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# Silicon in the turgidity maintenance of American lettuce

**Vanessa Cury Galati*, Kelly Magalhães Marques, Cristiane Maria Ascari Morgado, Ana Carolina Corrêa Muniz, Arthur Bernardes Cecílio Filho and Ben-Hur Mattiuz**

Faculdade de Ciências Agrárias e Veterinárias, UNESP - Univ Estadual Paulista, Campus de Jaboticabal, São Paulo, Brazil.

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**This study aimed to verify the influence of silicon application in hydroponics lettuce cv Lucy Brown, on post-harvest under refrigeration. In hydroponic production silicon was used in the doses of 0, 28, 56 and 84 mg $L^{-1}$ of potassium silicate. Lettuces were harvested early in the morning and immediately transported to UNESP, campus of Jaboticabal. Upon being received at the laboratory the plants were standardized in size and appearance, removing the three older leaves. The plants were placed in polystyrene trays (Styrofoam©) and packaged under the temperature at 8±2°C and 80 ± 3% relative humidity. The experimental design was completely randomized with three replications, and two plants per repetition. The fresh matter of shoots was analyzed together with the silicon content in the leaves, the firmness, the fresh matter loss, titratable acidity, pH and enzyme activity of polyphenoloxidize and peroxides. The evaluations were performed every four days, for a total of 16 days of storage. The concentration of 84 mg $L^{-1}$ silicon increased the fresh matter of the plant at harvest and post-harvest, provided less water loss and consequently greater firmness in the leaves during the storage period for lettuce at 8±2°C for 16 days.**

**Key words:** *Lactuca sativa*, hydroponic, potassium silicate, postharvest, enzyme activity, quality.

## INTRODUCTION

Lettuce (*Lactuca sativa*) is a vegetable of significant economic importance in Brazil for being the most consumed leaf in the country (CEAGESP, 2012), especially the American lettuce which is much appreciated *in natura* and used for minimal processing (Henz and Suinaga, 2009). The sales volume of this leafy vegetable in CEAGESP in 2012 was 30,188 tons (Agrianual, 2013). The maintenance of the appearance and the fresh consistency of lettuce is a challenge, since, after harvesting, the exposure to environmental conditions favor the water loss by the product damaging the quality and reducing the shelf life of the greenery (Agüero et al., 2011). Therefore it is important to adopt post-harvest and cultural practices aiming to prolong the commercial quality of the products. Among the pre-harvest factors highlight the mineral nutrition during the production phase, which, together with the cooling practices extend the life span of vegetables.

Recently, the silicon (Si) has been widely used in mineral fertilizer of plants. It is a beneficial element for

*Corresponding author. E-mail: vanessagalati@bol.com.br. Tel: (+55) 16-3209-2675. Fax: (+55) 16-3209-7408.

assisting in maintaining the tissues stiffness, providing greater resistance to pests and diseases attack (Korndorfer 2006; Kiirika et al., 2013). Furthermore, it can reduce water loss by the plant tissues due to deposition of silica on the leaves walls restricting transpiration (Haghighi and Pessarakli, 2013).

The NFT hydroponic system, Nutrient Film Technique or laminar flow of nutrients, has achieved highlight in lettuce production as the favorite among various available systems by the advantages of convenience and efficiency in the production in relation to soil cultivation (Ohse et al., 2001; Lee et al., 2006). In it, the nutrient solution flows over the channels of cultivation, where the roots are lodged, irrigating them and providing oxygen and nutrients to the plants (Staff, 1998), and the management of the solution is performed by monitoring pH, electrical conductivity and chemical composition of the solution.

The maintenance of the product to the optimum temperature for its preservation from harvest to its consumption is probably the most important factor in quality control, since the low temperatures reduce the respiratory rate as well as the microbiological and enzymatic activity, allowing the extension of the life span of the vegetable. Thus, the speed with which the plant loses heat to the environment is clearly related to the increased life span (Rickman et al., 2007).

Studies are needed relating lettuce fertilization to post-harvest technologies, for their conservation and increased life span. Therefore, the aim of this study was to verify the application of silicon in hydroponics and its influence on production and during cold storage of American lettuce 'Lucy Brown'.

