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Silicate fertilization contributes to the postharvest conservation of lettuce

Adubação silicatada contribui na conservação pós-colheita da alface

Sandro Dan Tatagiba
Doutor em Ciências Agrárias (Fisiologia Vegetal)
Instituto Federal Catarinense – *Campus* Videira, Brazil
sandro.tatagiba@ifc.edu.br

Henrique Rigo
Discente do Curso de Agronomia
Instituto Federal Catarinense – *Campus* Videira, Brazil
henriquerigo1709@gmail.com

Emily Cristina Sarmento
Técnica em Agropecuária
Instituto Federal Catarinense – *Campus* Videira, Brazil *emilycristinasarmento7@gmail.com*

Bruno José Dani Rinaldi
Mestre em Tecnologia de Processos Químicos e Bioquímicos
Instituto Federal Catarinense – *Campus* Videira, Brazil
bruno.rinaldi@ifc.edu.br

Abstract

The importance of silicate fertilization in postharvest conservation has been confirmed in some vegetables, such as radish, arugula and tomato. However, there is still a lack of further information on the effect of this element on postharvest conservation in lettuce. Thus, the objective of this work is to investigate the use of different doses of potassium silicate in the postharvest conservation of curly lettuce, grown in a protected environment. For this, lettuce seedlings, Lactuca sativa L., curly variety, cultivar "Vanda", were cultivated from March 20th to May 5th, 2024, in plastic pots containing 5 dm3 of substrate inside the greenhouse of the Federal Institute of Santa Catarina (Instituto Federal Catarinense), Campus Videira. The plants grew with the substrate kept close to the field capacity until the end of the

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experiment, lasting 45 days. Irrigation control was carried out by the gravimetric method (daily weighing of the pots), adding water until the mass of the pot reached the previous value determined, considering the mass of the soil and water. The application of potassium silicate doses was carried out through a manual sprayer with a capacity of 500 mL and a fan-type nozzle for application. Control plants in which Si was not applied were sprayed with distilled water. The simple foliar mineral fertilizer, potassium silicate (Flex Silicon®), was used at the doses: 0 (Control), 3.0 and 6.0 ml/L of potassium silicate, applied every 10 days after transplanting the seedlings to the pots. The experiment was set up in a completely randomized design, in split-plots in time [0, 3, 6 and 9 days after harvest – storage period], consisting of three doses of silicate fertilization [0, 3 and 6 ml/L of potassium silicate], with four replications. Each experimental unit was composed of a plant packed in low-density polyethylene bags. The plants were conditioned in a vertical refrigeration unit, maintaining an average temperature of 5ºC, for 9 days. The following variables were evaluated: Chlorophyll a, b and total levels; the plant's fresh matter, titratable acidity, pH and postharvest visual quality. The data were submitted to analysis of variance and the treatments were compared by Tukey's test (5% probability), using the R® software program, version 4.3.2. According to the results obtained, it was observed that silicate fertilization contributed to the preservation against oxidative damage, in the maintenance of chlorophyll contents and fresh mass of the plants, providing delay to senescence and, consequently, a better postharvest conservation of lettuce, especially at the dose of 6.0 ml/L of potassium silicate. However, the application of potassium silicate did not affect the titratable acidity and pH of lettuce throughout the storage period.

