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Comparative study on application of He-Ne and diode lasers for acceleration seeds germinative capacity and seedlings growth of saxaul (*Haloxylon aphyllum*)

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ABSTRACT

The purpose of this study is to prevent the uplift of salt and sand in the areas exposed after the desiccation of the Aral Sea and to improve ecological conditions in the region. Research conducted in the Aral Sea zone has shown that, among desert plants, black saxaul (*Haloxylon aphyllum*) demonstrates superior effectiveness on saline soils due to its ability to strengthen the soil layer with its roots during survival and growth, as well as its capacity to block shifting sands. However, since the germination period of this plant species coincides with the sharp reduction of soil moisture in the newly exposed areas of the dried Aral Sea, the efficiency of germination under conventional sowing methods has decreased. Hence, experimental treatment aimed at accelerating germination during the period of normal soil moisture (February to March) was conducted using He–Ne ($\lambda = 632.8$ nm) and diode ($\lambda = 532$ nm) lasers. For laser-based ecological biotechnology treatment of black saxaul, exposure durations of 3 s, 6 s, 9 s, 15 s, 30 s, and 45 s were selected. According to the results of the experiment, the 3 × 30 algorithm produced the most effective outcomes compared to the other algorithms. Under the 3 × 30 algorithm using the He–Ne laser, germination compared to the control increased from 42.22% to 72.22%; the number of seedlings that emerged within the first 10 hours increased from 0 to 15; the total number of germinated seeds increased from 38 to 65; and the energy retention period increased from 7 to 17 days. Under the 3 × 30 algorithm using the diode laser, germination increased from 42.22% to 90%; the number of seedlings emerged within the first 10 hours increased from 0 to 31; the total number of germinated seeds increased from 38 to 81; and the energy retention period increased from 7 to 25 days. Two years of field trials confirmed enhanced establishment, with laser-treated seeds germinating within 10 days compared to no germination in controls.

Keywords: He-Ne laser, diode laser light, seed quality, germination capacity.

INTRODUCTION

A comparative study was conducted to examine the effects of laser irradiation on treated and control seeds. The red laser increased germination percentage by 25%, shoot length by 4.68 cm, and root length by 0.64 cm. In contrast, the green laser initially resulted in a 6.25% lower germination percentage compared to untreated seeds. However, at later stages, the green laser caused an increase in shoot length by 9.67 cm and in root length by 5.39 cm relative to the untreated seeds (Samiya et al., 2020).

Laser-beam stimulation influenced the reduction of the mean germination time of *Scorzonera hispanica* L. seeds, as expressed by the Pieper coefficient. However, in most cases, no statistically significant differences were observed. Following laser treatment, the average germination time of *Scorzonera hispanica* L. seeds in batches 1–3 was shortened by 0.11–0.35 days (Krawiec et al., 2015).

The hypocotyls of irradiated seeds were generally longer than those of the untreated samples, increasing by 14% after only 30 seconds of exposure. When the exposure duration was extended to 1 minute, hypocotyl length increased by 20.9%, and by 22.5% at 2 minutes. Under a 2-minute exposure, the mean hypocotyl length reached 116.9 mm. When exposure times exceeded 2 minutes, the stimulatory effect on hypocotyl elongation declined, with increases of only 19.8% and 5.9% observed at 5-minute and 10-minute exposures, respectively. Improvements in root length were also recorded in both mung bean (*Vigna radiata*) and common bean (Phaseolus vulgaris) seedlings as a result of He–Ne laser irradiation (Janayon and Guerrero, 2019a).

No significant differences in germination index were observed among the irradiated samples. The highest growth index (up to 83–97% according to DOG 11) was recorded when seeds were both irradiated and treated with the vaccine, with the best results observed after laser treatment. Slightly lower indices were observed under the combination of irradiation and vaccine treatment (53–76% according to DOG 11). The lowest germination index was recorded in seeds subjected only to irradiation (Klimek-Kopyra et al., 2020).

After laser treatment, the seeds were transplanted into the field at a depth of 4–5 cm, with a plant spacing of 30 cm in length and 60 cm in width. Irrigation was applied based on 80 mm of evaporation according to class A and was scheduled every five days during the crop growth period. During the growing season, weeds were manually removed, and insect control was carried out using diazinon pesticide (1.5 kg/ha), applied 20 and 35 days after sowing (Hasan et al., 2020).

The seeds were irradiated with a He–Ne laser at a wavelength of 632.4 nm. Two doses of laser irradiation, based on surface power density, were applied: 6 and 8 $mW \cdot cm^{-2}$. Seeds were exposed 1, 3, and 5 times, with each exposure lasting approximately 0.1 seconds. Treatment of seeds with laser irradiation led to increases in germination capacity, root length, and seedling dry weight, as well as improvements in field emergence and partial enhancement of overall root yield. Germination capacity increased by 1.5–13.2% compared to the control, depending on the applied irradiation dose (Krawiec et al., 2016).

The stimulation induced by laser irradiation in seeds varies depending on the species and physiological state of the seed. Therefore, the optimal dose must be determined for each type. In this study, a 2-minute exposure to the He–Ne laser appeared to enhance cell activity, as indicated by lipid content, leaf area, leaf number, the fresh weight of new leaves, and the dry weight of leaves under water stress conditions. The increased fresh and dry weight observed in plants grown from He–Ne laser-treated seeds may also be related to enhanced photosynthetic pigments. Red and white light treatments, compared to other spectral combinations, increased chlorophyll a + b content and growth rate (Mahmood et al., 2021).

In some cases, the mean germination time of a single seed exposed to laser irradiation could be accelerated by more than 37 hours compared to the control (Hasan et al., 2021).

Short-wavelength (<350 nm) ultraviolet (UV) radiation has both direct and indirect negative effects on plant pathogens. Direct effects may be associated with DNA damage, protein polymerization, enzyme inactivation, and increased permeability of cell membranes (Vanhaelewyn et al., 2020). Data on the effect of different types and durations of laser irradiation on root length indicate that the longest roots (15.91 cm) were produced when shoots were exposed to green laser light for 10 minutes. Shorter roots, reaching up to 3.12 cm, were also observed under other conditions (Abou-Dahab et al., 2019).

Currently, one of the methods to achieve high productivity is the use of various types of laser irradiation. According to studies conducted by researchers, exposure of wheat seeds to argon laser light (514 nm) increased shoot length. For a laser power of 20 mW, the highest values observed were 3.5 cm and 3.75 cm at 15 and 30 days after sowing, respectively. Similarly, the maximum shoot length for a 40 mW laser was observed 30 days after sowing (3.87 cm per plant). It should be noted that when seeds were exposed to 10 mW for 0.5 and 1 hour, shoot length decreased after 15 and 30 days (AlSalhi et al., 2019).

The data indicate that pre-treatment with radiation significantly increased germination percentage compared to the control. Seeds irradiated with the He–Ne laser germinated faster than the control. Higher doses of He–Ne laser irradiation (120, 300, and 600 seconds) increased the number of germinated seeds more than lower-dose treatments (Ali Al-Jehani et al., 2016).

In another study, seeds were biostimulated with a He–Ne laser (632 nm, 10 mW). For each species, three replicates of 50 seeds each were considered, and five exposure treatments (30 s, 60 s, 90 s, 120 s, 150 s) along with a control were conducted. The results indicated that the highest germination percentage (96%) was obtained with 90 s and 150 s exposures; in contrast, the control seeds showed a lower germination rate (16%) (Costilla-Hermosillo et al., 2019).

