily night/day temperature regimes of 15/25°C, 20/30°C and 25/35°C in both alternating 12h light / 12h darkness and continuous darkness. The light period coincided with the higher temperature. Three replicate Petri dishes were used for each treatment, each with 25 seeds. The germination was conducted in 9-cm diameter plastic Petri dishes containing one disk of Whatman No. 1 filter paper, with 10 ml distilled water. During dark treatment, the Petri dishes were wrapped in aluminum foil to prevent light exposure before being placed in incubators. Seeds were considered to be germinated with the emergence of the radicals. Germinated seedlings were counted and removed every alternate day for 24 days following seed sowing. Seeds incubated in the dark were counted one time after 24 days because they were not exposed to any light during the incubation period.

Data analyses

The germination speed was assessed by calculating the germination rate index (GRI) using a modified Timson index of germination velocity = $\Sigma G/t$, where “G” is the percentage of seed germination at two days intervals, and “t” is the total germination period [4]. The germination rate was only calculated for seeds incubated under light conditions.

Three-way ANOVA (Analyses of Variance) was used to determine the effects of the three factors (storage condition, and light and temperature of incubation) and their interactions on final germination. Two-way ANOVA was used to assess the impact of storage condition and incubation temperature and their interactions on GRI. Tukey HSD test was used for multiple comparisons to determine significant differences among the treatments at $P = 0.05$. The germination percentages were arcsine-transformed and germination rate was log-transformed before statistical analysis to normalize the variance. All statistical analyses were performed using SYSTAT, version 13.0.

Results

Germination traits of seeds without pretreatment by NaOCl

There were significant effects ($P < 0.05$) of storage condition, and incubation temperature and light on the final germination of *C. prophetarum* seeds (Table 1). The germination had a negative relationship with incubation temperature (15/25°C: 34.3%, 20/30°C: 33.5% and 25/35°C: 28.7%). The seed germination was significantly greater in light (42.7%) than in dark (21.7%). For storage conditions, the overall germination of both fresh and freeze stored seeds (58.7% and 58.2%, respectively) was significantly greater than seeds stored in the field and room temperature (6.7 and 5.1%, respectively).

There were significant effects of interactions between storage conditions and light of incubation on the final germination of *C. prophetarum* seeds ($P < 0.001$, Table 1). In all the four storage conditions, the final

germination was significantly higher in light than dark. The germination of freeze stored seeds at 20/30°C was higher than at 25/35°C and 15/25°C, while germination at 15/25°C was the highest in fresh seeds (Fig. 1).

Table 1
Results of three-way ANOVA showing the effects of seed storage condition and temperature and light of incubation on final germination of *Cucumis prophetarum* for non-treated seeds. Ns, not significant at $P \geq 0.05$.

Source	df	Mean Squares	F-Ratio	p-Value
Storage condition (S)	3	2.195	134.826	< 0.001
Temperature (T)	2	0.057	3.473	< 0.05
Light (L)	1	1.363	83.686	< 0.001
S*T	6	0.033	2.05	Ns
S*L	3	0.301	18.507	< 0.001
T*L	2	0.036	2.196	Ns
S*T*L	6	0.024	1.489	Ns
Error	48	0.016		

In light, seed germination at 20/30°C was significantly greater than at 25/35°C and 15/25°C for fresh and freeze stored seeds while there was little difference between the three temperatures for the field and room temperature stored seeds. In the dark, conversely, the germination of fresh seeds at 15/25°C was significantly greater than at 25/35°C and 20/30°C, respectively. However, there was no germination for room temperature stored seeds at 25/35°C temperature regime (Fig. 1).

The germination speed of room temperature stored seeds was lowest than the other three storage conditions (Figs. 2 and 3).

Effect the sterilization by NaOCl on seed germination

There were significant effects of sterilization by NaOCl on seed germination of *C. prophetarum* ($P < 0.001$). The pretreatment of seeds by NaOCl resulted in reduced germination speed and percentage (Fig. 1). The germination percentage of seeds without and with sterilization were (32.2% and 17.6%, respectively), and the germination speed was 39.3 and 26.6, respectively. In all storage conditions, the final germination of non-sterilized seeds was higher than seeds treated by NaOCl except for the frozen seeds in light and at 15/25°C as there were small differences between them (Fig. 1). For germination speed, seeds without sterilization were faster than sterilized except for fresh seeds, where there was no significant difference recorded (Figs. 2 and 3).

