Vol. 17(10) pp. 223-232, October 2023
DOI: 10.5897/AJFS2023.2269
Article Number: 53FB48671324
ISSN: 1996-0794

http://www.academicjournals.org/AJFS

ACADEMIC JOURNALS
expand your knowledge

African Journal of Food Science

Full Length Research Paper

Interference of cultivar and ways of cultivation in lettuce (*Lactuca sativa*) yield and conservation

Ediorgenes Sousa Paes[1], Camila Sartori Pavan[1], Gabrielly Mylena Benedetti Tonial[2], Natalia Gatto[3], Carlos Guilherme Theodoro dos Santos[4], Marcio Roggia Zanuzo[4], Ivane Benedetti Tonial[5] and Luciano Lucchetta[6]*

[1]Food engineering, Federal University of Technology, Parana, C. P. 135, 85601-971, Francisco Beltrão, Paraná, Brasil.
[2]Chemistry Engineering, Federal University of Technology, Parana, C. P. 135, 85601-971, Francisco Beltrão, Paraná, Brasil.
[3]School of Food Technology, Federal University of Technology of Parana, Francisco Beltrão/Londrina-PR, - C. P. 135, 85601-971, Francisco Beltrão, Paraná, Brazil.
[4]College of Agronomy, Federal University of Mato Grosso, C. P. 135, 85601-971, Sinop-Mato Grosso, Brasil.
[5]Deparment of Chemistry e Biology Federal, University of Technology, Parana, C. P. 135, 85601-971, Francisco Beltrão, Paraná, Brasil.
[6]Department of Agrarian Sciences, Federal University of Technology of Parana, C. P. 135, 85601-971, Francisco Beltrão, Paraná, Brazil.

Received 17 July, 2023; Accepted 26 September, 2023

This study aimed to measure the yield and postharvest conservation of three lettuce varieties (Crisp, Mimosa, and Iceberg) grown in two different cultivation systems (Conventional and Hydroponic) and stored under two conditions (Ambient temperature and Refrigerated). The experiment used a randomized design with tree factors (cultivars, cultivation systems and storage types) and 4 repetitions. The samples were collected randomly, in the city of Francisco Beltrão-PR, Brasil, from a local producer. The yield (head diameter, leaf size, number of leaves, stem length and fresh weight), the physicochemical characteristics (moisture, ash, soluble solids, pH, titratable acidity, fiber, vitamin C and nitrate), and post-harvest conservation (color/darkness and occurrence of post-harvest rots) were evaluated. The results showed that lettuce from conventional cultivation had the highest yield. The physicochemical parameters presented different behaviors related to cultivars and cropping systems. The lettuce of conventional cultivation presented higher content of minerals (ash) and vitamin C. On the other hand, the hydroponic cultivation proved to be more efficient in post-harvest conservation. The refrigerated environment proved to be more suitable for the conservation of vegetables, since they presented a better overall appearance. Storage at ambient temperature, in turn, contributed to greatest deterioration of the plants.

Key words: Lettuce, cultivation systems, cultivate, pos-harvest conservation, fresh produce, refrigerated.

INTRODUCTION

Lettuce (*Lactuca sativa* L.) is a vegetable belonging to the Asteraceae family, cultivated since ancient times by the Asians (Queiroz et al., 2017) and brought to Brazil by the Portuguese in the 16th century (Da Silva et al., 2007).

It is one of the most important vegetables cultivated in Brazil (Sala and Costa, 2012), and can be grown in conventional, organic, and hydroponic systems.

The production of lettuce depends on the interaction between genotype and environmental conditions, that is, they respond differently to the practices and means of cultivation, which determines the quality of the vegetable (Zárate et al., 2010). The cultivation methods employed for lettuce production, the most widely used today are conventional planting (soil) and the hydroponic system (NFT-nutrient film technique).

Conventional planting is a system of lower cost to the producer because it uses less water, energy, and labor. However, it becomes necessary to control the physical and chemical conditions of the soil for the correct nutritional supply to the plant, besides the incidence of diseases and pests (Arbos et al., 2010; Henz and Suinaga, 2009). Hydroponic cultivation provides greater plant uniformity and quality, requires less physical space, and provides high productivity, allowing for better commercial exploitation throughout the year (Bhering et al., 2019).

Commercially, lettuce is classified as Iceberg lettuce, Crisp, Smooth, Virella lettuce (Mimosa) and Romaine (Trani et al., 2005), with the crisp and the smooth types being the best known and consumed in Brazil. The iceberg lettuce is characterized by the formation of leaf clusters (head), leaves with greater thickness and crispness (Mota et al., 2002; Sala and Costa, 2012; Yuri et al., 2004). It is used by the minimal processing industry and fast food chains for its texture and flavor, and for presenting good postharvest conservation, resistance to transport and handling (Hotta, 2008). The Crisp lettuce is the most commercialized, it has leaves with curly edges, does not form heads, is easy to handle, and is adapted for summer cultivation (Demartelaere et al., 2020). The Virella (Mimosa lettuce), on the other hand, presents well-cut, delicate, and creepy-looking leaves (Souza et al., 2021).

In addition to green coloration, it can be found in red and purple coloration that indicates the presence of anthocyanins (Rosa et al., 2014; da Silva Santana et al., 2009), compounds beneficial to health. Independent of the variety, in general, lettuce has a fragile physical structure, sensitive to dehydration and aging, and has a limited shelf life (Moraes, 2006). They are susceptible to variations in temperature and light, factors that have an effect on the absorption of nutrients and directly influence conservation (Bezerra Neto et al., 2005).

Postharvest preservation varies with the type of vegetable, good conditions for transport, storage, distribution, and marketing are as important as producing well. Thus the choice of post-harvest conservation techniques is necessary to avoid incorrect handling and the problems arising from inefficient transport and storage (Rosa et al., 2018).

