biology and life sciences forum

MDPI

Proceeding Paper

Innovative Technologies to Increase Bioactive Compounds in Carrots of the Chantenay Variety †

Diego Ricardo Gutiérrez [1,2,*], Silvana Cecilia Ruiz [3], Julio Federico Benites [1] and Silvia del Carmen Rodriguez [1,2,*]

[1] Food Science and Technology Institute, Faculty of Agronomy and Agroindustries, National University of Santiago del Estero (UNSE), Santiago del Estero CP4200, Argentina; fedebenites@gmail.com
[2] Applied Biophysics and Food Research Center, National Council for Scientific and Technical Research, National University of Santiago del Estero (CIBAAL-CONICET-UNSE), Villa El Zanjón, Santiago del Estero CP4209, Argentina
[3] National Institute of Agricultural Technology, Santiago del Estero Agricultural Experimental Station (INTA-EEASE), Santiago del Estero CP4200, Argentina; ruiz.silvana@inta.gob.ar
* Correspondence: diegorgutierrez@hotmail.com (D.R.G.); silviadepece@hotmail.com (S.d.C.R.)
† Presented at the 5th International Electronic Conference on Foods, 28–30 October 2024; Available online: https://sciforum.net/event/Foods2024.

Abstract: Carrots have become a functional food ingredient, providing various nutraceuticals such as carotenoids and phenols. The application of stress by cutting followed by incubation and UV-C radiation would induce a higher accumulation of bioactive compounds which would benefit the obtaining of a carrot flour to be used as a new food ingredient with improved functional properties. In this work, the effect of cutting (shredding) and different doses of UV-C radiation on the content of phenolic compounds and antioxidants, as well as the color of carrots of the Chantenay variety produced in Santiago del Estero, Argentina, was evaluated.

Keywords: cutting stress; UV-C; carrots

Academic Editor: Manuel Viuda-Martos

Published: 21 January 2025

Citation: Gutiérrez, D.R.; Ruiz, S.C.; Benites, J.F.; Rodriguez, S.d.C. Innovative Technologies to Increase Bioactive Compounds in Carrots of the Chantenay Variety. *Biol. Life Sci. Forum* **2024**, *40*, 16. https://doi.org/10.3390/blsf2024040016

1. Introduction

In Argentina, Carrot production (*Daucus carota*) in 2021 was 300,000 tons, and Santiago del Estero is the province with the second highest production of an annual variety called Chantenay, whose root is a source of carotenes (pro-vitamin A), compounds responsible for its orange color [1]. These vegetables are grown by large, medium, and small producers and, depending on the type of sale, they can also be collectors, whose production is generally destined for the local or internal market through its commercialization in the Central Market of Buenos Aires (MCBA) [2] through bulk sales and without greater added value.

Now, consumers are looking for safe foods with differentiated nutritional properties. In this sense, vegetables play an important role in human health, being a source of essential nutrients such as potassium, folic acid, and vitamins A and C, and carrot in particular has become a functional ingredient that provides various nutraceutical compounds such as carotenoids, other bioactive compounds, and dietary fiber, all of which are necessary for good health [3,4].

To improve the nutraceutical properties of foods, according to research, postharvest treatments such as cutting stress can increase the bioactive compounds in carrots so that they can be used as an ingredient in food formulations [5]. On the other hand, UV-C radiation, non-ionizing and germicidal at a wavelength of 190 to 280 nm, is a technology widely used for the decontamination of surfaces of cut fruits and vegetables [6,7], so it could be applied with a dual purpose: to prolong the shelf life and maintain the intrinsic

properties of the vegetables. Likewise, and according to the Innovative Argentina Plan 2020 (IAI-2020), more and more companies in the food sector adopt new technologies and undertake innovative processes to comply with new regulatory requirements and increase added value, with a view to responding to internal demands and growing external ones. It is important to note that the use of UV-C radiation is an accessible and low-cost technology [8].

The aim of the present work was to evaluate the effect of cutting stress (shredding) and the application of different doses of UV-C radiation on the color and content of phenolic and antioxidant compounds of carrots of the Chantenay variety produced in Santiago del Estero, Argentina.

