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# Laser Irradiation Effects at Different Wavelengths on Phenology and Yield Components of Pretreated Maize Seed

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**Abstract:** This study aims to compare the effects of different laser wavelengths, exposure times, and low-power-intensity laser irradiation on maize seeds. Seeds were exposed to He–Ne (632.8 nm) red laser, Nd:YAG second-harmonic-generation (532 nm) green laser, and diode (410 nm) blue laser. Four different exposure times (45, 65, 85, and 105 s) with different intensity (2 and 4 mW/cm$^2$), for each laser were tested. Phenology and yield components (plant height, leaf area, number of rows per ear, seed yield, harvest index, yield efficiency, and grain weight) were determined. The experiment was conducted in a randomized complete block design with three replications. Plant height was found comparatively high in blue laser light—211 cm at 85 s. Blue and green laser lights showed significant increases in the number of rows per ear to 39.1 at 85 s and 45 at 65 s, respectively, compared to the control of 36 rows/ear. The order of seed yield was blue (7003.4 kg/ha) > green (6667.8 kg/ha) > red (6568.01 t/ha) based on different exposure times of 85 s, 85 s, and 105 s, respectively, compared to the control of 6.9 kg/ha. The findings indicate the possibility of using blue laser light to manipulate the growth and yield of maize.

**Keywords:** *Zea mays* L.; laser stimulation; yield components; wavelengths

## 1. Introduction

Laser technology can be a convenient option to be incorporated into systems of agricultural production. Therefore, more attention was given in recent years to physical factors that may be applicable to processing of sowing material [1,2]. In order to ensure a high seed performance, various methods of processing are used, including chemical preparations, such as seed inoculation by chemical material and growth regulators, as well as physical factors, including laser light and magnetic fields [3–8]. Pre-sowing treatment was applied in order to stimulate the seeds to better germinate and grow faster in various sowing conditions [9]. The use of physical factors for controlling the influence of biological behavior during development and storage of different cultures is a modern trend in combining the intensification of plant technologies with ecological requirements [10]. Most physical factors that only modify physiological and biochemical processes in seeds are also safe for the environment [11–13], for instance, improving agriculture practices, such as by using chemical fertilizer and regular weed control [14]; however, this can affect the environment [15]. In contrast, laser stimulation does not cause harmful changes in the environment, which is of great importance in organic and integrated agriculture [16,17].

Light is an essential condition for photosynthesis and is needed in plant improvement; it can also affect the seed field performance, growth, and yield of some plants [18–20]. Among the previously used methods of seed refining [21], light laser is a physical factor that does not cause adverse changes in the environment. Research on the effects of pre-sowing bio-stimulation on plant crops showed that the best results of this treatment are obtained for plant vegetables, rather than for cereals and root crops. After applying radiation laser to tomatoes and cucumbers, a significant increase in yield was found, which accelerated the ripening and produced better fruit quality [8,22]. One of the methods of seed refinement is irradiation; a divergent beam laser light provides energy to modify physiological and biochemical processes, causing an increase in the field's performance to rise and yield crops [23].

Previous work on the effects of pre-sowing seed stimulation with laser light concerned annual plants [24]. Laser stimulation is a physical phenomenon; it depends on its ability to absorb and store the light energy of plant cells and tissues. In the case of seeds, the same phenomenon can be observed; they absorb energy light, transform it into chemical energy, and use it at a later time [3].

The research conducted so far on the laser stimulation of plant seed agricultural and horticultural products shows that it may affect the enzymatic system, accelerating the decomposition of starch, the germination of seeds [25], photosynthesis, and transpiration efficiency [10,26,27], as well as plant growth and development [28–30].

For this purpose, maize was selected as a model plant due to its significant economic value as a worldwide cultivated crop for its high starch content [31,32]. Furthermore, studies revealed that the laser is useful to improve the sanitary quality of maize seed [33]; this characteristic allows a seedling to have more strength to emerge from the soil [34].

The phenomenon of laser radiation is still poorly understood; there are only fragmentary studies or hypotheses that attempted to explain how laser light interacts with seeds [35–37]. So far, no studies were done on the effects of different wavelengths of laser light (i.e., blue, green, and red wavelengths) on maize seeds. Therefore, the aim of the study was to determine the effect of different doses and different wavelengths of laser irradiation for maize seeds during pre-sowing treatments in terms of yield value.