Using laser technology, it is possible to establish salt- and drought-tolerant protective plantations and to form plant cover on the dried areas of the Aral Sea, thereby mitigating the ecological situation. *Haloxylon aphyllum* contributes to soil stabilization, carbon sequestration, supports desert biodiversity, and provides forage in arid ecosystems. We hypothesize that laser pretreatment will enhance germination speed and seedling vigor, enabling earlier establishment during the brief period of adequate soil moisture (February–March). Hence, this study aims to investigate a comprehensive comparative study on application of He–Ne and diode Lasers for acceleration seeds' germinative capacity and seedlings growth of saxaul (*Haloxylon aphyllum*) in dried zones of Aral Sea.

MATERIALS AND METHODS

Sampling technique

After studying the plants being cultivated on the areas formed by the drying of the Aral Sea, black saxaul (*Haloxylon aphyllum*), a halophytic species tolerant to saline soils, was selected for ecological laser biotechnology treatment. Seeds of black saxaul were collected from the Forestry Research territory in Moynaq District, Republic of Karakalpakstan, and transported to the Forestry Research Institute for laboratory testing. Seed viability was determined in accordance with GOST 13056.1-75 requirements.

According to the methodology of GOST 13056.1-67 "Sampling of seeds from trees and shrubs", seeds stored in bags were manually selected to obtain samples. For each batch, the selected seeds were placed separately on a smooth surface and carefully compared for contamination, odor, color, luster, and other characteristics to ensure uniformity. If no significant differences were observed, the portions were combined to create the main sample.

Samples were initially divided using the cross-sectioning method (Figure 1). Seeds were then poured onto a smooth surface, thoroughly mixed, leveled to a thickness of up to 3 cm in a square shape, and diagonally divided into four triangles. Two opposite triangles were removed, and the remaining two were combined. The process was repeated until the number of seeds required to obtain the average sample of the set was reached.

Seed processing

In accordance with GOST 13056.6-97, the seeds of black saxaul (*Haloxylon aphyllum*) selected for sampling were soaked in water at 18–20 °C for 24 hours prior to sowing (Figures 1 and 2). After the soaking period, the seeds were rinsed with water on a metal mesh for 10–15 seconds.

Laser treatment

For the experiment with black saxaul (*Haloxylon aphyllum*), He–Ne laser (λ = 632.8 nm) and diode laser (λ = 532 nm) devices were selected. For the ecological laser biotechnology treatment of black saxaul (*Haloxylon aphyllum*), exposure durations of 3 s, 6 s, 9 s, 15 s, 30 s, and 45 s were chosen as the experimental algorithm (Table 1). Exposure times were selected based on preliminary tests showing detectable physiological responses between 3–45 s, with intervals chosen to capture nonlinear dose–response trends.

Seeds prepared under laboratory conditions, in collaboration with specialists from the Ion-Plasma and Laser Technologies Institute named after U. A. Arifov, were irradiated using laser devices. Experiments were conducted using He–Ne and diode lasers equipment. An experimental scheme was developed based on the selected algorithms (Figure 3).

Figure 1. Seed selection process for experimental plants according to the methodology

Figure 2. Soaking process of seeds selected for the sample

During the preparation of laser devices for the experiment, parameters such as laser beam distance, point of incidence, and exposure duration were carefully considered (Table 1). A series of investigations was conducted under laboratory conditions to ensure uniform and effective irradiation of seeds and to confirm that the laser beam reached all seeds consistently for testing purposes.

During the irradiation process, to ensure uniform power distribution, the laser beam incidence height on the seeds was set at 30 cm. The laser device was positioned 1 meter away from the seeds, and optical lenses were used to focus the beam, thereby determining the optimal point of incidence.

To determine the power and uniformity of the laser beams, the Nova II device was used, which allowed measurement of the evenly distributed power within the beam incidence area. For treatment of black saxaul (*Haloxylon aphyllum*) with He–Ne and diode lasers, the optimal spot (beam) diameter was set at d = 2 cm, with the laser power distributed equally over this spot (continuous-wave mode). The corresponding laser power was 27.9 mW for the He–Ne laser and 28.2 mW for the diode laser (Figures 4 and 5).

The beam incidence points of both laser devices were studied, and the experimental seeds were precisely positioned at these points. According to the experiment, it was determined that 30 seeds of black saxaul (*Haloxylon aphyllum*) could be placed at each laser beam incidence point.

Prior to selecting the parameters presented in Table 1, experiments were carried out on *Haloxylon aphyllum* to determine the minimum and maximum exposure times for laser irradiation, using time intervals from 1 second up to 1 minute. Analysis of the results showed noticeable changes at exposure durations of 3 sec, 6 sec, 9 sec, 15 sec, 30 sec, and 45 sec.

To ensure complete coverage of *Haloxylon aphyllum* seeds during irradiation with He–Ne and diode lasers, the seeds were placed on filter paper during the laser treatment process.

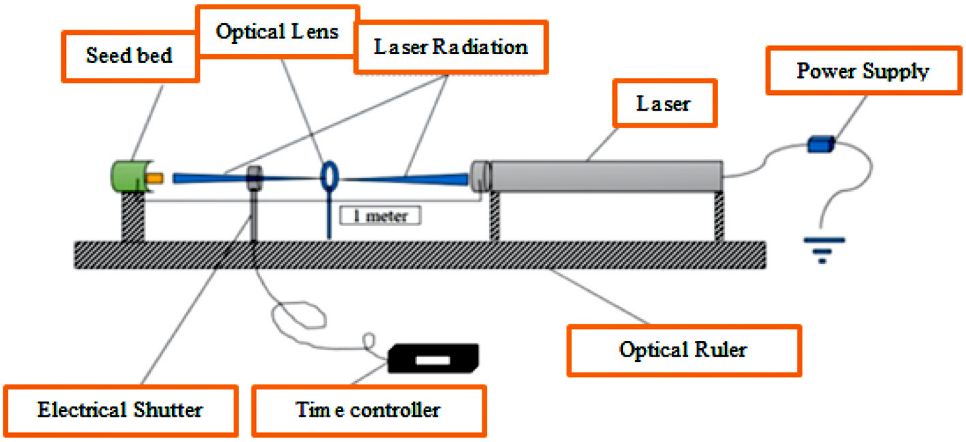

Figure 3. Experimental setup

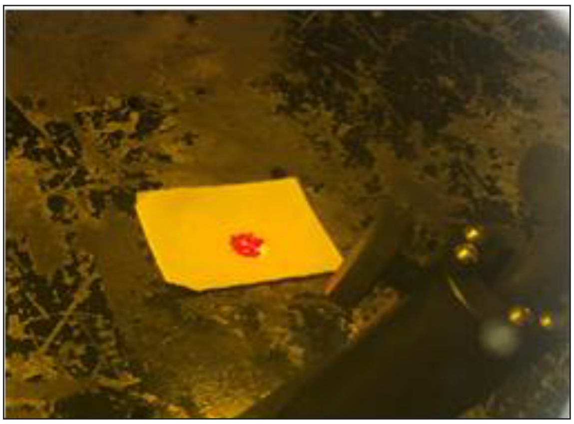

Figure 4. Beam incidence point of the He–Ne laser (λ = 632.8 nm)

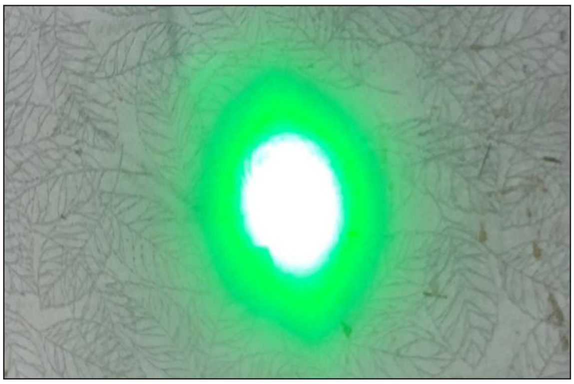

Figure 5. Beam incidence point of the diode laser (λ = 532 nm)

Water bath processing

In accordance with GOST 13056.6-75, the seeds were soaked using a "water bath" apparatus. *Haloxylon aphyllum* seeds were soaked for 24 hours in water at 20 °C, as specified in the protocol. After soaking, the seeds were rinsed on a metal mesh for 15 seconds.