## MATERIALS AND METHODS

The experiment was conducted at the Olericulture and Aromatic Medicinal Plants Sector (lat. 21º 14' 38,48" S; long. 48º 17' 12.94"; alt. 553 m) UNESP, Jaboticabal-SP. The cultivation period was characterized by average temperature of 24.6°C, with maximum and minimum of 32.5 and 18.3°C, respectively (Agrometeriological Station, 2013). The seedlings were grown in phenolic foams having dimensions of 2 × 2 × 2 cm, comprising one plant per cell. Then the plates were placed in a greenhouse for germination, emergence, and early seedling growth. The seeding took place on August 20th, 2012. About 10 days after emergence, seedlings were transferred to the nursery corresponding to growth phase, and remaining in hydroponic channels (NFT), with spacing of 5 cm × 6 cm, and recirculation on nutrient solution, where they remained for 13 days. Subsequently, they were transplanted to growth channels, also in NFT for receiving the treatments with increasing silicon doses. The hydroponic structure corresponded to the cultivation channels, represented by polyvinyl chloride tubes (PVC) of 10 cm diameter, cut longitudinally and covered with Tetrapak®, placed on racks with slope steepness of 3% in the channels. The spacing between plants was 25 cm.

The reservoirs of nutrient solution had lids and contained 150 L each of modified nutrient solution proposed by Furlani (1998) for lettuce. The pumps run through automatic operation, daily from 6 a.m. to 6 p.m., with 15-min intervals. The analysis of tap water used to prepare the nutrient solution showed the silicon content of 6.82 mg $L^{-1}$ and pH 7.86. It was used in the nutrient solution the following fertilizers: Calcium nitrate, potassium nitrate, MAP, magnesium sulfate, ammonium nitrate, potassium silicate, boric acid, copper sulfate, manganese sulfate, zinc sulfate, ammonium molybdate and EDDHMA-Fe with 6% of iron. It was evaluated the added concentrations of 0, 28, 56 and 84 mg $L^{-1}$ of Si, using as source the potassium silicate with 10.2% of K (11% of $K_2O$) and 11.7% of Si (25% $SiO_2$). The solutions of all treatments were balanced in order to present the same potassium concentrations. When the level of the solutions in the reservoirs was reduced to less than half, these were replaced. Daily monitoring was conducted for pH (5.5 to 6.5) and electrical conductivity (1.8 to 2.5 Sm $cm^{-2}$) of the solutions. During the growing season there was no incidence of pests and diseases so phytosanitary control was unnecessary.

The experiment was conducted in a randomized block design with four treatments and five repetitions. Each countertop contained four cultivation channels and 20 plants and the borders plants were not discarded.

The harvest was performed on October 17th, 2012 totaling 58 days crop cycle. Lettuces were harvested early in the morning and immediately transported to the Technology Department at the same Institution. Upon being received at the laboratory, not more than two hours after harvest, the plants were standardized in size and appearance, removing the three older leaves to improve homogeneity. The plants were placed in polystyrene trays (Styrofoam ©) and packaged under the temperature of 8°C and relative humidity of 80 ± 3%. The experimental design was completely randomized with three replications, and two plants per repetition. The fresh matter of shoots were analyzed together with the silicon content in the leaves, the firmness, the fresh matter loss, titratable acidity, pH and enzyme activity of polyphenoloxidize and peroxides.

The results were submitted to variance analysis (ANOVA) using the SAS software (SAS Institute Inc.) and the effect of treatments, when significant, submitted to *Test F*. Significant differences between the results were compared using least significant difference (LSD) with 95% confidence interval ($P \leq 0.05$).

## RESULTS AND DISCUSSION

At harvest it was found that lettuce fresh matter increased linearly with the increase of Si in the nutrient solution reaching 493.2 g for lettuces handled at concentration of 84 mg $L^{-1}$ of silicon (Figure 1). Similar results were found by Resende et al. (2007) who observed positive responses with Si spraying in crisphead lettuce, where an increase in commercial and total values on fresh matter was found. The silicon application on different varieties of plants has shown to improve the productivity and quality of vegetable because it provides nutrients to the vegetables, greater turgidity to the leaves, due to less water loss by the plant, since this nutrient tends to accumulate in the leaf epidermis serving as a barrier to water loss through transpiration by the plant (Barker and Pilbeam, 2007).

