Properties of Extruded Snacks Prepared from Corn and Carrot Powder with Ascorbic Acid Addition

Obradović, Valentina; Babić, Jurislav; Dragović-Uzelac, Verica; Jozinović, Antun; Ačkar, Đurđica; Šubarić, Drago

processes

MDPI

Article

Properties of Extruded Snacks Prepared from Corn and Carrot Powder with Ascorbic Acid Addition

Valentina Obradović [1,*], Jurislav Babić [2], Verica Dragović-Uzelac [3], Antun Jozinović [2], Đurđica Ačkar [2] and Drago Šubarić [2]

[1] Agricultural Department, Polytechnic of Požega, Vukovarska 17, 34000 Požega, Croatia
[2] Department of Food Technologies, Faculty of Food Technology Osijek, Josip Juraj Strossmayer University of Osijek, Franje Kuhača 20, 31000 Osijek, Croatia; jbabic@ptfos.hr (J.B.); ajozinovic@ptfos.hr (A.J.); dackar@ptfos.hr (Đ.A.); dsubaric@ptfos.hr (D.Š.)
[3] Department of Food Engineering, Faculty of Food Technology and Biotechnology, University of Zagreb, Pierottijeva 6, 10000 Zagreb, Croatia; vdragov@pbf.hr
* Correspondence: vobradovic@vup.hr

Abstract: The objective of this research was to investigate the potentiality of carrot powder (CP) utilization at levels 4, 6, or 8% as ingredient of corn snacks and evaluation of the extrusion influence on functionally important ingredients such as carotenoids (color), polyphenols, fiber, fat, and antioxidant activity. The influence of ascorbic acid (AA) as an external source at levels 0.5 and 1% on this particular extrusion was also investigated. A single-screw extruder at two temperature regimes (135/170/170 °C (E1) and 100/150/150 °C (E2)) carried out extrusion. The E1 temperature regime acted favorably on total polyphenol content and crude fiber, but fat preferred the E2 regime. Extrusion, especially the E1 temperature regime, increased the extractability of carotenoids. Ascorbic acid degraded during extrusion, but it still provided protection to carotenoids and color attributes of extrudates. Snacks with increased nutritional and functional value due to carrot powder addition were successfully produced, which is a starting point for production of a new type of extruded snacks.

Keywords: extrusion; carrot; ascorbic acid; carotenoids; antioxidant power

Citation: Obradović, V.; Babić, J.; Dragović-Uzelac, V.; Jozinović, A.; Ačkar, Đ.; Šubarić, D. Properties of Extruded Snacks Prepared from Corn and Carrot Powder with Ascorbic Acid Addition. *Processes* **2021**, *9*, 1367. https://doi.org/10.3390/pr9081367

Academic Editors: Luis Cruz, Erika Salas and Nuno Mateus

Received: 18 May 2021
Accepted: 2 August 2021
Published: 4 August 2021

1. Introduction

The carrot (*Daucus carota*) is considered a primary vegetable; in many countries, the consumption of carrots and their related products has increased steadily [1,2] mainly due to their pleasant flavor and the perceived health benefits related to their vitamins, minerals, and dietary fiber [2]. Carrots have been shown to contain numerous phytochemicals such as carotenoids and flavonoids, their type and percentage greatly dependent on the cultivar and color of the carrots [3]. Besides provitamin A activity, carotenoids may be also beneficial in preventing major health problems, such as cancer and cardiovascular/coronary heart diseases, due to their antioxidant activity [4–6]. They also have other physiological roles, such as cell-to-cell communication, immunomodulatory effects, and UV skin protection [7]. Considering these facts, it is important to enhance carrot utilization where possible, even in products in which it was not common until now. From this point of view, the application of extrusion cooking is especially interesting, since extruded products are popular, ready-to-eat, of crispy texture, and nicely shaped and colored. They are mainly composed of cereals, which form their structure, bulk and other desired characteristics of the finished product. [8]. However, they are often regarded as junk food because their composition is mainly based on carbohydrates and fat. Extrusion cooking is a high-temperature, short-time (HTST) process, which can apply the required amount of thermal and mechanical energy to raw materials in a relatively short period of time. The short residence time should reduce disliked reactions to vitamins, proteins, amino acids, and enzymes [9]. However, high temperatures and shear stresses can accelerate chemical reactions and losses

of labile functional ingredients [9]. The retention of sensitive bioactive compounds such as ß-carotene during the extrusion process is a challenge to the food industry [10]. Corn is often used as a source of corn starch in the production of popular extruded snack foods. Although corn is a source of lutein and zeaxanthin, it is certainly not enough to satisfy the needs of health-conscious consumers [8,11]. Extruded snacks fortification to increase the nutrient content is practiced by many studies [12,13], especially the addition of protein and fiber rich ingredients; the addition of fruits and vegetables is studied to a lesser extent [14]. The objective of this study was to investigate the addition of different proportions of dry carrot powder, as well as extrusion cooking on the nutritional and functional properties of used materials. The potential of carrot parts that cannot be used for other purposes, such as the peel, is particularly interesting in the context of the use of waste materials. The addition of carrots to extruded products has been studied by Stojceska et al. [15], but research focused primarily on dietary fiber, and Kaisangsri et al. [16], but they measured only total β-carotenoid content. Some studies have presented the influence of extrusion on carotenoids [17–19], but they did not originate from carrots, or only model substances were used. Besides carrots, ascorbic acid has also been added to the extrusion mixture since it is a strong antioxidant, and previous research showed that it can prevent pigment degradation during extrusion cooking [19,20].

2. Materials and Methods

2.1. Materials

Corn grits, particle size >500 µm (Žito Ltd., Osijek, Croatia). Dried carrots stripes (proteins 3.37%; crude fiber 4.76%, starch 5.81%, ash 1.91%) (Xinghualianfu food Co. Ltd., Xinghua, China). Ascorbic acid (T.T.T. Ltd., Sv. Nedjelja, Croatia).

2.2. Sample Preparation

The proportions of added carrots and moisture content were selected according to the preliminary studies, in order to achieve extrusion process continuity and products with satisfying organoleptic properties. Corn grits and carrot powder were mixed in 96:4, 94:6, and 92:8 ratios (dry to dry weight), and AA was also added to mixtures at 0, 0.5, and 1% levels (dry basis). The total moisture of the mixtures was set to 15%, and the mixtures were put in plastic bags, sealed, and left in the dark for 24 h before the extrusion.