Vegetables have different behaviors in front of cropping systems, post-harvest practices. Depending on the cropping system and climatic conditions, lettuce leaf nitrate contents can vary (Bourn and Prescott, 2002; Woese et al., 1997). In addition, the nutritional composition of vegetables can be affected by fertilizers. It comes to nutrient mineralization, due to the interaction conditions in the growing medium (soil/substrate), dosage, and application time (Cheynier et al., 2013; Chiomento et al., 2019; Lee and Kader, 2000).

One of the problems in postharvest one of the challenges is the low preservability of lettuce. The speed of lettuce deterioration increases rapidly at temperatures above 0°C. The shelf life of lettuce at 3°C is only 50% of the shelf life at 0°C. In storage, however, the temperature can never be lower than -0.5°C, because in this case freezing and deterioration of the product occurs (Moraes, 2006). Thus, in postharvest, the application of refrigeration technologies is a good option to slow the speed of these changes, increasing the shelf life and consequently the time of commercialization (Teruel, 2008).

Vegetable deterioration occurs naturally in the post-harvest life, by the respiratory process. However, the damage caused by manipulation or microorganisms, mainly with rupture in the tissues promote the acceleration of metabolic activity, which results in physiological alterations and increase in respiration speed (Mello et al., 2003). In this sense, the quality alterations in post-harvest are directly linked to the oxidative chemical and biochemical processes. In the cell wall structure, they affect components of the primary cell wall, such as cellulose, pectin and hemicellulose, compromising the texture. From the sensory point of view, it causes off-flavor formation, discoloration, and browning (Mello et al., 2003).

In addition, aerobic to anaerobic processes contribute to the formation of aldehydes and ketones favoring the appearance of off flavor. The loss of green color is due to the degradation of chlorophyll by chlorophyllase (a native enzyme) (Streit et al., 2005). Enzymatic and non-enzymatic browning accelerates the appearance of pinkish, brownish, or blackish colors, influenced by storage conditions, compromising postharvest visual quality. At this stage, degradation of nutritional compounds also occurs, as well as the growth of pathogenic bacteria (Flores, 2010).

Considering the aforementioned, the present study aimed to measure the yield and postharvest conservation of lettuce (Crisp, Mimosa and Iceberg lettuce) at room

*Corresponding author. E-mail: lucchetta@utfpr.edu.br. Tel: +55 46991417791.

temperature and refrigerated from conventional and hydroponic growing systems.

MATERIALS AND METHODS

Lettuce samples were used from three cultivars Lucy Brown (Iceberg lettuce), Vera (Crisp lettuce) and Virella (Mimosa lettuce) grown in two different production systems, conventional and hydroponic, in a rural production unit (rural farm company) in the municipality of Francisco Beltrão-PR-Brasil.

Conventional cultivation system

After 25 days of sowing (commercial seeds-trademark with rights reserved), the plantlets were transplanted to the cultivation area. Spacing of 0.30 × 0.30 m was used. Irrigation of its drip was done during the growth cycle according to need. The soil was prepared with recommended fertilizer dosage of 1600 kg/ha of the formulations 04-14-08 (NPK-Nitrogen, Phosphorus and Potassium) and 1000 kg/ha of simple superphosphate. Subsequently, at 20 and 40 days after transplantation, a dose of topdressing fertilization was applied, urea (40 kg/ha N) and potassium chloride (85 kg/ha K) (Mota et al., 2002; Queiroz et al., 2017; Yuri et al., 2004).

Hydroponic cultivation system

The hydroponic system was performed in an Nutrient Film Technique (NFT) in greenhouses covered with 200 µm polyethylene with anti-UV-A and UV-B treatment. The benches inside the structure had the following measurements 1.25 m wide and 6 m long gutters. The spacing of each gutter was 25 cm, totaling 5 gutters. The slope was 2%. To feed the system, a 1.0 hp motor-pump set was used. The flow rate of each channel was 1.5 L/h. The nutrient solution used was commercial with pH corrected to 5.8±0.5 to obtain a conductivity of 1.7 mS cm^{-1}. The system used was intermittence of 10 min between recirculations.

Sample collection

The vegetables were collected 55 days after planting, when they reached the maximum vegetative development, before starting the fixation process. This facilitates standardization of harvesting and comparison. The harvest was performed randomly for both cultivation systems. This procedure was carried out moment of milder temperature (early morning hours). The samples were immediately transported in plastic boxes under refrigeration to the Laboratory of Fruit and Vegetable Technology of the Federal Technological University of Paraná - Campus Francisco Beltrão. The laboratory has a structure for refrigerated storage, conservation simulations and for necessary post-harvest evaluations.

A completely randomized experimental design (CRD) was used, in factorial scheme 2×3×2 with 2 cultivation systems (Conventional and Hydroponic), 3 cultivars (Lucy Brown, Vera and Virella) and 2 types of storage (Ambient temperature and refrigerated) with 4 repetitions, each repetition was composed of 3 plants. The post-harvest preservation conditions are commercial refrigeration conditions (simulation, ±8°C) and at room temperature (±23°C) for 7 days.

Physical and physicochemical

Head diameter was measured individually with the aid of a pachymeter and expressed in centimeters (cm). Fresh weight determination was performed with the aid of an analytical balance and the weight expressed in grams of fresh matter ($g.plant^{-1}$). Total leaf count was obtained by manually counting the number of leaves of each vegetable ($Unit.planta^{-1}$). Leaf length and stem length were measured using a pachymeter and expressed in centimeters (cm).

Soluble solids was determined in °Brix using a portable refractometer (Vodex - Model RTA-80). pH and titratable acidity (TA) were performed according to Adolfo Lutz Institute (IAL, 2008). The pH was determined using a previously calibrated bench top digital potentiometer. Total titratable acidity (TA) was measured volumetrically by titration of 5 g of pulp, homogenized in 50 mL of distilled water with 0.1 $mol.L^{-1}$ NaOH until the turning point was reached. Acidity was expressed in %.