To prepare the water bath for the experiment, the water level was set 2–3 cm below the filter paper on which the seeds were placed, ensuring proper moisture supply. Distilled water, free of mineral content, was used to fill the water bath. This was necessary because using regular tap water could lead to the accumulation of rust in the apparatus.

Filter paper was cut into circular shapes resembling a glass lid. Before placing the seeds, cotton gauze and absorbent material were fully moistened to saturation (Figure 6a). 30 seeds, positioned to correspond with the uniform power distribution point of the laser devices, were placed in the water bath for each algorithm and control treatment in three replicates (Figure 6b).

Phenology

Pieper coefficient calculation

Seedling energy (typically expressed by the germination rate of seeds) was measured 4 days after sowing seeds on the drying paper, while germination capacity was assessed 8 days later [ISTA 2004]. Daily counting of normally germinating seeds allowed determination of the mean germination time using the Pieper coefficient [W] and germination rate based on the Maguire coefficient [E] (Krawiec et al., 2015).

The mean germination time was estimated from the following equation:

$$W = \sum(d \times pd)/k \text{ (days)} \tag{1}$$

Table 1. Selected algorithm for laser treatment of *Haloxylon aphyllum* seeds

Laser type	Exposure time (s)	Exposure distance (cm)	Replicates	Laser power
He-Ne laser 632.8 nm	3	30	3	27.9 mW
	6	30	3	
	9	30	3	
	15	30	3	
	30	30	3	
	45	30	3	
Diode laser 532 nm	3	30	3	28.2 mW
	6	30	3	
	9	30	3	
	15	30	3	
	30	30	3	
	45	30	3	

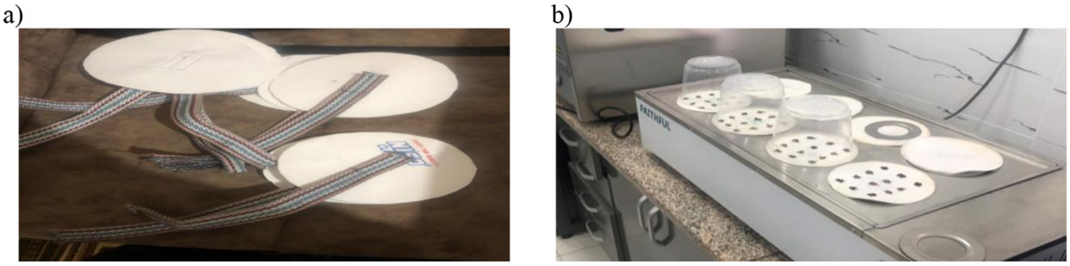

Figure 6. Placement of *Haloxylon aphyllum* seeds in the water bath apparatus to determine seed viability

where: W – Piper's coefficient, d – day of seeds germination, pd – number of normally germinating seeds given in day, k – total number of the normally germinating seeds.

The speed of germination was calculated according to the following Maguire equation:

$$E = \frac{k_1}{t_1} + \frac{k_2}{t_2} + \frac{k_n}{t_n} \tag{2}$$

where: E – Maguire coefficient, k – number of normally seeds germinating in the subsequent observation days, t – number of days from the day of sowing.

The phenology of plants was assessed using the traditional method of visual observations, which involves recording the timing of seasonal events. A comprehensive evaluation of plant species included: drought tolerance, growth rate assessment, adaptation to saline soils, disease resistance, and tolerance to high temperatures.

Dormancy in plants is a physiological state characterized by a sharp reduction in growth rate and metabolic activity. It has evolved as an adaptation that allows plants to survive under unfavorable environmental conditions during certain stages of their life cycle or seasons of the year (Mazurov, 1958).

Prior to sowing, laser treatment increased several parameters, including germination energy (a period over which seeds retained viability under stress), germination capacity, germination rate (final germination percentage), hypocotyl and root length, as well as the fresh and dry weight of seedlings. Laser stimulation was most effective for low-quality seeds, which initially had a germination capacity of 50.8%. Irradiation of seeds in this group also enhanced both seedling emergence and emergence rate (Krawiec et al., 2015).

Before sowing desert plants on areas formed by the drying of the Aral Sea, seed collection from the local population was carried out with the participation of scientists from the Forest Research Institute. The viability of desert plant seeds, including black saxaul (*Haloxylon aphyllum*), was tested under laboratory conditions.

According to the laboratory analysis conducted on January 27, 2023, the germination capacity of black saxaul seeds intended for planting in the Aral Sea region was 68.25%.

Thirty seeds were placed at the uniformly distributed beam point of the laser devices and irradiated in three replicates. Using the conventional method, the viability of *Haloxylon aphyllum* seeds became apparent 48 hours after analysis of the tested seeds.

RESULTS AND DISCUSSION

Haloxylon aphyllum seeds, irradiated with He–Ne and diode lasers began to germinate within 10 hours. During the laboratory experiments conducted according to the selected algorithms (3 s, 6 s, 9 s, 15 s, 30 s, 45 s), the seeds irradiated for 30 seconds showed the highest effectiveness (Figures 7 and 8).

According to the Pieper coefficient, seedling energy (typically expressed by the germination rate of seeds) was measured 4 days after sowing seeds on the drying paper, while germination capacity was assessed 8 days later. However, the Haloxylon aphyllum seeds set for the experiment began to germinate within the first 10 hours, during which no changes were observed in the control seeds. Therefore, seedlings that emerged during the first 10 hours were subjected to phenological observation to determine the germination rate.

Figure 8b shows the seeds that were counted on a separate white sheet to determine the number

Figure 7. Haloxylon aphyllum seeds irradiated with He–Ne laser (λ = 632.8 nm)

of seedlings that emerged during the first 10 hours after the experiment began. For comparison, under conventional germination experiments, *Haloxylon aphyllum* seeds typically emerged over a 48-hour period. This indicates that laser-treated seeds exhibited a shortened germination time of 38 hours under laboratory conditions.

From an agro-physical perspective, laser stimulation enables seeds to absorb and store light energy, convert it into chemical energy, and subsequently utilize it during germination, as well as for the growth and development of the plants (Gladiszewska, 2011).

When seeds were treated with laser radiation 3 times for 3 seconds, positive effects were observed in *Haloxylon aphyllum* compared to the control. In the 3×3 algorithm, for the He–Ne laser device, seed viability compared to the control was 42.22% < 66.6%, the number of seedlings emerged within the first 10 hours was 0 < 17, the total number of germinated seeds was 38 < 60, and the energy retention period was 7 < 17 days.

For the diode laser device, seed viability compared to the control was 42.22% < 78%, the number of seedlings emerged within the first 10 hours was 0 < 20, the total number of germinated seeds was 38 < 60, and the energy retention period was 7 < 20 days (Table 2).