Extrusion experiments were performed using a laboratory single-screw extruder (model Do-Coder, Brabender 19/20 DN, Duisburg, Germany). Extrusion parameters were as follows. Temperature profiles, 135/170/170 °C and 100/150/150 °C; 4:1 compression ratio screw; screw speed, 100 rpm; feed rate, 15 rpm. The obtained extrudates were air-dried at ambient temperature overnight, put in plastic bags, vacuum sealed, and stored in darkness until the analysis.

2.3. Color Analysis

Triplicate analyses were performed for each sample, and the procedure was previously described in detail [19]. Total color change of each extruded sample in relation to the color of raw materials ΔE was also calculated according to the Equation (1):

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

where subscript "0" indicates initial color values of the raw material [21].

2.4. Ascorbic Acid Determination

Triplicate analyses were performed for each sample, and the procedure was previously described in detail [20].

2.5. Fat and Crude Fiber Determination

Fat content was determined according to the ISO 6492:2001 method [22] and crude fiber content was determined according to ISO 6865:2000 [23]. Each sample was analyzed in 3 replications.

2.6. Total Polyphenols Content Determination

Polyphenols were determined according the Folin–Ciocalteu method [24], with modifications; the procedure has previously been described in detail [19].

2.7. Antioxidant Activity (ABTS)

Triplicate analyses were performed for each sample; the procedure has previously been described in detail [19].

2.8. Carotenoid Determination

Extraction of carotenoids was performed according to the method previously described by Kljak et al. [25], with modifications; the procedure has previously been described in detail [19].

2.9. Experimental Design and Data Analysis

Color analysis data were analyzed using Design expert 6.0.8. software (Stat-Ease, Inc., Minneapolis, MN, USA). RSM (response surface methodology) was chosen to build mathematical models using 3-level factorial design. Carrot (variable A) and ascorbic acid levels (variable B) were set as independent variables, since the chemical composition of mixtures is the focus of this investigation. Mathematical models were built in terms of coded values: variable A—4, 6, 8%/−1, 0, 1; and variable B—0, 0.5, 1%/−1, 0, 1. The statistical significance of the regression coefficients was determined by analysis of variance (ANOVA) at 95% level. The desirability function was used to determine optimal CP and AA levels in order to maximize pigment content in the final product. Chemical composition data were analyzed by Statistica 8 software (StatSoft Inc., Tulsa, OK, USA), using post hoc LSD at 95% level.

3. Results and Discussion

3.1. Ascorbic Acid Degradation

The ascorbic acid (AA) content in raw and extruded samples is shown in Table 1. The presented values are entirely a consequence of acid addition, since it was not present in other raw materials. During extrusion, AA degraded to a certain level, but under all conditions enough quantity of AA was left to preserve other compounds, which was the primary goal of the AA addition to the extrusion mixture. Degradation was higher at E1 extrusion temperatures (45–76%) than at lower extrusion temperatures (10–63%). Similar results were also obtained by other studies [19,20,26]. There are several reasons for degradation: (1) oxidation [27], (2) loss at the die together with the water evaporation as a consequence of solubility in water [26], (3) the nature of raw materials [20].

Table 1. Ascorbic acid content before and after extrusion in raw and extruded samples [A].

CP (%)	AA (%)	Ascorbic Acid (g kg^{-1}) *Before Extrusion*	Ascorbic Acid (g kg^{-1}) *After Extrusion E1*	Degradation (%)	Ascorbic Acid (g kg^{-1}) *After Extrusion E2*	Degradation (%)
0	0	n.d.	n.d.	-	n.d.	-
0	0.5	4.028 ± 0.017	0.952 ± 0.015	76.36	2.729 ± 0.013	32.25
0	1	7.898 ± 0.025	4.013 ± 0.019	49.19	5.713 ± 0.041	27.66
4	0	n.d.	n.d.	-	n.d.	-
4	0.5	4.201 ± 0.057	0.906 ± 0.022	78.43	2.171 ± 0.027	48.32
4	1	8.127 ± 0.229	1.876 ± 0.023	76.91	3.004 ± 0.027	63.04

Table 1. *Cont.*

CP (%)	AA (%)	Ascorbic Acid (g kg^{-1}) *Before Extrusion*	Ascorbic Acid (g kg^{-1}) *After Extrusion E1*	Degradation (%)	Ascorbic Acid (g kg^{-1}) *After Extrusion E2*	Degradation (%)
6	0	n.d.	n.d.	-	n.d.	
6	0.5	3.505 ± 0.098	1.120 ± 0.042	68.05	3.082 ± 0.035	12.04
6	1	8.234 ± 0.015	4.448 ± 0.016	45.98	7.405 ± 0.082	10.07
8	0	n.d.	n.d.	-	n.d.	-
8	0.5	4.742 ± 0.069	1.655 ± 0.002	65.05	2.871 ± 0.016	39.46
8	1	8.077 ± 0.068	4.358 ± 0.072	45.97	6.437 ± 0.045	20.30

[A] Contents are the mean ± standard deviation of three repetitions, CP—carrot powder level, AA—ascorbic acid level, E1—135/170/170 °C extrusion temperatures, E2—100/150/150 °C extrusion temperatures, n.d.—not detected.

3.2. Fat and Crude Fiber Content

Fat content in the raw and extruded samples is presented in Table 2. Extrusion caused fat degradation at both extrusion temperatures. Higher degradation occurred at higher extrusion temperatures, which was also observed by Lin et al. [28]. The difference between fat content in extrudates obtained at different temperatures was not significant in some samples. The deterioration of lipids can be attributed to both hydrolytic and oxidative rancidity, both of which can be affected by extrusion cooking. With an increase in extrusion temperature, autooxidation of lipid occurs, which might be enhanced by the breakdown of natural antioxidants and the increasing amount of prooxidant [28]. In this case, the addition of AA at 1% level promoted lipid degradation compared to the 0.5% level. During AA degradation, dehydroascorbic acid is formed [29], and it acts as a fat prooxidant. Since the addition of higher levels of AA resulted in higher levels of dehydroascorbic acid as well, lipid degradation was increased.

