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Hydrocooling efficiency on postharvest conservation and quality of arugula

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ABSTRACT

Arugula is mainly cultivated by small producers, being a leafy vegetable susceptible to water loss and wilting after harvest, which may result in changes in appearance, texture, color (yellowing), and nutritional value of the product. Hydrocooling is a cooling method that stands out for being simple, practical and efficient. Its use is to reduce the temperature and respiratory rate of vegetables after harvesting by immersion in ice or cold water, so they can be packed and stored. This study was conducted to evaluate the hydrocooling efficiency when associated with the storage period in the postharvest shelf life of arugula leaves. Arugula leaves were subjected to ten days of storage, and measurements were taken at 0, 2, 4, 6, 8 and 10 days. The experimental design was completely randomized in a 3×6 factorial scheme, consisting of three hydrocooling treatments [control (without cooling), and hydrocooling at 0 °C and 10 °C] and for six storage periods (0, 2, 4, 6, 8 and 10 days) with three replicates. Fresh mass loss, soluble solids, titratable acidity, pH and subjective evaluation of product appearance were measured. Hydrocooling at 0 °C proved to be the most appropriate treatment when compared to control, as reported by the values of fresh mass loss, soluble solids, and titratable acidity. Hydrocooling to 0 °C slowed leaf water loss (lower respiratory rate) and resulted in better overall leaf appearance up to the sixth day of storage, thereby increasing shelf life of arugula leaves.

Keywords: *Eruca sativa*, Storage, Cooling.

Eficiência do hidroresfriamento na conservação e qualidade pós-colheita de rúcula

RESUMO

A rúcula é cultivada principalmente por pequenos produtores, sendo uma hortaliça folhosa herbácea anual, suscetível à perda de água e murcha após a colheita, acarretando mudanças na aparência, no metabolismo, e consequentes alterações na cor e qualidade nutricional do produto. O hidroresfriamento é um método que se destaca por ser simples, prático e eficiente; sua utilização consiste no uso de água gélida para baixar a temperatura das hortaliças antes de serem embaladas e refrigeradas. O objetivo deste trabalho foi verificar a eficiência da utilização do hidroresfriamento associado ao período de armazenamento da vida útil pós-colheita das folhas de rúcula. As rúculas foram submetidas a dez dias de armazenamento, sendo avaliadas nos seguintes tempos: 0, 2, 4, 6, 8 e 10 dias. O delineamento foi inteiramente casualizado em esquema fatorial 3 x 6 (sem hidroresfriamento, com hidroresfriamento a 0 °C e a 10 °C e 6 tempos de armazenamento: 0, 2, 4, 6, 8 e 10 dias) com 3 repetições. Foram realizadas as seguintes avaliações: perda de massa, sólidos solúveis, acidez titulável, pH e avaliação subjetiva da aparência do produto. O hidroresfriamento a 0 °C demonstrou ser o tratamento mais satisfatório em relação à testemunha sobre a perda de massa fresca, sólidos solúveis e acidez titulável, pois retardou a perda de água e obteve a melhor aparência geral das folhas até o sexto dia de avaliação, aumentando assim a vida útil de prateleira das folhas de rúcula.

Palavras-chave: *Eruca sativa*, Armazenamento, Resfriamento.

1. Introduction

Arugula (Eruca sativa) is an annual leafy vegetable belonging to the Brassicaceae family, small in size and relatively thick leaves. The plant has a very characteristic pungent flavor, and its leaves are appreciated because of its high nutritional value. It is rich in vitamins A and C, potassium, sulfur, and iron, having anti-inflammatory effect in the intestine and detoxifying effect on the human organism (Pelá et al., 2017).

Leafy vegetables, such as arugula, are susceptible to water loss and wither after harvest, which can cause changes in appearance, metabolism, and consequently changes in color and nutritional quality of the product. After harvesting, plant organs continue to have active respiration and transpiration metabolism, and consequently, the leaves lose water, freshness, and turgidity. Through the transpiration, water loss from leaves results in qualitative and quantitative losses of vegetables (Finger et al., 2008; Taiz and Zeiger, 2009).