For seeds with pretreatment by NaOCl, there were significant effects ($P < 0.001$) of storage condition, light and temperature of incubation, and their interaction ($P < 0.01$) on the final germination (Table 2).

The sterilized seeds had the same trend as non-sterilized seeds; fresh seeds had the highest germination, followed by freeze, field, and room temperature stored seeds (35.6%, 29.3%, 4.9%, and 0.7%, respectively). Also, germination at lower temperature (i.e., 15/25°C) was higher than 20/30°C and 25/35°C (23.2%, 19.7%, and 10.0%, respectively). Overall, more seeds germinated in light (27.2%) than in the dark (8.0%).

Table 2
Results of three-way ANOVA showing the effects of seed storage condition and temperature and light of incubation on final germination of *Cucumis prophetarum* for seeds pretreated using NaOCl.

Source	df	Mean Squares	F-Ratio	p-Value
Storage condition (S)	3	0.636	82.336	< 0.001
Temperature (T)	2	0.145	18.819	< 0.001
Light (L)	1	0.838	108.392	< 0.001
S*T	6	0.073	9.393	< 0.001
S*L	3	0.337	43.613	< 0.001
T*L	2	0.051	6.614	< 0.01
S*T*L	6	0.077	9.956	< 0.001
Error	48	0.008		

Unlike untreated seeds, the overall germination of NaOCl treated freeze stored seeds was greater at 15/25°C than in other temperatures. Also, in both dark and light incubation, the seed germination was highest at 15/25°C than the other temperatures in freeze storage seeds (Fig. 1).

In the field stored seeds, the germination was faster at 20/30°C than the other two temperatures tested. The germination speed was very slow at 15/25°C in the room temperature stored seeds (Fig. 2). The germination speed in the light was lower in both field and room temperature storage seeds compared with the other two storage conditions (Fig. 3).

Discussion

The germination capacity and longevity of seed under different environmental conditions are considered critical factors for understanding the ecological dynamics of a plant species. The seed storage behavior has an important association with plant ecology [55]. According to this hypothesis, orthodox species might be originating from occasional or seasonal drought environments in which the desiccation tolerance of seeds is essential for seed survival and seedling establishment [56]. Seeds of most plants inhabiting arid and desert regions have an orthodox storage behavior [56, 8, 31]. Many studies reported

that viability of the orthodox seeds after freezing is not different from the original state [11, 57, 58]. In our study, seeds of *C. prophetarum* had good germination at the time of dispersal (i.e., fresh seeds), as about 58.6% of the seeds succeed in germinating at different temperatures and light conditions of incubation. This case did not differ almost for dried, and one-year freeze stored seeds; the germination was approximately 58.2%. Consequently, the storage behavior of *C. prophetarum* seeds can be classified as orthodox, and as a result, they can be stored under conventional seed banking conditions.

Achigan-Dako et al. (59) reported that stored seeds of *C. lanatus* subsp *mucosospermus* Fursa, *Cucumeropsis mannii* Naud. and *Lagenaria siceraria* (Molina) Standl. with moisture contents ranged from 4–10% at 25°C maintained their ability to germinate after 60 days. Also, seeds of *C. lanatus* germinated well after storage between 40°C and 55°C with moisture contents ranging from 4–10%. Other studies documented that stored seeds (2 to 12 months storage) of *C. lanatus* can give good germination with 3.6–9% moisture contents and temperatures between 20–40°C [60, 61]. In the present study, the germination of fresh and freeze stored seeds of *C. prophetarum* was high and almost identical. In contrast, germination of field and room temperature stored seeds was low. The lower germination of field and room temperature stored seeds may be due to their long-time storage in high humidity (above 35 %) with higher (more than 10%) seed moisture contents.

Temperature and light form the main ecological factors in regulating seed germination [19, 18, 62]. Many studies have reported the critical role of incubation light and temperatures on seed germination of Cucurbitaceae species. The present study showed that the seeds of *C. prophetarum* germinated well in low and moderate temperatures (15/25 and 20/30°C) than higher temperature regime (25/35°C). These results are incompatible with previous studies on Cucurbitaceae species as their seeds required high temperatures for greater germination and exhibited poor germination at low temperatures [54, 63, 4]. For example, in certain melon varieties, a combination of lower seed coat permeability for oxygen and hypoxia of embryo were considered the main factors that might have caused poor germination at low temperature [64]. But our results are consistent with the study of Saberali & Shirmohamadi-Aliakbarkhani [65], where the best seed germination percentage of *Cucumis melo* L. was at 15°C to 25°C, and any increase in temperature after this range will lead to a decrease of seed germination.

