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Effect of Supplementation of Freshly Pressed Carrot Juice with *Rhus coriaria* L. on Changes in Juice Quality

Emilia Osmólska [1], Monika Stoma [1,*], Agnieszka Sagan [2,*], Barbara Chudzik [3] and Agnieszka Starek-Wójcicka [2]

[1] Department of Power Engineering and Transportation, Faculty of Production Engineering, University of Life Sciences in Lublin, Akademicka 13 Str., 20-612 Lublin, Poland
[2] Department of Biological Bases of Food and Feed Technologies, University of Life Sciences in Lublin, Akademicka 13 Str., 20-612 Lublin, Poland
[3] Department of Biological and Environmental Education with Zoological Museum, Maria Curie-Skłodowska University, Akademicka 19 Str., 20-033 Lublin, Poland
* Correspondence: monika.stoma@up.lublin.pl (M.S.); agnieszka.sagan@up.lublin.pl (A.S.)

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Abstract: The creation of an environmentally friendly food system involves, e.g., the production of safe and healthy food and the reduction of its waste. Therefore, the main aim of this research was to determine the effect of the addition of ground sumac powder (in the amount of 0.5, 1.5, and 3.0 g/100 mL) on the physicochemical properties of freshly pressed carrot (*Daucus carota* L.) juice and to obtain a product with extended shelf life. The analyses revealed the multiplication of microorganisms in the control juice samples during storage and the inhibition of the multiplication in the sumac-enriched samples. After 72 h, the addition of sumac in the amount of 0.5, 1.5, and 3 g reduced the total number of microorganisms by 1.7, 2.9, and 3.1 $\log_{10}$ CFU/g, respectively, compared to the control. The supplementation of carrot juice with sumac in the amount of 3% increased the content of carotenoids and polyphenolic compounds on the first day of storage by 23% and 40%, respectively, compared to the control sample. The addition of sumac to the carrot juice extended the shelf life of the product with a simultaneous significant increase in polyphenols classified as health-promoting substances.

Keywords: sustainable food production; natural preservative; *Rhus coriaria* L.; carrot juice; quality

1. Introduction

Sustainable food systems start with the development of sustainable agricultural practices, more sustainable food distribution systems, a balanced diet, food safety, and the reduction of food waste worldwide [1–3]. In addition, sustainable food systems are at the heart of political agendas (e.g., the European Green Deal) aimed at the reduction of food waste worldwide [4,5].

One-day juices produced from fresh fruits and vegetables should be an integral part of a balanced diet. Since they are not subjected to enzymatic treatment, clarification, filtering, or pasteurization, they are a valuable source of biologically active compounds. Contrary to their counterparts prepared from concentrates, no water, concentrated juice, sugar, artificial colors, or preservatives should be added to one-day juices. The carrot raw material is characterized by a particularly high content of carotenoids, which give an orange color to beverages. The presence of vitamins effectively supports the proper functioning of the organism, and antioxidant ingredients contribute to the protection of cells against the harmful effects of free radicals [6–8].

Unfortunately, non-thermally fixed juices constitute a reservoir of natural microflora and may be a carrier of unwanted pathogenic microorganisms. Microbiological contamination occurs at the stage of the cultivation of raw material plants, wherein fruits or vegetables are exposed to contamination from soil, water, and air. It has been proven that a natural fertilizer, which is increasingly being used in the cultivation of fruits and vegetables on organic farms, is a source of pathogens in many cases. Despite food safety systems, cases of poisoning caused by the consumption of microbiologically contaminated juices are still recorded in the world. These products are mainly colonized by microorganisms that can grow at low pH values. When present in large numbers, non-pathogenic microorganisms mainly cause changes in the taste and smell of juice and finally lead to its complete spoilage [9–12].

Therefore, a significant problem for producers in the juice industry may be the microbiological instability of such products during longer storage manifested by unfavorable organoleptic and sensory changes and, most importantly, posing a danger to the consumer.

Natural plant powders or extracts have recently become an attractive subject for scientists. Due to their properties, plant powders or extracts can be used to extend the shelf life of freshly pressed juices. Essential oil components derived from plant extracts can preserve juices. It has been found that the process of natural acidification of watermelon juice (with a mixture of apple–lemon juice) in combination with antibacterial plant extracts effectively prolongs the shelf life of fruit juices with a minimal impact on quality/sensory parameters [13]. Green tea extracts have been reported to have antibacterial, antiviral, antifungal, and antioxidant activity. Nivea et al. [14] evaluated the ability of various combinations of natural antimicrobial agents, green tea extract (GTE), and citric acid to preserve the quality of fruit and vegetable smoothie blends and extend their shelf life. Their results suggest that the addition of GTE (0.2%) together with the antimicrobial agents yielded a product with enhanced antioxidant properties (more than 10 times higher than the control), meeting the consumer requirements for natural products. Studies have shown that tea tree oil added to cucumber juice successfully inhibited *L. monocytogenes* and *E. coli* growth at room temperature and in a refrigerator (25 °C and 4 °C), respectively, demonstrating its good preservative activities in the food system [15]. A study conducted by Dhiman et al. [16] compared the antimicrobial activities of spices, (*Curcuma longa*, *Zingiber officinale*, *Mentha arvensis*) and medicinal herbs (*Withania somnifera*, *Rauvolfia serpentina*, *Emblica officinalis*, *Terminalia arjuna*, *Centella asiatica*). The study confirmed the potential of selected extracts of spices as effective natural food preservatives in juices.