2. Materials and Methods

2.1. Sample Preparation and Treatments

Carrots of the Chantenay variety were obtained from farmers in Santiago del Estero, Argentina. The roots were washed and disinfected with chlorinated water (200 ppm-5 min) and dried with absorbent paper. Both ends of the carrots were cut with a sharp knife and they were subjected to grating using a food processor. Subsequently, the samples were subjected to the different treatments: T_1 (control): grated carrots; T_2 (control + I): incubation of the samples at 25 °C-24 h; $T_{3\text{-}5}$ (UV-C): applied doses of UV-C: 10, 25, and 50 kJ m^{-2}; $T_{6\text{-}8}$ (UV-C + I): carrots were incubated after being treated with the UV-C doses; $T_{9\text{-}11}$ (I + UV-C): incubated before UV-C. Incubation of the samples was carried out to stimulate the production of phenolic compounds. For this purpose, 100 g of grated carrots were placed in polyvinyl chloride (PVC) trays (BANDEX, Buenos Aires, Argentina) with dimensions of 15 cm × 10 cm × 4 cm and covered with bioriented polypropylene (BOPP) bags (35 µm thick and 20 × 15 cm^2 area) perforated with 0.3 mm diameter holes spaced 0.03 m apart to allow respiration. Absorbent paper was placed on the bottom of the trays to absorb excess moisture and they were stored in an incubator (TECNAL TE-4001, Piracicaba-Brazil) for 24 h at 25 °C. After each treatment, the influence on the color, total phenols and antioxidant capacity of the grated carrots was evaluated. The samples were stored at −80 °C (Ultrafrezzer Righi, Buenos Aires-Argentina) until chemical analysis was performed (within 15 days), in glass jars with screw lids. All the measures were made in triplicate and the results were expressed as means ± SD.

2.2. UV-C Radiation Equipment

Grated carrots were irradiated in a stainless steel cabinet as described by Gutiérrez et al. [6]. The cabinet was equipped with 12 germicidal lamps (254.7 nm, TUV 36W/G36, Philips, Amsterdam, The Netherlands) distributed equally on the top and bottom of the samples. The light intensity was kept constant (0.017 kW m^{-2}) and the received dose was measured with a portable digital radiometer (Cole-Parmer Instrument Company, Vernon Hill, IL, USA).

2.3. Color

The surface color of grated carrots was determined by measuring the color parameters L*, a*, and b* in CIE LAB space with a tri-stimulus colorimeter (Minolta CR 300, Ramsey, NJ, USA), with a viewing aperture of 8 mm diameter, D65 illuminant, and observation angle of 0°, previously calibrated using the manufacturer's standard white plate. Color parameters were expressed as lightness (L*), chroma (C*), and hue angle (h°). The hue angle [$h^\circ = 180 + \tan^{-1}(b^*/a^*)$] and the values of chroma [$C^* = (a^{*2} + b^{*2})^{1/2}$] were calculated from a* and b* values [9].

2.4. Preparation of Extracts for Total Phenols and Antioxidant Activity

The extraction of phenols was performed according to the procedure described by Gutiérrez et al. [10] with minor modifications. For this purpose, 5 g samples of frozen carrots were homogenized with 15 mL of methanol. Subsequently, the extract was transferred to caramel-colored vials and refrigerated at 5 °C for 24 h. After this time, the samples were centrifuged for 10 min at 12,000 rpm and the supernatant was taken for the determination of total phenols and antioxidant activity.

2.4.1. Total Phenol Content

They were determined according to the Folin–Ciocalteu methodology [11]. First, 0.15 mL of the supernatant was mixed with 1.05 mL of distilled water, 0.65 mL of Folin–Ciocalteu's reagent (1:1 v/v, diluted with distilled water), and 3.15 mL of 20% (w/v) Na_2CO_3. The solution was then stirred and heated at 50 °C for 10 min. The absorbance was measured in triplicate at 750 nm using a UV-visible spectrophotometer (JASCO V-630, Tokio-Japan). The calibration curve was performed with gallic acid, and the results of phenolic compounds were expressed as mg gallic acid equivalents (GAE) per g of fresh tissue (TF).

2.4.2. Antioxidant Capacity

Total antioxidant capacity was determined based on the evaluation of free radical scavenging capacity according to the methodology of Ozgen et al. [12], using 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) of absorbance ~1.1. The absorbance was measured at a wavelength of 515 nm, and the antioxidant capacity was expressed as a percentage: %INH = (1 − absorbance Sample/control absorbance) × 100.