Keywords: *postharvest physiology, perishability, silicon.*

Resumo

A importância da adubação silicatada na conservação pós-colheita vem sendo confirmada em algumas hortaliças, como rabanete, rúcula e tomate. Porém, ainda há carência de maiores informações sobre o efeito desse elemento na conservação pós-colheita em alface. Assim, objetiva-se com este trabalho investigar o uso de diferentes doses de silicato de potássio na conservação pós-colheita da alface crespa, cultivada em ambiente protegido. Para isso, mudas de alface, *Lactuca sativa* L., variedade crespa, cultivar “Vanda”, foram cultivadas no período de 20 de março a 05 de maio de 2024, em vasos plásticos contendo 5 dm3 de substrato no interior da casa de vegetação do Instituto Federal Catarinense, Campus Videira. As plantas cresceram com o substrato mantido próximo à capacidade de campo até o final do experimento, com duração de 45 dias. O controle da irrigação foi realizado pelo método gravimétrico (pesagem diária dos vasos), adicionando-se água até que a massa do vaso atingisse o valor prévio determinado, considerando-se a massa do solo e de água. A aplicação das doses de silicato de potássio foi realizada através de um pulverizador manual com capacidade de 500 mL e um bico tipo leque para aplicação. Plantas controles nas quais não foram aplicadas o Si, foram pulverizadas com água destilada. Utilizou-se o fertilizante foliar mineral simples, silicato de potássio (Flex Silício®), nas doses: 0 (Controle), 3,0 e 6,0 ml/L de silicato de potássio, aplicados a cada 10 dias após o transplante das mudas para os vasos. O experimento foi montado em um delineamento inteiramente casualizado, em parcelas subdivididas no tempo [0, 3, 6 e 9 dias após a colheita – período de armazenamento], composto por três doses de adubação silicatada [0, 3 e 6 ml/L de silicato de potássio], com quatro repetições. Cada unidade experimental foi composta de uma planta embalada em sacos de polietileno de baixa densidade. As plantas foram condicionadas em uma unidade de refrigeração vertical, mantendo-se a temperatura média de 5ºC, por 09 dias. Foram avaliadas as seguintes variáveis: índices de clorofila a, b e total; a matéria fresca da planta, a acidez titulável, pH e a qualidade visual pós-colheita. Os dados foram submetidos à análise de variância e os tratamentos comparados pelo teste de Tukey (5% de probabilidade), utilizando o programa software R®, versão 4.3.2. De acordo com os resultados obtidos foi observado que a adubação silicatada contribuiu para a preservação contra os danos oxidativos, na manutenção dos teores de clorofila e da massa fresca das plantas, proporcionando retardo à senescência e, consequentemente, uma melhor conservação pós-colheita da alface, principalmente na dose de 6,0 ml/L de silicato de potássio. No entanto, a aplicação de silicato de potássio não afetou a acidez titulável e o pH da alface ao longo do período de armazenamento.

Palavras-chave: fisiologia pós-colheita; perecibilidade; silício.

INTRODUCTION

The lettuce (*Lactuca sativa* L.) is the leafy vegetable with the highest commercial value grown in Brazil, preferably consumed in raw salads and sandwiches, and is appreciated for having anxiolytic properties, with a high content of vitamins A, B and C, as well as calcium, phosphorus, potassium and other minerals (Monteiro *et al*., 2015). In addition, it is a rich source of fiber, iron, folate, ascorbic acid, and other bioactive compounds (Kim *et al*., 2016). The plant has a short cycle, and the main organ consumed, the leaves (Filgueira, 2000).

The main production areas of this crop are concentrated near metropolitan areas, forming the so-called "green belts", due to its short post-harvest life (Henz and Suinaga, 2009), high perishability and low resistance to transport.

One of the main limiting factors in the production chain of this vegetable is related to the loss of quality during commercialization, as it presents a rapid deterioration of its tissues, which can be verified by appearance, sensory quality, nutritional and microbiological value (Azevedo *et al*., 2015). Factors such as temperature, humidity and post-harvest storage period interfere with the plant's respiration, leading to changes in the green color of the leaves and reduced biomass loss, which are essential for conservation and quality in the post-harvest.

An alternative to minimize losses of biomass, water, and leaf color, in order to provide better postharvest conservation of lettuce, is silicate fertilization (Tatagiba *et al*., 2024). The application of foliar fertilizers, containing silicon (Si) in formulation is being increasingly used by rural producers.

Si is the second most abundant element in the Earth's crust, surpassed only by oxygen. In soil, it is found only in combined forms, such as silica and silicate minerals (Epstein, 2006), and is not considered an essential element for plants. However, it stands out as fundamental for contributing to important physiological, biochemical and physical processes of various crops, making it a beneficial nutrient (Korndorfer; Pereira; Camargo, 2002).

The main benefits attributed to Si are related to the improvement of the photosynthetic efficiency of plants, by helping to capture light energy, by obtaining more upright leaves (Lavinsky *et al*., 2016), in the suppression of pests and phytopathogenic microorganisms, inducing metabolic reactions that form compounds, such as phytoalexins and lignin (Tatagiba *et al*., 2014).

