
# Protective Role of Selenium on Cucumber (Cucumis sativus L.) Exposed to Cadmium and Lead Stress During Reproductive Stage
## Role of Selenium on Heavy metals Stress



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**Table 1. Effects of Se supplementation on some reproductive parameters in cucumber plants exposed to Cd**

| Cd µm | Se mg/L | First flower node | | First flowering date | | Flower number | | Female/Male ratio | First fertilization node | First fertilization date |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Female | Male | Female | Male | Female | Male | | | |
| 0 | 0 | 8.33abc | 2.66abc | 75.00abc | 67.66bcd | 7.33b | 20.33d | 0.36bc | 9.33ab | 81.33abc |
| | 4 | 7.33cd | 1.66cde | 72.33d | 67.00cde | 8.66b | 19.33de | 0.45b | 6.66cd | 80.000c |
| | 6 | 4.66e | 1.33de | 72.33d | 65.66e | 10.33a | 16.33fg | 0.64a | 5.33d | 80.00c |
| | 8 | 8.00bc | 1.66cde | 74.33bc | 68.00bcd | 5.33c | 25.33c | 0.21d | 7.33bc | 80.33bc |
| 20 | 0 | 9.33ab | 2.66abc | 75.66a | 68.66bc | 4.33cd | 32.00b | 0.13de | 9.00a | 82.66ab |
| | 4 | 7.33cd | 1.33de | 72.66d | 67.33b-e | 8.33b | 21.66d | 0.38bc | 7.66abc | 80.33bc |
| | 6 | 6.00de | 1.00e | 72.33d | 66.66de | 8.66b | 20.33d | 0.43bc | 7.33bc | 80.33bc |
| | 8 | 7.00cd | 2.66abc | 75.00abc | 69.33b | 4.33cd | 30.33bc | 0.14de | 8.00abc | 81.00abc |
| 25 | 0 | 9.66a | 3.00ab | 75.66a | 68.66bc | 2.66e | 34.66a | 0.08e | 9.33ab | 83.00a |
| | 4 | 7.66c | 2.33bcd | 73.33cd | 66.66de | 7.33b | 14.33gh | 0.33c | 8.66ab | 81.33abc |
| | 6 | 7.00cd | 1.35de | 73.66bcd | 66.66de | 4.66c | 17.66ef | 0.41bc | 6.66cd | 81.00abc |
| | 8 | 7.00cd | 3.66a | 75.33ab | 69.00b | 3.00de | 31.33b | 0.09e | 8.33abc | 81.66abc |

The mean values in each column followed by different letters indicate significant differences between treatments according to the Duncan's multiple range test

**Table 2. Effects of Se supplementation on some reproductive parameters in cucumber plants exposed to Pb**

| Pb µm | Se mg/L | First flower node | | First flowering date | | Flower number | | Female/Male ratio | First fertilization node | First fertilization date |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Female | Male | Female | Male | Female | Male | | | |
| 0 | 0 | 8.33bc | 2.66bc | 75.00bcd | 67.66cd | 7.33bc | 20.33c | 0.36bc | 9.33ab | 81.33ab |
| | 4 | 7.33cde | 1.66de | 72.33e | 67.00cd | 8.66b | 19.33c | 0.45b | 6.66cde | 80.00b |
| | 6 | 4.66fg | 1.33de | 72.33e | 65.66d | 10.33a | 16.33cd | 0.64a | 5.33e | 80.00b |
| | 8 | 8.00cd | 1.66de | 74.33bc | 68.00cd | 5.33de | 25.33b | 0.21def | 7.33a-e | 80.33ab |
| 60 | 0 | 10.33ab | 3.33ab | 76.33ab | 73.33ab | 2.66f | 28.00b | 0.09fg | 9.00abc | 81.66ab |
| | 4 | 3.66fg | 1.30de | 73.66cde | 68.00cd | 7.00bc | 28.00b | 0.25cd | 6.33de | 79.66b |
| | 6 | 3.33g | 1.00e | 73.33de | 67.00cd | 8.00b | 13.00d | 0.61a | 6.66cde | 80.00b |
| | 8 | 7.00de | 1.67de | 76.33ab | 66.66cd | 5.00de | 19.66c | 0.25cd | 8.33a-d | 81.00ab |
| 100 | 0 | 11.66a | 3.67a | 76.33ab | 75.00a | 2.66f | 33.33a | 0.07g | 9.66a | 82.33a |
| | 4 | 7.66cde | 2.00cd | 77.66a | 68.33c | 4.00ef | 19.00c | 0.21c-f | 7.00b-e | 81.00ab |
| | 6 | 5.66ef | 1.32de | 75.66abc | 68.00cd | 5.00de | 26.00b | 0.19d-g | 6.66cde | 80.33ab |
| | 8 | 8.00cd | 3.64a | 76.33ab | 74.00ab | 3.00f | 36.00a | 0.08efg | 8.66a-d | 81.66ab |