2.5. Statistical Analysis

Results were analyzed by Analysis of Variance (ANOVA), using Infostat 2011 software (UNC-Argentina). All experiments were performed in triplicate. Means were compared by the least significant difference (LSD) test at a significance level of 0.05.

3. Results and Discussion

Color is one of the most important quality attributes, and one that the consumer considers when making a purchase [13]. L* parameter color and C* and hue° indices are shown in Table 1. Color results indicated that no significant differences were found between different treatments. It is important to note that no studies were found on the evaluation of color in grated carrots treated with UV-C.

Table 1. L* parameter color, C*, and hue° indices of grated carrots of the Chantenay variety untreated (control), treated with different doses of UV-C radiation, and incubated at 25 °C for 24 h after UV-C radiation.

Treatments	Color Parameters		
	L*	C*	hue°
Control	53.4 ± 0.30	39.69 ± 1.41	57.71 ± 0.12
10 kJ m^{-2}	51.9 ± 0.46	37.32 ± 0.63	58.07 ± 1.21
25 kJ m^{-2}	52.1 ± 1.32	40.13 ± 0.47	57.91 ± 0.55
50 kJ m^{-2}	54.14 ± 1.5	40.53 ± 2.52	58.46 ± 0.62
Control + I	53.4 ± 0.30	39.66 ± 1.4	57.69 ± 0.14
10 kJ m^{-2} + I	51.9 ± 0.46	37.32 ± 0.63	58.07 ± 1.21

Table 1. *Cont.*

Treatments	Color Parameters		
	L*	C*	hue°
25 kJ m^{-2} + I	52.1 ± 1.32	40.13 ± 0.47	57.91 ± 0.55
50 kJ m^{-2} + I	53.94 ± 1.51	40.53 ± 2.52	58.46 ± 0.62
p-value	0.7093	0.8451	0.7490

Results expressed as mean values ± standard error. Different significant when $p < 0.05$.

The phenolic compounds of untreated grated carrots incubated at 25 °C for 24 h before and after treatment with different doses of UV-C radiation are shown in Figure 1.

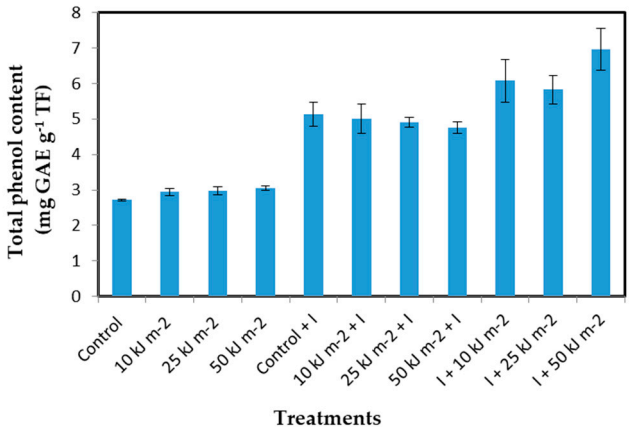

Figure 1. Phenolic compounds content of grated carrots of the Chantenay variety untreated (control) and incubated at 25 °C for 24 h before and after being treated with different doses of UV-C radiation. Data corresponds to mean values ± standard deviation.

As can be seen, the UV-C radiation treatments produced a significant increase of approximately 10% in total phenol content with respect to the untreated grated carrot samples (2.72 mg GAE g^{-1} FW). However, no significant differences were observed between UV-C doses. This increase in these phytochemicals observed in UV-C treated carrots is a response to the applied abiotic stress [14]. Viacava et al. [15] have reported that the application of abiotic stress induced significant increases in the p-cumaric acid and chologenic acid concentration, as the main bound phenolic compounds and free phenolic compounds in carrots, respectively. These increases have also been reported in other products such as tomatoes [16,17], Satsuma mandarin [18], yam slices [19], organic grapes [20], and tomato and cucumber [21]. The biosynthesis of phenolic compounds could be a defense mechanism against UV-C stress and possibly due to a modification of the cell wall by depolymerization and dissolution of polysaccharides by exposure to UV-C radiation, which facilitated the extraction of phenols [21].