However, the *Haloxylon aphyllum* seedlings that germinated under laboratory conditions appeared very weak and fragile

The main aim of our study was to cultivate this plant in February and March when the soil moisture content was at a normal level, thereby enabling the plant to survive until the rainy days of autumn by utilizing the moisture accumulated in its tissues as a reserve.

Even if the growth rate differs compared to the control, weak seedlings have a low chance of survival under the high temperatures of desert areas. Our goal is to ensure that seeds stimulated with laser radiation, when sown, perform effectively under adverse weather conditions, including drought and high temperatures, outperforming naturally grown seedlings and those cultivated using traditional sowing methods.

Germination tests of Scorzonera seeds under laboratory conditions showed that the germination capacity of the control seeds ranged from 50.8% to 93.0% (Krawiec et al., 2015).

In the 3 × 6 algorithm, the germination efficiency of the experiment using the He-Ne

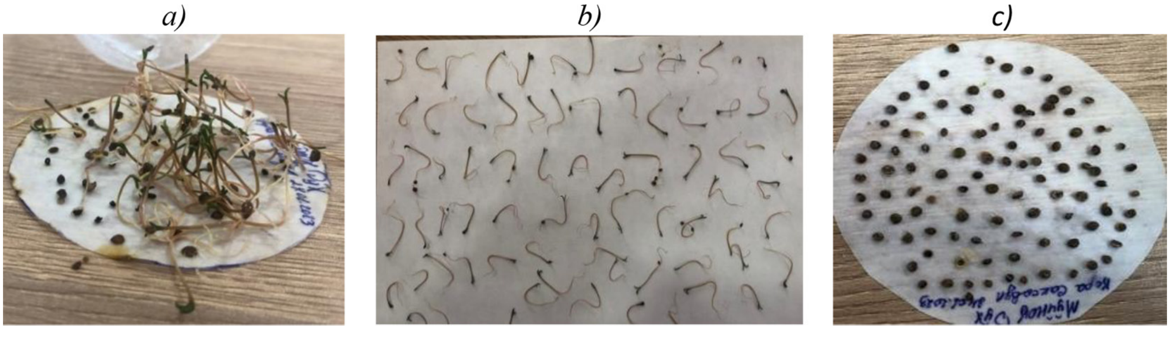

Figure 8. Haloxylon aphyllum seeds irradiated with diode laser (λ = 532 nm) (a, b – laser irradiated, c – control)

Table 2. The result of seeds exposed to laser light according to the 3 × 3 algorithm

№	Laser type	Repeatability	Exposure time (sec)	Exposure distance	Laser power	Number of seeds placed in the experiment	The number of sprouts that germinated in the first 10 hours	The number of normally grown seeds	Germination rate (hours)	Energy retention period (day)	The legth of the suprout steam (cm)			Germination rate %
											M±m	%	P%	
1	Control	1	0	-	-	30	0	10	48	7	6.1±0.26	100	4.3	33%
		2				30	0	15			5.9±0.22	97.66	3.7	50%
		3				30	0	13			5.8±0.24	94.84	4.2	43%
	Total					90	0	38						42,22%
2	He-Ne laser 632.8 nm	1	3	30	27.9 mVt	30	6	16	12	17	6.2±0.17	100	2.8	53%
		2				30	5	19			5.9±0.23	94.98	3.9	63%
		3				30	6	22			5.5±0.19	89.13	3.4	73%
	Total					90	17	60						66,6%
3	Diode laser 532 nm	1	3	30	28.2 mVt	30	6	25	12	20	6.4±0.16	100	2.5	83%
		2				30	6	23			5.9±0.20	94.06	3.4	76%
		3				30	10	23			5.6±0.20	90.81	3.5	76%
	Total					90	22	71						78.0%

laser device relative to the control was 42.22% < 71.11%; the number of seedlings germinated in the first 10 hours was 0 < 21, the total number of germinated seeds was 38 < 64, and the energy retention period was 7 < 17 days.

For the diode laser device, the germination efficiency relative to the control was 42.22% < 77.77%; the number of seedlings germinated in the first 10 hours was 0 < 24, the total number of germinated seeds was 38 < 70, and the energy retention period was 7 < 20 days (Table 3).

Based on the experiments conducted by the aforementioned researchers, it can be observed that the efficiency of seeds treated using laser biotechnology can increase up to 93%.

Laboratory tests conducted by the Forestry Research Institute on *Haloxylon aphyllum* seeds, which are traditionally sown in areas formed by the drying of the Aral Sea, showed a germination efficiency of 68.25%.

When seeds were treated with laser radiation for 6 seconds, three times, the highest germination efficiency of 77.77% was observed using the diode laser device.

Notably, with the He-Ne laser device under the 3 × 3 algorithm, the germination efficiency of the treated seeds was 66.6%, which increased to 71.11% under the 3 × 9 algorithm. According to observations, the results showed a progressive increase.

However, for the diode laser, the germination efficiency under the 3 × 3 algorithm reached 78.0%, while under the 3 × 9 algorithm it slightly decreased to 77.77%, showing a minor reduction in performance.

Under the 3 × 9 algorithm, for the He-Ne laser device, the experiment showed that compared to the control, germination efficiency increased from 42.22% to 75.55%. The number of seedlings emerged within the first 10 hours increased from 0 to 19, the total number of germinated seeds increased from 38 to 68, and the energy retention period increased from 7 to 17 days.

For the diode laser device, compared to the control, germination efficiency increased from 42.22% to 68%. The number of seedlings emerged within the first 10 hours increased from 0 to 21, the total number of germinated seeds increased from 38 to 62, and the energy retention period increased from 7 to 20 days (Table 4).

According to the results of the 3 × 9 algorithm experiments with He-Ne and diode laser devices, statistical analysis of growth parameters showed that the He-Ne laser had an advantage. The total number of germinated plants reached 75.55%.

When treating plants with laser radiation, the wavelength and light intensity are considered the main factors affecting growth. Exposing a plant to laser light relies on the plant cells' and tissues' ability to absorb, store, and utilize the photons from the laser. The enhancement of biochemical processes and seed physiology varies depending on the plant species, seed type, and environmental conditions (Ćwintal and Sowa, 2010).

The results of the study conducted using the 3 × 9 algorithm correspond to the previously

Table 3. The result of seeds exposed to laser light according to the 3 × 6 algorithm

№	Laser type	Repeatability	Exposure time (sec)	Exposure distance	Laser power	Number of seeds placed in the experiment	The number of sprouts that germinated in the first 10 hours	The number of normally grown seeds	Germination rate (hours)	Energy retention period (day)	The length of the sprout steam (cm)			Germination rate %
											M±m	%	P%	
1	Control	1	0	-	-	30	0	10	48	7	6.1±0.26	100	4.3	33%
		2				30	0	15			5.9±0.22	97.66	3.7	50%
		3				30	0	13			5.8±0.24	94.84	4.2	43%
	Total					90	0	38						42.22%
2	He-Ne laser 632.8 nm	1	6	30	27.9 mVt	30	7	19	12	17	6.2±0.21	100	3.3	63%
		2				30	7	19			6.3±0.27	102.56	4.2	63%
		3				30	7	26			5.7±0.24	93.20	4.2	86%
	Total					90	21	64						71.11%
3	Diode laser 532 nm	1	6	30	28.2 mVt	30	8	25	12	20	6.3±0.16	100	3.0	83%
		2				30	10	20			6.1±0.23	101.31	4.0	66%
		3				30	6	25			6.0±0.23	93.78	4.4	83%
	Total					90	24	70						77.77%