Si also enhances the activity of plant defense enzymes (Silveira *et al*., 2021), reducing agrochemical applications, improving the quality of the product consumed. This element acts by benefiting the antioxidative action of plants, in relation to the increase in temperature, reducing the oxidative damage caused by functional molecules such as hydrogen peroxide (Crusciol *et al*., 2009). In addition, Si can stimulate plant growth and production by reducing lodging, due to the greater structural rigidity of the tissues (Epstein, 2006).

In plant organs, Si forms a double layer of silica, causing an increase in the rigidity of the cell wall, reducing transpiration and consequently the loss of water by the plant (Tatagiba; DaMatta; Rodrigues, 2016), contributing to the quality of leafy vegetables, such as lettuce, prolonging the shelf exposure time (Galati *et al*., 2015).

Galati *et al*., (2015) have found beneficial results from the use of Si in lettuce using silitated fertilization, applied via foliar, such as greater firmness of the leaves in minimally processed plants, leaving them more turgid, preserving their useful life. More recently, Gonzaga *et al*., (2020) and Neves *et al*., (2020) have shown that silicate fertilization benefits the increase in fresh and dry matter of lettuce plants, improving vegetative growth. It is evident that the supply of Si via foliar, through small amounts, can be a viable alternative, meeting the need and benefiting the desirable physiological and biochemical processes of lettuce plants. In this sense, in order to support the farmer on the effects of silicate fertilization on the quality of the vegetable, the objective of this work is to investigate the use of different doses of potassium silicate in the postharvest conservation of curly lettuce, cultivar Vanda, grown in a protected environment.

MATERIAL AND METHODS

The study was carried out at the Federal Institute of Santa Catarina (*Instituto Federal Catarinense*) - Videira Campus, located on the SC 135 highway, km 125, Campo Experimental neighborhood, in the municipality of Videira, state of Santa Catarina.

Lettuce seedlings, *Lactuca sativa* L., curly variety, cultivar "Vanda", were grown inside a greenhouse, in plastic pots containing 5 dm^{-3} of substrate, consisting of a mixture of soil extracted from the 0.40 to 0.80 m deep layer of a Dystrophic Red Ultisol and commercial substrate Tropstrato® (Vida Verde, Mogi Mirim, SP) in a 3:1 ratio, respectively. A particle size analysis of the substrate was carried out, obtaining the textural classification as very clayey, obtaining the following proportions: 6% sand, 42% clay and 52% silt.

Substrate samples were chemically analyzed, resulting in good availability of exchangeable bases (SB = 28.1 cmolc.dm^{-3}), base saturation (V = 88.9%) and phosphorus availability (94.8 mg.dm^{-3}).

Before planting, it was not necessary to correct soil acidity (pH = 6.3). Planting and topdressing fertilizations were carried out according to the Manual of Liming and Fertilization for the states of Rio Grande do Sul and Santa Catarina (Comissão de química e fertilidade do solo - RS/SC, 2016).

An experiment was set up in a completely randomized design, in split-plots in time [0 (Harvest time), 3, 6 and 9 days after harvest - storage period], consisting of three doses of silicate fertilization [0 (Control treatment), 3 and 6 ml/L of potassium silicate], with four replications. Each experimental unit was composed of a plant packed in LDPE bags. The post-harvest conservation evaluations were started on day 0 (zero), at the time of harvest, and ended on day 09 (nine), being carried out every three consecutive days, completing 9 days of storage (shelf time).

Nitrogen was supplied in the form of NPK urea (45-0-0), divided into three times (three topdressing applications). Phosphorus (P_2O_5) supplied in NPK (0-18-0) was applied at planting (single dose) and potassium (K_2O) supplied in NPK (0-0-60) applied in the form of potassium chloride (two applications in topdressing). In view of this, in the planting, the following were provided 1.62 g vase-1 of phosphate. Cover fertilization was carried out every ten days after transplantation (DAT) of the seedlings to the pots, providing 0.14 g and 0.12 g of urea and potassium chloride, respectively, in the first top dressing. In the second top dressing, 0.24 and 0.14 g of urea and potassium chloride were given, respectively, and in the third 0.31 g of urea.

After reaching commercial growth, at 45 days, the plants were collected, identified and individually packaged in low-density polyethylene (LDPE) bags, commonly used in the packaging of processed vegetables. Then, they were stored in a vertical refrigeration unit, maintaining an average temperature of 5ºC, for 9 days.