Postharvest quality of leafy vegetables can be measured by analyzing a set of attributes or characteristics that determine them as appreciable food (Chitarra and Chitarra, 2005). The evaluation of vegetable conservation capacity has been performed to determine the efficiency of conservation methods concerning the protection of vegetables against oxidation and loss of commercial and nutritional value. The postharvest quality parameters used are physical, such as fresh mass loss, color and appearance, and chemical parameters such as soluble solids, pH and titratable acidity (Mendonça et al., 2015).

Refrigeration is a process that has great benefits for the conservation of leafy vegetables, especially in tropical climate countries, such as Brazil. Rapid cooling methods are considered extremely important and efficient postharvest treatments to maintain the quality of fruits and vegetables, increasing their shelf life. There are different methods for improving food conservation through refrigeration, such as using forced air, cold water, ice, and vacuum cooling (Teruel, 2008).

Hydrocooling is a cooling method consisting of the use of ice or cold water and is a conservation method that stands out for being simple, practical, and efficient for reducing the temperature of the vegetable before it is packed and refrigerated. This method removes heat from freshly harvested products in the field and is designed to slow metabolism and reduce product deterioration (França, 2015).

Studies that evaluated the effect of hydrocooling on some leafy vegetables showed satisfactory results, which showed delayed visual wilting, increased shelf life and reduced water loss in lettuce leaves (França et al., 2015), welsh onion (Travassos et al., 2017) and basil

(Teixeira et al., 2016). However, this information for arugula crop is unknown.

Postharvest loss control methods are employed to slow or minimize deterioration processes of the products through different storage methods, transport, and treatment techniques, and hydrocooling is an advantageous method for fresh vegetables (Teixeira et al., 2016). This study aimed to evaluate the hydrocooling efficiency when associated with the storage period in the postharvest shelf life of arugula leaves.

2. Material and Methods

The experiment was carried out at the State University of Goiás (UEG) in June 2018. Arugula leaves were harvested early in the morning in a commercial vegetable production area located in the municipality of Ipameri, GO, Brazil, and transported to the Post Harvest Technology Laboratory. The leaves used in the research were previously selected, and leaves with physical and physiological defects were discarded. The leaves were then disinfected in a sodium hypochlorite solution containing 100 mg L^{-1} of active chlorine, where they were soaked for three minutes. After this procedure, the leaves were dried in an environment with temperature and relative humidity of 28 °C and 35%, respectively.

The arugula leaves were divided into 20-gram samples and then subjected to the following treatments: control (without cooling), hydrocooling at 0 °C for 5 minutes (H 0°C), and hydrocooling at 10 °C for 5 minutes (H 10°C). The hydrocooling was performed by immersing the leaves in the mixture of cold water and ice at a 1:3 ratio (v:v) at 0 °C and 10 °C for 5 minutes. Temperature control was performed with the aid of a digital thermometer (model TP-101).

After the hydrocooling treatments, the samples were placed in expanded polystyrene trays, covered with polyvinyl chloride (PVC) film, and immediately stored at 8.5 °C (± 2 °C) and 90% relative humidity in a refrigerator, which simulates the conditions found at the point of sale.

Every two days, the postharvest quality parameters of the arugula were evaluated: fresh mass loss, soluble solids, titratable acidity, pH, and subjective evaluation of product appearance. Arugula samples were stored for ten days.

Fresh mass loss (FML) was determined using a semi-analytical balance (model S5201 with accuracy of 0.01g) using the following equation proposed by França et al. (2015): FML (%) = [(IFM − FFM) × 100]/IFM, where IFM is the initial fresh mass of leaves and FFM is the final fresh mass of leaves.