The seed coat of *Cucumis* species is thinner than some of the Cucurbitaceae species, such as *Citrullus* species. Therefore, the seed coat of *C. prophetarum*, perhaps, is no obstacle for the diffusion of the oxygen and the water required for germination. In addition, the ability of *C. prophetarum* seeds to germinate in tested temperatures is probably correlated with the temperature range that the plant experience in the natural habitat as it grows mostly in mountain regions which have a lower temperature than the other desert habitats in UAE.

Seeds of many Cucurbitaceae species have negative photoblastic behavior, whereas their germination is better in the dark than in light, as reported in *C. lanatus*, *ucurbita maxima*, *L. siceraria*, *Benincasa hispida* and *Momordica harantia* [53], *C. lanatus* var. *citroides* [66] and *C. colocynthis* [4, 67]. Our results did not agree with these patterns where the seed germination percentage of *C. prophetarum* was almost double

in light than in the dark. Species that require light for germination have seeds surrounding them maternal tissues that contain chlorophyll, which reduces the R: FR ratio in the seeds throughout maturation and consequently needs light for germination [68, 69, 67].

The *C. prophetarum* plants have green dense and large leaves during their growth stages, and fruits remain attached with the parent plant partially under the canopy until dispersal time. In addition, the fruits are green at the younger stage then convert to yellow color when starting to ripe. Therefore, a large amount of chlorophyll can reduce R: FR ratio in the seeds, and consequently, they need light for germination [see 67]. These plants thrive in mountain areas, and their seeds may fall deep between the rocks that limit seedling emergence. Still, the seeds might have adapted their position in the soil surface to ensure the continuity of plant growth after germination.

Although the germination percentage of fresh and freeze storage seeds was very close in the present study, it varied under the tested temperature regime. The highest germination of freeze stored seeds was at 20/30°C, while for fresh seeds, it was highest at 15/25°C. This difference is probably due to the effects of the light condition on the germination at these temperatures. In the dark, the fresh seeds had the highest germination at 15/25°C, but the freeze stored seeds had the highest germination at 20/30°C (Fig. 1). El-Keblawy et al. [4] supposed that the storage did not affect seed viability but might have changed phytochrome sensitivity in the dark [68, 70].

In the present study, the purpose of using the NaOCl prior to the germination process of *C. prophetarum* was to sterilize seeds against bacteria, viruses, and fungi. For ensuring the validity of the results and the sterilization did not adversely affect the seed germination experiment outcome, we performed an additional experiment without seed sterilization (control). As we expected, the treatment of the seeds by NaOCl adversely affected the germination of *C. prophetarum* seeds. We recorded a considerable decrease in germination of seeds from all storage conditions and under light and temperature of incubation.

It has been reported that the treatment of seeds by NaOCl can cause changes in seed metabolism that influence the seed germination process [71, 72]. NaOCl has been reported to promote, inhibit and be ineffective at the seed germination stage in different species [73, 74, 75, 76]. These varying results may be caused by the differences in treatment duration and NaOCl concentrations used [77, 78]. NaOCl was an effective treatment for stimulating germination or breaking dormancy in some species, such as *P. convolvulus* and *S. vaccaria* [38]. For these species, NaOCl might have increased the permeability of the seed coat to oxygen and loss of germination inhibitors [39, 36]. Also, Wenny and Dumroese [79] reported that sterilizing conifer seeds with NaOCl resulted in increased germination percentage, which was probably due to reduced fungal infection [42]. Yildiz & Er [34] linked the mechanism of NaOCl action to induce seed germination and partial degradation of the seed coat.

However, for the same species (*P. convolvulus* and *S. vaccaria*), long-duration treatment by NaOCl reduces germination of seeds [38, 36]. On the other hand, Hsiao [38] supposed that NaOCl treatment of seeds for a longer duration than the optimum result in a decrease of germination due to disintegration of the seed or the effect of NaOCl on seed biochemical and metabolism processes. Ditommaso & Nurse [37]

indicated that the concentration and exposure time of NaOCl could affect seed germination. For example, the germination of *A. powellii* seeds increased when soaked in 6% NaOCl for less than 60 seconds but started to decline as treatment duration increases [37]. For *Linum usitatissimum* L., higher concentrations of disinfectant reduced the germination of its seeds, where the best germination was obtained at 40% concentration of NaOCl [34]. According to Akbari et al. [42], the treatment of seeds by 2% NaOCl could increase the germination percentage of *Oryza sativa* L. and increasing the concentration leads to a decrease in the germination. Moreover, Hsiao & Quick [80] reported that the seed germination of *Avena fatua* L. decreased when seeds were treated with more than optimal concentration of NaOCl, which could lead to damage to some of the seeds beyond their capacity to repair.