## 2. Materials and Methods

### 2.1. Study Site

The present study was carried out in 2018 at the experimental field located at the Faculty of Agriculture and Laser Laboratory at the Institute of Laser for Postgraduate Studies, University of Baghdad (33°16′26″ north (N), 44°22′39″ east (E)) (Figure 1).

### 2.2. Experimental Set-Up

The lasers set-up was conducted at Laser Lab Institute of Laser for Postgraduate Studies (ILPS). The set-up structure of different laser devices included putting each laser in a special bed in the open part of the optical ruler, which provided good cooling conditions so that it could operate in a normal mode for an indefinite period of time. The laser devices for three different types of laser were provided separately by a metal stand, and silicone coating was applied to the front peripheral edge for better fixing contact. The optics were used to get the optimum power of the lasers. In addition, the intensity of the laser irradiation power was set at 2 and 4 $mW/cm^2$, which was measured by a power meter.

In fixing, the three laser irradiator mechanisms were designed to secure the continuation of the laser irradiation. They were fixed to a steady stand in specially designed beds in such a way that the total laser spot remained fixed. The collimation optics were mounted on the laboratory laser irradiators.

The laser irradiation energy necessary for the pre-sowing seed irradiation was evenly distributed in compliance, with a total spot of 4 mm at a distance of 1 m from the laser fronts.

**Figure 1.** Red box: plant growth stages (sowing at field, emergence stage, and vegetative growth stage). Blue box: plant growth stages (flowering stage, maturity stage, and harvest stage).

Three types of laser were used: He–Ne (red), Nd:YAG second harmonic generation (green), and diode (blue), generated at 632.8, 532, and 410 nm, respectively. The maize seeds were irradiated by the abovementioned lasers in exposure durations of 45, 65, 85, and 105 s. A time controller device was used to get the optimum time for each treatment. The device parts and position of the treated samples are shown in Figure 2.

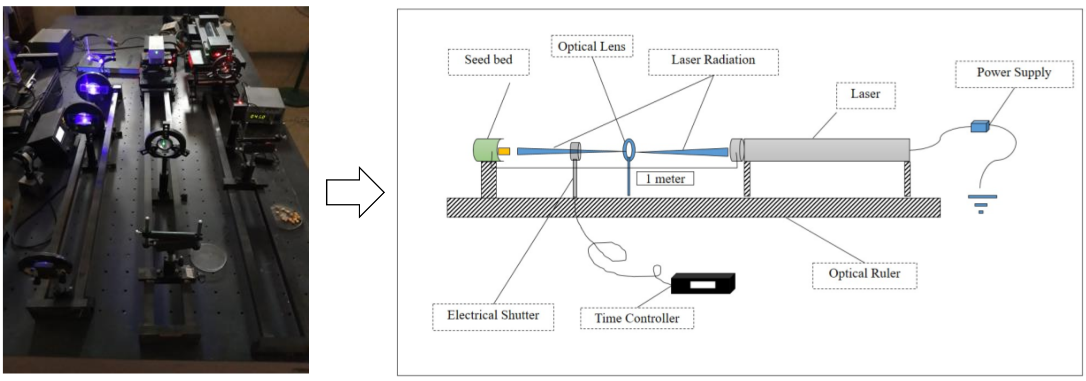


**Figure 2.** Set structure for the laser irradiation on maize seeds.

### 2.3. UV–Visible Test

The UV–visible analysis of samples was carried out using a UV–Vis Shimadzu Spectrophotometer (Shimadzu, Milton Keynes, UK) (UV–1800) to obtain the two statuses of wet and dry seed spectra, where the wet seed was moistened overnight by water before the analysis. Information was recorded using a silicon photodiode in the absorbance and transmittance mode with wavelength ranging from

190 to 1100 nm. Dry seeds were chosen for irradiation by the lasers due to absorbing more of the visible wavelength as compared to the wet seeds (Figure 3).