It was observed that the silicon content in the older leaves and in the new leaves on crisphead lettuce increased according to the increase of Si in the nutritive solution (Figure 2). Voogt and Sonneveld (2001) observed that the silicon uptake in American lettuce was small, and the Si content in plants that received treatment was slightly higher compared to the treatment without Si.

The lettuces stored at 8±2°C treated with 84 mg $L^{-1}$

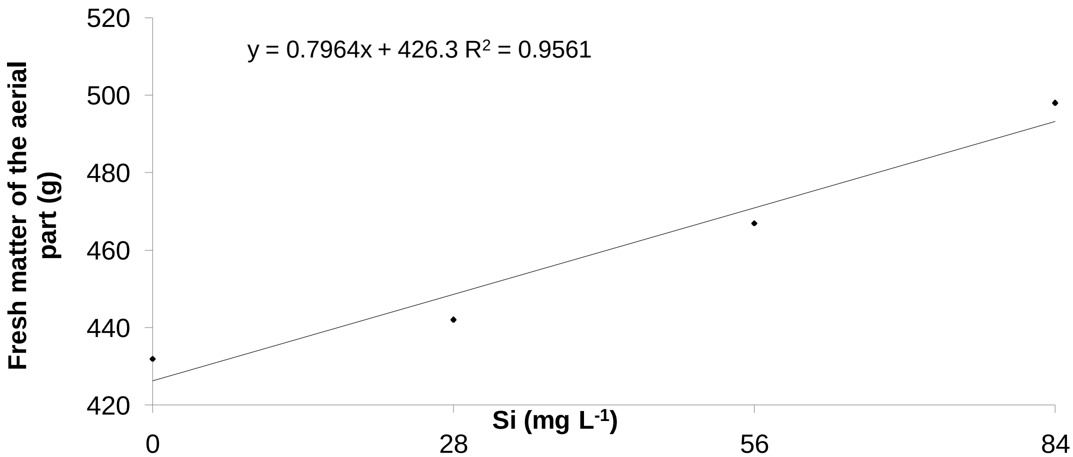


**Figure 1**. Fresh matter of the aerial part (g) of 'Lucy Brown' lettuce due to silicon concentrations (Si) in the nutrient solution.

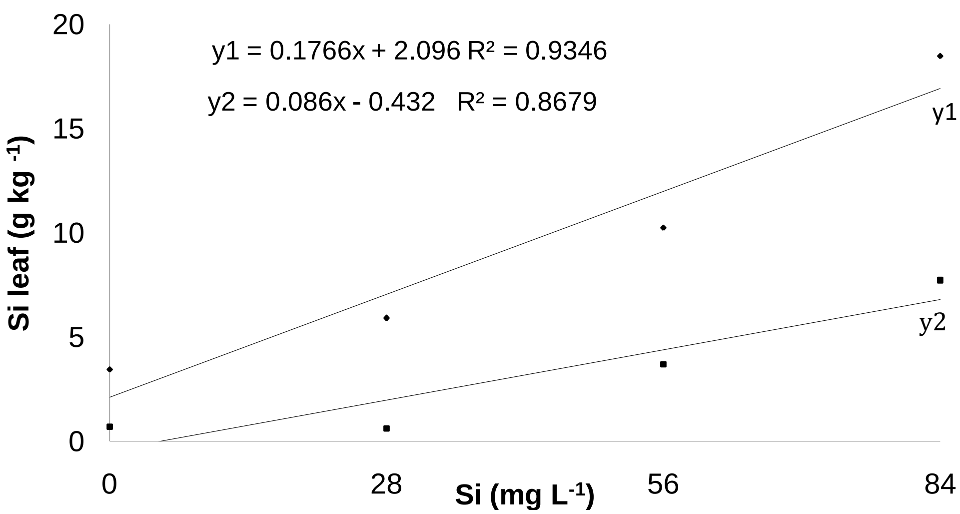


**Figure 2.** Silicon content (g $kg^{-1}$ of dry matter) in the outer leaves of the head (y1) and in the head leaves (y2) of 'Lucy Brown' lettuce as a function of silicon concentrations (Si) in the nutritive solution.

silicon had higher firmness values (Figure 3A). This can be explained by the fact that when vegetable crop begins to lose water, the silicon which is in the form of monossilicic acid is transformed into polysilicic acid, and when polymerize, reduces the flexibility of the walls of the stoma so that they remain closed. In this way occurs reduction of water loss by transpiration, which favors the maintenance of the moisture of the tissues during the storage period, keeping them more turgid (Luz et al., 2006).