The crude fiber, moisture and ash content were done according to Association of Official Analytical Chemists (AOAC, 2016) method. Moisture and ash content were carried out gravimetrically. For this, 5 g of each sample was dehydrated in an oven at 105°C until constant weight to obtain the moisture content. After this analysis, the samples were placed in a muffle furnace at 600°C until a light ash was obtained to determine the ash content. Crude fiber was measured by acid digestion of the defatted, desiccated sample (1.25% sulfuric acid) for 30 min, followed by an alkaline digestion (1.25% sodium hydroxide) for another 30 minutes, the total fiber being determined gravimetrically after incineration of the residue. Vitamin C was determined volumetrically by the iodometric method, using starch as an indicator, titrating the solution with potassium iodate (IAL, 2008). Nitrate content was obtained from a nitrite analysis by UV/VIS spectrophotometry at 450 nm where the sodium nitrate concentration (mg/kg) was obtained by multiplying the nitrite by 1.231 (IAL, 2008).

In addition to the objective analyzed in this study, the visual and/or appearance aspects were evaluated. For this analysis, the following parameters were adopted: fresh/wilted product; color change/darkening; and absence/occurrence of intense rot. This evaluation did not aim to establish a scale, but to assist in the description of the results and discussion.

Statistical analysis

The data was submitted to analysis of variance by the -F test ($P<0.05$), (ANOVA) and the means were compared by the Tukey test ($P<0.05$) using Statistical Package's (STATSOFT INC, 2004; Jamovi, 2022).

RESULTS AND DISCUSSION

The yield of vegetables is directly related to the species, cultivar, and cultivation system. The results of the yields of Crisp lettuce (Vera), Virella lettuce (Mimosa) and Iceberg lettuce lucy Brown) grown in conventional and hydroponic systems are presented in Table 1.

Head diameter, according to Martins et al. (2017), is a very important characteristic in the choice and marketing of vegetables. In this study, the highest mean head diameters were observed in the cultivars Vera and Virella ($P>0.05$) with mean values of 28.33 and 26.00 cm, respectively. The cultivar Lucy Brown averaged 18.83 cm, being lower ($P<0.05$) than the others analyzed.

There was no significant difference ($P>0.05$) between conventional and hydroponic environments. When unfolding the interaction, the only cultivar that showed a difference between the environments was Lucy Brown,

Table 1. Morphological characteristics of Crisp lettuce (Vera), Virella lettuce (Mimosa) and Iceberg lettuce (Lucy Brown) grown in conventional and hydroponic systems.

Variable	Cultivation system (CS)	Cultivars/Groups			Mean (Cultivar)	F Value			CV (%)
		Lucy Brown (Iceberg lettuce)	Vera (Crisp lettuce)	Virella (Mimosa lettuce)		CS	C	CS×C	
DC	HS	21.66^{Ab}	25.66^{Aa}	27.66^{Aa}	25.00^{A}	2.81*	65.58*	9.37^{*}	6.34
	CCS	16.00^{Bb}	26.33^{Aa}	29.00^{Aa}	23.77^{A}				
Mean (Cultivation system)		18.83^{B}	26.00^{A}	28.33^{A}					
PF	HS	191.00^{Ba}	193.33^{Ba}	184.66^{Bb}	189.66^{B}	2.600*	572.00*	398.00*	1.24
	CCS	272.00^{Ab}	296.00^{Aa}	200.66^{Ac}	256.22^{A}				
Mean (Cultivation system)		231.50^{B}	244.66^{A}	192.66^{C}					
NF	HS	17.33^{Ab}	18.33^{Ab}	35.66^{Aa}	23.77^{A}	46.28*	50.96*	41.47*	9.00
	CCS	16.33^{Aa}	18.66^{Aa}	18.33^{Ba}	17.77^{B}				
Mean (Cultivation system)		16.83^{B}	18.50^{B}	27.00^{A}					
CF	HS	21.66^{Aa}	22.00^{Aa}	16.66^{Ab}	20.11^{B}	26.88*	0.61^{ns}	10.64*	8.49
	CCS	21.66^{Aa}	21.33^{Aa}	24.66^{Ba}	21.55^{A}				
Mean (Cultivation system)		21.66^{A}	21.66^{A}	20.66^{A}					
CC	HS	12.00^{Aa}	6.00^{Ac}	10.00^{Bb}	9.33^{B}	20.05*	81.72*	17.05*	2.27
	CCS	12.00^{Ab}	6.33^{Ac}	16.00^{Aa}	11.42^{A}				
Mean (Cultivation system)		12.00^{B}	6.16^{C}	13.00^{A}					

CS: Cultivation system; CCS: conventional system; HS: hydroponic system; C: cultivar; DC: head diameter (cm); PF: fresh weight (g plant^{-1}); NF: number of leaves (units Plant^{-1}); CF: sheet length (cm): CC: stem length (cm). Uppercase letters in columns and lowercase letters in rows differ from each other by Tukey's test (P<0.05).

with a difference of 35.37% in head diameter, being larger in the hydroponic system than in the conventional. The cultivar Lucy Brown has shown better adaptability for hydroponic system. When unfolding the behavior of cultivars as a function of environments, both cultivars Vera and Virella were superior to Lucy Brown in both systems.

In the hydroponic environment, cultivars Virella and Vera were superior to Lucy Brown at 27.70 and 18.46%, respectively. In the conventional environment, both Virella and Vera were superior to Lucy Brown by 81.25 and 64.56%, respectively. However, with the data presented, it is observed that both cultivars were better adaptable to conventional growing conditions. The hypothesis accepted for the low development of head diameter may be related to the electrical conductivity of the materials. According to Costa et al. (2001) the increase in electrical conductivity in lettuce cultivation results in a lower vegetative development. This increase in the diameter of the head in conventional cultivation is interesting from a commercial point of view because it increases the volume of material sold.