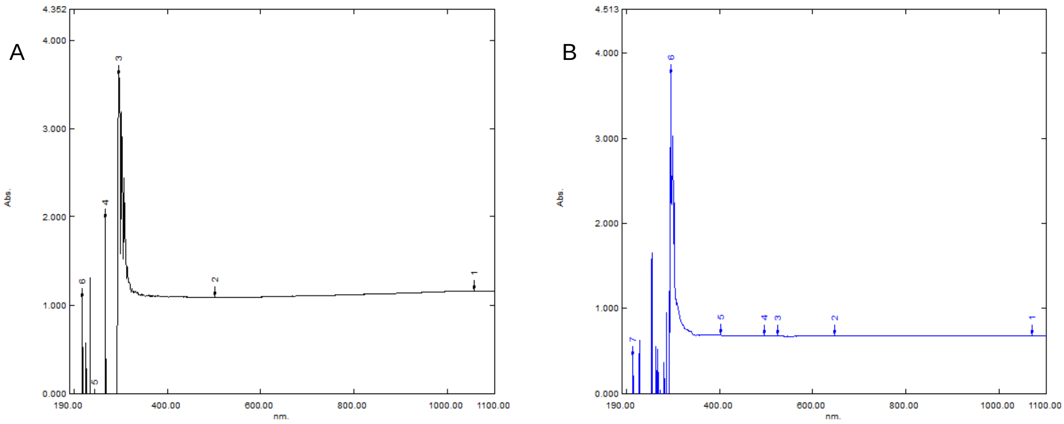

**Figure 3.** UV–visible analysis for two statuses of maize seed (dry (**A**) and wet (**B**)) by wavelength, ranging from 190–1100 nm.

### 2.4. Field Experiment

The experiment was conducted with a randomized complete block design (RCBD) with three replications, three types of laser, four irradiation times, and two levels of laser intensity with control (without laser treatment) (24 treatment × 3 replications). Field area was 6 m × 25 m = 300 $m^2$, the total number of irradiated and planted seeds was 1200, and, after two weeks, the seeds thinned to 300 plants. The experimental field area was plowed in the fall. Fields were cultivated, disced, furrowed, and then plotted in early July 2018 before sowing the seeds. Soil samples were collected randomly from the field and then transferred to the lab to measure the physical–chemical parameters (Table 1). Fields were fertilized with 520 kg/ha compost (46:18 N:$P_2O_5$), and, before sowing, the soil was fertilized by urea of 436 kg/ha (half at 14 days after sowing and the rest at the flowering stage). The seeds were collected from the Office of Agriculture Research, and the variety used in this experiment was cultivar Baghdad 3; all seeds were filtered to have the same size. Before sowing, maize seeds were irradiated by three types of laser (red, green, and blue laser) for different exposure times—45, 65, 85, and 105 s—and with two level of laser intensity (4 and 2 mW/$cm^2$); additionally, seeds without irradiation were used as control plants. After laser treatment, the seeds were transferred to the field and sown at 4–5 cm depth with plant spacing of 30 cm length and 60 cm width. Irrigation was adjusted based on 80 mm of evaporation from pan class A and every five days during crop growth period. Weeds were hand-removed during growing seasons, and diazinon pesticide was used to control insects (1.5 kg/ha), applied 20 and 35 days after sowing. Above ground, parts of the crop were harvested at 110 days (at maturity) from sowing.

**Table 1.** Initial physical and chemical properties of the experimental soil.

| Parameters | Value |
|---|---|
| pH | 7.2 |
| Electrical conductivity meq/100g soil | 3.8 |
| Potassium (mg/L) | 1.6 |
| Phosphorus (mg/kg soil) | 43.2 |
| Silt (g/kg soil) | 28.9 |
| Clay (g/kg soil) | 38.5 |
| Sand (g/kg soil) | 32.6 |
| Nitrate (%) | 0.0017 |
| Ammonia nitrogen (%) | 0.009 |
| Texture | Silty clay |

### *2.5. Experimental Parameters*

Data were recorded for phenology (physiological maturity) and yield components (plant height, leaf area, number of rows per ear, seed yield, harvest index, yield efficiency, and grain weight). From each treatment, 10 ears were selected; plant length and the number of rows per ear were calculated and then averaged. Grain weight was determined by weighing 300 grains, randomly taken from the grain lot of each subplot. This was repeated three times in order to calculate the average grain weight. At maturity, 10 plants from each subplot were harvested. Ears were dried, shelled, and weighed. Grain yield was expressed in $kg \cdot ha^{-1}$ at the moisture ratio of 15%. The harvest index was calculated according to the following formula: harvest index (%) = grain yield/biological yield × 100. The yield efficiency was calculated by grain yield/leaf area, and the leaf area was measured [38] using the following formula: leaf area = $(\text{length leaf})^2 \times 0.75$.