Table 4. The result of seeds exposed to laser light according to the 3 × 9 algorithm

№	Laser type	Repeatability	Exposure time (sec)	Exposure distance	Laser power	Number of seeds placed in the experiment	The number of sprouts that germinated in the first 10 hours	The number of normally grown seeds	Germination rate (hours)	Energy retention period (day)	The length of the sprout steam (cm)			Germination rate %
											M±m	%	P%	
1	Control	1	0	-	-	30	0	10	48	7	6.1±0.26	100	4.3	33%
		2				30	0	15			5.9±0.22	97.66	3.7	50%
		3				30	0	13			5.8±0.24	94.84	4.2	43%
	Total					90	0	38						42.22%
2	He-Ne laser 632.8 nm	1	9	30	27.9 mVt	30	7	23	12	17	6.2±0.19	100	3.1	76%
		2				30	5	21			6.4±0.30	102.89	4.3	70%
		3				30	7	24			5.8±0.24	94.46	4.2	80%
	Total					90	19	68						75.55%
3	Diode laser 532 nm	1	9	30	28.2 mVt	30	8	20	12	20	6.3±0.20	100	3.1	66%
		2				30	8	20			6.1±0.25	91.78	4.2	66%
		3				30	5	22			6.0±0.24	93.33	4.0	73%
	Total					90	21	62						68%

presented data. That is, during the experiment, increasing the exposure time of the laser showed results in the 3 × 3, 3 × 15, and 3 × 30 algorithms for seeds stimulated with the diode laser 532 nm, which repeated the trend of germination and growth. However, in the 3 × 9 algorithm, germination reached a lower level of only 68%. This indicator may be associated with the imbalance of the cells and tissues responsible for absorbing energy in the seeds selected for the 3 × 9 algorithm.

In the 3 × 15 algorithm, for the He-Ne laser device, the experiment's germination compared to the control was 42.22 < 66.6%; the number of seedlings germinated within the first 10 hours was 0 < 18; the total number of germinated seeds was 38 < 60, and the energy retention period was 7 < 17 days.

For the diode laser device, the experiment's germination compared to the control was 42.22 < 66.6%; the number of seedlings germinated within the first 10 hours was 0 < 28; the total number of germinated seeds was 38 < 73, and the energy retention period was 7 < 20 days (Table 5).

Based on the reviewed literature during the scientific research, studies conducted using

Table 5. The result of seeds exposed to laser light according to the 3 × 15 algorithm

№	Laser type	Repeatability	Exposure time (sec)	Exposure distance	Laser power	Number of seeds placed in the experiment	The number of sprouts that germinated in the first 10 hours	The number of normally grown seeds	Germination rate (hours)	Energy retention period (day)	The length of the sprout steam (cm)			Germination rate %
											M±m	%	P%	
1	Control	1	0	-	-	30	0	10	48	7	6.1±0.26	100	4.3	33%
		2				30	0	15			5.9±0.22	97.66	3.7	50%
		3				30	0	13			5.8±0.24	94.84	4.2	43%
	Total					90	0	38						42.22%
2	He-Ne laser 632.8 nm	1	15	30	27.9 mVt	30	6	20	12	17	6.4±0.18	100	2.9	53%
		2				30	6	22			6.2±0.25	98.07	3.9	63%
		3				30	6	26			5.8±0.22	90.55	3.9	73%
	Total					90	18	60						66.6%
3	Diode laser 532 nm	1	15	30	28.2 mVt	30	10	25	12	20	6.1±0.26	100	4.2	83%
		2				30	9	23			6.0±0.20	97.83	3.3	76%
		3				30	9	25			6.1±0.22	99.08	3.5	83%
	Total					90	28	73						81.1%

laser irradiation emphasized the effectiveness of the He-Ne laser device with a wavelength of 632.8 nm.

Based on the results of the laser irradiation experiment conducted on *Haloxylon aphyllum*, the findings above are contradicted. According to tests carried out using a diode laser, increasing the exposure time positively affected the germination parameters of *Haloxylon aphyllum*. In the 3 × 15 algorithm, increasing the exposure by 6 seconds compared to the 3 × 9 algorithm led to an increase in the total number of germinated seedlings from 68% to 81.1%, achieving a 13.1% improvement in efficiency.

This suggests that the efficiency of experiments conducted using laser devices depends on the type of laser, its frequency, intensity, and the physiological characteristics of the plant.

The study conducted using the diode laser 532 nm showed that although there were changes in the plant's growth parameters across the 3 × 3, 3 × 6, 3 × 9, 3 × 15, 3 × 30, and 3 × 45 algorithms, the survival duration without a nutrient medium and the germination period remained almost the same across all algorithms.

In the 3 × 30 algorithm, the results for seed germination were as follows: He-Ne laser: Germination increased from 42.22% (control) to 72.22%, the number of seedlings emerging in the first 10 hours increased from 0 to 15, the total number of germinated seeds increased from 38 to 65, and the energy retention period was 7–17 days. diode laser: Germination increased from 42.22% (control) to 90%, the number of seedlings emerging in the first 10 hours increased from 0 to 31, the total number of germinated seeds increased from 38 to 81, and the energy retention period was 7–25 days (Table 6).

The hypocotyls of laser-irradiated seeds were generally longer than those of untreated samples. After 30 s of exposure, hypocotyl length increased by 14%. Extending the exposure to 1 minute led to a 20.9 % increase, and 2 minutes resulted in a 22.5% increase, with the average hypocotyl length reaching 116.9 mm. Exposures longer than 2 minutes reduced the effect on hypocotyl elongation: 5 minutes gave only a 19.8% increase, and 10 minutes only 5.9%. Additionally, He-Ne laser irradiation improved root length in mung bean (Vigna radiata) seedlings (Janayon and Guerrero, 2019b).

According to the results of experiments with *Haloxylon aphyllum* using laser devices, the 3 × 30 algorithm – that is, exposing seeds three times for 30 seconds each – produced the highest performance compared to the 3 × 3, 3 × 6, 3 × 9, 3 × 15, and 3 × 45 algorithms.

Based on these findings, for crops like mung bean and common bean, laser irradiation is applied in minutes, whereas for *Haloxylon aphyllum*, seconds are sufficient. This suggests that the larger the seed size and the thicker its seed coat, the longer and more repeated the laser exposure should be when conducting experiments with laser devices.

Table 6. The result of seeds exposed to laser light according to the 3 × 30 algorithm

№	Laser type	Repeatability	Exposure time (sec)	Exposure distance (см)	Laser power	Number of seeds placed in the experiment	The number of sprouts that germinated in the first 10 hours	The number of normally grown seeds	Germination rate (hours)	Energy retention period (day)	The length of the sprout steam (cm)			Germination rate %
											M±m	%	P%	
1	Control	1	0	-	-	30	0	10	48	7	6.1±0.26	100	4.3	33%
		2				30	0	15			5.9±0.22	97.66	3.7	50%
		3				30	0	13			5.8±0.24	94.84	4.2	43%
	Total					90	0	38						42.22%
2	He-Ne laser 632.8 nm	1	30	30	27,9 mVt	30	5	25	12	17	5.9±0.19	100	3.2	83%
		2				30	5	20			6.3±0.27	98.07	4.3	66%
		3				30	5	20			6.0±0.26	90.55	4.3	66%
	Total					90	15	65						72.22%
3	Diode laser 532 nm	1	30	30	28,2 mVt	30	10	27	12	25	7.4±0.29	100	3.9	90%
		2				30	9	26			7.0±0.17	95.94	2.5	86%
		3				30	12	28			7.0±0.16	94.93	2.3	93%
	Total					90	31	81						90%

In the 3 × 45 algorithm, according to the He-Ne laser device, the germination of the experiment relative to the control was 42.22 < 67%, the number of seedlings that sprouted in the first 10 hours was 0 < 19, the total number of germinated seeds was 38 < 61, and the energy retention period was 7 < 11 days. According to the diode laser device, the germination of the experiment relative to the control was 42.22 < 78.8%, the number of seedlings that sprouted in the first 10 hours was 0 < 20, the total number of germinated seeds was 38 < 71, and the energy retention period was 7 < 17 days (Table 7).