Measurement of soluble solids, titratable acidity, and pH was performed following the Adolf Lutz Institute Analytical Standards and the Official Methods of AOAC International (Oliveira et al., 2015b). Soluble solids (SS) were determined through the juice of 10 grams of macerated leaves using a manual refractometer (model RM-T32, 0-32% BRIX), and the results were expressed as °Brix. The pH was determined by direct reading of the homogenization with the addition of distilled water, using a pH meter calibrated with 4.0 and 7.0 buffer solution. The titratable acidity (TA) was determined by titration with 0.1 M NaOH solution, obtained by homogenizing 10 g of macerated arugula leaves in 10 mL of distilled water and 10 drops of phenolphthalein as indicator solution, and the results were expressed as a percentage of citric acid (% of citric acid). The SS/TA ratio was obtained through the ratio of soluble solids (SS) and titratable acidity (TA) measurements.

Subjective evaluation was determined by the adapted methodology of Feba et al. (2017). Scores were assigned during the storage period, according to the general appearance criteria, using an evaluation index (Scores) ranging from 1 to 3, where, (3) maximum commercial value, (2) darkening, and initial wilting signs, (1) not feasible for marketing. The experimental design was completely randomized in a 3×6 factorial scheme, consisting of three hydrocooling treatments [control (without cooling), and hydrocooling at 0 °C and 10 °C] and for six storage periods (0, 2, 4, 6, 8 and 10 days) with three replicates. Data were subjected to analysis of variance and means compared by Tukey test at 5% probability level. Regression analysis was used for storage periods, and significant equations (F-test; p ≤ 0.05) with the highest coefficients of determination were adjusted. The statistical program used was SISVAR 5.1, version 5.6 for Windows (Ferreira, 2011).

3. Results and Discussion

Analysis of variance reported significant effects (p <0.05) of hydrocooling and storage period on fresh mass loss, soluble solids, and soluble solids/titratable acidity ratio (SS/TA) of arugula leaves (Table 1). There was no significant interaction between hydrocooling and storage periods for these variables. However, significant effects of interaction between hydrocooling and storage periods were reported for pH and titratable acidity.

Hydrocooling at 0 °C had a lower of fresh mass loss during storage, with a loss of 25.93%, followed by hydrocooling at 10 °C with 31.16%, and a without hydrocooling treatment with a loss of 33.51% (Table 1).

Postharvest storage caused an increase in fresh mass loss of arugula leaves throughout the storage period, regardless of the use of hydrocooling. Data were adjusted to a quadratic regression model, and the maximum fresh mass loss point was 44.45%, which was obtained with a storage period of 8.6 days (Figure 1). The loss of fresh mass in vegetables is represented by the decrease in fresh weight over the storage period of the product. There was variation due to the storage period, regardless of the hydrocooling treatment.

Hydrocooling at 0 °C and 10 °C improved the arugula shelf life compared to the control treatment by presenting leaves visually without signs of senescence, an essential factor for consumer acceptance. According to Álvares et al. (2010), the maximum acceptable level of weight loss for vegetables varies depending on the species and the level of consumer market demand. For most fresh vegetables, the maximum weight loss observed without surface wilting or wrinkling ranges from 5 to 30%. Similar results to those presented here were obtained by Oliveira et al. (2015a) in coriander and by França et al. (2015) in parsley, which showed that hydrocooling reduced the loss of fresh leaf mass during the storage period. These results proved the importance of using hydrocooling in order to preserve the food safety of vegetables.

With the advancement of the normal senescence process, there is a tendency for an increase in soluble solids content, a situation compatible with that found in this study, in which the soluble solids (SS) content in arugula leaves increased with the senescence of leaves, due to greater degradation and accumulation of sugars. In this study, it was observed that the treatment without hydrocooling had the highest SS content compared to the treatments with hydrocooling.
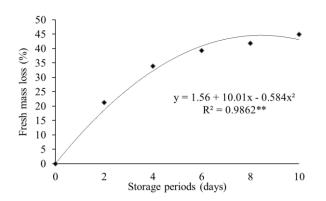
The hydrocooling at 0 °C and 10 °C presented SS values of 4.38 °Brix and 4.33 °Brix, respectively (Table 1), which may be related to lower fresh mass loss when compared to treatment without hydrocooling, and these results confirm those obtained by Nascimento et al. (2017) on lettuce leaves. According to Chitarra and Chitarra (2005), the soluble solids content tends to increase with the advancement of senescence. Thus, the use of hydrocooling on arugula leaves promoted a containment in advance of soluble solids content.