### *2.6. Statistical Analysis*

Genstat® Statistical software version 19 was used to analyze the data by applying an analysis of variance (ANOVA) at a probability of $p < 0.01$; significant differences among means were defined using the Fisher's test. All measurements were carried out in triplicate.

## 3. Results and Discussion

The effects of laser application on the plant height parameters of maize are shown in Table 2. Laser treatment significantly affected plant height of maize, along with different exposure time and power density. Generally, laser treatment increased plant height, as compared to those seeds without treatment (control). The pre-sowing irradiation of blue laser for 85 s at 4 mW/cm$^2$ significantly increased the plant height (211 cm) with respect to the seedlings from the control seeds (201 cm). A similar trend was observed for the red laser (Table 2), and the highest plant height (207 cm) resulted from 105 s of exposure in 2 mW/cm$^2$ as compared to the control seeds.

**Table 2.** Growth and yield component of maize seeds pretreated with lasers of different wavelength and exposure times.

| Treatments | No. of Row (ear) | Leaf Area (cm$^2$) | Plant Height (cm) | Weight of 300 Seed (g) | Seed Yield (kg/ha) | Harvest Index (%) | Yield Efficiency (g/cm$^2$) |
|---|---|---|---|---|---|---|---|
| | | | Red laser | | | | |
| $L_1T_1S_1$ | 22.5 $^{i,h}$ | 435.0 $^{i,j}$ | 192 $^{g–j}$ | 53.21 $^{a}$ | 4744.57 $^{k}$ | 21.6 $^{a}$ | 12.02 $^{l}$ |
| $L_1T_1S_2$ | 28.5 $^{g}$ | 457.5 $^{f,g}$ | 197 $^{e–h}$ | 52.0 $^{a}$ | 5370.53 $^{i–k}$ | 21.3 $^{a}$ | 12.94 $^{i–l}$ |
| $L_1T_2S_1$ | 22.5 $^{i,j}$ | 397.5 $^{m}$ | 201 $^{b–f}$ | 54.0 $^{a}$ | 5724.33 $^{f–i}$ | 20.9 $^{a}$ | 15.87 $^{a–d}$ |
| $L_1T_2S_2$ | 34.5 $^{d,e}$ | 480.0 $^{c,d}$ | 204 $^{b–d}$ | 55.0 $^{a}$ | 5597.33 $^{h–j}$ | 22.4 $^{a}$ | 12.85 $^{i–l}$ |
| $L_1T_3S_1$ | 31.0 $^{f}$ | 472.5 $^{d,e}$ | 192 $^{g–j}$ | 51.0 $^{a}$ | 5787.83 $^{e–i}$ | 22.9 $^{a}$ | 13.09 $^{i–l}$ |
| $L_1T_3S_2$ | 34.5 $^{d,e}$ | 442.5 $^{h,i}$ | 196 $^{f–i}$ | 52.3 $^{a}$ | 4889.72 $^{j,k}$ | 22.1 $^{a}$ | 12.18 $^{k,l}$ |
| $L_1T_4S_1$ | 30.5 $^{f,g}$ | 412.5 $^{l}$ | 200 $^{c–f}$ | 52.9 $^{a}$ | 6323.07 $^{a–g}$ | 21.7 $^{a}$ | 16.9 $^{a,b}$ |
| $L_1T_4S_2$ | 21.5 $^{j}$ | 450.0 $^{g,h}$ | 207 $^{a}$ | 51.0 $^{a}$ | 6568.01 $^{a–d}$ | 22.3 $^{a}$ | 16.09 $^{a–d}$ |
| | | | Green laser | | | | |
| $L_2T_1S_1$ | 25.5 $^{h}$ | 465.0 $^{e,f}$ | 203 $^{b–e}$ | 54.2 $^{a}$ | 6368.43 $^{a–f}$ | 21.8 $^{a}$ | 15.1 $^{b–h}$ |
| $L_2T_1S_2$ | 29.0 $^{f,g}$ | 427.5 $^{j,k}$ | 199 $^{c–f}$ | 54.8 $^{a}$ | 6286.79 $^{a–h}$ | 20.2 $^{a}$ | 16.21 $^{a–c}$ |
| $L_2T_2S_1$ | 40.0 $^{a}$ | 442.5 $^{h,i}$ | 203 $^{b–e}$ | 53.2 $^{a}$ | 6885.53 $^{a–c}$ | 22.1 $^{a}$ | 16.86 $^{a,b}$ |
| $L_2T_2S_2$ | 37.5 $^{b,c}$ | 472.5 $^{d,e}$ | 189 $^{i}$ | 51.2 $^{a}$ | 5415.89 $^{i–k}$ | 20.7 $^{a}$ | 12.63 $^{j–l}$ |
| $L_2T_3S_1$ | 20.5 $^{j}$ | 472.5 $^{d,e}$ | 190 $^{i,j}$ | 53.1 $^{a}$ | 5660.8 $^{f–i}$ | 20.9 $^{a}$ | 13.21 $^{i–l}$ |
| $L_2T_3S_2$ | 30.0 $^{f,g}$ | 420.0 $^{k,l}$ | 202 $^{b–f}$ | 53.9 $^{a}$ | 6667.8 $^{a–c}$ | 21.7 $^{a}$ | 17.5 $^{a}$ |
| $L_2T_4S_1$ | 28.5 $^{g}$ | 495.0 $^{b}$ | 191 $^{h–j}$ | 51.7 $^{a}$ | 6205.1 $^{c–h}$ | 22.3 $^{a}$ | 13.82 $^{f–l}$ |
| $L_2T_4S_2$ | 26.0 $^{h}$ | 450.0 $^{g,h}$ | 205 $^{a–c}$ | 53.6 $^{a}$ | 5923.9 $^{d–i}$ | 22.2 $^{a}$ | 13.61 $^{g–l}$ |