The average root length of untreated seeds is 81.9 mm, which increases to 90.8 mm (10.8% growth) and 105.5 mm (28.8% growth) in the 1 minute and 2 minute treatment intervals, respectively. As with hypocotyl length, if the treatment duration exceeds 2 minutes, root length decreases. For 5 minute and 10 minute treatments, the increase in length is 21.8% and 8.2%, respectively.

Based on the data presented by the researchers above, it has been noted that increasing the exposure time on the plant seed can lead to a decrease in its growth parameters. Importantly, when applying laser light to plants, each plant species requires a specific approach that considers its growth environment. For example, in studies conducted by Rayno Vic B. and his research team, when experiments were performed on leguminous plants such as mung bean and common bean, extending the stimulation time beyond 2 minutes caused an adverse reaction in the plants.

Considering that *Haloxylon aphyllum* belongs to desert plant species, its vegetation period coincides with the hot season of the year, in June and July. However, when using laser treatment, increasing the exposure time by 15 seconds from the 3 × 30 algorithm to the 3 × 45 algorithm was enough to worsen the plant's growth parameters. From this, it can be concluded that for productive plants, the ability to absorb energy from sunlight during the vegetation period differs among perennial species.

According to the results of the experiment, when treating *Haloxylon aphyllum* seeds with a laser, using the diode laser device with the 3 s, 9 s, and 15 s algorithms, it can be observed that the efficiency increases slightly. When treated with the diode 30 s algorithm, the experiment achieved the most effective results (Figure 9). When treated with the diode 45 s algorithm, a decrease in experimental indicators was observed.

Observed effects of diode laser treatment on *Haloxylon aphyllum* seeds, showing positive changes for 3 s, 9 s, and 15 s algorithms, with optimal results at the 30 s algorithm (Figure 10).

In comparison, treatment with the He-Ne laser device at 3 s, 9 s, 15 s, 30 s, and 45 s showed lower indicators relative to the diode laser. This can be observed in Tables 6, 7 and analytical graphs presented in Figures 10 and 11. The superior performance of the diode laser may be

Table 7. The result of seeds exposed to laser light according to the 3 × 45 algorithm

№	Laser type	Repeatability	Exposure time (sec)	Exposure distance (см)	Laser power	Number of seeds placed in the experiment	The number of sprouts that germinated in the first 10 hours	The number of normally grown seeds	Germination rate (hours)	Energy retention period (day)	The length of the sprout steam (cm)			Germination rate %
											Length (M) ± Width (m)	%	P%	
1	Control	1	0	-	-	30	0	10	48	7	6,1±0,26	100	4,3	33%
		2				30	0	15			5,9±0,22	97,66	3,7	50%
		3				30	0	13			5,8±0,24	94,84	4,2	43%
	Total					90	0	38						42,22%
2	He-Ne laser 632,8 nm	1	45	30	27,9 mVt	30	6	17	12	11	6,0±0,23	100	3,8	67%
		2				30	7	19			6,2±0,21	102,63	3,3	53%
		3				30	6	22			6,0±0,17	99,17	2,9	63%
	Total					90	19	61						67%
3	Diode laser 532 nm	1	45	30	28,2 mVt	30	7	25	12	17	6,2±0,21	100	3,4	83%
		2				30	7	24			5,8±0,22	93,24	3,8	80%
		3				30	6	23			6,0±0,23	97,30	3,8	76%
	Total					90	20	71						78,8%

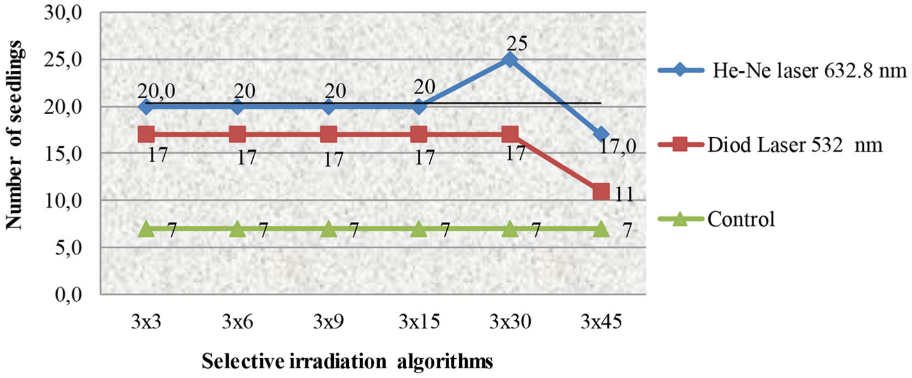

Figure 9. The number of seedlings emerged within the first 10 hours

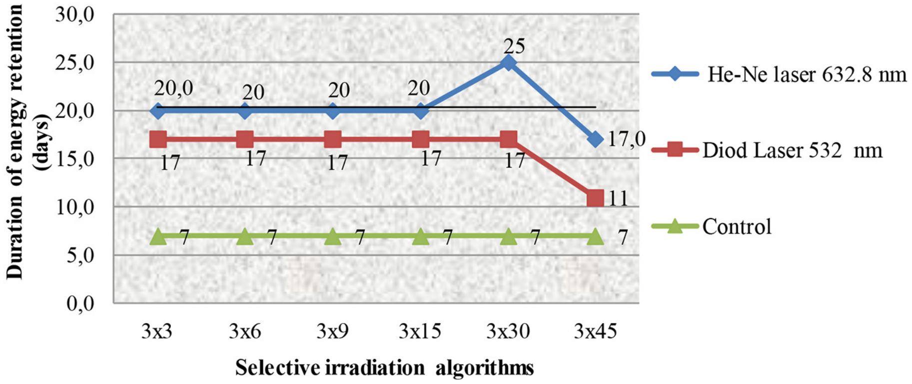

Figure 10. Energy retention period in the experimental *Haloxylon aphyllum* plants

attributed to better absorption by chlorophyll b and photoreceptors such as phytochromes, which peak in the green–red region, potentially enhancing photosynthetic priming, metabolic activation and photomorphogenic responses. In contrast, He–Ne laser may be less efficiently