In relation to the fresh weight, a significant independent effect was observed for environment, cultivars and the interaction between both. In relation to the environment, the CCS was superior on average about the environment HS with an increment of 74%. About cultivars, Vera (Crisp lettuce) was superior to Lucy Brown (Iceberg lettuce) and Virella (Mimosa lettuce) with averages of 244.66, 231.50 and 192.66 g plant^{-1}, respectively. When unfolding the cultivars within each environment, they were all superior in fresh weight in CCS. In HS, Lucy Brown and Vera were superior to Virella but did not differ (P>0.05). In CCS, the behavior was different among the cultivars with the higher average for the Vera cultivar followed by Lucy Brown and Virella, respectively. This difference between the genotypes and the environmental behavior (salinity, fertility, temperatures, humidity, light intensity, among others) can directly influence the performance of the species (Blind and Silva Filho, 2015).

The number of leaves is an important attribute from the point of view of consumer presentation and is related to the adaptation of the genetic material in the environment (Diamante et al., 2013). Regarding the number of leaves, there was a significant difference (P<0.05) between environments, cultivars and the interaction between both. Among the environments, the H system showed higher average compared to CA for Virella, while it is not different statistically (P>0.05) for varieties Lucy Brown and Vera. As for cultivars, the highest number of leaves was for Virella (P<0.05), followed by Lucy Brown and Vera, which are not different (P>0.05). Souza et al.

Table 2. Physicochemical characteristics of Lucy Brown (Americana), Vera (Crespa) and Virella (Mimosa) lettuce grown in conventional and hydroponic systems.

Variable	Cultivation System (CS)	Cultivars/groups				F Value			CV (%)
		Lucy Brown (Iceberg lettuce)	Vera (Crisp lettuce)	Virella (Mimosa lettuce)	Mean (Cultivar)	CS	C	CS×C	
pH	HS	6.22	6.11	6.08	6.14	0.02^{ns}	$0.86n^{s}$	0.49^{ns}	1.95
	CCS	6.15	6.10	6.14	6.13				
Mean (cultivation system)		6.19	6.10	6.11					
TA (%)	HS	1.00	1.00	1.00	1.00	0.05^{ns}	0.05^{ns}	0.05^{ns}	22.33
	CCS	1.00	1.33	1.00	1.11				
Mean (cultivation system)		1.00	1.16	1.00					
SS (ºBrix)	HS	4.00^{Aa}	4.00^{Aa}	4.00^{Aa}	4.00^{A}	0.0001*	0.0001*	0.0001*	0.00
	CCS	4.00^{Aa}	3.00^{Bb}	3.00^{Bb}	3.33^{B}				
Mean (cultivation system)		4.00^{A}	3.50^{B}	3.50^{B}					
Moisture (%)	HS	93.66^{Aa}	93.33^{Aa}	93.33^{Aa}	93.44^{A}	1.50^{ns}	2.16^{ns}	0.50^{ns}	0.62
	CCS	93.33^{Aa}	93.66^{Aa}	93.33^{Aa}	93.77^{A}				
Mean (cultivation system)		93.50^{A}	94.00^{A}	93.33^{A}					
Ash ($g.100g^{-1}$)	HS	1.35^{Aa}	0.48^{Bc}	1.03^{ABb}	0.67^{B}	643.08*	288.54*	29.81*	4.30
	CCS	1.08^{Aa}	1.03^{Aa}	0.44^{BCc}	1.13^{A}				
Mean (cultivation system)		1.12^{A}	0.74^{B}	0.75^{B}					

TA: Titratable acidity; SS: soluble solids; CS: cultivation system; CCS: conventional system; HS: hydroponic system; C: cultivar. Uppercase letters in columns and lowercase letters in rows differ from each other by Tukey's test (P<0,05). ns: Not significant.

(2021) did not observe differences in the number of leaves as a function of environments for the cultivar Veronica (Crisp). Possibly the difference observed in this study is related to the temperature factor because in milder regions the development of lettuce is better because high temperatures influence the precocious setting of the leaves, thus reducing the number of leaves.

Regarding the length of the leaves, there was a significant difference (P<0.05) only between the environments for the variety Virella, as well as in the interaction between both. For Virella, the leaf length was greater in the CCS when compared with the HS (Table 1). Among the cultivars evaluated, the interaction was only observed in the cultivar Virella (mimosa). Another interesting factor observed is that Virella has adapted better to open field conditions. This cultivar is influenced by the electrical conductivity of the medium, which interferes with growth and development, thus reducing leaf length.

Stem length differed statistically (P<0.05) among cultivars and for Virella it differed also in the cultivation system, showing larger stem size in the CCS. This same observation was reported by Martins et al. (2017) for Rubra and Cristal cultivars grown in conventional, hydroponic, and organic systems.

In general, it was observed that the variety Virella (mimosa) showed the greater influence on the cultivation system, having greater numbers of leaves, however smaller size. The cultivation system influenced the yield in mass (g) of the vegetables, being lower in the hydroponic system, which reflected in the amount of ash in the samples (Table 2). This lower mass yield may be related to extrinsic and intrinsic factors, such as production factors (climate, soil, water, production system), and genetic characteristics of the vegetable (Blind and Silva Filho, 2015). Crops grown directly in the soil undergo cultural treatments that induce greater nutrient uptake and dry matter production (Zárate et al., 2010). Moreover, the differences between cultivars demonstrate the plants' ability to self-regulate in relation to the interaction genotype and growing medium (Freitas et al., 2007). This behavior is observed in other studies that deal with different cultivation systems (Merlini et al., 2018; Santana et al., 2006). Also, low tunnel-protected soil cultivation favors the growth and yield of American lettuce cultivars more than the open field system (Brzezinski et al., 2017), while other cultivars show similar growth and yield in both growing conditions.

Physicochemical characteristics

The physicochemical variables of lettuce belonging to the cultivars Lucy Brown, Vera and Virella are presented in

Table 3. Fiber, vitamin C and nitrate content of lettuce Lucy Brown (Iceberg lettuce), Vera (Crisp lettuce) and Virella (Mimosa lettuce) cultivated in conventional and hydroponic systems.