Table 2. Fat and crude fiber content in raw and extruded samples [A, B].

		Fat (g kg^{-1})			Crude Fibre (g kg^{-1})		
CP (%)	AA (%)	*Before Extrusion*	*After Extrusion E1*	*After Extrusion E2*	*Before Extrusion*	*After Extrusion E1*	*After Extrusion E2*
0	0	3.15 ^{b} ± 0.07	0.78 ^{a} ± 0.01	0.83 ^{a} ± 0.01	5.4 ^{y} ± 0.1	5.3 ^{y} ± 0.1	4.9 ^{x} ± 0.1
0	0.5	3.15 ^{b} ± 0.07	0.64 ^{a} ± 0.01	0.55 ^{a} ± 0.00	5.1 ^{y} ± 0.1	5.2 ^{y} ± 0.1	4.7 ^{x} ± 0.1
0	1	3.15 ^{c} ± 0.07	0.57 ^{a} ± 0.04	0.93 ^{b} ± 0.10	5.0 ^{y} ± 0.1	5.0 ^{y} ± 0.1	4.5 ^{x} ± 0.1
4	0	3.55 ^{b} ± 0.35	0.36 ^{a} ± 0.05	0.84 ^{a} ± 0.04	6.8 ^{y} ± 0.1	6.7 ^{y} ± 0.2	5.5 ^{x} ± 0.1
4	0.5	3.45 ^{c} ± 0.07	0.54 ^{a} ± 0.01	0.96 ^{b} ± 0.04	6.3 ^{y} ± 0.2	6.2 ^{y} ± 0.1	5.3 ^{x} ± 0.1
4	1	2.85 ^{c} ± 0.21	0.10 ^{a} ± 0.11	0.74 ^{b} ± 0.07	6.0 ^{y} ± 0.1	6.0 ^{y} ± 0.1	5.1 ^{x} ± 0.2
6	0	3.50 ^{c} ± 0.00	0.58 ^{a} ± 0.01	0.98 ^{b} ± 0.18	7.8 ^{y} ± 0.1	7.8 ^{y} ± 0.2	6.5 ^{x} ± 0.0
6	0.5	3.40 ^{c} ± 0.00	1.03 ^{a} ± 0.09	1.15 ^{b} ± 0.02	7.5 ^{y} ± 0.2	7.4 ^{y} ± 0.1	6.3 ^{x} ± 0.3
6	1	2.95 ^{b} ± 0.07	0.74 ^{a} ± 0.02	0.95 ^{a} ± 0.02	7.0 ^{y} ± 0.1	6.8 ^{y} ± 0.2	5.6 ^{x} ± 0.2
8	0	2.95 ^{b} ± 0.21	0.77 ^{a} ± 0.00	0.81 ^{a} ± 0.14	8.1 ^{z} ± 0.1	7.8 ^{y} ± 0.1	6.5 ^{x} ± 0.2
8	0.5	2.85 ^{b} ± 0.21	0.95 ^{a} ± 0.08	0.82 ^{a} ± 0.11	7.9 ^{z} ± 0.2	7.5 ^{y} ± 0.1	6.0 ^{x} ± 0.1
8	1	3.05 ^{b} ± 0.35	0.86 ^{a} ± 0.10	0.75 ^{a} ± 0.14	6.5 ^{y} ± 0.1	6.5 ^{y} ± 0.1	5.1 ^{x} ± 0.1

[A] Results are expressed as the mean of three repetitions ± standard deviation. [B] Means followed by the same letter in the lines are not statistically different at 5% probability. CP—carrot powder level, AA—ascorbic acid level, E1—135/170/170 °C extrusion temperatures, E2—100/150/150 °C extrusion temperatures.

Typically, fibers such as wheat, corn, and rice have been used in food production in the past, both for their health attributes and technical functions. However, novel sources of fiber have been discovered and utilized. One of these sources is the by-product fraction of different types of food processing, especially from fruit and vegetable processing [3]. The carrots used in this research had a much higher content of crude fiber (47.6 g kg^{-1}) than corn grits (5.4 g kg^{-1}). Thus, the addition of carrots to corn grits increased the fiber content

in extrusion mixtures (Table 2). E1 extrusion temperatures had no influence on crude fiber content, which is a similar observation to that of Wang and Ryu [30]. However, they did notice a slight decrease in total fiber content, but this was statistically insignificant. E2 extrusion temperatures caused a decrease in crude fiber content, which was also the case in some other studies involving fruit or vegetable material extrusion [15,19,31]. Stojceska et al. [32] found that this could be explained by the loss of soluble fiber components, primarily pectic substances, in the processing water, together with a loss of non-fiber substances.

3.3. Total Polyphenols Content and Antioxidant Activity of Samples

Natural antioxidants are very susceptible to oxidation/degradation under thermo-mechanical conditions during extrusion; in order to preserve them, different antioxidants have been studied [14]. Synthetic antioxidants such as BHA (butylated hydroxyanisole), BHT (butylated hydroxytoluene), PG (propyl gallate), and TBHQ (tert-butylhydroquinone) have potential health hazards [33]; therefore, increased usage of natural antioxidants is desirable. Yen et al. [34] successfully protected the natural antioxidants of dried carrots by adding AA and glucose.

The addition of carrot powder increased the total polyphenol content (Table 3). Polyphenol content in raw samples with the addition of AA was not determined, since the Folin–Ciocalteu reagent reacts with AA [35]. Total polyphenol content decreased after extrusion in samples without the addition of AA, wherein E2 extrusion temperatures increased degradation. During extrusion, phenolic compounds may undergo decarboxylation due to higher melt temperature and moisture content, which may promote the polymerization of phenols, leading to a reduced extractability and antioxidant activity [36]. E1 extrusion temperatures favored Maillard reactions whose products also might react with the Folin–Ciocalteu reagent. Additionally, extrusion can cause the liberation of bound phenolics from cell wall structural components [37], which was, in this case, promoted by high extrusion temperatures. Extrudates containing AA showed much higher levels for total polyphenol content than samples without AA, but it cannot only be explained by the reaction of AA and the Folin–Ciocalteu reagent, because AA degraded more at higher extrusion temperatures (E1) (Table 1), contrary to the polyphenols. The correlation between polyphenols and antioxidant activity is very high (R^2 = 0.9921; R^2 = 0.9969) at both extrusion regimes, which is not always the case because antioxidant activity strongly depends on the reaction mechanism of the antioxidant and free radical and on structural conformation of the antioxidant [38].