**Table 2.** *Cont.*

| Treatments | No. of Row (ear) | Leaf Area ($cm^2$) | Plant Height (cm) | Weight of 300 Seed (g) | Seed Yield (kg/ha) | Harvest Index (%) | Yield Efficiency ($g/cm^2$) |
|---|---|---|---|---|---|---|---|
| | | | | Blue laser | | | |
| $L_3T_1S_1$ | 30.5 $^{f,g}$ | 435.0 $^{i,j}$ | 198 $^{d–g}$ | 52.8 $^{a}$ | 5279.8 $^{i–k}$ | 21.8 $^{a}$ | 13.38 $^{h–l}$ |
| $L_3T_1S_2$ | 36.0 $^{c–e}$ | 442.5 $^{h,i}$ | 202 $^{b–f}$ | 53.3 $^{a}$ | 5615.4 $^{g–i}$ | 22 $^{a}$ | 13.99 $^{e–k}$ |
| $L_3T_2S_1$ | 24.0 $^{h,i}$ | 480.0 $^{c,d}$ | 197 $^{e–h}$ | 52.1 $^{a}$ | 5352..3 $^{i–k}$ | 23.1 $^{a}$ | 12.29 $^{k,l}$ |
| $L_3T_2S_2$ | 24.0 $^{h,i}$ | 457.5 $^{f,g}$ | 189.3 $^{i,j}$ | 53.4 $^{a}$ | 6468.2 $^{a–e}$ | 22.8 $^{a}$ | 15.58 $^{b–f}$ |
| $L_3T_3S_1$ | 39.1 $^{a,b}$ | 510.0 $^{a}$ | 211 $^{a}$ | 53.7 $^{a}$ | 7003.4 $^{a}$ | 23.6 $^{a}$ | 15.14 $^{b–h}$ |
| $L_3T_3S_2$ | 38.0 $^{a–c}$ | 517.5 $^{a}$ | 207 $^{a}$ | 55.3 $^{a}$ | 6939.9 $^{a,b}$ | 22.9 $^{a}$ | 14.38 $^{d–j}$ |
| $L_3T_4S_1$ | 29.5 $^{f,g}$ | 435.0 $^{i,j}$ | 200 $^{c–f}$ | 54.9 $^{a}$ | 6232.3 $^{b–h}$ | 21.9 $^{a}$ | 15.79 $^{a–e}$ |
| $L_3T_4S_2$ | 34.0 $^{e}$ | 450.0 $^{g,h}$ | 196 $^{f–h}$ | 51.5 $^{a}$ | 5833.1 $^{e–i}$ | 22.2 $^{a}$ | 15.33 $^{b–g}$ |
| Control | 36.5 $^{c,d}$ | 487.5 $^{b,c}$ | 201 $^{b–f}$ | 52.7 $^{a}$ | 6259.5 $^{b–h}$ | 20.7 $^{a}$ | 14.51 $^{c–i}$ |
| | | | | Interaction | | | |
| L | ** | ** | Ns | Ns | ** | Ns | Ns |
| T | ** | ** | Ns | Ns | ** | Ns | ** |
| S | ** | Ns | Ns | Ns | Ns | Ns | Ns |
| L × T | ** | ** | ** | Ns | ** | Ns | ** |
| L × S | Ns | ** | ** | Ns | Ns | Ns | Ns |
| T × S | ** | ** | ** | Ns | Ns | Ns | ** |
| L × T × S | ** | ** | ** | Ns | ** | Ns | ** |