Variable	Cultivation system (CS)	Cultivars/Groups				F Value			CV (%)
		Lucy Brown (Iceberg lettuce)	Vera (Crisp lettuce)	Virella (Mimosa lettuce)	Mean (Cultivar)	CS	C	CS×C	
Fiber (g.100 g^{-1})	HS	0.66^{Aa}	0.68^{Aa}	0.64^{Ba}	0.69^{A}	6.37*	7.93*	14.74*	3.84
	CCS	0.63^{Ab}	0.69^{Ab}	0.76^{Aa}	0.66^{B}				
Mean (cultivation system)		0.64^{B}	0.68^{A}	0.70^{A}					
Vit.C (mg.100 g^{-1})	HS	20.66^{Bb}	25.33^{Ba}	27.00^{Ba}	29.66^{A}	65.08^{*}	40.76^{*}	0.76^{ns}	5.19
	CCS	25.00^{Ab}	31.66^{Aa}	32.33^{Aa}	24.33^{B}				
Mean (cultivation system)		22.83^{B}	28.50^{A}	29.66^{A}					
Nitrate (g.100 g^{-1})	HS	0.18^{Aa}	0.16^{Ab}	0.13^{Bc}	0.15^{B}	37.48*	366.59*	714.42*	1.23
	CCS	0.17^{Ba}	0.13^{Bb}	0.18^{Aa}	0.16^{A}				
Mean (cultivation system)		0.17^{A}	0.14^{C}	0.15^{B}					

CS: Cultivation system; CCS: conventional system; HS: hydroponic system; C: cultivar. Uppercase letters in columns and lowercase letters in rows differ from each other by Tukey's test (P<0.05).

Table 2.

The pH, TA, and moisture values were not shown to be influenced by the cultivation systems, which is not different statistically (P>0.05), which is also described by other studies (Fontana et al., 2018; Martins et al., 2017; Ohse et al., 2009). Low acidity levels were observed for the varieties studied, and thus, they may be susceptible to deterioration by microorganisms (Beharielal et al., 2018), in addition to the sensitivity itself promoted by the intense respiratory process of the leaves.

The contents of soluble solids were influenced by the cultivation systems in all cultivars, being higher in hydroponic systems, especially for the Lucy Brown, reflecting the better balance of the nutritional medium. This variable, according to Andriolo et al. (2005) can be influenced, among other factors, by temperature, fertilization, luminosity and planting density. Different results to those found in this study for soluble solids were reported by da Silva et al. (2011) and Fontana et al. (2018).

Contrary to soluble solids (SS), ash contents were higher in the conventional production system, indicating that this type of vegetable tends to accumulate mineral compounds, present in the soil. Ash values intermediate (0.61 - 0.77 g.100 g^{-1}) to those found in the present study were presented by Ohse et al. (2009) in different lettuce cultivars produced by hydroponics. Kurubas et al. (2019), working with other cultivars describes a different behavior, where conventional cultivation showed higher contents of total soluble solids, titratable acidity and total phenolics.

The contents of fiber, vitamin C and nitrate present in the lettuce samples grown in conventional and hydroponic systems evaluated in the present study are presented in Table 3.

There was no significant difference (P>0.05) in the fiber content of the lettuce among the cultivars, except for the Virella cultivar which presented a higher amount for the conventional cultivation system. Fiber values lower than those observed in the present study (0.25 - 0.48 g.100 g^{-1}) were presented by Ohse et al. (2009) in different lettuce cultivars. According to these authors, a lower fiber content may be due to the cycle and growing conditions, and time of year.

Vitamin C content varied among cultivars, which is possibly due to the influence of physiology and antioxidant capacity of each species, as well as plant nutrition (Pereira et al., 2015). The lowest indices of vitamin C were presented by hydroponic cultivation (P<0.05), which may be related to the fact that Nitrogen (N) is readily available in the aqueous solution, which facilitates its absorption by the plant decreasing the accumulation of ascorbic acid in vegetables (Lee and Kader, 2000). Physiologically, plants are induced to increase proteins and carbohydrates at the expense of secondary metabolism compounds, such as ascorbic acid (Lee and Kader, 2000; Da Silva et al., 2007).

Nitrate indices showed variation among cultivars and different behavior in the cropping system. Previous studies (Beninni et al., 2002; Ohse et al., 2009; Rezende et al., 2017) with different lettuce cultivars, described similar values (0.13 to 0.18 g.100 g^{-1}) to those found in the present study. The hydroponic system tends to provide increases in nitrate indices, because the nitrogen fertilizer is supplied mainly in the form of nitrate dissolved in water, facilitating its absorption, which did not occur with the cultivar Virella in this study.

The recommended limit of daily intake of nitrate, without health risk, is 3.65 mg.day^{-1} per kg of body

A - Storage at ambient temperature for 4 days B - Refrigerated storage for 4 days

Figure 1. Visual of the lettuces stored at 4 days of post-harvest storage.

weight. FAO (2002) considering a person weighing 70 kg, the safe intake limit would be 255 mg. In our study, the NO_3^{-1} contents (Table 3) were significant for 100 g, and exceed the limits if we consider the fresh mass of the whole head (Table 1). Nitrate levels in lettuce vary with the season. The indexes considered acceptable for human consumption are not yet established in the Brazilian legislation, as occurs in Europe (Luz et al., 2008).

The application of nitrogen in pre-harvest was able to aid in the retention of color, ascorbic acid content and extended the shelf life of lettuce by up to 6 days (Mampholo et al., 2019; Peng and Simko, 2023; Simko, 2020). The higher ascorbic acid concentration coincided with a reduction in the onset of browning in the leaves of fresh cuts. In another study (Lei et al., 2018), it was observed that in hydroponic cultivation the application of exogenous Selenium (Se) increased the photosynthetic capacity of lettuce. The assimilation and transport of NO_3^{-1} were markedly increased, but decreased accumulation in leaves, as increased the activity of nitrate reductase (NR), nitrite reductase (NiR), glutamine synthase (GS), and glutamate synthase enzyme (GOGAT) (Bian et al., 2020a, b). In other words, exogenous Se shows a positive effect on reducing NO_3^- accumulation by regulating transport and increasing nitrogen metabolism enzyme activities in lettuce.