On the other hand, incubation at 25 °C for 24 h (I) produced a greater increase in phenolic compounds in all samples. This increase agrees with Viacava et al. [15], who reported that incubation of grated carrots for 48 h at 15 °C stimulates the production of phenolic compounds. The control + I treatment showed an increase of approximately 48% with respect to the untreated samples. On the other hand, when incubation was applied in combination with UV-C treatments, the increase depended on whether it was applied before or after the treatments. When incubation was performed after the UV-C treatments (UV-C + I), they did not show significant differences ($p > 0.05$) with respect to the control + I. However, when incubation was performed before the UV-C treatments (I + UV-C), phenolic compounds showed an increase ($p < 0.05$) with respect to the UV-C + I

combination and of approximately 60% with respect to the control. In all combinations, no significant differences were observed between the different UV-C doses.

Therefore, to produce fresh grated carrots enriched with phenolic compounds, either in households or on an industrial scale for later commercialization, the grated tissue could be stored for at least 24 h at 15 °C and then UV-C could be applied. This additional radiation stress further increases the accumulation of phenolic compounds induced by cutting damage and, therefore, the health benefits of consuming carrots.

The antioxidant capacity of untreated grated carrots incubated at 25 °C for 24 h before and after being treated with different doses of UV-C radiation is shown in Figure 2. The antioxidant capacity of carrots is mainly due to their content of phenolic compounds [14]. In this sense, it was observed that the antioxidant capacity was related to phenolic compounds.

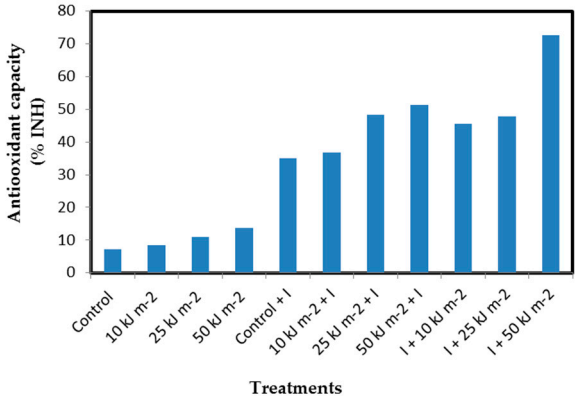

Figure 2. Antioxidant capacity of grated carrots of the Chantenay variety untreated (control) and incubated at 25 °C for 24 h before and after being treated with different doses of UV-C radiation. Data corresponds to average percentage values.

UV-C treatments caused stress in carrots, inducing an increase in antioxidant capacity relative to the control of approximately 15%, 33%, and 48% for doses of 10, 25, and 50 kJ m^{-2}, respectively. However, similar to phenolic compounds, combinations of incubation with UV-C doses induced higher antioxidant capacity depending on whether the incubation was performed before or after the treatments.

The incubation of the control and after the application of UV-C radiation induced a significant increase in the antioxidant capacity with respect to the control. This increase was approximately 80, 81, 85, and 86% in the control + I, 10 kJ m^{-2} + I, 25 kJ m^{-2} + I, and 50 kJ m^{-2} + I, respectively. On the other hand, when incubation was performed before the UV-C treatments, the 10 kJ m^{-2} + I and 25 kJ m^{-2} + I treatments showed no variation compared to when incubation was performed before the treatments. However, the higher dose of 50 kJ m^{-2} + I induced a significant increase of about 90% over the control.

These results suggest that the stress caused by cutting combined with UV-C radiation, after incubation, improved the antioxidant capacity of grated carrots, probably as a result of the increase in total phenolic content. To prevent or delay oxidative damage in humans induced by free radicals, it is necessary to consume sufficient antioxidant compounds with food [14].

4. Conclusions

In this study, the effect of cutting stress combined with UV-C radiation on phenolic compounds and antioxidant capacity, as well as on the color, of carrots of the Chantenay variety, grown under the soil and climatic conditions of the province of Santiago del Estero, Argentina, was reported. Cutting stress was applied by grating the carrots and incubating the tissue at 25 °C for 24 h before or after UV-C radiation. All treatments showed higher

total phenol content compared to the control (2.71 mg g^{-1}). UV-C treatments registered an increase of approximately 10%; however, when UV-C was combined with incubation, the increase was significantly higher, approximately 60 and 48% when performed before and after UV-C, respectively. Treatment I + 50 kJ m^{-2} exhibited the highest value (6.97 mg g^{-1}). Antioxidant capacity presented a similar behavior to total phenols. As for color parameters, no significant differences were observed between all the treatments applied.