Laser types: $L_1$ = red, $L_2$ = green, and $L_3$ = blue. Exposure time: $T_1$ = 45 s, $T_2$ = 65 s, $T_3$ = 85 s, and $T_4$ = 105 s. Power density: $S_1$ = 4mW/cm$^2$, and $S_2$ = 2mW/cm$^2$. Means of treatments were compared using the least significant difference (LSD) at $p \leq 0.01$. ** = significant difference at $p \leq 0.01$. a-l = Mean values with the same letters are statistically equal (Fisher's, $\alpha$ = 0.01); Ns = not significant.

The laser treatments also significantly affected the number of rows per ears of maize, as shown in Table 2. Increases in the number of rows per ears for both power densities were noted. The best results (40 rows/ear) were obtained from the exposure time of 65 s at 4 mW/cm$^2$ with the green laser, followed by 85 s at 4 mW/cm$^2$ for the seed irradiated with the blue laser (39.1 rows/ear). The minimum number of rows per ears (20.5) was obtained with green laser at 85 s at 4 mW/cm$^2$. In the case of the leaf area, data in Table 2 showed significant differences when using various lasers and exposure times. A significant leaf size (517.5 and 510 cm$^2$) was obtained by the blue laser for exposure time of 85 s and laser power at 2 and 4 mW/cm$^2$, respectively, whereas the leaf size for the unexposed control plant was recorded as 487.5 cm$^2$.

The present study shows that most of the parameters (number or rows/ear, plant height, leaf area, seed yield, and yield efficiency) were significantly affected, except for weight of 300 seed and harvest index. Yet, low-radiation dose intensity activates the plants, resulting in an increase in the bio-energetic potential of the cells and greater activation of their biochemical and physiological processes, while high doses of irradiation influence the genetic material of cells, causing genetic changes in the plants [39].

A significantly larger leaf area was observed for the plants treated by the blue laser during the harvesting stage due to the increase in the photosynthesis activity, which, in turn, led to an increase in the leaf surface area of maize, as compared to the un-irradiated seeds (control). However, there was no significant effect on the leaf area for the seeds irradiated by various laser treatments. There was also an increase in the number of rows per ears as a result of an increase in the surface area of one leaf or an increase in the number of leaves per plant. In both cases, this led to an increase in the productivity of photosynthesis. Morphological changes in the plants grown from the seeds treated by He–Ne laser light of 50 mW were observed; they were taller and thicker than plants from seeds without irradiation (control), as reported by Srećković et al. [40]. Recently, some research studies were carried out on different light intensities and their effect on phases of plant growth [22,41,42]. Bio-stimulation using He–Ne laser and laser diodes was applied to improve the physiological quality of certain crops [16].

Hence, only a few studies were conducted on the influence of laser light on the formation of physiological indicators of plant productivity; this makes it difficult to compare the results obtained by the present study with the results of other studies. The synergy of simultaneous events that happen when the seed is irradiated by laser light makes the mechanisms of bio-stimulation unclear [23]. Yet, tomato seeds (Solanum *lycopersicum* L.) were studied by applying a laser of 25 mW with exposure times of 5, 10, 20, 30, and 60 s [20]. It was found that the height of the plants showed a significant difference with respect to control (non-irradiated) samples.

Our results were confirmed by Abu Elsaoud and Tuleukhanov [43], whose study found that seeds pretreated with a laser (I = 5 mW/mm$^2$) significantly increased the germination and growth parameters of four wheat varieties after seven days of treatment. Muthusamy et al. [44] applied treatment of low-intensity laser light at different irradiation doses on eggplant seeds (*Solanum melongena* L.) and observed significant changes in later growth stage and yield; the best results were found radiation doses of 25 and 30 mJ/cm$^2$. The highest value of stimulation in the height of the plants was obtained at t = 20 s, with significantly increased growth (stem diameter, root length, and height of plants) for the exposure times of 5, 10, and 20 s [45].