The mean values in each column followed by different letters indicate significant differences between treatments according to the Duncan's multiple range test

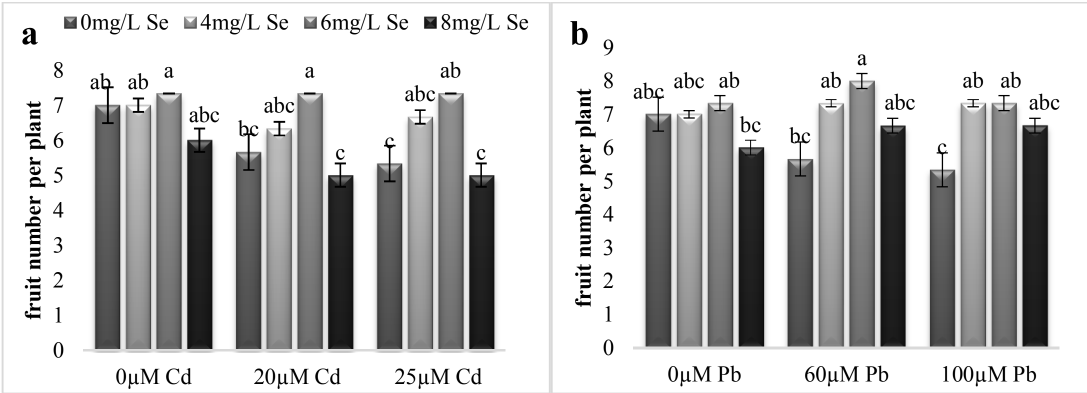


Fig. 1 Effects of Se supplementation on fruit number in cucumber plants exposed to Cd and Pb. The mean values followed by different letters indicate significant differences between treatments according to the Duncan's multiple range test at $p<0.05$.

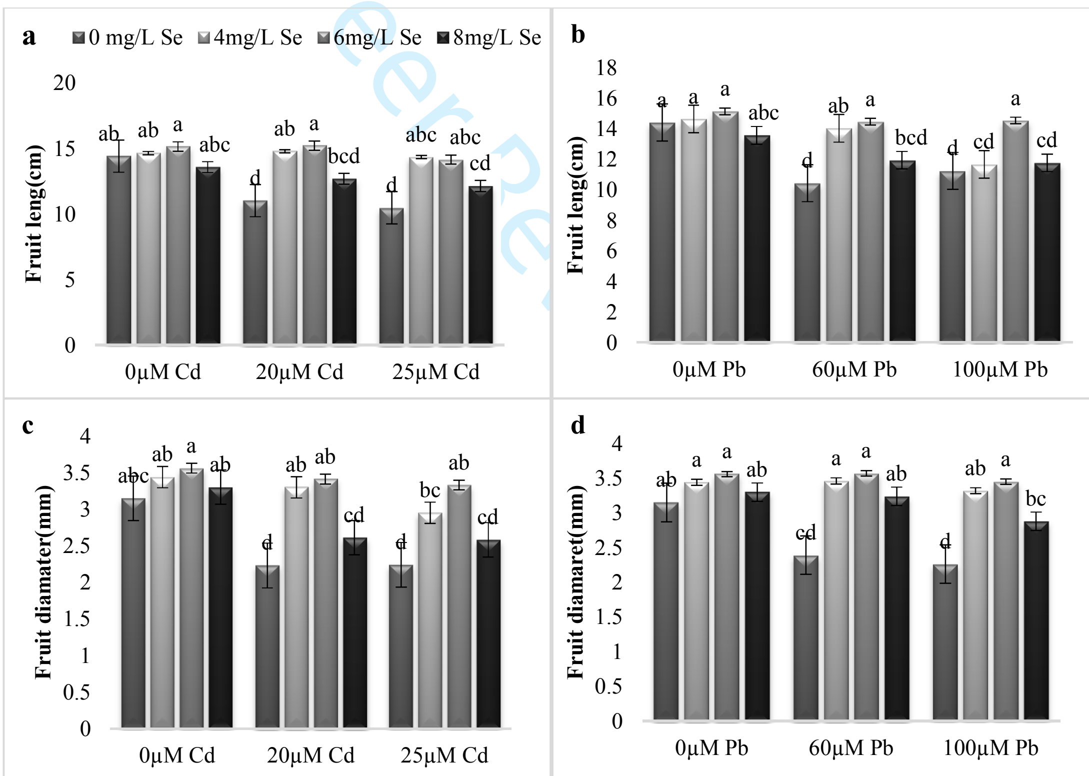


Fig. 2 Effects of Se supplementation on fruit length (a, b) and fruit diameter (c, d) in cucumber plants exposed to Cd and Pb. The mean values followed by different letters indicate significant differences between treatments according to the Duncan's multiple range test at $p<0.05$.