Future research should explore the possible use of grated carrots with increased functional properties obtained by the procedure proposed in this work as raw material for obtaining, for example, carrot flour, which could be used as a new food ingredient for the preparation of sweet cookies or bread, among others.

Author Contributions: Conceptualization, D.R.G., S.C.R., J.F.B. and S.d.C.R.; methodology, D.R.G., S.C.R., J.F.B. and S.d.C.R.; software, D.R.G. and S.C.R.; validation, D.R.G., S.C.R., J.F.B. and S.d.C.R.; formal analysis, D.R.G., S.C.R. and J.F.B. and S.d.C.R.; investigation, D.R.G., S.C.R., J.F.B.; resources, S.d.C.R. and D.R.G.; data curation, D.R.G., S.C.R., J.F.B. and S.d.C.R.; writing—original draft, D.R.G., S.C.R., J.F.B. and S.d.C.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received funding from a project awarded by the Federal Council for Science, Technology and Innovation (COFECYT) of the Ministry of Science and Technology in the call for Federal Projects for Productive Innovation 2022. Project N° SE-2-PFI2022.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: This work was carried out at the Faculty of Agronomy and Agroindustry of the National University of Santiago del Estero and Research Center in Applied Biophysics and Food-National Council for Scientific and Technical Research, Argentina.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Secretariat of Livestock and Fisheries, Ministry of Economy, Argentina. Carrot Production in Argentina. Evolution of the Crop Until the 2021/2022 Season. 2023. Available online: https://www.argentina.gob.ar/sites/default/files/produccion-zanahoria-argentina-hasta-2021-2022.pdf (accessed on 20 January 2025).
2. Della Gáspera, P.G. El Zapallo: Comercio y Producción. Boletín de Frutas y Hortalizas del Convenio INTA-CMCBA. 2017, Nº 69, 13 pág. Available online: https://mercadocentral.gob.ar/sites/default/files/docs/boletin-INTA-CMCBA-69-zapallo_0.pdf (accessed on 20 January 2025).
3. Duthie, S.J.; Duthie, G.G.; Russell, W.R.; Kyle, J.A.M.; Macdiarmid, J.I.; Rungapamestry, V.; Stephen, S.; Megias-Baeza, C.; Kaniewska, J.J.; Shaw, L.; et al. Effect of increasing fruit and vegetable intake by dietary intervention on nutritional biomarkers and attitudes to dietary change: A randomised trial. *Eur. J. Nutr.* **2018**, *57*, 1855–1872. [CrossRef] [PubMed]
4. Schreinemachers, P.; Simmons, E.B.; Wopereis, M.C.S. Tapping the economic and nutritional power of vegetables. *Glob. Food Secur.* **2018**, *16*, 36–45. [CrossRef]
5. Viacava, F.; Santana-Gálvez, J.; Heredia-Olea, E.; Pérez-Carrillo, E.; Jacobo-Velázquez, D.A. Combined application of wounding stress and extrusion as an innovative tool to obtain carrot powders with modified functional properties. *CyTA-J. Food* **2019**, *17*, 613–621. [CrossRef]
6. Gutiérrez, D.R.; Chaves, A.R.; Rodríguez, S.D.C. Use of UV-C and gaseous ozone as sanitizing agents for keeping the quality of fresh-cut rocket (*Eruca sativa* mill.). *J. Food Proc. Preserv.* **2016**, *41*, e12968. [CrossRef]
7. Darré, M.; Vicente, A.R.; Cisneros-Zevallos, L.; Artéz-Hernández, F. Postharvest ultraviolet radiation in fruit and vegetables: Applications and factors modulating its efficacy on bioactive compounds and microbial growth. *Food* **2022**, *11*, 653. [CrossRef] [PubMed]
8. Innovative Argentina Plan 2020. Available online: https://www.argentina.gob.ar/ciencia/argentina-innovadora-2030/plan-argentina-innovadora-2020 (accessed on 13 December 2024).