The loss on fresh weight was lower in lettuce subjected to treatment with 84 mg $L^{-1}$ of silicon during cold storage (Figure 3B). These data reaffirm that one observed for firmness which allows attributing to silicon the maintenance of turgid, since silicon plays an important role in the structural rigidity of the walls cell (Toresano-Sánchez et al., 2012).

The increase in Si doses may provide less weight loss in vegetables compared to treatments without silicon (Guimarães et al., 2010; Paulino et al., 2013). The loss of fresh matter is mainly by dehydration or perspiration of the vegetable considering the Si is deposited on the epidermis of the plant's tissue it contributes to the reduction of water loss. This shows the importance of silicon in maintaining fresh matter and the post-harvest quality of the leaves, thus representing a possibility for producers and traders to achieve more and more distant markets.

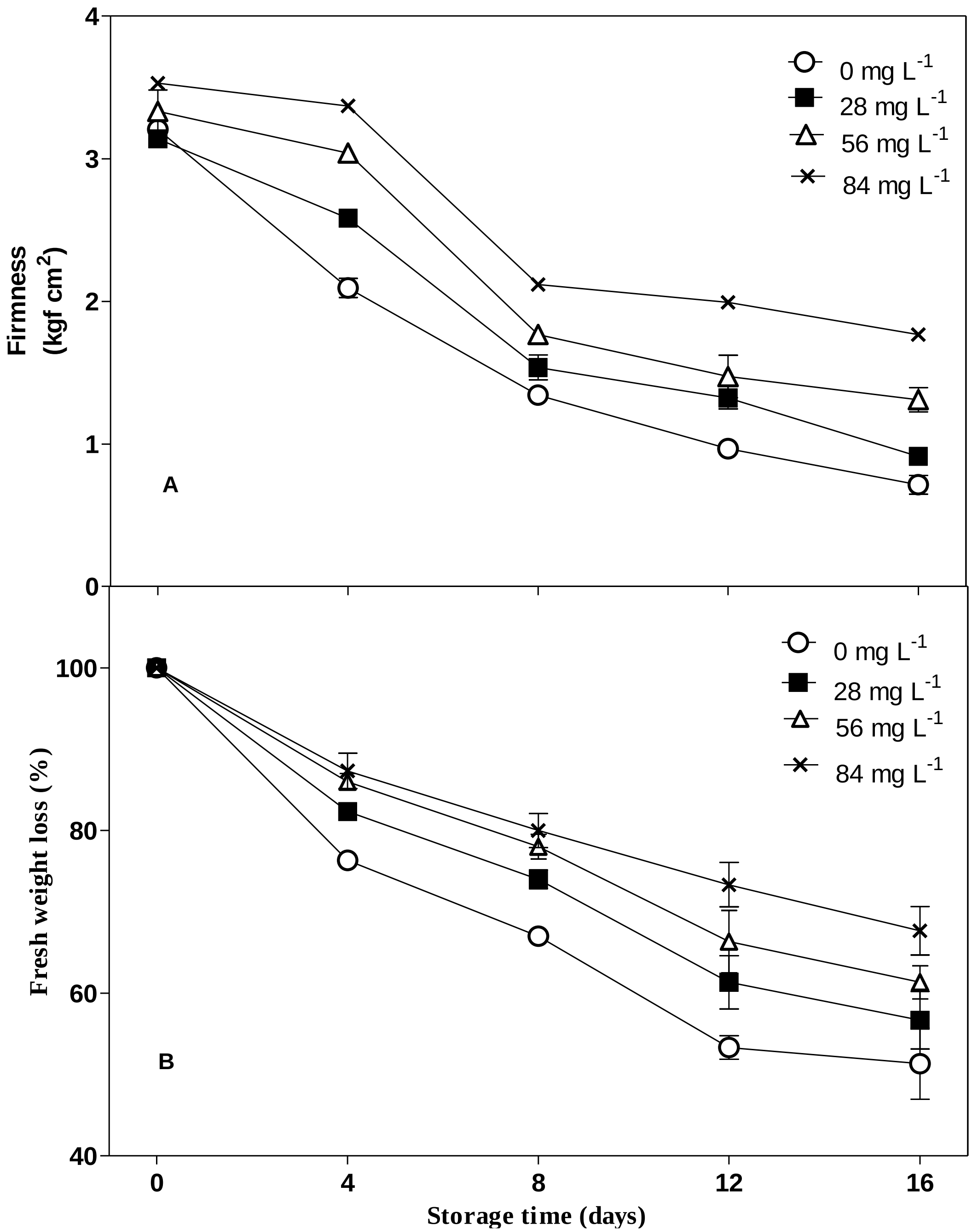


**Figure 3.** Firmness (A) and loss on fresh weight (B) on 'Lucy Brown' lettuce, stored at 8±2°C and 80 ± 3% relative humidity in function of silicon concentration in nutrient solution.

In studies with lettuce 'Lores' submitted to two conditions of optimum relative humidity (95-98%) and low (70-72%), during the storage temperature at 0 to 2°C resulted in fresh matter losses of up to 18% after 5 days of storage for plants subjected to the condition of low relative humidity, while for treatment under optimal conditions of relative humidity that loss was up to 5%, indicating the importance of the relative humidity controlling for the quality of vegetable products (Agüero et al., 2011). The shriveling and wrinkling of the greenery occur due to perspiration which is caused due to the vapor pressure difference that exists between the plant and the environment (Paliyath et al., 2008).

During the storage period at 8±2°C there was an increase in titratable acidity until day 12, followed by reduction, especially in the control treatment (Figure 4A), what is associated with the small variation in pH values in the lettuces throughout the storage period, which showed