Table 3. Polyphenols and antioxidant activity in raw and extruded samples [A,B].

		Polyphenols (g_{GAE} kg^{-1})			**Antioxidant Activity ($mmol_{TE}$ kg^{-1})**		
CP (%)	**AA (%)**	***Before Extrusion***	***After Extrusion E1***	***After Extrusion E2***	***Before Extrusion***	***After Extrusion E1***	***After Extrusion E2***
0	0	$0.729^{c} \pm 0.016$	$0.513^{b} \pm 0.028$	$0.412^{a} \pm 0.010$	$1.212^{y} \pm 0.007$	$0.880^{x} \pm 0.020$	$0.885^{x} \pm 0.029$
0	0.5	*	$1.411^{b} \pm 0.010$	$0.846^{a} \pm 0.004$	$30.932^{z} \pm 0.351$	$4.068^{y} \pm 0.050$	$2.552^{x} \pm 0.007$
0	1	*	$2.393^{b} \pm 0.014$	$1.813^{a} \pm 0.022$	$44.699^{z} \pm 0.877$	$7.657^{y} \pm 0.070$	$5.434^{x} \pm 0.042$
4	0	$0.752^{b} \pm 0.042$	$0.707^{b} \pm 0.005$	$0.485^{a} \pm 0.025$	$2.061^{z} \pm 0.056$	$1.763^{y} \pm 0.052$	$0.953^{x} \pm 0.049$
4	0.5	*	$1.329^{b} \pm 0.036$	$0.907^{a} \pm 0.032$	$30.188^{z} \pm 0.702$	$4.099^{y} \pm 0.021$	$2.165^{x} \pm 0.021$
4	1	*	$1.629^{a} \pm 0.029$	$2.012^{b} \pm 0.035$	$51.644^{z} \pm 0.526$	$5.955^{x} \pm 0.007$	$6.635^{y} \pm 0.030$
6	0	$0.822^{c} \pm 0.041$	$0.751^{b} \pm 0.025$	$0.541^{a} \pm 0.017$	$2.044^{z} \pm 0.025$	$1.738^{y} \pm 0.035$	$1.121^{x} \pm 0.028$
6	0.5	*	$1.486^{b} \pm 0.027$	$1.042^{a} \pm 0.039$	$30.436^{z} \pm 0.351$	$4.568^{y} \pm 0.011$	$3.276^{x} \pm 0.035$
6	1	*	$1.970^{b} \pm 0.022$	$1.664^{a} \pm 0.018$	$54.249^{z} \pm 0.00$	$6.549^{y} \pm 0.011$	$5.221^{x} \pm 0.035$

Table 3. *Cont.*

		Polyphenols (g_{GAE} kg^{-1})			Antioxidant Activity ($mmol_{TE}$ kg^{-1})		
CP (%)	**AA (%)**	***Before Extrusion***	***After Extrusion E1***	***After Extrusion E2***	***Before Extrusion***	***After Extrusion E1***	***After Extrusion E2***
8	0	$1.010^{c} \pm 0.032$	$0.871^{b} \pm 0.036$	$0.629^{a} \pm 0.002$	$2.110^{y} \pm 0.050$	$2.324^{z} \pm 0.035$	$1.495^{x} \pm 0.042$
8	0.5	*	$1.493^{b} \pm 0.022$	$1.234^{a} \pm 0.027$	$31.428^{z} \pm 0.656$	$4.844^{y} \pm 0.077$	$3.807^{x} \pm 0.040$
8	1	*	$1.937^{a} \pm 0.002$	$2.227^{b} \pm 0.023$	$55.861^{y} \pm 1.227$	$7.454^{x} \pm 0.063$	$7.191^{x} \pm 0.042$

[A] Results are expressed as the mean of four repetitions ± standard deviation. [B] Means followed by the same letter in the lines are not statistically different at 5% probability. * not determined. CP—carrot powder level, AA—ascorbic acid level, E1—135/170/170 °C extrusion temperatures, E2—100/150/150 °C extrusion temperatures.

3.4. Carotenoids Content in Raw and Extruded Samples

Lutein and zeaxanthin are the main carotenoids in corn; their concentration varies depending on genotype: 0–28 µg/g lutein and 0.01–8.1 µg/g zeaxanthin [39]. Carrot additions to corn grits did not increase lutein and zeaxanthin content in raw extrusion mixtures (Table 4). E1 extrusion temperatures increased determined lutein content, especially in samples containing AA. An increase in lutein content was also observed in extrudates obtained at E2 temperatures compared to raw mixtures, to a much lesser extent than at E1 temperatures, but still statistically significant. A similar effect was observed in the previous research on the influence of pumpkin powder addition to corn grits [19], but the stability of lutein depended upon the source of lutein. Corn lutein was very stable at high extrusion temperatures, as in this case, while pumpkin lutein was very susceptible to high temperatures, and better results were obtained at lower extrusion temperatures. An increase in lutein content in extruded samples can be explained by the increased extractability of carotenoids because of the macromolecular structure destruction at high temperatures and pressures in the extruder.

Table 4. Carotenoids content in samples before and after extrusion [A].