Spices can be a natural alternative to synthetic preservatives used in the food industry. One of them is sumac *Rhus coriaria* L. (Anacardiaceae), which is one of the most characteristic elements of Turkish, Iranian, Syrian, Lebanese, and Sicilian cuisines. Research on the identification of the main components of *Rhus coriaria* and its bioactive compounds has shown that sumac is rich in valuable vitamins, minerals, omega-3 acids, and many antioxidants. These include polyphenols and flavonoids, such as gallic acid, methyl gallate, kaempferol, and quercetin. The accumulation of valuable nutrients means that this spice has great health-promoting properties, including anti-inflammatory, antifungal, antibacterial, and antioxidant properties. Recently, the phytochemical structure of sumac has been extensively studied, and it has been established that sumac extract has high potential in the treatment of COVID-19 [17–21].

Researchers have been analyzing its potential as a meat preservative and an antioxidant [22–26]. The hypothesis that Syrian sumac (*Rhus coriaria*) could have a meat-tenderizing effect was supported by the results reported by Sakhr and Khatib [27] showing a significant decrease in shear stress and protein content with an increase in collagen solubility. Moreover, an effect on the content of meat fat was detected, as the aqueous sumac extract decreased the fat percentage in meat significantly. Özcan [28] investigated the effect of sumac extracts and butylated hydroxyanisole (BHA) applied in various concentrations on the peroxide value of peanut oil. He found that sumac extracts generally inhibited the formation of hydroperoxides. However, after prolonged storage (28 days), their antioxidant activity decreased significantly, compared to BHA. The author explained the decrease in the antioxidant activity of the extracts by a decrease in the content of polyphenols. In addition, Dziki et al. [29] included sumac flour in a wheat bread recipe. Its addition enhanced the antioxidant activity of the product. In general, the authors of the study found that sumac flour (used in an appropriate amount) can be used to produce good quality bread with reduced salt content.

In order to explore all the promising potentials of this spice, more research has to be done into its wider application in sustainable food science. The aim of the present study was to evaluate the effect of *Rhus coriaria* L. supplementation on the quality of freshly pressed carrot juice during refrigerated storage.

2. Materials and Methods

2.1. Raw Material

Carrots (*Daucus carota* L.), Nerac F1 variety, obtained from a Polish farm from the 2021 harvest, were the experimental material. The vegetables were characterized by a cylindrical shape of the root; they were healthy, without visible mechanical damage. Tannery sumac (*Rhus coriaria* L.) was purchased from a health-food store. Before adding to juices, the product was ground in a ChemLand laboratory mill, model FW 100 (Stargard, Poland).

2.2. Juice Preparation

The carrots were washed and blotted dry with laboratory tissue paper. To speed up and facilitate the pressing process, the roots were divided into smaller parts. Fresh juice was obtained using a Sana EUJ-707 slow-speed juicer (Seul, South Korea). Ground sumac was added to the prepared juice in an amount of 0.5, 1.5, and 3.0 g per 100 mL of the product. Juice without the spice was the control sample. All juices were placed in a refrigerator (6 °C) and tested after 24, 48, and 72 h of storage.

2.3. Characterization of Juice Quality

2.3.1. pH Measurement

A digital pH meter (780 pH meter from Metrohm, Herisau, Switzerland) with a built-in magnetic stirrer was used to measure the pH of the juices. The control material and the sumac-enriched samples were collected in a sufficient volume to immerse the electrode with the diaphragm thoroughly. Before the measurement, the device was properly calibrated according to the manufacturer's instructions. Then, the samples with the test material were placed in a designated place, and the pH was measured (for each sample in three replications).

2.3.2. Determination of Total Acidity (TA)

The carrot juice acidity test was performed using a potentiometric titrator TitraLab AT1000 (Ames, IA, USA). A total of 25 mL of juice was poured into a beaker, and the volume was increased to 60 mL with distilled water. Then, the vessel was placed on the designated measuring field with the measuring electrode. A total of 0.1 M NaOH–analytical grade (POCH, Gliwice, Poland) was used as the titrant. The obtained results were converted automatically into citric acid [g/L]. The tests were carried out in three repetitions.