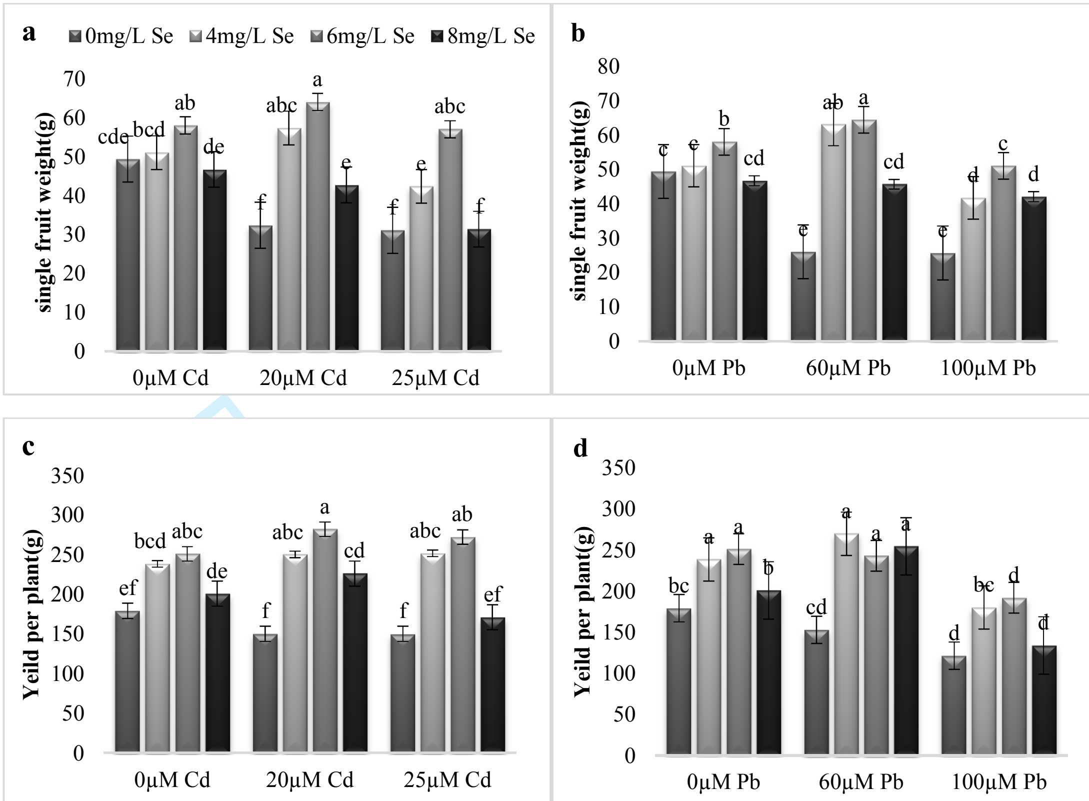


Fig. 3 Effects of Se supplementation on days tosingle fruit weight (a, b), and yeild (c, d) in cucumber plants exposed to Cd and Pb. The mean values followed by different letters indicate significant differences between treatments according to the Duncan's multiple range test at $p<0.05$.

# Protective Role of Selenium on Cucumber *(Cucumissativus* L.*)* Exposed to Cadmium and Lead Stress During Reproductive Stage

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# Protective Role of Selenium on Cucumber *(Cucumis sativus* L.*)* Exposed to Cadmium and Lead Stress During Reproductive Stage

## Role of Selenium on Heavy metals Stress


**ABSTRACT**

The present study aimed to investigate the effect of selenium on flowering indices, sex determination of flowers, and yield of cucumber plant under heavy metal stress conditions. Treatments consisted of selenium (0, 4, 6, 8 $mgL^{-1}$) and heavy metals of cadmium (0, 20, 25 µM) and lead (0, 60, 100 µM), which were applied in three stages during the experiment period. The results of this study showed that the stress of heavy metals with a negative effect on flowering indices resulted in delayed flowering and changing flower's sex toward male flowers. Furthermore, delayed fruiting and significant decreases in fruit growth indices and total yield was observed in plants treated with cadmium and lead. Adding selenium to the culture medium resulted in accelerated flowering (reducing the time and number of nodes needed until the first flower emerges), the emergence of more male flowers, increased the ratio of the number of female flowers to male flowers in plants under stress, and the highest effect of this element was observed at the concentration 6 mg/L. Based on this results, the application of 4and 6mg/L selenium in stress and non-stress conditions enhanced fruiting (a significant reduction in the time required from cultivation to fertilize the first flower and the formation of fruit in lower nodes) and significantly increased the number of fruits, fruit length and diameter, single fruit weight and total yield, and the greatest effect of this element was observed in 6 mg/L concentration. The results of this study showed that selenium has a positive effect on control of stress conditions and improvement of flowering indices and total yield in cucumber plant under the stress of heavy elements of lead and cadmium.