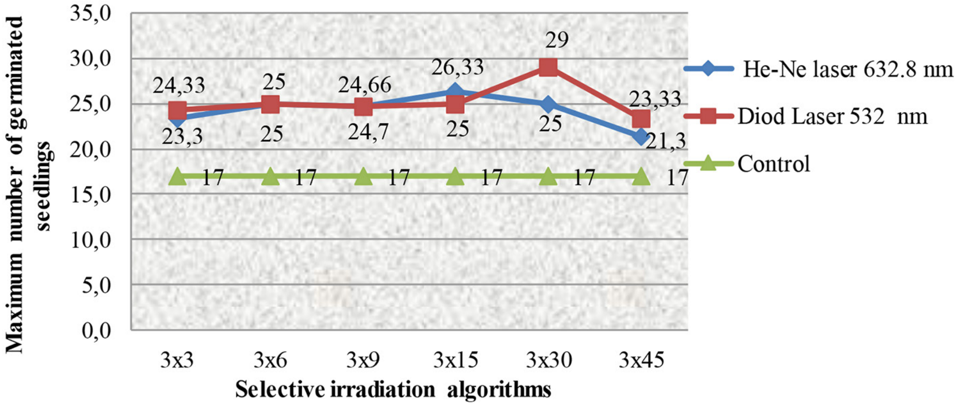

Figure 11. The maximum number of germinated seedlings

absorbed by desert plant photoreceptors adapted to high-light environments. In addition, laser biostimulation likely involves photobiomodulation pathways, including ROS-mediated signaling, phytochrome activation, and upregulation of germination-related enzymes (e.g., α-amylase). This metabolic priming accelerates water uptake, reserves mobilization, and cell division. A schematic diagram of the proposed mechanism (laser photobiostimulation pathway) is shown in Figure 12. This schematic illustrates the mechanistic pathway by which 512 nm (green) diode laser irradiation enhances germination and salt tolerance in *Haloxylon aphyllum* seeds. The pathway demonstrates how precise photonic energy is converted into biochemical signals that overcome dormancy and prime stress-resilient growth.

When treated with the diode (X = 532 nm) laser using the 45 s algorithm, stress conditions were observed in the plant, and the indicators of laser energy absorption decreased.

Based on the laboratory experiment, for *Haloxylon aphyllum*, the most optimal laser treatment algorithm was selected as irradiation with the diode laser at a height of 30 cm for 30 seconds, repeated 3 times. Field experiments were conducted in areas formed by the drying of the Aral Sea, under the jurisdiction of the Moynaq Forest Enterprise in Moynaq District, Republic of Karakalpakstan.

Field research results: Aral Sea

The selected land area is 0.05 hectares. According to the norm, the number of seeds of the first variety is 67 kg/ha, the number of seeds of the second variety is 83 kg/ha, and the third variety is 100 kg/ha. At least 70% of the seeds must be grown in laboratory conditions. According to the conducted laboratory tests, the average is 83.33%. For the experiment, 900 grams of *Haloxylon* seeds were planted on a field area of 0.05 hectares.

According to the established planting procedure, in the field area with sandy soil, *Haloxylon aphyllum* seeds should be stratified under sand for 3–4 days or soaked in water for 1 day. In the course of laser seeding, the seeds were planted at a distance of 60 cm and at a depth of 1.5–2.0 cm. Wet soil was pulled over the planted seeds. planting of roots was carried out on 15.03.2023. During the field trial, the average temperature was 20 °C and air humidity 28%.

Implementation of field experiments Dospekhov's method based on the method of checkerboard was planted. Equal distribution of the fertile part of the soil for experimental and control seeds was taken into account (Figure 13).

Based on the analysis of the reviewed literature, it can be stated that Haloxylon seeds sown by the traditional method begin to germinate within a period of 1 to 2 months. In contrast, seeds treated according to the most optimal algorithm – irradiation with the diode laser from a height of 30 cm for 30 seconds, repeated 3 times – began to germinate within 10 days. During this period, germination was not observed in the control seeds (Figure 14).

The period for sowing Haloxylon plants in the dried bed of the Aral Sea lasts from the beginning of February to the middle of March. By the end of March and the beginning of April, the plants enter the vegetative stage with the development of generative buds (Shamsutdinova and Shamsutdinov, 2022).

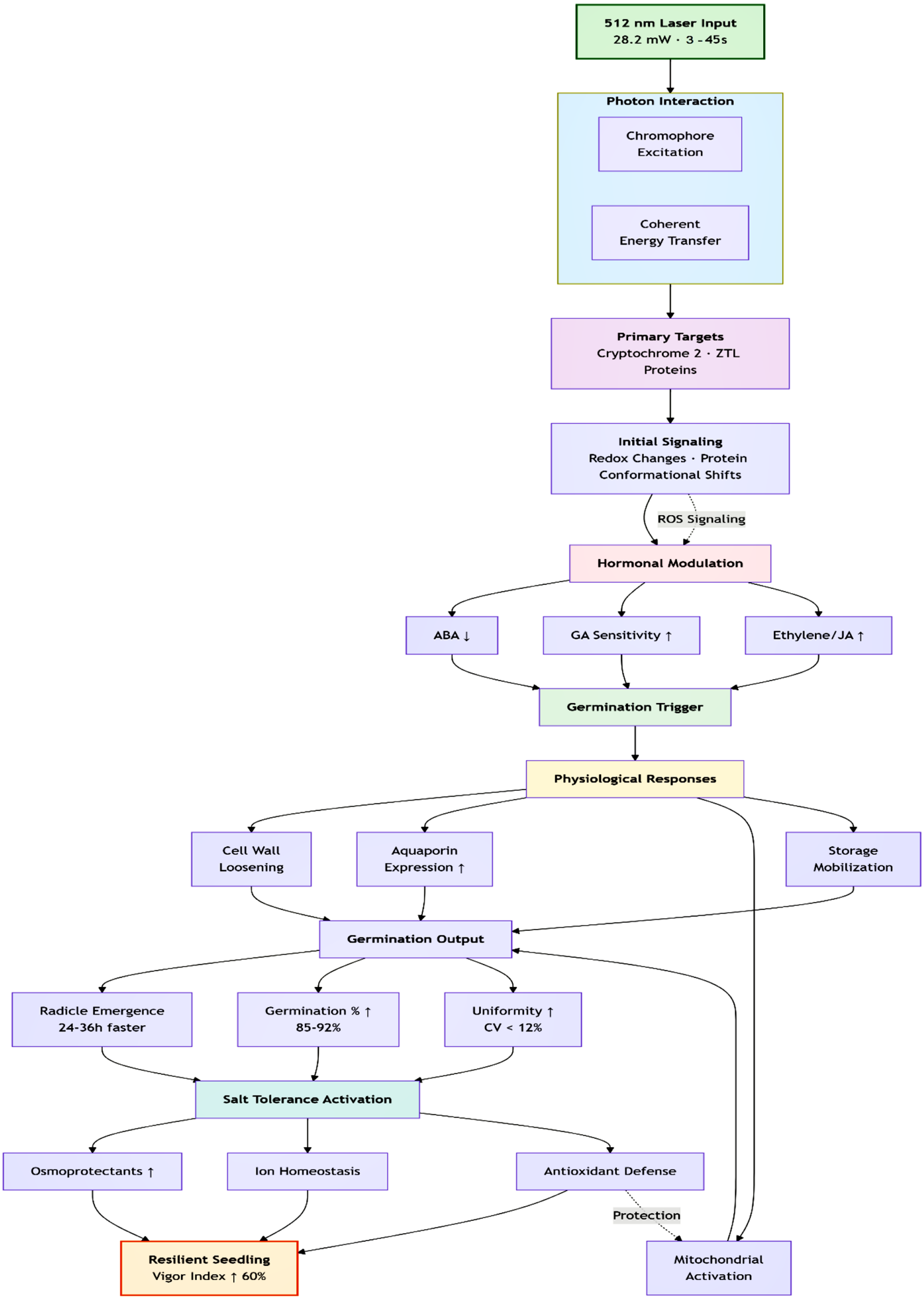

Figure 12. Laser photobiostimulation pathway in Saxaul Seeds

Under the soil conditions of the Aral region, for the growth of Haloxylon seedlings, the granulometric composition of the soil should be suitable to a depth of at least 100 cm. Salt concentration on the soil surface does not negatively affect the growth of living trees, but if the salt layer is located at a depth of 80–100 cm, it is known to have an adverse effect (Kusainova et al., 2023).

seeds of experience	control seeds	seeds of experience	control seeds
control seeds	seeds of experience	control seeds	seeds of experience
seeds of experience	control seeds	seeds of experience	control seeds

Figure 13. Planting scheme by Dospekhov's method

Since the vegetative period of *Haloxylon aphyllum* occurs during the hot summer season, phenological observations were planned for the autumn to study the germination capacity and survival characteristics of the seeds. By that time, no germination was observed in the seeds planted for control. According to the phenological observations conducted, the average number of seeds that germinated per meter distance was 278. The average number of germinated seeds per plot was 1.668. During its season, 1.439 seeds survived under hot and arid conditions. Thus, it was determined that 86.27% of the seeds planted during their season retained their viability, while 13.73% perished (Table 8).