Post-harvest preservation

Appearance and shape are among the main quality attributes, denoting fresh appearance, acceptable color, and is free of defects. In lettuce, appearance is greatly influenced by defects arising from enzymatic browning, which is initiated by the oxidation of phenolic compounds, via polyphenol-oxidase (Mampholo et al., 2019; Peng and Simko, 2023). These reactions produce insoluble, brown-colored polymers, melanins, thus affecting visual quality and consequently reflecting on product quality.

Application of exogenous Selenium (Se) increased the photosynthetic capacity of lettuce. The assimilation and transport of NO_3^{-1} were markedly increased, but decreased accumulation in leaves, as Se increasing the activity of nitrate reductase (NR), nitrite reductase (NiR), glutamine synthase (GS), and glutamate synthase enzyme (GOGAT) (Bian et al., 2020a, b). Se shows a positive effect on reducing NO_3^{-1} accumulation by regulating transport and increasing nitrogen metabolism enzyme activities in lettuce. In the follow-up performed in our study, it was verified that the most effective losses of quality in the lettuce started at 4 days postharvest (Figure 1). In the experimental conditions tested, the lettuces in the hydroponic system presented better conservation of the characteristics of color, freshness, and lower leaf wilting index, both in storage at room temperature and in refrigerated conditions, even at 4 days of storage.

However, all samples submitted to refrigeration presented greater leaf wilting, considering that the refrigerated environment provided (commercial simulation), maintains lower relative humidity indexes. It is known that if we maintained adequate temperature and humidity levels, this effect would decrease (Yuri et al., 2005).

In the case of the lettuce that was left at room temperature, there was a greater yellowing of the leaves and the appearance of brownish pigments, described as russet spoting. This is a postharvest disorder that can develop during the transportation and storage of lettuce. This disorder is characterized by the appearance of numerous brown spots around the central vein of the leaves as a result of enzymatic browning.

At 7 days of storage (Figure 2), all lettuce had qualitative defects in coloration, freshness, and the

A - Storage at ambient temperature for 7 days

B - Refrigerated storage for 7 days

Figure 2. Visual of the lettuces stored at 7 days of post-harvest storage.

occurrence of rotting, as expected.

The lettuces that were at room temperature stood out negatively for the appearance of browning and unpleasant flavor. The senescence of plant tissues is influenced by ethylene, which can increase membrane permeability. In lettuce, ethylene induces the activity of the enzyme phenylamine ammonia-lyase, which when associated with phenolic compounds can develop russet spotting. Another important enzyme is lipoxygenase, which catalyzes peroxidation reactions, causing the formation of foreign odors.

Besides the general quality of the product, these injuries or deteriorations can cause loss of commercial value and lead to public health risk, since the contaminating microbiota tend to increase at high temperatures, being a potential risk to consumers.

The conventional cultivated plants presented an almost complete deterioration, mainly for the Lucy Brown and Vera cultivars. On the other hand, it was found that lettuce grown in the hydroponic system showed less damage in conservation, with less deterioration mainly of the leaves of the inner parts, with bright colors and less degree of wilting. So, refrigerated storage was the determinant in the conservation of lettuce from both cultivation systems. The lettuce of both cultivars from hydroponic system maintained better quality until 4 days of storage, at a temperature of 23 and 23°C. At 7 days of storage in refrigeration, the lettuce from hydroponic system showed greater capacity to maintain quality. Freire Júnior et al. (2002) described results in hydroponic lettuces stored under refrigeration and at a temperature of 10°C, where on the third day of treatment the cultivars did not show significant differences in their structure, but after the seventh day the differences between the lettuces stored under refrigeration showed better results. The hydroponic cultivation system, as well as refrigerated storage systems, has been shown to have an important positive effect on the preservation of lettuce (Freire Júnior et al., 2002; da Silva Nascimento et al., 2017). So also, the organic production system is shown to have a positive effect, being more effective in extending the postharvest life and protects the quality of lettuce heads stored in modified atmosphere packaging (Kurubas et al., 2019).

Conclusions

The yield and physicochemical characteristics showed different behaviors related to the cultivars and the lettuce growing systems. Conventional cultivation resulted in higher rates of mineral content (ashes), vitamin C, and fresh mass. On the other hand, lettuce from hydroponic cultivation had a better performance than lettuce from conventional cultivation in terms of postharvest conservation. In a refrigerated environment, they had a better plant structure and a more satisfactory overall appearance, while at room temperature, the degree of deterioration was similar among the lettuces from both growing systems.

ACKNOWLEDGEMENTS

The authors thank the Brazilian National Council for Scientific and Technological Development (CNPq), Araucária Foundation and Federal Technological University of Paraná.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Andriolo JL, Luz GL, Bortolotto OC, Godoi RD (2005). Produtividade e qualidade de frutos de meloeiro cultivado em substrato com três doses de solução nutritiva. Ciência Rural *35*(4):781-787.

Arbos KA, Freitas RJ, Stertz SC, Dornas MF (2010). Atividade antioxidante e teor de fenólicos totais em hortaliças orgânicas e convencionais. Ciência e Tecnologia de Alimentos 30(2):501-506.

Association of Official Analytical Chemists, AOAC (2016). Official methods of analysis of AOAC International (Livro, 2016) *[WorldCat.org]* (G. W. Latimer (ed.)). https://www.worldcat.org/title/Official-methods-of-analysis-of-AOAC-International/oclc/981578728

Beharielal T, Thamaga-Chitja J, Schmidt S (2018). Pre-and post-harvest practices of smallholder farmers in rural KwaZulu-Natal, South Africa: Microbiological quality and potential market access implications. Food Control 92:53-62.

Beninni ER, Takahashi HW, Neves CS, Fonseca IC (2002). Teor de nitrato em alface cultivada em sistemas hidropônico e convencional. Horticultura Brasileira 20(2):183-186.

Bezerra Neto F, Rocha RC, Negreiros MZ, Rocha RH, Queiroga RC. (2005). Produtividade de alface em função de condições de sombreamento e temperatura e luminosidade elevadas. Horticultura Brasileira 23(2):189-192.