For the pH, there was significant interaction between the hydrocooling treatments and storage time, and the values had little variation, but with special effect during the storage period. Arugula leaves initially presented pH values ranging from 4.86, 4.75, and 4.88 for the control and with hydrocooling at 0 °C and 10 °C, respectively. Subsequently, in all treatments, there was an increase in pH values during the storage period, with 10-day pH values of 5.85, 6.42, and 6.81 for the control and with hydrocooling at 0 °C and 10 °C, respectively (Figure 2). The hydrocooling at 0 °C had the largest increase in the pH value from the eighth day, where the values increased from 6.44 to 6.81 on the tenth day.

Table 1. Average values of fresh mass loss (FML), soluble solids (SS) and soluble solids/titratable acidity ratio (SS/TA) of arugula leaves after harvest and submitted to treatments without hydrocooling (control) and hydrocooling at 0 °C (H 0°C) and 10 °C (H 10°C) for 10 days of storage.

Treatments	FML (%)	SS (° Brix)	SS/TA ratio
Hydrocooling			
Control	33.51 b	5.19 b	4.97 b
H 0 °C	25.93 a	4.38 a	6.38 ab
H 10°C	31.16 ab	4.33 a	6.67 a
Storage periods (days)			
0	Q**	4.88 a	L**
2		4.84 a	
4		5.12 a	
6		4.56 a	
8		4.31 a	
10		4.09 a	
CV (%)	24.75	4.15	33.22

* Means followed by the same letter in the column do not differ by the Tukey test at 5% probability. ** significant at the 1% level by the F test.

Figure 1. Percentage of fresh mass loss of arugula leaves in the different storage periods.

Equation in Figure 1: $y = 1.56 + 10.01x - 0.584x^2$, $R^2 = 0.9862**$

Figure 2. pH values of arugula leaves in the different storage periods.

Equations in Figure 2:
Control $y = 5.02 + 0.296x - 0.024x^2$ $R^2 = 0.523**$
H 0°C $y = 4.96 + 0.345x - 0.019x^2$ $R^2 = 0.796**$
H 10°C $y = 5.07 + 0.38x - 0.026x^2$ $R^2 = 0.853**$

Titratable acidity values increased during the storage period for all treatments. Regarding the different hydrocooling treatments, only on the sixth day, significant differences were observed, and hydrocooling at 0 °C and 10 °C maintained similar acidity values compared to the control. The hydrocooling at 10 °C was the only one that decreased from 1.43 to 1.10% from the eighth to the tenth day. The leaves subjected to hydrocooling at 0 °C and 10 °C had lower levels of citric acid concentration compared to the control from the sixth day until the tenth day of evaluation, with values of 1.63 and 1.10%, respectively, while the highest titratable acidity value was 2.06% for the control (Figure 3). Souza et al. (2017) reported that hydrocooling resulted in an increase in titratable acidity from the sixth day and a decrease after the sixth day in fresh coriander leaves. The initial titratable acidity values (0.50 to 0.60% citric acid) observed in the present study are slightly above the values reported by Vasconcelos et al. (2011), which evaluated the chemical characterization of arugula leaves showed titratable acidity values ranging from 0.37 and 0.40% citric acid.