2.3.3. Sugar Content

The extract content in the juices was determined using a PAL-1 Atago pocket refractometer (Tokyo, Japan). The values are expressed in Brix degrees, i.e., the ratio of the weight of sugar to the weight of water in which a fixed volume of sugar was dissolved. The samples were applied three times to the clean field of the measuring prism, which was washed with distilled water after each use and dried with laboratory tissue paper.

2.3.4. Determination of Carotenoid Content

The carotenoid content in the carrot juice was determined on a Thermo Scientific UV–vis Helios Omega 3 spectrophotometer (Massachusetts, USA). The method consisted of extracting the compounds with a 100 mL mixture (1:1:2) of acetone (analytical grade) (STANLAB, Lublin, Poland) with 0.2% butylated hydroxytoluene (BHT) (analytical grade) (POCH, Gliwice, Poland), ethanol (analytical grade) (POCH, Gliwice, Poland), and hexane (analytical grade) (POCH, Gliwice, Poland) from the tested sample (1 g) and determining their content by measuring the absorbance of the hexane phase (wavelength light beam λ = 450 nm) according to the methodology described by Gonzales-Casado [30]. The tests were carried out in three repetitions.

2.3.5. Determination of Total Polyphenolic Compounds (TPC)

Total polyphenols were determined with the Folin–Ciocalteu method [31]. An aliquot (0.1 mL) of juice was mixed with 2 mL of distilled water, 0.2 mL of Folin–Ciocalteu phenol reagent (analytical grade) (CHEMPUR, Piekary Śląskie, Poland), and 2 mL of sodium carbonate (analytical grade) (POCH, Gliwice, Poland) solution (20%). The mixture was incubated for 1 h in darkness. The absorbance was measured at 765 nm on a UV–vis spectrophotometer (Helios Omega, Massachusetts, USA). Total polyphenolic compounds were expressed as milligrams of gallic acid per 100 mL.

2.3.6. Color Parameters

The color indicators were tested with the use of the SF80 spectrophotometer by 3 Color (Marcq-en-Barœul, France). Measurements of all components were made in the CIE L*a*b* system using the illuminant D65 and 10° observer. The instrument was standardized each time with a white and black ceramic plate (L*: 92.37, a*: −0.82, b*: 1.82). The total color difference (ΔE) was calculated as well. It showed a numerical difference in the color of the carrot juice samples supplemented with sumac compared to the control sample (without the addition) according to Equation (1):

$$\Delta E = \sqrt{(L^* - L_0\ )^2 + (a^* - a_0\ )^2 + (b^* - b_0\ )^2} \tag{1}$$

where L_0, a_0, and b_0 are the color values of the control juice samples.

Determination of the total number of aerobic microorganisms and the number of yeasts and molds

The total number of aerobic microorganisms and the number of yeasts and molds in the juice samples were determined according to the PN-EN ISO 4833-1: 2013 standard and the PN-ISO 21527 standard, respectively. In order to conduct the research, it was necessary to make a series of 10-fold dilutions in an exponential process. For this purpose, 1 mL of juice was transferred to a falcon containing 9 mL of peptone water with the use of a sterile pipette. Then, 1 mL was withdrawn from the first dilution (1:10) into 9 mL of the diluting fluid, yielding a 1:100 dilution. Further progress was made in the same way. Each prepared sample was inoculated with 0.5 mL onto the surface of solid agar medium located on 60 mm diameter Petri dishes. This procedure was performed in sterile conditions—in a laminar chamber with a CRUMA 670FL UV lamp (El Prat de Llobregat, Barcelona, Spain). The plates were incubated at 30 °C in a POL-EKO incubator type CLN 115 SMART (Wodzislaw Ślaski, Poland) for three days to determine the total number of microorganisms and at 25 °C for five days in the case of yeasts and molds. The number of microorganisms per gram of sample was calculated from the number of colonies obtained on plates containing less than 300 colonies. Microbiological inoculations were made after 24, 48, and 72 h of storage of the juice in cooling conditions at 6 °C. The tests were performed in four repetitions; mean values were given with standard deviation.

2.3.7. Statistical Analysis of Research Results

All the results were subjected to a statistical analysis performed using the statistical package Statistica 10, StatSoft Inc., Tulsa, OK, USA. First, the mean and standard deviation were calculated to determine the measure of the variability of the observed results. The ANOVA analysis of variance was performed to test the significance of differences between the values obtained in the individual trials. The inference was made at the significance level of 0.05. Tukey's test was employed for a thorough analysis of the mean confidence intervals.