CP (%)	AA (%)	Lutein mg kg^{-1} before E	Lutein mg kg^{-1} E1	Lutein mg kg^{-1} E2	Zeaxanthin mg kg^{-1} before E	Zeaxanthin mg kg^{-1} after E1	Zeaxanthin mg kg^{-1} after E2	9-*cis*-β-Carotene mg $_{E\beta C}$ kg^{-1} before E	9-*cis*-β-Carotene mg $_{E\beta C}$ kg^{-1} E1	9-*cis*-β-Carotene mg $_{E\beta C}$ kg^{-1} E2
0	0	32.8 ± 2.5	87.7 ± 2.4	38.7 ± 1.8	32.8 ± 2.6	42.9 ± 2.5	28.2 ± 2.6	n.d.	n.d.	n.d.
0	0.5	31.6 ± 2.1	85.9 ± 1.9	46.4 ± 2.1	39.3 ± 1.9	71.0 ± 2.2	49.5 ± 2.1	n.d	n.d	n.d
0	1	32.6 ± 2.8	84.5 ± 1.7	48.4 ± 2.9	41.8 ± 2.1	49.2 ± 1.6	39.3 ± 2.4	n.d.	n.d.	n.d.
4	0	21.7 ± 1.9	36.7 ± 2.5	31.1 ± 2.6	25.3 ± 3.0	29.0 ± 2.3	21.5 ± 2.5	0.52 ± 0.00	n.d.	n.d.
4	0.5	23.7 ± 2.5	87.7 ± 2.3	43.4 ± 2.7	32.4 ± 3.0	32.8 ± 2.6	38.9 ± 1.5	0.30 ± 0.10	1.13 ± 0.03	0.48 ± 0.16
4	1	21.8 ± 1.2	53.9 ± 2.1	28.6 ± 2.2	32.4 ± 2.5	30.9 ± 2.3	29.2 ± 1.6	0.56 ± 0.10	0.31 ± 0.02	0.36 ± 0.02
6	0	21.2 ± 2.0	52.0 ± 1.7	22.9 ± 2.5	19.1 ± 2.0	24.4 ± 2.7	22.3 ± 2.0	0.44 ± 0.00	0.44 ± 0.02	0.59 ± 0.02
6	0.5	29.6 ± 2.0	70.2 ± 2.1	30.5 ± 2.8	41.4 ± 2.8	49.6 ± 2.5	28.6 ± 1.9	0.34 ± 0.10	1.29 ± 0.20	0.81 ± 0.02
6	1	21.3 ± 2.3	90.0 ± 1.8	21.5 ± 1.3	27.1 ± 2.1	35.0 ± 2.3	21.9 ± 2.2	0.33 ± 0.10	1.64 ± 0.03	0.85 ± 0.02
8	0	16.7 ± 3.0	39.9 ± 2.5	30.3 ± 1.7	25.9 ± 2.7	25.8 ± 1.6	36.2 ± 1.9	0.74 ± 0.05	0.79 ± 0.10	1.00 ± 0.02
8	0.5	25.0 ± 2.6	59.4 ± 1.5	36.9 ± 1.9	34.0 ± 2.6	38.6 ± 2.0	34.9 ± 2.1	0.77 ± 0.10	0.74 ± 0.02	1.38 ± 0.01
8	1	28.8 ± 2.3	75.0 ± 2.4	46.0 ± 2.3	40.8 ± 1.9	27.8 ± 2.3	43.2 ± 2.5	0.67 ± 0.15	1.15 ± 0.02	0.95 ± 0.01

[A] Contents are the mean ± standard deviation of three repetitions, CP—carrot powder level, AA—ascorbic acid level, E1—135/170/170 °C extrusion temperatures, E2—100/150/150 °C extrusion temperatures, n.d.—not detected.

Zeaxanthin content was also increased by E1 extrusion temperatures, except in the sample containing 8% of carrot powder and 1% of AA, but this can be attributed to the sample inhomogeneity. A higher increase was observed in samples without the addition of carrot powder. Lower extrusion temperatures had a variable impact on zeaxanthin content.

The only isomer of β-carotene detected in the samples was 9-*cis*-β-carotene (Table 4), since the raw material used in this research was dried carrot. The all-trans isomer was lost during the drying process and/or during storage primarily due to thermal degradation and isomerization [1]. Viacava et al. [40] observed the increase in β-carotene-*cis*-isomers due to extrusion, but they applied relatively low extrusion temperatures (63 and 109 °C, respectively), with the intention to induce wounding stress in carrots, not to produce ready-to-eat puffed snacks as a final product. Kaisangsri et al. [16] observed a decrease in

β-carotene content in carrot pomace/corn mixtures during extrusion and concluded that starch acts as a protector of β-carotene, but only when carrot pomace is added in relatively low amounts (5%).

In this research, 9-*cis*-β-carotene was detected only in raw samples containing carrot powder, but the concentrations were very low. E1 extrusion temperatures increased the amount of 9-*cis*-β-carotene in all samples except in the sample with 4% of carrot powder without the addition of AA, which is contrary to the results presented in the previous research [19]. The same isomer originated from pumpkin significantly decreased during extrusion. Knoackert et al. [41] observed an increase in cis-isomers of β-carotene during high pressure homogenization of carrot puree, while high pressure did not have a significant influence on the all-trans form, thermodynamically the most stable form. E2 extrusion temperatures also increased 9-*cis*-β-carotene content compared to raw samples, but the increase was much lower than at E1 temperatures. A statistically significant increase can be observed only in samples with an addition of 6 and 8% of carrot powder with the addition of AA. On the other hand, Qiu et al. [42] demonstrated that β-carotene was more stable at lower heating temperatures. AA had positive influence on 9-*cis*-β-carotene stability at both extrusion temperatures, which is also confirmed by the positive influence on color attributes of the samples. Yen et al. [34] also observed a positive influence of AA on β-carotene content during the storage of dried carrot.

3.5. Color of the Extrudates

Color is an important physical property and quality factor directly related to the acceptability of food products [21]. It is also directly connected to the chemical compounds that affect the color of the products, such as pigments and some non-specific compounds including products of Maillard browning. Alam et al. [43] observed that the addition of raw materials rich in fiber enhance Maillard reactions during extrusion. In general, higher extrusion temperatures (E1) resulted in lower L* values (darker color of the extrudates) compared to lower extrusion temperatures (E2) (Figure 1). This can be explained by the fact that higher temperatures favor Maillard reactions [44]. The influence of the additives (independent variables in this case) on L* value is described by quadratic mathematical models:

$$L^* \text{ E1} = 77.23 - 0.25 \times A + 2.35 \times B - 0.50 \times A^2 - 0.012 \times B^2 + 0.10 \times AB \quad (2)$$

$$L^* \text{ E2} = 79.00 - 0.083 \times A - 0.20 \times B + 0.24 \times A^2 - 0.87 \times B^2 + 0.65 \times AB \quad (3)$$