The exposure of maize seeds for 85 s with 2 mW/cm$^2$ power density of blue laser increased the weight of 300 seed (55.3 g); however, compared to the control (52.7 g), there was no significant difference (Table 2). The yield of maize seed (t/ha), as shown in Table 3, exhibited significant differences. In general, using different wavelengths with different exposure times led to an increase in the seed yield. For the blue laser, 85 s of exposure in 4 mW/cm$^2$ had higher yield (7003.4 kg/ha), followed by seeds irradiated with power density 2 mW/cm$^2$ (6939.9 kg/ha), which significantly increased yield compared to control (6259.5 kg/ha). However, the application of different lasers at both powers with different exposure times significantly increased the yield efficiency (g/cm$^2$) for maize seeds (Table 2). As a general trend, increasing exposure time using the green laser led to a remarkable increase in yield efficiency. The maximum yield efficiency (17.5 g/cm$^2$) of different types of lasers was obtained with exposure (85 s) to the green laser for 2 mW/cm$^2$ followed by 16.9 g/cm$^2$ exposure to the He–Ne laser in seeds irradiated for 105 s combined with power 4 mw/cm$^2$. The control (unexposed) group resulted in yield efficiency of 14.5 g/cm$^2$.

The values of the harvest index (%) of maize, as shown in Table 2, showed that all different laser types and the various exposure times resulted in a marked increase in the harvest index, but no significant effect was observed according to statistical analysis. The highest value, 23.6%, was obtained from the third exposure time (85 s) of the blue laser at 4 mW/cm$^2$, as compared to the control group, which exhibited the lowest harvest index percentage (20.7%). The irradiation of the maize seeds by various lasers and exposure times had a significant influence on the harvesting index and yield efficiency. Hence, in the case of the seeds irradiated by the blue laser, an increase in yield was due to a change in other growth and yield-generating features.

Furthermore, Álvarez et al. [22] found that laser bio-stimulation of tomatoes increased the number of flowers, fruits, bunches, polar mean diameter, equatorial mean diameter, weight of the fruits, and yield per plant. However, Sánchez et al. [41] indicated a positive bio-stimulation in bean seeds, which were irradiated by blue laser and obtained an enhancement of 47% in germination as compared to the control sample. Jakubiak and Gdowska [21] found that laser irradiation accelerates the growth and biomass of willow varieties (*Salix* sp.).

Similarly, the effects of the spectral impact of the laser on seed performance were reported [27]; laser irradiation induces a change in the plant development and makes the cell divide faster, which results in faster initial rate of growth and improvement. Therefore, the significant effect of laser light on growth and yield parameters in the present study could have been due to an increase in cell division. Jevtić et al. [9] found that irradiating wheat seeds with laser in dry and humid conditions produced greater yield, as compared to non-irradiated seeds (control). The best efficiency was obtained with the 532-nm laser at two regimes of irradiation, with the effects of bio-stimulation being more evident at a higher salt concentration [46]. Irradiation with laser could be an alternative to control diseases in maize seeds (*Zea mays* L.) and, in this way, could improve the sanitary quality of the seed and possibly of the final product obtained from the plants with seeds treated with a laser. Likewise, Reyes et al. [5] found that, for barley seeds (*Hordeum vulgare* L.), all exposure times showed an improvement in the sanitary quality of the seed. Using a laser diode produced significant statistical differences in germination, as well as in performance, for maize seeds [47].

In the present study, the pre-sowing seeds irradiated with blue (410 nm), red (632.8 nm), and green (532 nm) laser lights had significant effects on the seed yield and the harvesting index characteristics of the plant. The results of seed yield indicated that the blue laser light had a better influence on maize seed than without the light condition (the control experiment), whereas the influence of the blue laser light was higher than the other laser lights used. Long irradiation times and high wavelength can cause considerable damage to the seed structures. Furthermore, laser stimulation is a physical phenomenon that consists of absorbing and storing radiant energy by plant cells and tissues. The same phenomenon can be observed in the case of seeds when they first absorb the radiation energy and then transform it into chemical energy and use it for subsequent growth [48].