Bhering A, da S, Sediyama MAN, Santos CA dos, Martins BNM, Mendonça VZ, de Jorge LG (2019). Cultivo hidropônico de alface americana pode aumentar produtividade em até 50%. Revista Campo & Negócios. https://revistacampoenegocios.com.br/cultivo-hidroponico-de-alface-americana-pode-aumentar-produtividade-em-ate-50/

Bian Z, Lei B, Cheng RF, Wang Y, Li T, Yang QC (2020a). Selenium distribution and nitrate metabolism in hydroponic lettuce (*Lactuca sativa* L.): Effects of selenium forms and light spectra. Journal of Integrative Agriculture 19(1):133-144.

Bian Z, Wang Y, Zhang X, Li T, Grundy S, Yang Q, Cheng R. A (2020b). A review of environment effects on nitrate accumulation in leafy vegetables grown in controlled environments. Foods *9*(6):732.

Blind AD, Silva Filho DF (2015). Desempenho produtivo de cultivares de alface americana na estação seca da Amazônia central. Bioscience Journal 31(2):404-414.

Bourn D, Prescott J (2002). A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. Critical Reviews in Food Science and Nutrition 42(1):1-34.

Brzezinski CR, Abati J, Geller A, Werner F, Zucareli C (2017). Produção de cultivares de alface americana sob dois sistemas de cultivo. Revista Ceres 64(1):83-89.

Cheynier V, Comte G, Davies KM, Lattanzio V, Martens S (2013). Plant phenolics: Recent advances on their biosynthesis, genetics, and ecophysiology. Plant Physiology and Biochemistry 72:1-20.

Chiomento JL, Frizon P, Costa RC, Trentin NS, Nardi FS, Calvete EO (2019). Water retention of substrates potentiates the quality of lettuce seedlings. Advances in Horticultural Science 33(2):197-204.

Costa PC, Didone EB, Sesso TM, Cañizares KA, Goto R (2001). Condutividade elétrica da solução nutritiva e produção de alface em hidroponia. Scientia Agricola 58(3):595-597.

da Silva EM, Ferreira RL, Araújo Neto SE, Tavella LB, Solino AJ. (2011). Qualidade de alface crespa cultivada em sistema orgânico, convencional e hidropônico. Horticultura Brasileira 29(2):242-245.

Da Silva ML, Villela Junior LV, Colovatto GF, Sartori RA (2007). Produção hidropônica de quatro cultivares de alface em garça (SP). Revista Científica Eletrônica de Agronomia 6(11):1-7.

da Silva Nascimento GA, Sanches AG, Moreira EG, Cordeiro CA. (2017). Tratamento hidrotérmico na conservação e qualidade pós-colheita de alface. Revista Trópica: Ciências Agrárias e Biológicas 9(1):65-76.

da Silva Santana CV, de Almeida AC, Turco SH (2009). Produção De Alface Roxa Em Ambientes Sombreados na Região do Submédio São Francisco (BA). *Revista Verde de Agroecologia e Desenvolvimento Sustentável* 4(3):01-06.

Demartelaere AC, Preston HA, dos Santos Feitosa S, Preston W, da Silva RM, Rosado AK, de Medeiros DC, dos Santos Ferreira M, dos Santos Rodrigues AL, Benjamim RF (2020). A Influência Dos Fatores Climáticos Sob As Variedades De Alface Cultivadas No Rio Grande Do Norte/ the Influence Climatics Factors on Lettuce Cultivated Varieties in Rio Grande of Norte. Brazilian Journal of Development 6(11):90363-90378.

Diamante MS, Seabra Júnior S, Inagaki AM, Silva MB, Dallacort R (2013). Produção e resistência ao pendoamento de alfaces tipo lisa cultivadas sob diferentes ambientes. Revista Ciência *Agronômica* 44(1):133-140.

FAO (2002). Evaluation of Certain Food Additives. Fifty-ninth report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series 913. TRS 913-JECFA 59/75. https://apps.who.int/iris/handle/10665/42601

Flores ME (2010). Alocação de matéria fresca, escurecimento enzimático e processamento mínimo de alface. https://locus.ufv.br//handle/123456789/1138

Fontana L, Rossi CA, Hubinger SZ, Ferreira MD, Spoto MH, Sala FC, Verruma-Bernardi MR (2018). Physicochemical characterization and sensory evaluation of lettuce cultivated in three growing systems. Horticultura Brasileira 36(1):20-26.

Freire Júnior M, Deliza R, Chitarra AB (2002). Alterações sensoriais em alface hidropônica cv. Regina minimamente processada e armazenada sob refrigeração. Horticultura Brasileira 20(1):63-66.

Freitas JG, Crisóstomo JR, da Silva FP, Pitombeira JB, Távora FJ. (2007). Interação entre genótipo e ambiente em híbridos de melão Amarelo no Nordeste do Brasil. Revista Ciência Agronômica 38(4):176-181.

Henz GP, Suinaga FA (2009). *Tipos de alface cultivados no Brasil.* Embrapa Hortaliças - Comunicado Técnico (INFOTECA-E). https://doi.org/http://www.infoteca.cnptia.embrapa.br/handle/doc/783588

Hotta LFK (2008). *Interação de progênies de alface do grupo americano por épocas de cultivo* [Universidade Estadual Paulista, Faculdade de Ciências Agronômicas de Botucatu,]. https://doi.org/http://hdl.handle.net/11449/93486%3E

IAL (2008). Normas Analíticas do Instituto Adolfo Lutz. v. 1: Métodos químicos e físicos para análise de alimentos. http://www.ial.sp.gov.br/ial/publicacoes/livros/metodos-fisico-quimicos-para-analise-de-alimentos

Jamovi P (2022). Jamovi (Version 2.3) [Computer Software]. https://www.jamovi.org

Kurubas MS, Maltas AS, Dogan A, Kaplan M, Erkan M (2019). Comparison of organically and conventionally produced Batavia type lettuce stored in modified atmosphere packaging for postharvest quality and nutritional parameters. Journal of the Science of Food and Agriculture 99(1):226-234.