The model for E1 extrusion temperatures (Equation (2)) is statistically significant (Table 5) and has excellent correlation with the experimental data ($R^2 = 0.9453$). On the contrary, the model for E2 (Equation (3)) has poor correlation ($R^2 = 0.6667$) and is not significant at $p < 0.05$ level (Table 5); however, compared to all other mathematical models that have been attempted to fit the data, this one had the best correlation. As can be seen in Table 6, the addition of carrot powder did not have a statistically significant influence on L* at E1 extrusion temperatures, but the addition of AA had a positive linear influence. This means that AA reduced browning reactions at high temperatures. At E2 extrusion temperatures, AA caused an increase in L* values at 0.5% level, but at 1.0% level caused a decrease (Figure 1), so AA addition had a significant quadratic influence (Table 6). The carrot powder did not show any significant influence on L* at lower temperatures.

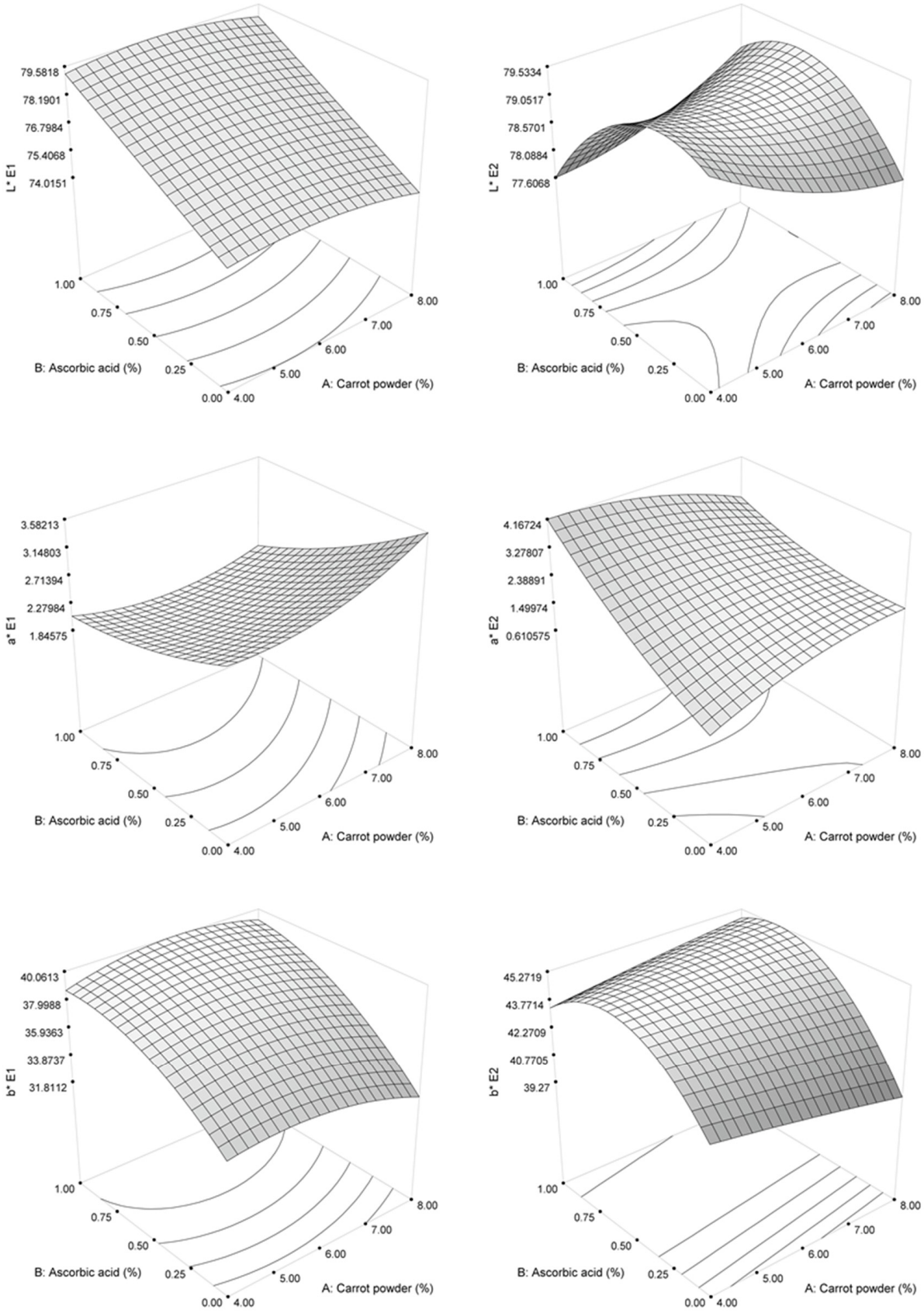

Figure 1. Response surface plots for color values as a function of carrot powder level and ascorbic acid level.

Table 5. Analysis of variance results for fitted models of product properties *.

Response	Source	df	Sum of Squares	Mean Squares	F-Value	*p*-Value
L* E1	Regression	5	34.42	6.88	24.22	0.0003
	Lack of fit	3	1.99	0.66		
	Pure error	4	8.00×10^{-4}	2.00×10^{-4}	3315.49	<0.0001
	Residual	7	1.99	0.28		
	Total	12	36.41			
L* E2	Regression	5	4.08	0.82	2.80	0.1060
	Lack of fit	3	2.04	0.68		
	Pure error	4	1.72×10^{-4}	4.30×10^{-4}	1581.44	<0.0001
	Residual	7	2.04	0.29		
	Total	12	6.13			
a* E1	Regression	5	2.58	0.52	5.11	0.0272
	Lack of fit	3	0.70	0.23		
	Pure error	4	4.52×10^{-3}	1.13×10^{-3}	207.27	<0.0001
	Residual	7	0.71	0.10		
	Total	12	3.29			
a* E2	Regression	5	9.86	1.97	20.30	0.0005
	Lack of fit	3	0.67	0.22		
	Pure error	4	0.014	3.47×10^{-3}	64.00	0.0008
	Residual	7	0.68	0.097		
	Total	12	10.54			
b* E1	Regression	5	74.95	14.99	30.75	0.0001
	Lack of fit	3	3.41	1.14		
	Pure error	4	4.80×10^{-3}	1.20×10^{-4}	9476.88	<0.0001
	Residual	7	3.41	0.49		
	Total	12	78.37			
b* E2	Regression	5	44.80	8.96	14.57	0.0014
	Lack of fit	3	4.30	1.43		
	Pure error	4	1.32×10^{-3}	3.30×10^{-3}	4348.19	<0.0001
	Residual	7	4.31	0.62		
	Total	12	49.11			
ΔE E1	Regression	5	122.46	24.49	10.45	0.0038
	Lack of fit	3	16.41	5.47		
	Pure error	4	8.80×10^{-4}	2.20×10^{-4}	24857.04	<0.0001
	Residual	7	16.41	2.34		
	Total	12	138.86			
ΔE E2	Regression	5	236.05	47.21	8.78	0.0063
	Lack of fit	3	37.64	12.55		
	Pure error	4	9.20×10^{-4}	2.30×10^{-4}	54544.89	<0.0001
	Residual	7	37.64	5.38		
	Total	12	273.69			