For the establishment of water in the substrate, the water level was used, defined from the total porosity of the soil, with a value above 80% of the total volume of pores occupied by water (field capacity), and the irrigation control was carried out by the gravimetric method (daily weighing of the pots), adding water until the mass of the pot reached the previous determined value, considering the soil and water mass, according to the methodology described by Freire *et al*. (1980).

The application of Si doses on the leaves was carried out through a manual sprayer with a capacity of 500 mL and a fan-type nozzle for application. Control plants where Si was not applied were sprayed with distilled water. Potassium silicate, Flex Silicon®, was used at the following doses: 0 ml/L (Control), 1.5; 3,0; 4.5 and 6.0 ml/L in three applications performed every ten DAT of seedlings for pots (10, 20 and 30 DAT). The product used has an EC (Emulsifiable Concentrate) type formulation, being recommended for lettuce crops, presenting the following water-soluble nutrients in the weight/volume scale: 165.6 g/L of K_2O (Potassium) and Si (Silicon).

In each storage period, the fresh matter of the plant obtained by weighing the commercial fresh mass (leaves and stem) was evaluated, using a semi-analytical electronic balance (Model AD 500S, Marte®).

The content of chlorophylls *a*, *b* and *total* was determined using portable equipment (ClorofiLOG - Electronic Chlorophyll Content Meter, model CFL1030, Falker®). The evaluation was performed optically, keeping the camera of the equipment closed on the sheet for 2 seconds, until two short sound alerts were issued, indicating that the evaluation had been performed. The measurement scale is given by the Chlorophyll Index (ICF) which can vary from 0 to 100.

The chlorophyll contents were determined in each collection period, in the second leaf, from the outside to the inside of the rosette of the plant.

The titratable acidity was determined in each collection period, in duplicate using the sample taken from the second leaf, from the outside to the inside of the rosette of the plant, which were crushed with distilled water in a domestic blender in a proportion of 1:2 (30 g of the sample and 60 mL of distilled water). In the erlenmeyer, 50 mL of distilled water and three drops of 1.0% alcoholic phenolphthalein were added to 10 mL of the crushed lettuce sample. Next, titration was carried out with a previously standardized 0.1 N NaOH solution (Freire et al., 2009). The results were expressed as a percentage (%) of citric acid.

The pH was determined through samples taken from the second leaf, from the outside to the inside of the rosette of the plant, which were crushed with distilled water in a domestic blender in a 1:2 ratio (30 g of the sample and 60 mL of distilled water) (Freire *et al*., 2009). In a 100 mL becker, homogenized material was added and read in a digital potentiometer model (HI 9321 from Hanna Instruments®) calibrated with buffer solutions of pH 4.0 and 7.0.

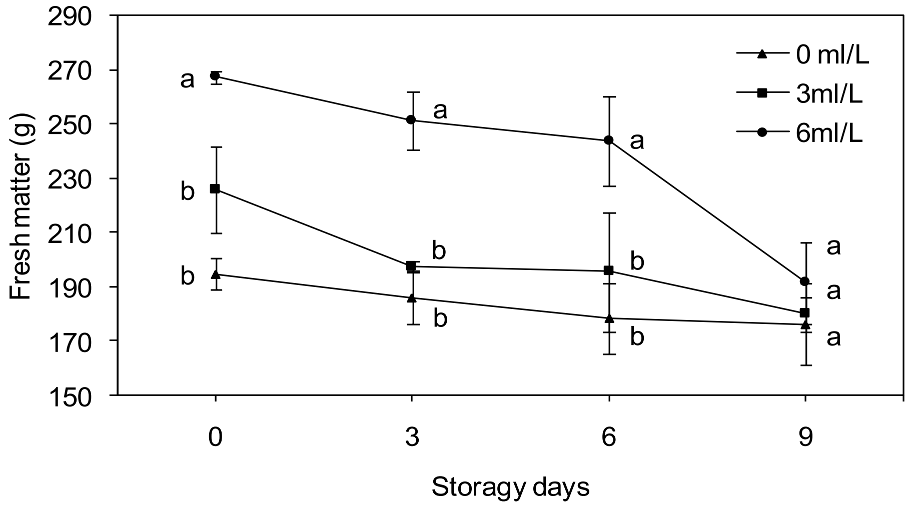
The evaluation of postharvest visual quality was carried out in each collection period, following the criterion of scores according to Feba *et al*., (2017): Grade 0 - heads with only two leaves or less (not in a condition for commercialization); Note 1 - heads with more than 3 deteriorated leaves (still suitable for commercialization); Note 2 - heads with a maximum of 3 deteriorated leaves (suitable for commercialization); Note 3 - Heads suitable for commercialization without deterioration. The attribution of the scores was carried out through the average of four plants per treatment, evaluated in each storage period.