3. Results and Discussion

The acidity of food products, including drinking juices, mainly proves their quality and freshness. Table 1 shows the changes in the acidity of the products converted into citric acid. The highest amounts, i.e., 3.31 g/L, 3.40 g/L, and 3.80 g/L, were observed in carrot juice with a 3 g addition of sumac after 24, 48, and 72 h of storage, respectively. In the control sample, the TA parameter had the lowest values ranging from 0.43 g/L to 0.86 g/L throughout the storage period.

Table 1. Effect of sumac supplementation on the chemical properties of carrot juice stored for 72 h.

Chemical Parameters	Sumac Content in the Juice (g/100 mL)	Time Storage (Hours)		
		24	**48**	**72**
Acidity (pH)	0 (control)	6.38 ± 0.03 [e]	6.34 ± 0.02 [e]	5.88 ± 0.01 [f]
	0.5	5.57 ± 0.01 [b]	5.57 ± 0.01 [b]	5.50 ± 0.07 [b]
	1.5	4.81 ± 0.01 [a]	4.83 ± 0.00 [a]	4.88 ± 0.03 [a]
	3.0	4.34 ± 0.04 [c]	4.38 ± 0.01 [cd]	4.42 ± 0.01 [d]
Total acidity (g/L)	0 (control)	0.43 ± 0.01 [b]	$0.52 \pm 0{,}01$ [bc]	$0.85 \pm 0{,}01$ [abc]
	0.5	0.93 ± 0.04 [a]	1.00 ± 0.01 [a]	1.07 ± 0.05 [a]
	1.5	1.97 ± 0.19 [d]	2.06 ± 0.07 [d]	2.25 ± 0.04 [d]
	3.0	3.31 ± 0.26 [e]	3.40 ± 0.25 [ef]	3.80 ± 0.38 [f]
Extract (°Brix)	0 (control)	8.90 ± 0.17 [ab]	8.87 ± 0.06 [ab]	8.73 ± 0.38 [a]
	0.5	9.23 ± 0.31 [abc]	8.87 ± 0.21 [ab]	8.83 ± 0.06 [a]
	1.5	9.50 ± 0.17 [c]	9.63 ± 0.21 [c]	9.23 ± 0.23 [abc]
	3.0	9.27 ± 0.15 [abc]	9.43 ± 0.15 [bc]	9.43 ± 0.06 [bc]
Carotenoids (mg/100 g)	0 (control)	15.81 ± 0.06 [c]	14.33 ± 0.00 [g]	11.03 ± 0.16 [b]
	0.5	16.02 ± 0.04 [a]	16.00 ± 0.05 [a]	11.62 ± 0.06 [e]
	1.5	17.32 ± 0.04 [a]	16.39 ± 0.04 [d]	11.27 ± 0.02 [b]
	3.0	20.47 ± 0.07 [i]	16.69 ± 0.02 [h]	12.13 ± 0.05 [f]
Total polyphenolic compounds (mg/100 mL)	0 (control)	22.26 ± 1.04 [a]	21.96 ± 1.56 [a]	20.85 ± 0.09 [a]
	0.5	$23.49 \pm 0{,}26$ [ab]	22.51 ± 0.17 [ab]	22.57 ± 0.26 [ab]
	1.5	25.43 ± 1.17 [bc]	27.08 ± 0.39 [c]	26.65 ± 0.04 [c]
	3.0	31.79 ± 0.71 [d]	34.70 ± 0.85 [d]	33.45 ± 0.64 [d]

The results are expressed as a mean ± standard deviation. Different letters mean statistically significant differences ($p < 0.05$).

Similarly, the products differed in terms of pH. This parameter had a value of 6.38 in the control carrot juice analyzed after 24 h of storage and 5.57 in the product with the 0.5 g sumac supplementation. In turn, the enrichment of the juice with the highest amount of this additive resulted in a 32% decrease in pH (compared to the control sample).

Sumac fruits are characterized by high content of organic acids, with malic acid as the dominant acid. Its content can reach 1.5 g/kg [17]. The addition of dried sumac to carrot juice increased the natural acidity of this product.

An increase in acidity expressed by pH during storage was found only in the control juice sample. After 72 h of storage, the value of this parameter decreased by about 8% in relation to the juice tested after 24 h. A statistically significant increase in the total acid content (converted into citric acid) was observed for the juice containing 3 g of sumac after 72 h storage. This may be related to the extraction of organic acids from the spice.

The extract content in the tested juices ranged from 8.73 to 9.63 °Brix. In the case of the drink without the additives, the total extract content was determined at the level of 8.73–8.90 °Brix. Products enriched with sumac in the amount of 1.5 and 3.0 g per 100 mL were characterized by higher extract content. The mean values of the parameter assessed during the several research days ranged from 9.23 to 9.63 °Brix. No effect of the addition of the spice on the total extract content was found in the juices stored for 24 h.