**KEY WORDS:** Selenium, heavy metals, flowering indices, flower sex, yield, cucumber

## 1. INTRODUCTION

Cucumber (*Cucumis sativus* L.) is a widely cultivated plant in the Cucurbitaceae family. The appearance of flower's sex in this plant is affected by many environmental factors such as day length, sunlight intensity, temperature, and vegetative growth regulators and environmental stresses (Kielkowska, 2013).Therefore, cucumber is used as a model plant in many studies to examine the effect of environmental factors on the appearance of flower's sex in monoecious plants.

Flowering is the most important stage in the life cycle of higher plants, which directly affects plant performance (Yung et al., 2012). The plant is interacting not only with environmental conditions (such as light, temperature, and humidity) but also with soil-related factors (such as salinity) and biological factors (such as weeds and pathogens) during its life, all of which cause internal stresses (Levitt, 1980). In addition, environmental stresses such as the presence of toxic concentrations of heavy metals that are added to the soil through human activity can cause stress and serious damage to the plant (Bui et al., 2016; Antoniadis et al., 2017; Rehman et al., 2017). Decreased growth and development and, finally, plant yield are the direct consequences of physiological disturbances in the efficiency of many of the essential systems and processes due to the accumulation of heavy metals in plant tissues (Wu et al., 2015). According to the studies, the toxicity of these elements negatively affects chlorophyll biosynthesis and destroys chloroplast structure, impairs biochemical activity of photosynthesis, impairs mineral absorption and carbohydrate metabolism (Ahmad and Ozturk, 2012; Gratao et al., 2015 ),causes imbalance in the absorption and transfer of essential elements (Saikkonen et al., 1998; Wu et al., 2015), and impairs the synthesis and function of many enzymes and hormones of the plant, which altogether create shortages of energy and hormonal stimuli necessary for plant -reproductive (Luo and Rimmer, 1995). Saleem Khan and Chaudhry (2010) showed that heavy metal stress conditions caused delayed flowering, reduced number of flowers, decreased the number of female flowers, and eventually decreased plant yield in cucumber.

Selenium is a micronutrient with antioxidant, anti-cancer and antiviral properties essential for the health of humans and animals (Pilon-Smits, 2015). Despite the fact that selenium plays an important role in increasing growth, the function and strengthening of the defense system of many crops such as wheat, it is still not considered as an essential element for fruit trees and vegetables. (Nawaz et al., 2015; Thiruvengadam and Chung, 2015; Winkel et al., 2015).

Many studies have shown that application of low selenium increases plant growth and yield (Pilon-Smits, 2015; Soleimanzadeh, 2012).The protective and antioxidant role of this element in reducing many oxidative stresses caused by temperature, drought, salinity, mechanical stress, UV radiation, pathogens and heavy metals have also been addressed by many researchers in recent years (Qing et al., 2015;

Haghighi et al., 2016; Pandy et al., 2015). Studies show that selenium acts as a stress reliever by increasing the antioxidant capacity of the plant through increasing the activity of enzymatic antioxidants (Lin et al., 2012; Saeidi et al., 2014) and non-enzymatic antioxidants (Sharma et al., 2014; Schiavon et al., 2013).

The direct effect of availability and absorption of nutrients by the plant on flowering and sex determination of flowers has been widely accepted among botanists (Harrison, 1956). Selenium can improve the environmental stress conditions (Saffaryazdi et al., 2012; Khoshgoftarmanesh, 2010; Hajiboland and Sadeghzadeh, 2014), increase flowering and ultimately increase plant yield by improving the absorption and transfer of nutrients.

The balance in the synthesis and activity of plant hormones is the most important factor in the appearance of sex in monoecious plants. The synthesis and transfer of cytokinin from roots to shoots are responsible for the emergence of female flowers, and the synthesis of the gibberellin in the leaves is responsible for the emergence of male flowers in these plants (Dellaporta and Calderon-Urrea, 1993). Based on the limited evidence available, selenium can alter the hormonal balance towards an increase in the synthesis and function of the hormones responsible for femaleness in the plant (Soldatov and Khrianin, 2006).

Despite numerous studies on the beneficial effects of selenium in modulating environmental stresses, little research has been done on the effect of this element on the reproductive stage of stressed plants. The present study aimed to investigate the effect of selenium on flowering indices, sex determination of flowers and yield of cucumber plant under heavy metal (cadmium and lead) stress conditions.