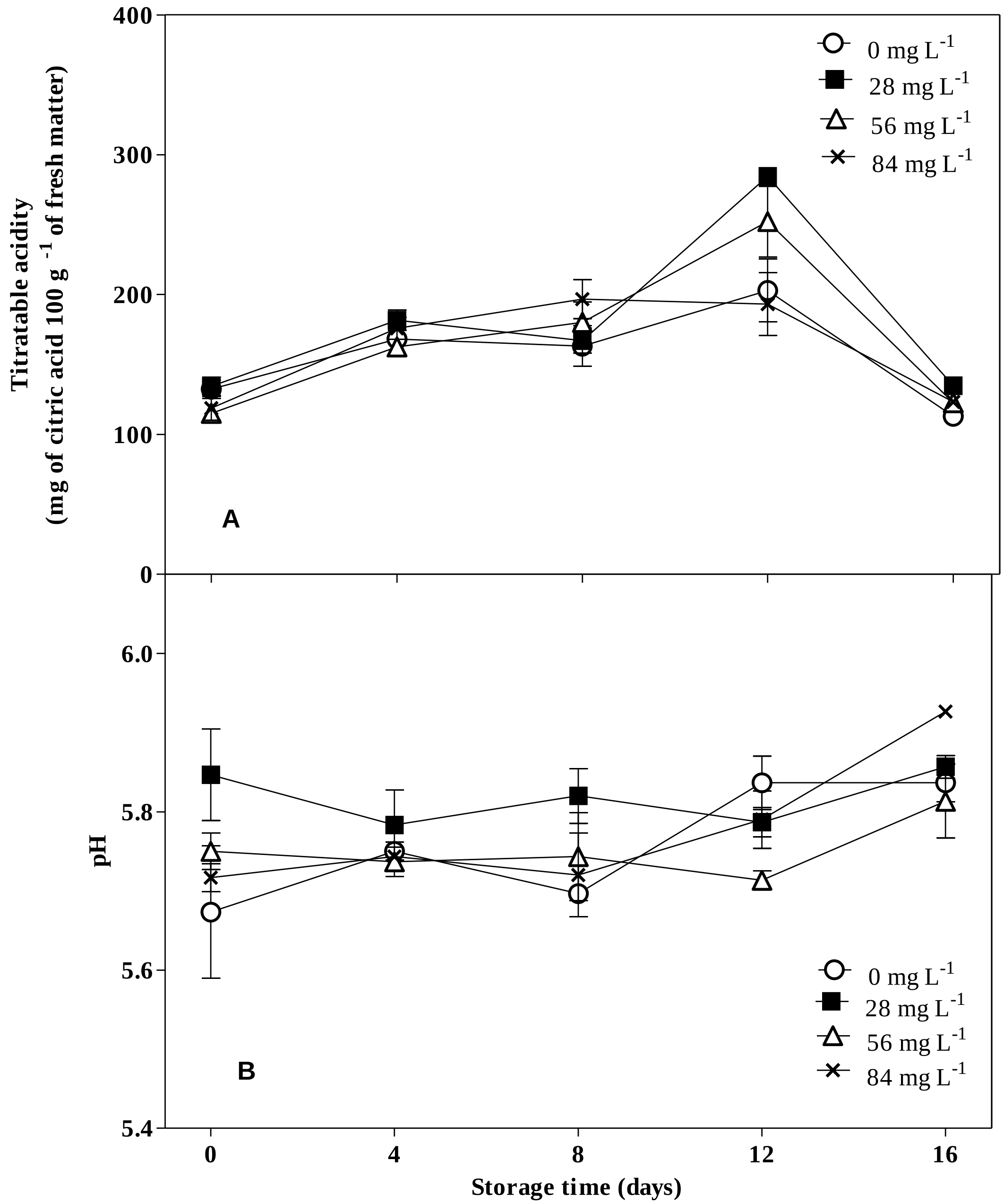


**Figure 4.** Titratable acidity (A) and pH (B) in 'Lucy Brown' lettuce, stored at 8 ± 2°C and 80 ± 3% RH, in terms of silicon concentration in the nutrient solution.

an increase in the values at the end of storage (Figure 4B).

The reduction on the content of organic acids at the end of the storage period was probably caused by the breakdown of starch into reducing sugars and their conversion into pyruvic acid caused by breathing due to the senescence (Chitarra and Chitarra, 2005).

According to Figueiredo et al. (2010) the use of silicon in fertigation on strawberries showed a linear increase in the concentrations of organic acids during storage. These results were similar to those found in this experiment up to 12 days of storage. Morais et al. (2011) storing hydroponic lettuce under refrigeration (7.6 ± 1ºC and 27 ± 5% RH) also found an increase on titratable acidity after four days of storage.

During the storage period it was observed increasing the activity of polyphenol oxidase (PPO) and peroxidase (POD) enzyme on lettuce stored at 8±2°C (Figure 5A and B). It is observed that the control treatment showed higher values for PPO activity in plants at 12 and 16 days, as well as the activity of POD at 16 days, showing that the use of silicon in hydroponics reduced the activity