Another assessed quality factor was the content of carotenoids, which are of great importance both for nutritional and sensory reasons. They capture free radicals and active atomic oxygen, thereby preventing oxidative stress. They exert, e.g., anti-cancer, rejuvenating, and regenerating effects. The content of these substances in vegetables and fruits gives them their characteristic orange, red, or yellow color. The greatest amount of these beneficial compounds, i.e., 20.47 mg/100 g, was found on the first research day in carrot juice with the 3 g addition of sumac. The control product was characterized by approximately 23% lower content of these dyes. The storage time resulted in a statistically significant decrease in the content of carotenoids. After 72 h, the carotenoid content in all analyzed samples was at the level of 10.84–12.14 mg/100 g.

Plant polyphenols are secondary metabolites characterized by one or more hydroxyl groups binding to one or more aromatic rings. They belong to natural antioxidants that prevent heart or cancer diseases and help to stop the aging process. This makes polyphenol-rich plant raw materials particularly attractive to food producers due to the increasing consumer demand for natural and safe food ingredients [32–35]. The total content of polyphenols determined in the control sample of the carrot juice ranged from 20.85 mg/100 mL to 22.26 mg/100 mL. This amount was similar to that reported by Szczepańska et al. [36]. The content of polyphenolic compounds in the tested juices increased with the amount of added sumac. The supplementation of the carrot juice with sumac in the amount of 1.5% and 3% increased TPC in the juices on the first day of storage by 14% and 42%, respectively, compared to the control sample. After 72 h, the differences were 28% and 60%, respectively. This confirms previous reports that *Rhus coriaria* fruits are a good source of these bioactive compounds [37,38]. However, no effect of the storage time on the total content of polyphenols was observed.

The examination of the color of the juices and the assessment of the scale of changes gave full information not only about their sensory quality but also about the influence of the additive used on the rate of occurrence of the changes. All measured color parameters of the juices are shown in Table 2. On the first day of the research, a decrease in the color values (L*, a*, and b*) was observed in the sumac-supplemented carrot juice samples supplemented. The addition of the natural preservative led to a slight darkening of the samples, compared to the control juice ($p < 0.05$) after 48 and 72 h of refrigerated storage. Moreover, the sumac-containing juices were less red and yellow than the control carrot juice on the study days.

The calculated coefficient, known as the total color difference (ΔE), in most cases was within the range of $2 < \Delta E < 3.5$, which meant that the changes were evident even to inexperienced observers. There are several scientific reports describing the effect of sumac addition on the color of various food products. The effect of sumac extract and BHT (butylated hydroxytoluene) addition on the quality of sucuk (Turkish dry-fermented sausage) was investigated by Bozkurt [39] during the ripening period. The author found that the control recipe was the worst sample with respect to overall sensory quality and that the addition of either the sumac extract or BHT increased the overall sensory quality of sucuk. The color attributes of sucuk were not significantly different between samples with the addition of the sumac extract or BHT. The study demonstrated that the sumac extract had a greater effect on the quality of sucuk during the ripening period; hence, it can be added to sucuk to enhance the quality of the product. In investigations carried out on sea bream (*Sparus aurata* L.), the highest L* value was determined in the sumac-oil-supplemented product, while the highest value of the a* parameter was recorded in meat with the addition of the sumac spice. Sumac influenced the marinade redness values. As in the case of L*, meat supplemented with sumac oil had the highest value of the b* index, [40].

Table 2. Effect of sumac supplementation on the coloring-index of carrot juice stored for 24, 48, and 72 h.

Sumac Content in the Juice (g/100 mL)	Time Storage (Hours)	Coloring-Index			ΔE
		L*	a*	b*	
0 (control)		34.76 ± 0.08 [e]	11.34 ± 0.06 [h]	11.83 ± 0.06 [d]	---
0.5	24	33.98 ± 0.08 [c]	12.07 ± 0.16 [b]	13.22 ± 0.13 [f]	1.77 ± 0.14 [d]
1.5		33.93 ± 0.10 [c]	12.05 ± 0.09 [b]	12.48 ± 0.37 [e]	1.29 ± 0.17 [d]
3.0		35.26 ± 0.11 [f]	12.96 ± 0.13 [i]	13.95 ± 0.14 [g]	2.72 ± 0.17 [a]
0 (control)	48	39.53 ± 0.07 [ab]	16.22 ± 0.11 [fg]	19.89 ± 0.03 [a]	---
0.5		39.58 ± 0.08 [ab]	16.58 ± 0.03 [ag]	19.66 ± 0.07 [a]	0.43 ± 0.08 [c]
1.5		38.06 ± 0.10 [g]	15.87 ± 0.05 [ef]	17.48 ± 0.15 [b]	2.85 ± 0.13 [ab]
3.0		38.49 ± 0.09 [h]	14.98 ± 0.07 [c]	17.48 ± 0.13 [b]	2.91 ± 0.15 [ab]
0 (control)	72	39.32 ± 0.10 [a]	16.87 ± 0.20 [a]	20.16 ± 0.24 [a]	---
0.5		39.68 ± 0.08 [b]	16.91 ± 0.17 [a]	20.04 ± 0.20 [a]	0.38 ± 0.03 [c]
1.5		37.33 ± 0.11 [d]	15.34 ± 0.18 [cd]	16.92 ± 0.20 [c]	4.10 ± 0.48 [d]
3.0		37.53 ± 0.08 [d]	15.70 ± 0.25 [de]	17.32 ± 0.24 [bc]	3.57 ± 0.52 [bd]