We can deduce from the previous studies that germination of NaOCl sterilized seeds of *C. prophetarum*, which have no hard coats, was decreased due to an increase in the concentration of the solution than the optimum limit, and perhaps reducing the concentration of NaOCl leads to increases in the germination. Secondly, the long exposure time of NaOCl and probably reducing the exposure time may leads towards maintaining or increasing the germination percentage.

Interestingly, in our study, the germination of sterilized freeze stored seeds of *C. prophetarum* increased at low temperature than untreated seeds. Though the interpretation of this result still unclear but perhaps the combination of freeze condition “low-temperature” and the light of incubation has an effect of NaOCl efficiency on seed germination.

Only sterilized fresh seeds of *C. prophetarum*, despite the decrease of their germination, had the same trend of germination of non-sterilized seeds in light and temperature conditions (Fig. 1). Also, similar germination speed for both the sterilized and non-sterilized fresh seeds remains unclear and require further study.

Conclusion

Our results confirm that *C. prophetarum* seeds have an orthodox seed storage behavior and can be dried without losing viability. The overall results indicate that the seed germination of *C. prophetarum* is sensitive to seed storage conditions and light and temperature of incubation and the sterilization of seeds by NaOCl. The germination results of *C. prophetarum* was incompatible with many studies of Cucurbitaceae species as it was higher in light than dark and low and moderate temperature than high temperature. Regarding the negative effect of NaOCl on the germination traits of *C. prophetarum*, we recommend a priori test for a small number of seeds with a diluted NaOCl concentration (i.e., 0.6% or lower) within a short exposure time (i.e., 30 seconds) to determine optimal concentrations and exposure periods for species having similar seed coat characteristics. Our results highlight the importance of understanding the germination traits of *C. prophetarum* in arid environments. However, further research is required to understand the seed biology and germination physiology of *C. prophetarum*.

Abbreviations

GRI
Germination rate index
NaOCl
Sodium hypochlorite

Declarations

Acknowledgements

The authors would like to thank Prof. Amr Abdel-Hamid, Director General of Sharjah Research Academy, for encouragement and support. The authors extend their gratitude to Mrs. Ghada Sakr for her assistance in formatting this manuscript, Mr. Mohamed Fiaz and Mr. Mohamed Abo Al Nour for their assistance in fieldwork. Ms. Reena Cordeiro helped in linguistic revision of the manuscript, we thank her.

Authors' contributions

All authors read and approved the final manuscript. HS conceived the idea and performed the data analyses. HS, TM, and SG collected the seeds, designed the research and wrote the manuscript. AA, MA1, MA2 conducted the lab work, and contributed in writing the manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Availability of data and materials

Seeds used in this study and the datasets are available from the corresponding author on request.

Ethics approval and consent to participate

In this study, all seeds were collected under international standard seed bank guidelines for scientific research. The permission was not needed to collect such samples for research purposes. We confirm that this study did not involve endangered or protected species. The voucher specimens (SSBH 1237 & SSBH 1255) were deposited in the herbarium of SSBH, Sharjah, UAE.

Consent for publication

Not applicable.

Competing Interests

The authors declare that they have no conflict of interest.

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Figures

Figure 1

Effect of seed storage condition and incubation temperature on final germination (mean $\pm$ SE) of *Cucumis prophetarum* seeds. Non-treated seeds (a) light and (b) dark, and pretreated seeds by NaOCl (c) light and (d) dark.

Figure 2

Effect of seed storage condition and temperature of incubation on germination rate index (mean $\pm$ SE) of *Cucumis prophetarum* seeds. (a) Non-treated seeds and (b) pretreated by NaOCl.

Figure 3

Effect of seed storage condition on germination rate index (mean $\pm$ SE) of *Cucumis prophetarum* seeds. (a) Non-treated seeds and (b) pretreated by NaOCl.