## 2. MATERIAL AND METODS

### 2.1. Cultivation and treatments application

This research was carried out for two consecutive years (2016-2017). Treatments included selenium (0, 4, 6, 8 $mgL^{-1}$) from the source of $Na_2SeO_3$, cadmium (0, 20, 25 µM) from the source of $CdCl_2$ and lead (0, 60, 100 µM) from the source of $PbCl_2$. In order to more accurately control the presence and absorption of the elements in the culture medium, the experiment was carried out hydroponically and in 4-liter pots containing peat moss and perlite medium with a 1:1 ratio. During the growth period, the pots were irrigated three times a day, 100 cc per time, with a Hoagland nutritional solution, so that the pot moisture content was kept constant at the farm's capacity. The treatments were applied by giving the solution of selenium and heavy metals simultaneously during three stage of seedling, the emergence of the first flower and formation of the first fruit. In order to prevent the accumulation of elements in the culture, the pots were completely washed with water before each treatment.

**2.2. Recording flowering indices and flower sex determination**

In order to record the flowering indices, the number of days from the beginning of seed planting to the appearance of the first flower on the plant was measured, and the time of emergence of the first male and female flowers, and also the first nod carrying of flowers per plant was recorded separately. Counting the number of flowers from the beginning to the end of the cycle was performed every other day, and the ratio of female flowers to male flowers was calculated using the obtained data.

**2.3. Recording the flower fertilization and fruiting indices**

In order to record the date of the first flower fertilization (fertilization criterion was ovarian growth and drying of petals), the first fertilized node in each plant and then fruit growth indices, the first fertilized flower was identified and marked and after fruiting, its growth was recorded by measuring the length and diameter of the fruit.

During the experimental period fruits were harvested every other day when they reached a minimum length of 10 cm, and the number of harvested fruits was counted up to the end of the production cycle for each treatment and replicate. In order to measure total yield, the weight of harvested fruits was measured at each stage and finally, the final yield was calculated for each treatment. The average single fruit weight of each plant was calculated by dividing the final yield of each plant by the total number of fruits of the same plant.

**2.3. Experiment and statistical analysis**

In order to reduce the error rate due to environmental factors, the test was repeated with the materials and methods for two consecutive years. The mean of the results obtained in the first and second repetitions was considered as the main results of the experiment.

The study was arranged by factorial in base of randomize complete block design with three replications per each treatment, and six plants per repetition. All the data collected were subjected to two-way analysis of variance (ANOVA) and the means were separated for significance by applying the Duncan's least significant difference (LSD) test at $p < 0.05$. The Statistix 10 (Tallahassee FL, USA) software package was used to perform statistical analysis. The results of statistical analysis presented in the table and figures represent the effect of interaction between Cd×Se and Pb×Se.

**3. RESULTS**

**3.1. Flowering indices and flower sex determination**

**3.1.1. Flowering and the emergence of the first flower**

The onset of flowering was delayed by heavy metals and flowering happened in higher nodes (Table 1, 2). Application of 4 and 6 mg/L selenium alone in non-stress conditions reduced the number of nodes until the onset of flowering and led to the early appearance of male flowers. Under cadmium stress conditions, treatment with 6 mg/L selenium caused flowering onset on lower nodes (male flower emergence earlier), while application of 8 mg/L selenium, in interaction with 25μM cadmium, increased the nodes and delayed the appearance of male flowers. Selenium, in all studied concentrations, reduced the time needed for the appearance of male flowers and the formation of male flowers in lower nodes under lead stress, but the effect of this element decreased with increasing lead concentrations.

Application of selenium alone in non-stress conditions reduced the time and nodes needed until the appearance of female flowers. Selenium under the stress of cadmium has a significant effect on the flowering date and appearance of female flowers in lower nodes, despite the higher toxicity of lead than cadmium, the greatest effect of selenium on the emergence of female flowers was observed in treatment 6 mg/L and under 60 µM lead stress conditions.

### 3.1.2. Flower sex appearance (number of male and female flowers)

Application of selenium alone under non-stress conditions, had a significant effect on the number of flowers in all experimental treatments, so that 4 and 6 mg/L selenium treatments decreased and 8 mg/L significantly increased the number of male flowers compared to the control (Table 1, 2). Under the influence of heavy metals, the number of male flowers increased and the highest number of male flowers was observed under the 100 µM lead and 25 µM cadmium treatments. Adding selenium under heavy metal stress conditions reduced the number of male flowers compared to the stress conditions and no use of selenium, except for the 8 mg/L selenium treatment under maximum lead stress conditions (100 µM) that increased the number of male flowers in comparison with the control treatment, as well as the stress conditions and the non-use of selenium.

Treatment of 25 µM cadmium, 60and 100 µM lead resulted in a notable decrease in the number of female flowers compared to the control, but no significant difference was observed between the treatments. Application of low concentrations of selenium alone in non-stress conditions resulted in an increase in the number of female flowers, and the highest effect was that of 6 mg/L treatment, however, increasing the concentration of this element to 8 mg/L caused a significant reduction in the number of female flowers compared to the control. Application of selenium in stress conditions increased the number of female flowers in all experimental treatments compared to the stress conditions and the no use of selenium, however, the greatest effect of this element was in minimum stress conditions.