The results are expressed as a mean ± standard deviation from three independent experiments. Different letters mean statistically significant differences ($p < 0.05$).

On the basis of the results presented in Figure 1, it was found that the average level of contamination of the control samples of carrot juice with mesophilic aerobic microorganisms after the first day of refrigerated storage was, on average, 6.11 $\log_{10}$ CFU/g. However, in the juice samples with the addition of sumac in the amount of 3 g/100 mL, the total number of aerobic microorganisms decreased on average by 0.28 $\log_{10}$ CFU/g, compared to the control. After 48 h of storage of the juice samples, a clear bacteriostatic effect of the additive was found, as the number of aerobic bacteria in the control samples increased and, on average, reached the value of 7.30 $\log_{10}$ CFU/g. In turn, the number of CFU/g in the samples enriched with sumac in the amount of 1.5 and 3.0 g/100 mL was lower by about 2 log than in the control and about 0.5 $\log_{10}$ CFU/g lower than that in the samples tested after 24 h of storage. After 72 h storage, the bacteria in the control juice had multiplied in a fairly large amount (8.30 $\log_{10}$ CFU/g), while the use of sumac in the amount of 0.5, 1.5, and 3 g reduced the total number of microorganisms by 1.7, 2.9, and 3.1 $\log_{10}$ CFU/g, respectively, compared to the control. In the samples with the addition of sumac in the amount of 1.5 and 3.0 g/100 mL, the complete inhibition of the multiplication of aerobic bacteria during storage was observed, as the number of CFU/100 mL was lower than in the juice tested after 24 h of storage, which contributed to the extension of the shelf life of this product.

The contamination of the control carrot juice with yeasts and molds after 24 h of refrigeration was on average 2.3 $\log_{10}$ CFU/g (Figure 2). The addition of sumac caused only a slight reduction in the number of these microorganisms, with the highest average reduction by 0.4 $\log_{10}$ CFU/g in samples with the sumac addition dose of 3.0 g/100 mL. After 48 and 72 h of storage, the number of yeasts and molds in the control samples increased significantly, reaching 4.3 and 5.8 $\log_{10}$ CFU/g, respectively, which made the juice unsuitable for consumption. The addition of the spice significantly slowed down the multiplication of microscopic fungi. The use of 0.5 g/100 mL sumac after 72 h of storage reduced the number of yeasts and molds by an average of 1.7 $\log_{10}$ CFU/g, compared to the control. An even more pronounced reduction by 2.8 and 3.1 $\log_{10}$ CFU/g was obtained after adding 1.5 and 3.0 g/100 mL of sumac, respectively, compared to the control.