The basis of laser stimulation mechanisms in some physiological states of plants is synergism between the monochromatic and polarized laser light beam and the photoreceptors of light. The irradiation effect of the maize sowing seeds stimulates an increase in seed yield. An analysis of the yield structure showed that an increase in maize yield resulted from an increase in row number per ear, which, in maize, is the property that most often changes due to the activity of other yield-generating factors; the number of seeds per ear was the least changeable property. In the bio-stimulation of plants in their different phases of development, three classes of photoreceptors were discovered: phytochromes, phototropins, and cryptochromes. These photoreceptors absorbed different wavelengths, i.e., 600–750, 320–500, and 500–630 nm, respectively [49–52]. One of the hypotheses about the energy absorption by the seeds is that light is absorbed by different crop stages in their life cycle; the light is then transformed into chemical energy, and the seeds use it for their subsequent growth processes [53]. Evidence of thermal changes due to laser irradiation was demonstrated by Hernández-Aguilar et al. [41], where an irradiated maize seed was placed in different containers. They found that the temperature of the seed was modified according to the optical and thermal properties of the seeds; it also depended on the container on which the seed was placed.

A laser with a wavelength of 532 nm and 25 mW of power was applied in soybeans (*Glycine max*), resulting in early emergence during germination when compared with the control group [54]. The vegetative growth of soybean seedlings was significantly higher after laser treatment; the magnitude of the stimulation for seedling growth was a function of the time exposed to laser treatment [17]. Rassam et al. [55] stated that laser treatment could be used to control the fungal infection in wheat seeds and improve their growth and development. Table 3 summarizes the progress of studies on the effects of lasers on maize according to recent studies.

**Table 3.** Presenting the bio-effects of low-intensity laser light in maize seeds.

| Author | Wavelength (nm) | Intensity ($mW/cm^2$) or Power (mW) | Times of Exposition | Finding |
|---|---|---|---|---|
| Srećković et al. [40] | 632.8 | 50 mW | 10 and 1000 s | Morphological changes in the plants with higher, thicker, and larger ears in the case of corn. |
| Hernández-Aguilar et al. [47] | 655 | 4.6 $mW/cm^2$ | 30, 60, 180, 300, and 600 s | Laser irradiation could be an alternative to control diseases in corn seeds. |
| Hernández-Aguilar et al. [56] | 632.8 | 25 mW | 10 and 30 s | Irradiated seeds significantly increased crop yield in some variants. |
| Hernández-Aguilar et al. [49] | 660 | 30 mW | 30, 60, 120, and 300 s | The experimental results indicated that there was bio-stimulation by the interaction of the laser light with the corn seed photoreceptors. |
| Hedimbi and Singh [57] | 650 | 27.4 mW | 20 s | No significant bio-stimulation effects were found for A and B genotypes, and a negative bio-stimulation effect was found for genotype C. |

**Table 3.** *Cont.*

| Author | Wavelength (nm) | Intensity (mW/cm$^2$) or Power (mW) | Times of Exposition | Finding |
|---|---|---|---|---|
| Samuilov and Garifullina [58] | 663 | 40 W | Every two hour | Decrease in the height, diameter of stem, and number of leaves in the plants exposed to laser with the increase in the time of exposure. |
| Hernández-Aguilar et al. [59] | 632.8 | 50 mW | 0.60 s | Effect of laser irradiation on rotational correlation time expressed in seconds in seed endosperm was less pronounced but also led to an increase in probe mobility. |
| Asghar et al. [60] | 650 | 3.04 mW/cm$^2$ | 15, 30, 45, and 60 s | The experimental results showed that the interaction between the laser light and maize seeds affected the carotenoid content in the leaves of seedlings. |
| Present study | 632.8, 532, 410 (combined) | 4 and 2 mW/cm$^2$ | 45, 65, 85, and 105 s | The blue laser significantly increased the morphological parameters and yield component of maize. |

## 4. Conclusions

The effects of different laser wavelengths, exposure times, and low-power-intensity laser irradiation on maize seeds were determined. It can be concluded that the pre-sowing laser treatment of seeds had a positive impact on the growth and development of maize plants. The plants grown from the irradiated seeds by the blue laser at 85 s reached a significantly higher plant height compared to plants grown at different wavelengths and to non-irradiated seeds. The irradiation of the sowing material had a positive influence on the seed yield of maize. An increase in yield was found for the seeds irradiated by the blue laser at 85 s, followed by the green laser at 65 s.

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