The data were submitted to analysis of variance and the treatments were compared by Tukey's test (5% probability) using the R® software, version 4.3.2.

RESULTS AND DISCUSSION

For the fresh matter of the plants, there was a significant difference between the doses of silicate fertilizer after zero, three and six days of storage. However, no difference was found after 9 days of storage (Figure 1).

Figure 1 - Average values of fresh matter of curly lettuce, cultivar Vanda, minimally processed, submitted to different doses of potassium silicate in a protected environment and stored at 5 °C, for 9 days.



*Means followed by the same letter in each storage period do not differ from each other by Tukey's test (p<0.05). Bars at each point represent the standard error of the mean.

On day 0 (zero) of storage, at harvest, the doses of 3.0 ml/L and 0 ml/L of potassium silicate (Control) showed significant reductions in the mean fresh matter of 15.4 and 27.1%, compared to plants maintained under the dose of 6.0 ml/L of potassium silicate. On the third day of storage, the doses of 3.0 and 0.0 ml/L of potassium silicate provided reductions of 21.3 and 25.9%, respectively, in relation to the plants maintained under the dose of 6.0 ml/L of potassium silicate. After six days of storage, the reductions were 19.6 and 26.8% for the dose of 3.0 and 0.0 ml/L, respectively, compared to the dose of 6.0 ml/L of potassium silicate, showing that silicate fertilization, applied via foliar, can contribute to the postharvest conservation of the fresh matter of lettuce plants, leading to less mass loss. as observed until the sixth day of storage.

Gonzaga *et al*. (2020), using silicate fertilization in the substrate for the production of lettuce seedlings, cultivars Mônica SF31 and Rafaela recommended, more specifically, calcium silicate, as an alternative for better performance in the fresh and dry matter of the aerial part of the plants. The foliar application of Si also increased the fresh and dry matter of the aerial part of lettuce plants in a study carried out by Neves *et al*. (2020), which was related to the function of Si, providing greater structural rigidity of the tissues (Ferreira *et al*., 2010).

Si can accumulate in epidermal cells and stomatal walls in the form of H_4SiO_4 (monosilicic acid). When polymerizing, Si decreases the flexibility of the walls of the stomata and the tendency is for them to remain more closed. With the stomata more closed, transpiration decreases and so does water loss (Taiz; Zeiger, 2024). Thus, the role of Si in postharvest conservation may be linked to the fact that this element participates in the structuring of the cell wall in lettuce plants, increasing the content of hemicellulose and lignin, thus increasing the rigidity of the cell, regulating transpiration and causing the plant to lose less water (Rodrigues, Oliveira, Korndorfer, 2011). Observed fact for the fresh matter of plants maintained at a dose of 6.0 ml/L of potassium silicate until the sixth day of storage (Figure 1).

Regarding the chlorophyll a, b and total index of lettuce plants (Figure 2 - A, B and C), after three and six days of storage, the dose of 0.0 ml/L of potassium silicate showed reductions in the chlorophyll index a of 19.4 and 10.1% compared to the dose of 6.0 ml/L of potassium silicate, demonstrating that during these two storage periods there was a greater conservation of chlorophyll a content in the leaf tissues of the plants (Figure 2A). However, for the chlorophyll b index, no differences were recorded in the means between potassium silicate doses during the entire storage period (Figure 2B). For the total chlorophyll index, differences were observed on the sixth and ninth days of storage (Figure 2C). On the sixth day, there were reductions in total chlorophyll index of 7.9 and 10.1% for the doses of 3.0 ml/L and 0.0 ml/L of potassium silicate, respectively, compared to the dose of 6.0 ml/L of potassium silicate. While for the ninth day of storage, there were reductions of 8.6 and