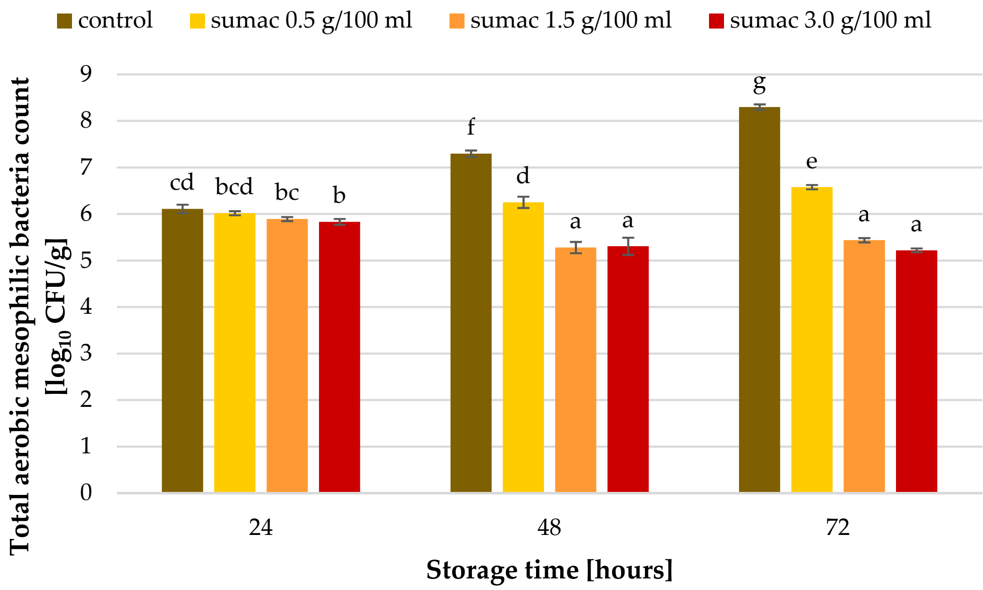

Figure 1. Effect of sumac supplementation on the total number of mesophilic aerobic bacteria in carrot juice stored chilled for 24, 48, and 72 h. The mean values are given with standard deviation. Different letters means statistically significant differences ($p < 0.05$).

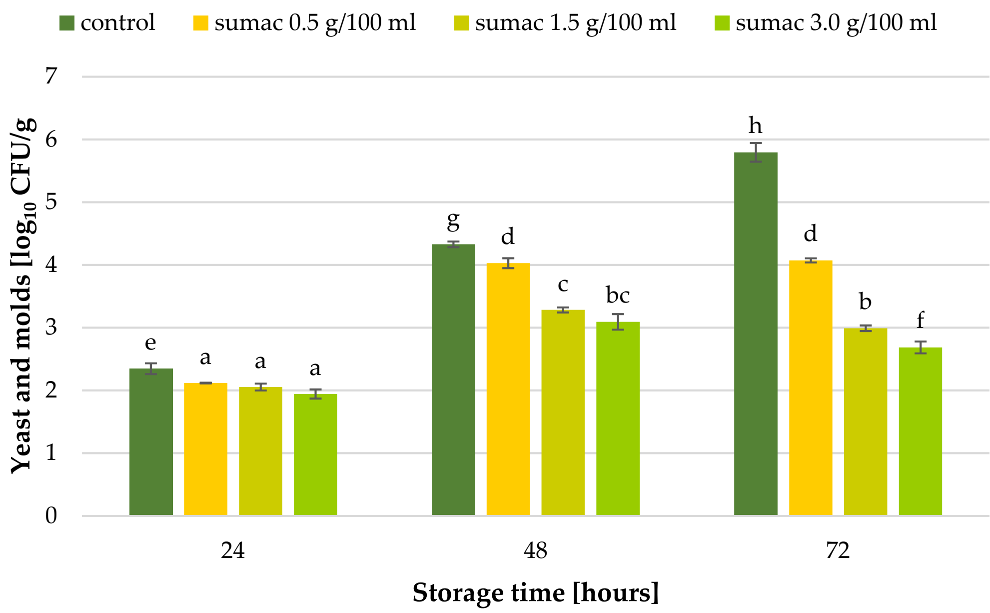

Figure 2. Effect of sumac supplementation on the content of yeasts and molds in carrot juice kept chilled for 24, 48, and 72 h. The mean values are given with standard deviation. Different letters means statistically significant differences ($p < 0.05$).

The obtained results indicate that sumac exhibits bacteriostatic properties, i.e., it inhibits the multiplication of bacteria, yeasts, and molds. The inhibition of the multiplication of microorganisms as a result of the addition of sumac powder significantly extended the shelf life of the juice.

Numerous scientific studies report the bactericidal and bacteriostatic properties of aqueous or alcoholic extracts of sumac fruit. The available tests were carried out on isolated specific strains of bacteria in an optimal medium with the method of micro-dilution in a liquid medium or by disc diffusion in an agar medium. The results of these studies showed high antibacterial efficacy of alcoholic sumac fruit extracts against strains of Gram-positive and Gram-negative bacteria isolated from food products. *Staphylococcus aureus* and

Salmonella enteric turned out to be the most sensitive of the tested strains. For *S. aureus*, a minimum inhibitory concentration (MIC) of 0.125–0.5 mg/mL and a minimum bactericidal concentration (MBC) value of 0.25–1 mg/mL were achieved [41,42].