3.1.3. **Female to male flowers index**

The toxicity of the studied heavy metals resulted in a significant decrease in the ratio of female to male flowers in the treated plants, and with the increase in cadmium and lead concentration led to a more significant decrease in this index (Table 1, 2). The use of 4 and 6mg/L selenium alone in a non-stress condition significantly increased the ratio of female to male flowers, while increasing the concentration of this element to 8 mg/L decreased the index compared to the control treatment. Low levels of selenium in cadmium and lead stress conditions led to a significant increase in the ratio of female to male flowers per plant, and the highest effect of this element was observed in the treatment of 6 mg/L selenium under stress. Despite the higher toxicity of lead than cadmium (in comparison with the same control treatment), reducing the proportion of female to male flowers, selenium and lead interaction had a more significant effect on this index, so that the highest proportion of female to male flower was observed in 6mg / L selenium under the stress conditions of 60μM lead treatment.

3.1.4. **The first flower fertilization**

Application of selenium alone in non-stress condition accelerated the fertilization of the first flower and the formation of fruit in the lower nodes compared to the control (Table 1, 2). The toxicity of heavy metals delayed fruiting in treated plants (the date of fertilization of the first flower and the formation of fruit in higher nodes). Applying selenium under heavy metal stress in all treatments reduced the required time from cultivation to fertilization of the first flower and fruit formation in lower nodes.

2.3. **Fruit indicators and total yield**

**3.2.1. Number of fruits**

Selenium in 6 mg/L concentration (alone) caused a significant increase in the number of fruits per plant compared to the control (Figure 1). As expected, heavy metal stress caused a significant reduction in the number of fruits compared to the control However, there was no significant difference between cadmium and lead toxicity. The number of fruits per plant decreased with increase of heavy metals concentrations. Increasing selenium concentration to 8 mg/L under cadmium stress treatment (20 and 25 μM) reduced the number of fruits in plants compared to the non stress conditions and the absence of selenium. Under lead stress conditions, selenium increased the number of fruits per plant in all concentrations.



**3.2.2. Fruit Length and diameter**

The presence of cadmium and lead in the culture medium significantly reduced the length and diameter of the fruits compared to the control (Figure 2). No significant difference was observed between cadmium concentrations, but increased lead concentration caused a significant decrease in fruit length and diameter. Selenium treatments under cadmium stress in all concentration increased fruit length and diameter compared to the stress conditions and the absence of selenium. Under lead toxicity conditions, adding selenium increased the length and diameter of the fruits compared to the stress conditions and the absence of selenium, and the greatest effect of this element was observed in 6 mg/L concentration.

**3.2.3. Single fruit weight and total yield**

Application of selenium alone Under non-stress conditions increased single fruit weight and total yield per plant in the studied treatments compared to control (Figure 3). The highest effect of this element was observed in 6 mg/L concentration. Increasing the concentration of heavy metals caused a significant decrease in the single fruit weight and total yield compared to the control treatment. Under heavy metals stress, application of selenium increased the single fruit weight and the greatest effect was that of 6 mg/L concentration. The effect of selenium in modulating stress conditions was reduced with increasing the concentration of cadmium and lead.

Addition of selenium in all treatments increased total yield in plants under cadmium stress and the maximum effect was observed in 6 mg/L concentration (Figure 3). Under the toxicity of 60 μM lead treatment, application of all selenium concentrations increased total yield in treated cucumber plants, and no significant difference was observed between treatments. Application of low concentrations of selenium increased the total yield in maximum lead stress (100μM) conditions, while 8 mg/L concentration had no significant effect on reducing stress conditions.

## 4. DISCUSSION

### 4.1. Flowering indices and flower sex emerge

#### 4.1.1. Flowering and the emergence of the first flower

The effect of heavy metals on inhibition of vegetative and reproductive growth has been widely studied over the last 30 years as a well-known plant reaction (Das et al., 1997; Saikkonen et al., 1998; Deckert, 2005; Ali et al., 2016; Antoniadis, 2017). In this study, the onset of flowering was delayed by heavy metals and flowering happened in higher nodes. Salemkhan (2008) also reported delayed flowering and reduced number of flowers in a high concentration of mercury in *Cucurbitaceae* family *(Cucumis sativus* L. and *Momordica charantia* L.*)* which was consistent with the results of the present study. Saikkonen*et al.* (1998) reported that under heavy metal stress, flowering in plant *(Potentilla anserine* L.*)* was severely delayed and significantly decreased or totally disrupted by increased heavy metal concentration in the culture medium. These researchers showed that heavy metals decrease the amount of assimilates and reduce the energy for vegetative and reproductive growth by disrupting the photosynthetic system of the plant. Saleem Khan and Chaudhry (2010) reported a delay in flowering and a significant reduction in the number of flowers in *Cucurbitaceae* family (*C.sativus* and *M.charantia*) under the lead tension and considered that as a result of the effect of heavy metals on hormonal balance in the plant.