* significant at $p < 0.05$; df—degrees of freedom; E1—135/170/170 °C extrusion temperatures, E2—100/150/150 °C extrusion temperatures

Table 6. Degree of significance (*p*-values) of the polynomial regression model coefficients corresponding to each response *.

Source	L* E1	L* E2	a* E1	a* E2	b* E1	b* E2	ΔE E1	ΔE E2
A	0.2826	0.7167	0.1934	0.7816	0.2849	0.5585	0.2110	0.0360
B	<0.0001	0.3983	0.0033	<0.0001	<0.0001	0.0007	0.0066	0.0008
A^2	0.1651	0.4879	0.2473	0.1143	0.0358	0.8741	0.1980	0.0983
B^2	0.9706	0.0321	0.5142	0.1251	0.0099	0.0011	0.0046	0.0743
AB	0.7120	0.0463	0.3072	0.0045	0.1335	0.0559	0.6236	0.2402

* significant at $p < 0.05$.

The mathematical models for a* values:

$$a^* \text{ E1} = 2.28 + 0.19 \times A - 0.57 \times B + 0.24 \times A^2 + 0.13 \times B^2 - 0.17 \times AB \quad (4)$$

$$a^* \text{ E2} = 2.36 - 0.037 \times A + 1.14 \times B - 0.34 \times A^2 + 0.33 \times B^2 - 0.64 \times AB \quad (5)$$

The mathematical models for a* values (Equation (4), $R^2 = 0.7849$; Equation (5), $R^2 = 0.9355$) show acceptable correlation to experimental data at E1 extrusion temperatures and excellent correlation at E2 temperatures. An analysis of variance for both models (Table 5) shows that the models are statistically significant, although the lack of fit is also significant. The addition of AA at higher extrusion temperatures had a significant negative linear influence, and it caused faster degradation of the red color. On the other hand, at E2 extrusion temperatures, it had a positive linear influence and it caused the preservation of red pigments (Figure 1). The interaction between variables also had a significant negative influence at lower extrusion temperatures.

The mathematical models for b* values:

$$b^* \text{ E1} = 38.41 - 0.33 \times A + 3.11 \times B - 1.09 \times A^2 - 1.47 \times B^2 + 0.59 \times AB \quad (6)$$

$$b^* \text{ E2} = 44.80 - 0.20 \times A + 1.85 \times B - 0.078 \times A^2 - 2.51 \times B^2 + 0.90 \times AB \quad (7)$$

Both mathematical models for b* values (Equation (6), $R^2 = 0.9565$; Equation (7), $R^2 = 0.9123$) have excellent correlation to experimental data, and analysis of variance shows high statistical significance (Table 5). At E1 extrusion temperatures, the addition of carrots had a significant quadratic influence on b* values, and AA also had a positive linear and negative quadratic influence.

On the other hand, at E2 extrusion temperatures, carrots did not have a significant influence, but AA had the same effect as it was already mentioned at E1 temperatures (Table 6; Figure 1). The positive influence of AA on preserving both a* and b* color values during extrusion was shown by Obradović et al. [19] during the extrusion of pumpkin powder and corn grits. Similar results were also obtained by Maga and Kim [45] with the addition of citric acid.

The mathematical models for total color change ΔE:

$$\Delta E \text{ E1} = 6.88 - 1.62 \times A - 3.48 \times B + 1.76 \times A^2 + 1.93 \times B^2 - 0.98 \times AB \quad (8)$$

$$\Delta E \text{ E2} = 1.61 - 1.30 \times A - 3.61 \times B + 1.98 \times A^2 + 5.72 \times B^2 + 0.60 \times AB \quad (9)$$

Considering the significant influence of AA on L*, a*, and b* parameters, it is logical to assume that it also influences total color change ΔE. This is confirmed by the mathematical models (Equation (8), $R^2 = 0.8818$; Equation (9), $R^2 = 0.8625$) and analysis of variance (Table 5). At higher extrusion temperatures, AA had a significant negative linear and positive quadratic influence on total color change (Table 6), so it reduced pigment destruction and browning reactions. Carrot powder did not have a significant influence. On the other hand, at E2 extrusion temperatures, both carrots and AA addition had a significant negative linear influence on total color change.

The optimal levels of CP and AA obtained by the RSM desirability function are given in Table 7. To maximize pigment content, preserve desirable red color, and minimize unwanted Maillard browning, the optimal solution is established and experimentally verified (Table 8). According to previous research [15,46,47], the addition of higher levels of CP than 8% is not desirable, since non-starchy materials rich in fibers, such as vegetables, cause a decrease in expansion and consequently low acceptability of the product. Ascorbic acid has been shown as an important factor in pigment and color preservation, but levels higher than 0.5% are not recommended since it can promote browning and pigment degradation.

Table 7. Optimal levels of CP and AA obtained by RSM.

Parameter	Optimal Levels
CP (%)	8
AA (%)	0.5
Desirability	0.609

Table 8. Validation of optimal color parameters obtained by RSM.