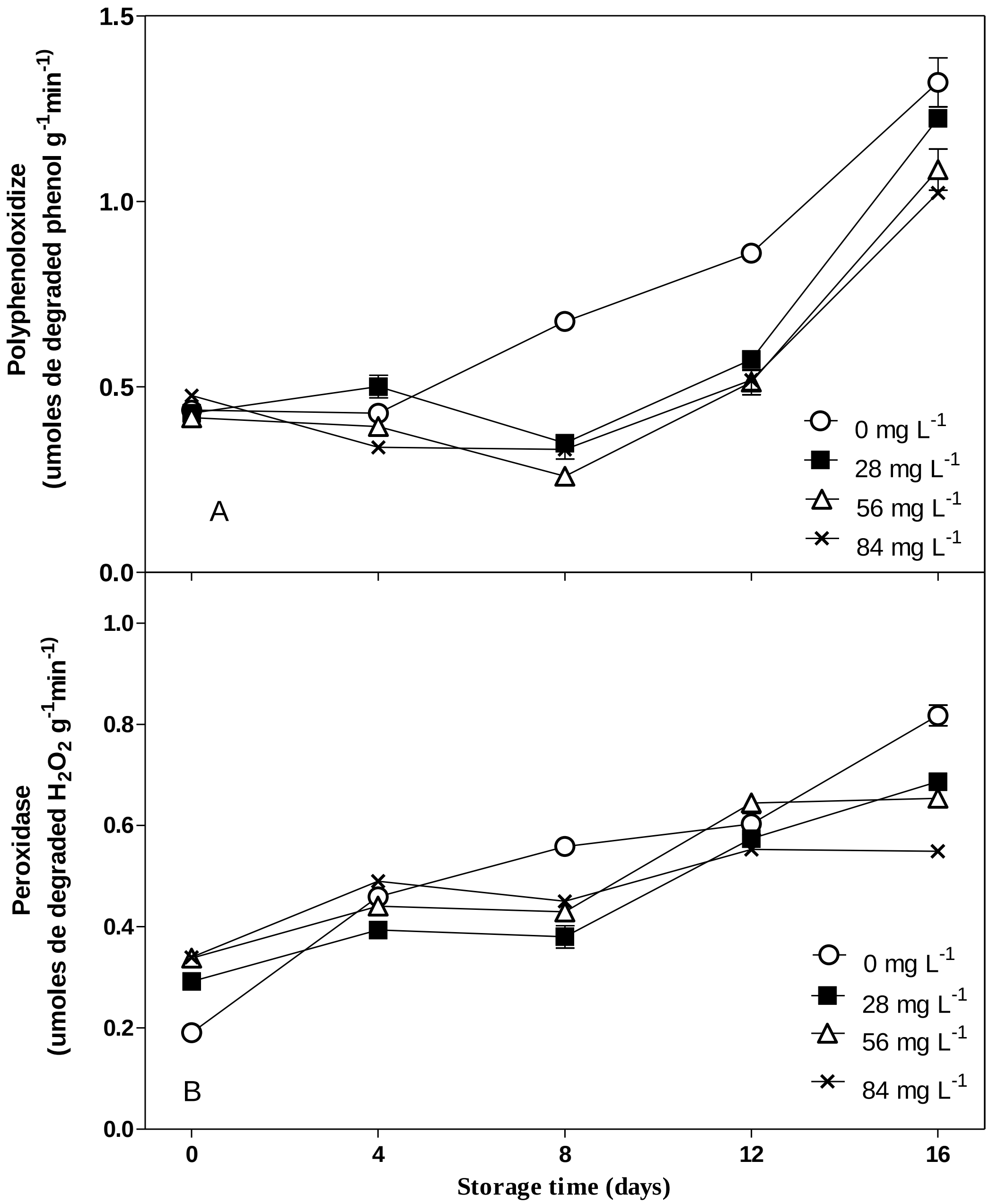


**Figure 5.** Enzymatic activity of polyphenol oxidize (PPO) (A) and peroxidase (POD) (B) on 'Lucy Brown' lettuce, stored at 8°C and 80 ± 3% RH, as function of applied silicon amount in nutrient solution.

of these enzymes.

The increase in enzyme activities and POD PPO indicates that phenolic substrates are being consumed, which causes the browning. PPO catalyses two reactions involving oxygen (Gomes et al., 2001): Hydroxylation of monophenols to ortho-diphenols and ortho-defenóis the oxidation of ortho-quinones while the POD catalyzes the oxidation of phenolic compounds to quinones in the presence of peroxide hydrogen (Dunford and Stillman, 1976).

Abiotic stress, such as low temperatures, was associated with increased activity of enzymes such as polyphenol oxidase in six lettuce varieties grown in different temperatures. Enzymatic browning in lettuce is initiated by oxidation of phenol compounds through polyphenol oxidize activity and peroxidase (Romani et al., 2002).

## Conclusion

The concentration of 84 mg $L^{-1}$ of Si increased the fresh matter of the plant at harvest and post-harvest, provided less water loss and consequently greater firmness in the leaves during the lettuce storage period at 8±2°C for 16 days.

## Conflict of Interests

The authors have not declared any conflict of interests.


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