The reproduction process requires energy from the beginning of the process associated with flowering until the time of the fruit ripening. Based on the results of this study, applying low concentrations of selenium in cadmium and lead stress concentrations accelerated the beginning of flowering (reducing the number of nodes to the onset of flowering and earlier appearance of male and female flowers). Due to the lack of information on the effect of selenium on flowering indices and based on previous studies, this element can increase the plant vegetative capacity under stress (Hawrylak-Nowak, 2014; Saidi et al., 2014) and thus accelerate the flowering process by positively influencing the control and modification of the damage caused by heavy metal stress (Hawrylak-Nowak et al., 2014; Mozafariyan et al., 2014; Haghighi and Teixeira da Silva, 2016; Sun et al., 2016), improving the performance of the plant photosynthetic system, increasing the rate of photosynthesis and energy production (Malik, 2012; Filek et al., 2010, 2012; SalvaNaz, 2015), improving the absorption and transfer of minerals required by the plant (Lin et al., 2012; Filek et al., 2012; Hu et al., 2014) and improving the enzymatic activity involved in the synthesis and hydrolysis of starch and protein (Jahid et al., 2010).

**4.1.2. Flower sex appearance and the ratio of female to male flowers**

Male flowers increase under stressful conditions and a shortage of energy resources, while female flowers emerge under optimum conditions of resources and assimilates (Dawson and Bliss, 1989). The results of this study showed a significant increase in male flowers and reduction of female flowers and, finally, a decrease in the female/male ratio of plants under cadmium and lead treatment. In a study conducted by Soldatov and Khrianin (2010) lead treatment significantly increased male flowers and decreased the female/male ratio of flowers in three different types of *Marijuana* compared to the control treatment, which is consistent with our *in vitro* results. Measuring the amount of hormones in the treated plant tissues, the researchers found that the presence of lead in the culture, by affecting the hormonal balance, increased the amount of gibberellin, reduced cytokinin, and consequently increased the number of male flowers and reduced the number of female flowers (Soldatova and Khryanin, 2010).

Many studies on the effect of heavy metals on dioecious plants showed a greater resistance of the male plant in tolerating stress and accumulation of heavy metals in plant tissues. Han et al. (2013) reported that lead toxicity had a more negative effect on the female *Populus cathayana* than the male plant. They found that the production of biomass and the rate of photosynthesis in male plants were less affected by stress conditions, which could be due to the effect of hormones on the absorption and inactivation of heavy metals in plant tissues. Chen et al. (2013) reported that the tolerance of male *Populus cathayana* of heavy metal stress was more than the female plant, and that physiological processes in the male plant were less influenced by the accumulation of heavy metals in plant tissues, which is consistent with the results of Jiang et al. (2013). Chen et al. (2013) considered the lower ability of the female plant in suppressing active radicals and more susceptibility to secretion of the ABA hormone under stress conditions due to sex-related responses and hormonal balance in the female plant. Regarding the limited data on the effect of heavy metals on the appearance of sex of monoecious plants, it appears that cucumber plants, under severe stress conditions, use changing the hormonal balance towards increasing the synthesis and activity of male stimulating hormones as a defense mechanism to reduce absorption and transfer of heavy metals and increased resistance to damage caused by the accumulation of these metals in plant tissues.

The results of this study showed that low concentrations of selenium in stress and non-stress conditions had a significant effect on reducing the number of male flowers and increasing the female flowers and increasing the ratio of female/male flowers. Soldatova and Khryanin (2006) reported that selenium treatment affected hormonal balance, and increased the concentration of cytokinin and decreased gibberellin and, as a result, increased femaleness in the *Cannabis* plant. Through its effect on reducing the absorption and transfer of heavy metals in plant tissues, selenium can also improve stress conditions and restore hormonal balance to reduce male flower production and increase the number of female flowers. He et al. (2004) reported that the use of selenium under cadmium and lead stress conditions reduced the absorption and accumulation of heavy metals in the lettuce (*Lactuca sativa* L.) tissue, which was consistent with the results of many researchers (Filek et al., 2012; Lin et al., 2012; Sun et al., 2016).