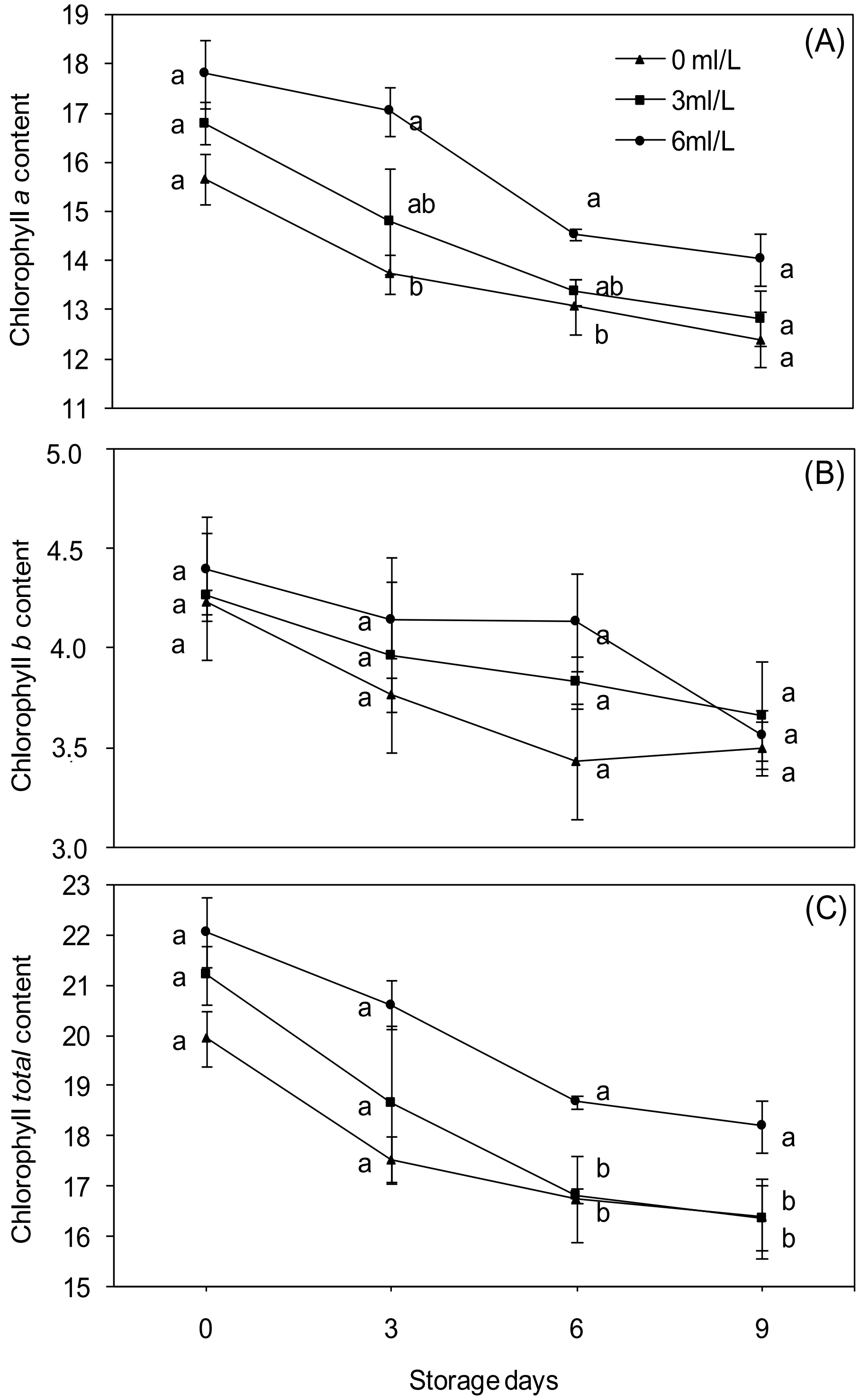
11.6% for the doses of 3.0 ml/L and 0.0ml/L of potassium silicate, respectively in relation to the dose of 6.0 ml/L of potassium silicate, thus indicating that silicate fertilization benefited the postharvest conservation of total chlorophyll levels in lettuce. It is evident that the degradation of chlorophyll during the nine days of storage was significant, and that the use of Si contributed to the maintenance of the green color in the lettuce leaves, being able to be consumed until the end of storage. Results found by Galati *et al*., (2015), studying the application of silicate fertilization in 'Lucy Brown' iceberg lettuce, minimally processed and stored for 16 days, found that the total chlorophyll contents remained stable during the storage period, however, the control treatment (0.0 mg/L of potassium silicate) presented the lowest averages (60 mg of fresh matter), not statistically different from other treatments.