9. Koukounaras, A.; Siomos, A.S.; Sfakiotakis, E. Postharvest CO_2 and ethylene production and quality of rocket (*Eruca sativa* Mill.) leaves as affected by leaf age and storage temperature. *Postharvest Biol. Technol.* **2007**, *46*, 167–173. [CrossRef]
10. Gutiérrez, D.R.; Char, C.; Escalona, V.H.; Chaves, A.R.; Rodríguez, S.D.C. Application of UV-C radiation in the conservation of minimally processed rocket (*Eruca sativa* Mill.). *J. Food Process. Preserv.* **2015**, *39*, 3117–3127. [CrossRef]
11. Singleton, V.L.; Orthofer, R.; Lamuela-Raventós, R.M. Analysis of total phenols oxidation substrates and antioxidants by means of Folin–Ciocalteau reagent. *Method Enzymol.* **1999**, *299*, 152–153.
12. Ozgen, M.; Reese, R.N.; Tulio, A.Z.; Scheerens, J.C.; Miller, A.R. Modified 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) method to measure antioxidant capacity of selected small fruits and comparison to ferric reducing antioxidant power (FRAP) and 2,2′-diphenyl-1-picrylhydrazyl (DPPH) methods. *J. Agr. Food Chem.* **2006**, *54*, 1151–1157. [CrossRef]
13. Cuastumal Conacuan, H.G.; Valencia Murillo, B.L.; Ordóñez Santos, L.E. Efectos de los tratamientos térmicos en la concentración de vitamina C y color superficial en tres frutas tropicales. *Rev. Lasallista Investig.* **2016**, *13*, 85–93. [CrossRef]
14. Formica-Oliveira, A.C.; Martínez-Hernández, G.B.; Díaz-López, V.; Artés, F.; Artés-Hernández, F. Effects of UV-B and UV-C combination on phenolic compounds biosynthesis in fresh-cut carrots. *Postharvest Biol. Technol.* **2017**, *127*, 99–104. [CrossRef]
15. Viacava, F.; Santana-Gálvez, J.; Heredia-Olea, E.; Pérez-Carrillo, E.; Nair, V.; Cisneros-Zevallos, L.; Jacobo-Velázquez, D.A. Sequential application of postharvest wounding stress and extrusion as an innovative tool to increase the concentration of free and bound phenolics in carrots. *Food Chem.* **2020**, *307*, 125551. [CrossRef]
16. Bravo, S.; García-Alonso, J.; Martín-Pozuelo, G.; Gómez, V.; Santaella, M.; Navarro-González, I.; Periago, M.J. The influence of post-harvest UV-C hormesis on lycopene, β-carotene, and phenolic content and antioxidant activity of breaker tomatoes. *Food Res. Int.* **2012**, *49*, 296–302. [CrossRef]
17. Liu, C.H.; Cai, L.Y.; Lu, X.Y.; Han, X.X.; Ying, T.J. Effect of postharvest UV-C irradiation on phenolic compound content and antioxidant activity of tomato fruit during storage. *J. Integrat. Agric.* **2012**, *11*, 159–165. [CrossRef]
18. Shen, Y.; Sun, Y.; Qiao, L.; Chen, J.; Liu, D.; Ye, X. Effect of UV-C treatments on phenolic compounds and antioxidant capacity of minimally processed Satsuma mandarin during refrigerated storage. *Postharvest Biol. Technol.* **2013**, *76*, 50–57. [CrossRef]
19. Li, S.T.; Lasekan, O.; Adzahan, N.M.; Hashim, N. The effect of combinations of UV-C exposure with ascorbate and calcium chloride dips on the enzymatic activities and total phenolic content of minimally processed yam slices. *Postharvest Biol. Technol.* **2016**, *120*, 138–144. [CrossRef]
20. Pinto, E.P.; Perin, E.C.; Schott, I.B.; da Silva Rodrigues, R.; Lucchetta, L.; Manfroi, V.; Rombaldi, C.V. The effect of postharvest application of UV-C radiation on the phenolic compounds of conventional and organic grapes (*Vitis labrusca* cv. 'Concord'). *Postharvest Biol. Technol.* **2016**, *120*, 84–91. [CrossRef]
21. Olaiya, C.O.; Karigidi, K.O.; Ogunleye, A.B.; Kareem, R.O. Possible enhancement of nutrients and antioxidant capacity of two tropical fruits by UV radiation treatment. *Adv. Life Sci. Technol.* **2016**, *46*, 80–85.