Lee SK, Kader AA (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biology and Technology 20(3):207-220.

Lei B, Bian ZH, Yang, Q C, Wang J, Cheng RF, Li K., Liu WK, Zhang Y, Fang H, Tong YX (2018). The positive function of selenium supplementation on reducing nitrate accumulation in hydroponic lettuce (*Lactuca sativa* L.). Journal of Integrative Agriculture 17(4):837-846.

Luz GL, Medeiros SL, Manfron PA, Amaral AD, Müller L, Torres MG, Mentges L (2008). A questão do nitrato em alface hidropônica e a saúde humana. Ciência Rural 38(8):2388-2394.

Mampholo BM, Maboko M, Soundy P, Sivakumar D (2019). Postharvest responses of hydroponically grown lettuce varieties to nitrogen application rate. Journal of Integrative Agriculture 18(10):2272-2283.

Martins LM, da Silva EC, Carlos LD, Ferraz L, Maciel GM, Cruz JL. (2017). Physical and chemical characteristics of lettuce cultivars grown under three production systems. Bioscience Journal 621-630.

Mello JC, Dietrich R, Meinert EM, Teixeira E, Amante ER (2003). Efeito do cultivo orgânico e convencional sobre a vida-de-prateleira de alface americana (*Lactuca sativa* L.) minimamente processada. Food Science and Technology 23(3):418-426.

Merlini VV, Pena FD, da Cunha DT, de Oliveira JM, Rostagno MA, Antunes AE (2018). Microbiological quality of organic and conventional leafy vegetables. Journal of Food Quality 2018:1-7

Moraes IVM (2006). *Dossiê técnico: Pós-colheita e conservação de hortaliças*. Serviço Brasileiro de Respostas Técnicas.

http://www.respostatecnica.org.br/dossie-tecnico/downloadsDT/MzE=
Mota JH, Yuri JE, Freitas SD, Rodrigues JJ, Resende GD, Souza RD (2002). Comportamento de cultivares de alface americana quanto à queima dos bordos ("tip-burn") na região Sul de Minas Gerais. *Anais* Do 42 Congresso Brasileiro de Olericultura; 11 Congresso Latino Americano e Horticultura, Uberlândia, Jul. 2002., 20(2). http://ainfo.cnptia.embrapa.br/digital/bitstream/CPATSA/24838/1/OPB761.pdf

Ohse S, Ramos DM, Carvalho SM, Fett R, Oliveira JL (2009). Composição centesimal e teor de nitrato em cinco cultivares de alface produzidas sob cultivo hidropônico. Bragantia 68(2):407-414.

Peng H, Simko I (2023). Extending lettuce shelf life through integrated technologies. Current Opinion in Biotechnology 81:102951.

Pereira EM, dos Santos YM, Leite Filho MT, Fragoso SP, Pereira BBM (2015). Qualidade pós-colheita de frutas e hortaliças cultivadas de forma orgânica. Revista Verde de Agroecologia e Desenvolvimento Sustentável 10(2):56.

Queiroz A, Cruvinel V, Figueiredo KM (2017). Produção de alface americana em função da fertilização com organomineral. Enciclopédia Biosfera 14(25):1053-1063.

Rezende R, Souza RS, Maller A, Freitas PS, Gonçalves AC, Rezende GS (2017). Produção e qualidade comercial de alface fertirrigada com nitrogênio e potássio em ambiente protegido. Revista Ceres 64(2):205-211.

Rosa AM, Seó HL, Volpato MB, Foz NV, Silva TC, Oliveira JL, Pescador R, Ogliari JB (2014). Production and photosynthetic activity of Mimosa Verde and Mimosa Roxa lettuce in two farming systems. Revista Ceres 61(4):494-501.

Rosa CI, Moribe AM, Yamamoto LY, Sperandio D (2018). Pós-colheita e comercialização. In *Hortaliças-fruto* (pp. 489-526). EDUEM.

Sala FC, Costa CP (2012). Retrospectiva e tendência da alfacicultura brasileira. Horticultura Brasileira 30(2):187-194.

Santana LR, Carvalho RD, Leite CC, Alcântara LM, Oliveira TW, Rodrigues BD (2006). Qualidade física, microbiológica e parasitológica de alfaces (*Lactuca sativa*) de diferentes sistemas de cultivo. Ciência e Tecnologia de Alimentos 26(2):264-269.

Simko I (2020). Genetic variation in response to N, P, or K deprivation in baby leaf lettuce. Horticulturae 6(1):15.

Souza SV, de Almeida MG, do Nascimento Oliveira LE, Sabbag OJ (2021). Análise do crescimento de alface sob diferentes sistemas de cultivo. Agricultura Familiar: Pesquisa, Formação e Desenvolvimento 14(2):107-120.

STATSOFT INC (2004). Statistica data analysis system version 7.0. (7.0).

Streit NM, Canterle LP, Canto MW, Hecktheuer LH (2005). As clorofilas. Ciência Rural 35(3):748-755.

Teruel BJM (2008). Tecnologias de resfriamento de frutas e hortaliças. Current Agricultural Science and Technology 14(2)):199-220.

Trani P, Tivelli S, Purquerio L, Azevedo Filho JA (2005). *Hortaliças Alface (Lactuca sativa L.)*. Instituto Agrnômico de Campinas (IAC).

Yuri JE, Resende GM, Mota JH, Souza RJ, Rodrigues Júnior JC. (2004). Comportamento de cultivares e linhagens de alface americana em Santana da Vargem (MG), nas condições de inverno. Horticultura Brasileira 22(2):322-325.

Yuri JE, Souza RJ, Resende GM, Mota JH (2005). Comportamento de cultivares de alface americana em Santo Antônio do Amparo. Horticultura Brasileira 23(4):870-874.

Zárate NA, Vieira MD, Helmich M, Heid DM, Menegati CT (2010). Produção agroeconômica de três variedades de alface: cultivo com e sem amontoa. Revista Ciência Agronômica 41(4):646-653.