### 4.1.3. The first flower fertilization

The toxicity of heavy metals delayed fruiting in treated plants (the date of fertilization of the first flower and the formation of fruit in higher nodes). According to recent studies, reactive oxygen species (ROS) created under oxidative stress conditions reduce the yield of plants under stress by reducing pollen germination (Yousefi et al., 2011a), preventing pollen tube growth by damaging pollen cell membrane and the surface of stigma (Zafra et al., 2010; Speranza et al., 2012), causing developmental abnormalities in the anther, ovaries and production of infertile eggs (Yousefi et al., 2011b). On the other hand, the absorption and transfer of heavy metals to the tissue and components of the flower contaminates pollen and flower nectar in addition to damaging the flower structure and reducing the attractiveness of petals and thus reduces pollinator insect visitation with infected plants (Meindl and Ashman, 2014; Meindl et al., 2014).

According to the results of this study, the use of selenium in non-stress conditions and also under heavy metal stress accelerated the fertilization of the first female flower and the formation of fruit in lower nodes than the control treatment. Tedeschini et al. (2013) showed that under the drought stress conditions, selenium worked as an antioxidant, suppresses ROS, and increased the survival and pollen germination, pollination, and fertilization in *Olea europaea*. There have been many reports on the effects of selenium on reducing free radicals and improving heavy metals stress conditions in recent years (Saidi et al., 2015; Malik et al., 2012; Hawrylak-Nowak et al., 2014; Balakhninaa and Nadezhkinab, 2017). On the other hand, selenium reduces the damage to the cell membrane of pollen grains and the surface of the stigma by increasing the absorption of essential nutrients in maintaining cell membrane stability (Barrientos et al., 2012; Hawrylak-Nowak, 2014). Selenium also reduces the absorption and transfer of heavy metals to plant tissues(Filek et al., 2012; Sun et al., 2016) can reduce the damage to petals and accumulation of heavy metals in the pollen, stigma, and flower nectar, thereby attracting pollinator insects and increasing pollination and fertilization of flowers.

### 4.2. Fruit indicators and total yield

According to the results of this study, heavy metal stress caused a significant decrease in the number of fruits, fruit growth indices (fruit length and diameter), single fruit weight and total yield as compared to the control treatment. Chandrashekar et al. (2011) reported that cadmium toxicity significantly reduced the number and weight of fruit in the tomato plant such that no fruit was formed at high concentrations of cadmium.

Hédij et al. (2010) also reported a decrease in fruit yield and total yield in tomato plants under cadmium stress, which was consistent with the results of this study. According to Eun et al. (2000) the effect of heavy metals on plant yield reduction can be attributed to drought and the prevention of food absorption due to an imbalance in the structure of the meristem cells of the root. According to Siddhu et al. (2008) the presence of cadmium in the culture medium reduced the fertility of the pollen, and thus flower loss and reduced fruit formation, and if the fruit was formed at lower concentrations, optimum growth of the fruit was prevented by reduced fertilization and seed formation.

Based on the results of this study, low concentrations of selenium in stress and non-stress conditions increased fruit number, fruit length and diameter, single fruit weight, and total yield. Ekanayake et al. (2015) reported a 10% increase in total yield of lentil under treatment with selenium due to improved plant system photosynthesis. The results of Liu et al. (2010) showed that selenium application significantly increased the size of pear fruit and increased total yield. Yassen et al. (2011) also reported that selenium application increased the growth, function, and quality of the tuber in the potato plant. According to Mozafariyan et al. (2014) applying selenium improved cadmium stress conditions and increased fruiting and total yield, which was consistent with the results of Wu et al. (2016) on cabbage and the results of this study. They considered this as a positive effect of selenium on stimulating growth during plant vegetative period and reducing the absorption and transfer of cadmium to plant tissues.

## 5. CONCLUSION

The yield in farm and commercial varieties of cucumber is variable due to the direct dependence on female/male flowers ratio due to various environmental factors such as environmental stresses. The results of this study showed that the cadmium and lead stress delayed flowering and changing flower's sex toward male flowers in the monoecious cucumber plant with a negative effect on flowering indices and appearance of sex resulted. Also, toxicity with heavy metals delayed the fertilization of the first flower, significantly reduced the number of fruits, fruit growth indices and total yield, which could be due to the negative effect of the transfer of these metals to the tissue and components of flowers, and the reduction of pollination and fertilization of flowers. The use of selenium in heavy metal stress conditions had a beneficial effect on flowering indices and the appearance of more female flowers. Selenium can improve stress conditions and accelerate flowering and increase the female/male flowers ratio per plant with effects on reducing the absorption and transfer of heavy metals to plant tissues. Selenium antioxidant properties under stress conditions can improve pollination and fertilization of produced flowers through suppression of free radicals. Increased fruiting, fruit growth indices and total yield per plant were observed due to the presence of selenium, which could be due to the positive effect of this element on improving the absorption of plant nutrients under stress and non-stress conditions. The results of this study showed that selenium has a positive effect on control of stress conditions, improvement of flowering indices, and total yield in cucumber plant under lead and cadmium stress conditions.



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