A study of a 1.0% aqueous sumac fruit extract with the disc diffusion method to determine its activity of against food-borne bacteria, including pathogenic bacteria, showed its high effectiveness in inhibiting the growth of Gram-positive bacteria, such as *Bacillus* spp. and *Staphylococcus aureus*, and Gram-negative bacteria, including *Salmonella* spp., *Escherichia coli*, *Proteus vulgaris*, and *Hafnia alvei*. Some of the bacterial strains tested, e.g., *Listeria monocytogenes* and *Citrobacter freundii*, turned out to be insensitive to the aqueous sumac extract [43]. Using the viable count technique, the same authors demonstrated that, after an hour of treatment with the 1.0% aqueous solution of the sumac fruit extract, the number of CFU/mL was reduced by 4–5 $\log_{10}$ in the case of *Bacillus* spp. and by 2–3 $\log_{10}$ in the other strains tested.

The effectiveness of treatment with an aqueous sumac fruit extract in extending the shelf life of raw meat, e.g., broiler wings, was also investigated. The results showed that 10 min deconamination of the raw wings reduced the number of CFU/g by about 1 $\log_{10}$ and extended the shelf life from 7 to 14 days without degrading the taste and aroma properties of the meat, unlike treatment with a lactic acid solution [44].

The supplementation of the juice with ground sumac powder (in appropriate amounts) extended the shelf life with a significant increase in the content of carotenoids and polyphenols (Figure 3). To the best of our knowledge, there are currently no published articles regarding the use of sumac powder or extract as a preservative for fruit or vegetable juice. Perhaps this is caused by the specific spicy–sour taste of this additive, which nevertheless may enhance the taste of carrot juice.

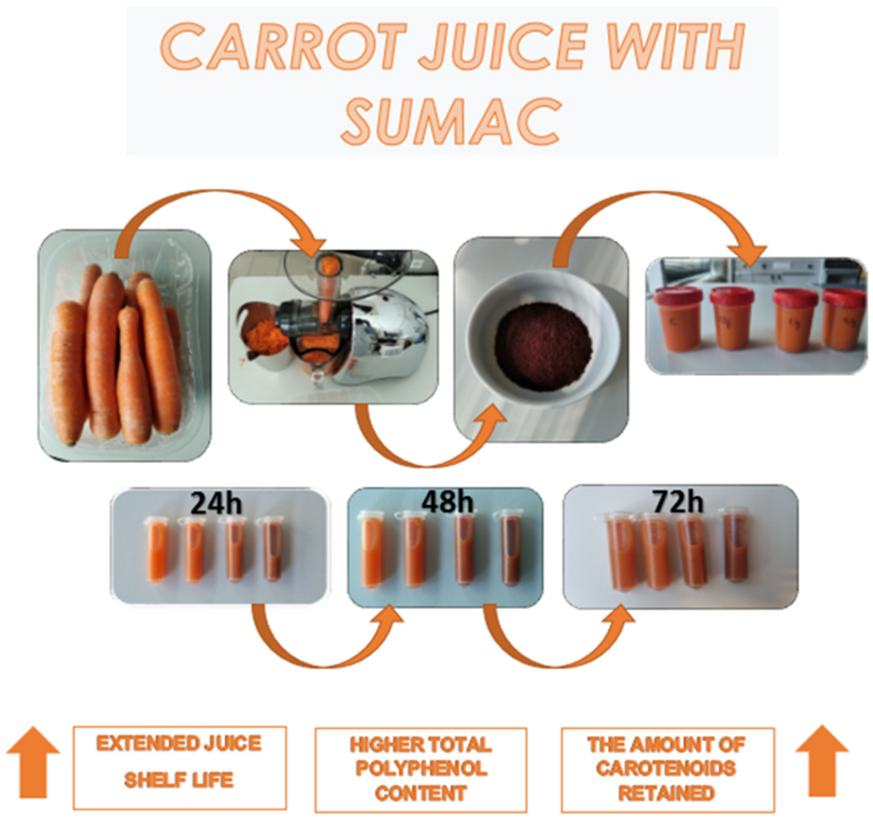

Figure 3. Diagram showing the process of making carrot juice with sumac.

4. Conclusions

Currently, consumers are demanding natural products that help prevent many diseases and that are safe and environmentally friendly. Freshly pressed juices are undoubtedly characterized by many health-promoting substances. Unfortunately, if they are not heat-treated, they deteriorate very quickly. On the other hand, the content of biologically active substances may decrease during the processing and storage of these products. Sumac is one of the spices with high antioxidant and antimicrobial potential. In this study, it was found that the enrichment of freshly pressed carrot juice with sumac in an amount not exceeding 3% contributed to the inhibition of the multiplication of microorganisms in the juice during storage. Generally, the natural sumac spice provided better preservation and shelf life to the perishable vegetable juice.

The use of the spice resulted in the better preservation of carotenoids in the final product, thus increasing its nutritional value. Importantly, the sumac-enriched juices were characterized by a higher content of total polyphenols, even after 72 h of storage. This study demonstrated that sumac (*Rhus coriaria*) can be easily used to enhance the quality of carrot juice.

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