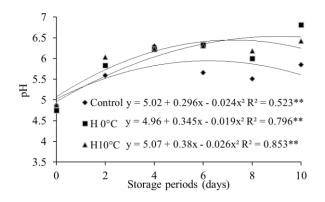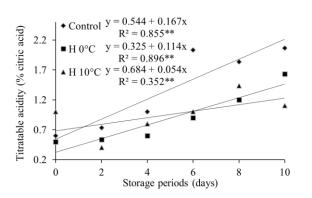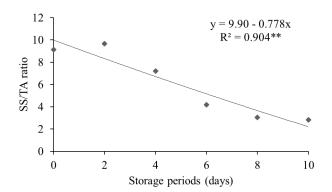The ratio between soluble solids and titratable acidity (SS/TA) had a significant effect on hydrocooling treatments and storage period; however, there was no significant interaction between both factors. The SS/TA ratio had a decreasing response during the storage period; the initial value of 9.13 decreased to 2.83 on the tenth day (Figure 4). The SS/TA ratio is one of the indices that can be used to evaluate the maturation of the products, as it indicates their taste through the balance of sugars and acids. The results presented confirm those reported by Nascimento et al. (2017) in lettuce crop, which found a reduction in SS/TA ratio with storage time. The authors attributed this effect to a decrease in sugar content and an increase in acid consumption caused by water loss, which leads to deterioration.

The overall appearance of the arugula leaves in the treatment with hydrocooling at 0 °C obtained scores ranging from 3.00 to 2.66 until the sixth day of storage, differing significantly from the other treatments (Table 2).

Considering the scale of appearance, the grade 3.00 corresponds to the criterion where the leaves have the maximum commercial value, that is, the leaves showed no signs of leaf darkening and wilting, and the use of hydrocooling was effective in postharvest conservation.

Figure 3. Titratable acidity (% citric acid) of arugula leaves in the different storage periods.

Figure 4. Soluble solids and titratable acidity ratio (SS/TA) of arugula leaves in the different storage periods.

Table 2. Subjective evaluation of the appearance of arugula leaves after harvest and submitted to treatments without hydrocooling (control) and hydrocooling at 0 °C (H 0°C) and 10 °C (H 10°C) for ten days of storage.

Hydrocooling	Storage period (days)					
	0	2	4	6	8	10
	----------------------------------- Scores -----------------------------------					
Control	3.00a	3.00a	2.00b	1.66b	1.33b	1.00b
H 0°C	3.00a	3.00a	2.66a	2.66a	1.50b	1.33b
H 10°C	3.00a	3.00a	2.33b	2.00b	1.66b	1.00b
CV (%)	0	0	17,50	28.82	49.69	34.74
LSD	0	0	1.19	2.26	2.75	1.44

* Means followed by the same letter in the column do not differ by the Tukey test at 5% probability. LSD: least significant difference.

The control treatment and hydrocooling at 10 ° C showed signs of leaf darkening and wilting from the sixth day and unfeasible for commercialization until the tenth day, with scores 1.33, 1.33, and 1.00, making it unfeasible for commercialization. Hydrocooling at 0 °C improved leaf appearance until day six, with a score of 2.66, where the leaves were still green and whole with little wilting. However, as there was considerable loss of fresh mass during this period, hydrocooling at 0 ° C on the fourth day can be considered as the best and, therefore, the most viable for commercialization.

From the eighth day of storage, none of the treatments was efficient to maintain a good appearance of arugula leaves, with scores below 1.66. Also, these treatments had a fresh mass loss greater than 40%. As a result, the leaves showed signs of darkening and apparent wilting, making them unfeasible for commercialization.

The subjective assessment provides information on the physical quality of leafy vegetables because by being chosen by consumers, they are judging in some way whether the overall appearance of the product meets their expectations and requirements (Oliveira et al., 2017). The appearance attribute is of fundamental importance for marketing, as the consumer makes the purchase decision based on the physical aspect of arugula leaves.

4. Conclusions

Under the conditions under which this study was conducted, hydrocooling proved to be a satisfactory method concerning fresh mass loss, soluble solids, and titratable acidity, and effective in delaying water loss, thus increasing the shelf life of arugula leaves.

Hydrocooling at 0 °C after arugula harvest was effective in maintaining physical and chemical quality until day 4th of storage and maintaining the visual appearance of the product until day 6th of storage.

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