The growth parameters of the Black Saxaul (*Haloxylon aphyllum*) plant, which was grown in the experimental field 2 years after planting on March 15, 2025, and processed using a 3 × 30 algorithm using a diode laser laser device, were measured. Samples were taken from the plant body to determine any changes that may occur in the plant body as a result of laser irradiation.

The hypocotyl length of the control plant was 90 cm, while that of the experimental plant was 210 cm. Accelerated germination allows saxaul seedlings to establish root systems before soil moisture declines sharply in late spring, critical for survival in the Aral Sea region. The root length of the control plant was 40 cm, compared to 120 cm in the experimental plant (Figure 15). In addition, Figure 16 highlights the nutritional capacity (calorific value) of *Haloxylon aphyllum* was tested under laboratory conditions and result showed that calorific value for laser treated group was higher than the control (2085 and 1491 kcal/kg).

Figure 14. Germinated *Haloxylon aphyllum* seeds (within 10 days) irradiated with a Diode laser 532 nm germinated

Table 8. Field results of seeds exposed to laser light according to the 3 × 30 algorithm.

Experiment	Repeatability	Laser power	Planting time	The number of sprouts in 1 meter	Average number of seedlings germinated in a 0.6×6m experimental plot	Germination time (per day)	The average number of seedlings that survived the summer seasons	Length of sprout stem (cm)			The number of shoots (pieces)		
								M±m	%	P%	M±m	%	P%
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Control	1		15.03.2023	0	0	0	0	0	0	0	0	0	0
	2			0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4			0	0	0	0	0	0	0	0	0	0
	5			0	0	0	0	0	0	0	0	0	0
	6			0	0	0	0	0	0	0	0	0	0
Diode laser 532 nm	1	28.2 mVt	15.03.2023	203	1218	10	1003	6.0±0.10	100	1.7	6.0±0.10	175	3.0
	2			258	1548	10	1258	6.1±0.26	100	4.3	6.1±0.26	200	3.9
	3			304	1820	10	1603	6.0±0.23	100	3.8	6.0±0.23	267	3.0
	4			343	2058	10	1749	6.2±0.21	100	3.4	6.2±0.21	275	3.5
	5			314	1884	10	1689	5.9±0.19	100	3.2	5.9±0.19	119	3.2
	6			247	1482	10	1332	5.9±0.22	97.66	3.7	5.9±0.22	237	2.9

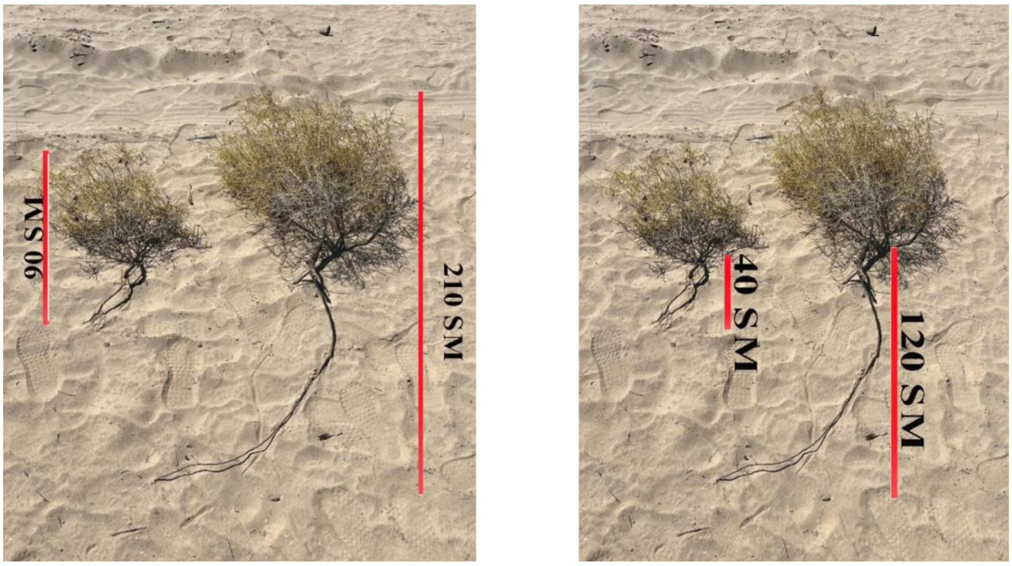

Figure 15. The process of obtaining phylogenetic measurements from 2-year-old seedlings

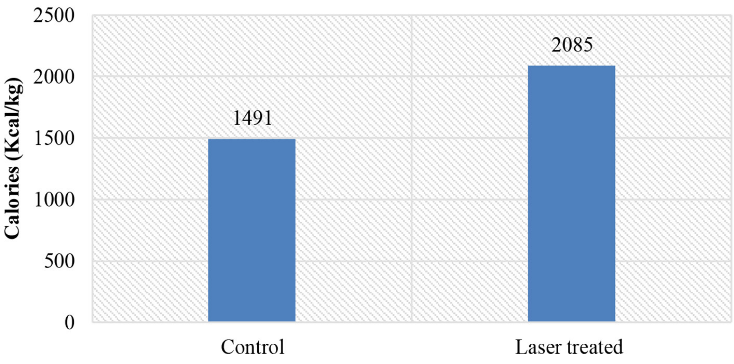

Figure 16. Comparison of calorific values of *Haloxylon aphyllum* grown in field experiments

CONCLUSIONS

When conducting experiments with laser devices, it should be taken into account that the larger the seed size and the thicker the seed coat, the longer the irradiation time and the greater the number of repetitions required. According to the data cited by scientists, increasing the exposure time of the seed to laser irradiation can lead to a decrease in the seed's growth parameters. It is noteworthy that for each plant species, a specific approach must be applied, taking into account the growth environment of selected species.

The effectiveness of experiments conducted using laser devices depends on the type, frequency, and intensity of the lasers, as well as the physiology of the plant. For perennial plants, the capacity to absorb solar energy during the vegetation period varies among species compared to annual crops. When conducting experiments with laser devices, identifying a uniform power distribution point is crucial, which in turn affects the efficiency and reliability of the research results.

According to the analysis of the literature studied during the scientific research, in experiments with laser devices, He-Ne laser devices are mainly distinguished by their efficiency. However, in this experiment, the main indicators were shown by the diode laser device, which showed its efficiency in the tested plant. It was found that the efficiency of the diode laser device was higher in terms of the hypocotyl length of the plant 40 < 120 cm, in terms of the full length of the plant 90 < 210 cm, and in terms of the nutritional (calorific) value 1491 < 2085 (kcal/kg).

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