Pigmentation changes are very important for the quality and post-harvest conservation of lettuce. Chlorophyll losses in leafy vegetables are a relevant factor in the quality of minimally processed products during the period in which they are exposed to storage (Silva *et al*., 2007). The chlorophyll content has been used as an indicator of the shelf life of lettuce, as well as the degree of freshness of these products.

Regarding the mean values of titratable acidity (Figure 3), on day 0 of storage, there were differences between the doses. Acidity in vegetables is mainly attributed to organic acids that are dissolved in cell vacuoles, either in free form or combined with salts, esters, glycosides, etc (Chitarra and Chitarra, 2005).

From the third day of storage until the end of the experimental period, no significant differences were found between the mean doses for titratable acidity (Figure 3). The stress caused in the plant due to the cut in minimal processing may have contributed to changes in the enzymatic activity of the cell wall and changes in pH. The reduction of titratable acidity in minimally processed products occurs as a consequence of normal CO_2 metabolism, or in tissue response, by neutralizing the acidity generated by CO_2 during the respiratory process (Galati *et al*., 2015). In minimally processed lettuce, Mattos *et al*. (2007) found a reduction in the content of organic acids during the experimental period, presenting results similar to those found in the present study.

Figure 2 - Average values of chlorophyll index a, b and total in curly lettuce, cultivar Vanda, minimally processed, submitted to different doses of potassium silicate in a protected environment and stored at 5 ºC, for 9 days.

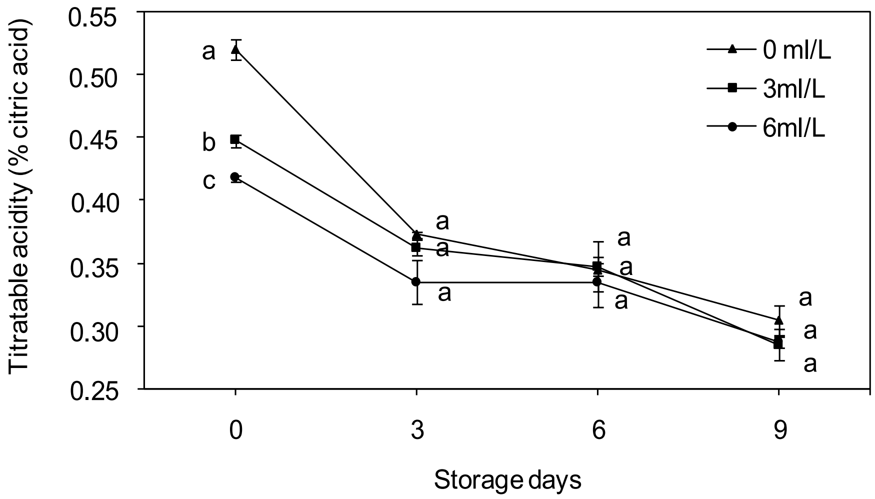


*Means followed by the same letter in each storage period do not differ from each other by Tukey's test ($p<0.05$). Bars at each point represent the standard error of the mean.

For the hydrogen potential (pH), it was found that only on the sixth day of storage there were significant differences. In the remaining periods, 0, 3 and 9 days of storage, there were no significant differences for the mean pH (Figure 4).

Bezerra Neto *et al*. (2006), working with lettuce plants of the cultivar 'Tainá' in intercropping with carrot under the conditions of Mossoró, RN, found a variation in pH from 6.17 to 6.27. For lettuce cultivar 'Iceberg', Bolin and Huxsoll (1991) found average pH values of 6.0. The pH in lettuce can be influenced by environmental and nutritional conditions, and can also vary from cultivar to cultivation. In the present study, the pH varied very little, with minimum and maximum values ranging from 6.5 to 7.3; found at doses of 6.0 and 0.0 ml/L of potassium silicate, respectively.

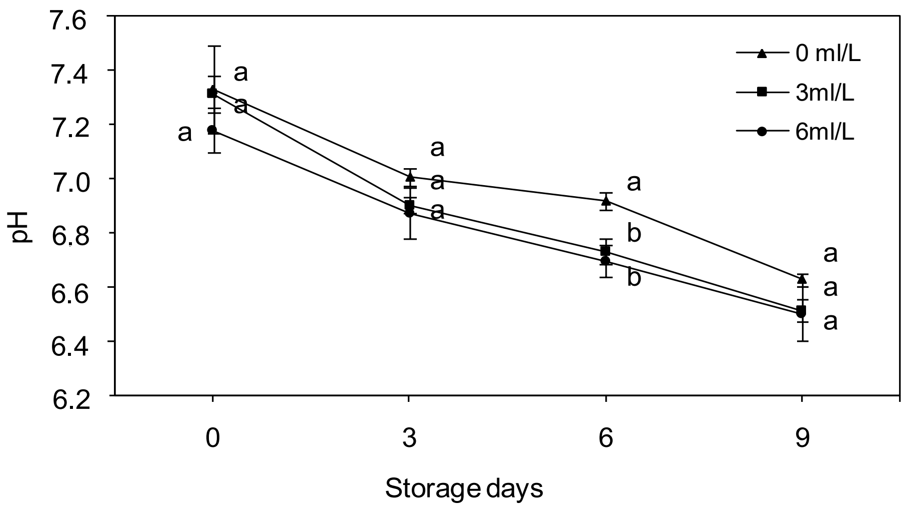
Figure 3 - Average values of titratable acidity (% of citric acid) in curly lettuce, cultivar Vanda, minimally processed, submitted to different doses of potassium silicate in a protected environment and stored at 5 ºC, for 9 days.



*Means followed by the same letter in each storage period do not differ from each other by Tukey's test (p<0.05). Bars at each point represent the standard error of the mean.

Titratable acidity and pH are important variables in the evaluation of the use of foliar silicate fertilization in plants, because when analyzing the level of acceptance of a product by the consumer, if it finds it excessively acidic, it may be rejected.

Figure 4 - Average values of hydrogen potential (pH) in curly lettuce, cultivar Vanda, minimally processed, submitted to different doses of potassium silicate in a protected environment and stored at 5ºC for 9 days.



*Means followed by the same letter in each storage period do not differ from each other by Tukey's test (p<0.05). Bars at each point represent the standard error of the mean.

Analyzing the averages obtained from the visual evaluation of the plants (Table 1), it was noticed that the desirable characteristics were affected throughout the storage period, with a reduction in the averages in the scores in all treatments. In addition, in the doses where potassium silicate was applied (3.0 and 6.0 ml/L) the averages were higher than the control treatment (0.0 ml/L) on the third, sixth and ninth days of storage, confirming that silicate fertilization apparently benefited the postharvest conservation of lettuce. This may have contributed to the better visual evaluation of the plants. However, at the control dose (0.0 ml/L of potassium silicate), there was a slightly faster deterioration of the tissues, leading to leaf wilting and depreciation of the appearance of the plants from the third day of storage.

Thus, we can conclude that silicate fertilization contributed to the preservation against oxidative damage, in the maintenance of chlorophyll levels and the fresh mass of the plants, providing a delay to senescence and consequently a better postharvest conservation of lettuce, being able to extend the shelf life at the dose of 6.0 ml/L of potassium silicate. However, the application of potassium silicate in general did not affect the titratable acidity and pH of lettuce throughout the storage period.

Tabela 1 – Programas de Pós-Graduação do Campus de Engenharias e Ciências Agrárias/Ufal

Potassium silicate concentration (ml/L)	Storage days			
	0	3	6	9
	Grades			
0.0	3.0	2.7	2.0	1.7
3.0	3.0	3.0	2.3	2.0
6.0	3.0	3.0	2.5	2.0

FINAL CONSIDERATIONS

Thus, we can conclude that silicate fertilization contributed to the preservation against oxidative damage, in the maintenance of chlorophyll levels and the fresh mass of the plants, providing a delay to senescence and consequently a better postharvest conservation of lettuce, being able to extend the shelf life at the dose of 6.0 ml/L of potassium silicate. However, the application of potassium silicate in general did not affect the titratable acidity and pH of lettuce throughout the storage period.

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