Color Parameters	Predicted Values	Obtained Results
L* E1	76.48	78.23
a* E1	2.71	2.58
b* E1	36.99	36.38
L* E2	79.16	80.05
a* E2	1.99	1.89
b* E2	44.53	44.87

4. Conclusions

Color attribute responses were dependent on carrot powder and ascorbic acid levels. Although ascorbic acid degraded partially during extrusion, it had a positive influence on the color of the extrudates and carotenoid content. Extrusion caused fat degradation; higher extrusion temperatures (E1) and ascorbic acid addition at 1% level promoted degradation. Low extrusion temperatures increased fiber and polyphenol degradation.

Snacks with increased nutritional and functional value due to carrot powder addition were successfully produced, which is a starting point for production of a new type of extruded snacks.

Author Contributions: Conceptualization, V.O. and J.B.; methodology, V.O.; software, V.O.; validation, Đ.A.; formal analysis, V.D.-U., V.O. and A.J.; resources, A.J. and Đ.A.; writing—original draft preparation, V.O.; writing—review and editing, J.B.; supervision, D.Š. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

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

References

1. Hiranvarachat, B.; Suvarnakuta, P.; Devahastin, S. Isomerisation kinetics and antioxidant activities of β-carotene in carrots undergoing different drying techniques and conditions. *Food Chem.* **2008**, *107*, 1538–1546. [CrossRef]
2. Du, W.X.; Avena-Bustillos, R.J.; Breksa, A.P., III; McHugh, T.H. Effect of UV-B light and different cutting styles on antioxidant enhancement of commercial fresh-cut carrot products. *Food Chem.* **2012**, *134*, 1862–1869. [CrossRef]
3. O'Shea, N.; Arendt, E.K.; Gallagher, E. Dietary fibre and phytochemical characteristics of fruit and vegetable by-products and their recent applications as novel ingredients in food products. *Innov. Food Sci. Emerg. Technol.* **2012**, *16*, 1–10. [CrossRef]
4. Eggersdorfer, M.; Wyss, A. Carotenoids in human nutrition and health. *Arch. Biochem. Biophys.* **2018**, *652*, 18–26. [CrossRef]
5. Rodriguez Concepcion, M.; Avalos, J.; Bonet, M.L.; Boronat, A.; Gomez-Gomez, L.; Hornero-Mendez, D.; Limon, M.C.; Meléndez-Martínez, A.J.; Olmedilla-Alonso, B.; Palou, A.; et al. A global perspective on carotenoids: Metabolism, biotechnology, and benefits for nutrition and health. *Prog. Lipid Res.* **2018**, *70*, 62–93. [CrossRef]
6. Martins, N.; Ferreira, I.C.F.R. Wastes and by-products: Upcoming source of carotenoids for biotechnological purposes and health-related applications. *Trends Food Sci. Technol.* **2021**, *62*, 33–48. [CrossRef]
7. Lavelli, V.; Zanoni, B.; Zaniboni, A. Effect of water activity on carotenoid degradation in dehydrated carrots. *Food Chem.* **2007**, *104*, 1705–1711. [CrossRef]
8. Anton, A.A.; Fulcher, R.G.; Arntfield, S.D. Physical and nutritional impact of fortification of corn starch-based extruded snacks with common bean (*Phaseolus vulgaris* L.) flour: Effects of bean addition and extrusion cooking. *Food Chem.* **2009**, *113*, 989–996. [CrossRef]
9. Hirth, M.; Leiter, A.; Beck, S.M.; Schuchmann, H.P. Effect of the extrusion cooking process on the retention of bilberry anthocyanins in starch based food. *J. Food Eng.* **2015**, *125*, 139–146. [CrossRef]
10. Ying, D.Y.; Cheng, L.J.; Chibracq, G.; Sanguansri, L.; Oiseth, S.K.; Augustin, M.A. The format of ß-carotene delivery affects its stability during extrusion. *LWT Food Sci. Technol.* **2015**, *60*, 1–7. [CrossRef]

11. Cueto, M.; Farroni, A.; Shoenlechner, R.; Schleining, G.; Buera, P. Carotenoid and color changes in traditionally flaked and extruded products. *Food Chem.* **2017**, *229*, 640–645. [CrossRef]
12. Prabha, K.; Ghosh, P.; Abdullah, S.; Rosmin, M.J.; Krishnan, R.; Rana, S.S.; Pradhan, R.C. Recent development, challenges, and prospects of extrusion technology. *Future Foods* **2021**, *3*, 100019. [CrossRef]
13. Bhat, N.A.; Wani, I.A.; Hamdani, A.M.; Gani, A. Effect of extrusion on the physicochemical and antioxidant properties of value added snacks from whole wheat (*Triticum aestivum* L.) flour. *Food Chem.* **2019**, *276*, 22–32. [CrossRef]
14. Obradović, V.; Babić, J.; Šubarić, D.; Ačkar, Đ.; Jozinović, A. Improvement of nutritional and functional properties of extruded food products. *J. Food Nutr. Res.* **2014**, *53*, 189–206.
15. Stojceska, V.; Ainsworth, P.; Plunkett, A.; Ibanoglu, E.; Ibanoglu, S. Cauliflower by-products as a new source of dietary fibre, antioxidants and proteins in cereal based ready-to-eat expanded snacks. *J. Food Eng.* **2008**, *87*, 554–563. [CrossRef]
16. Kaisangsri, N.; Kowalski, R.J.; Wijesekara, I.; Kerdchoechuen, O.; Laohakunjit, N.; Ganjyal, G.M. Carrot pomace enhances the expansion and nutritional quality of cornstarch extrudates. *LWT Food Sci. Technol.* **2016**, *68*, 391–399. [CrossRef]
17. Emin, M.A.; Mayer-Miebach, E.; Schuchmann, H.P. Retention of β-carotene as a model substance for lipophilic phytochemicals during extrusion cooking. *LWT Food Sci. Technol* **2012**, *48*, 302–307. [CrossRef]
18. Waramboi, J.G.; Gidley, M.J.; Sopade, P.A. Carotenoid contents of extruded and non-extruded sweetpotato flours from Papua New Guinea and Australia. *Food Chem.* **2013**, *141*, 1740–1746. [CrossRef]
19. Obradović, V.; Babić, J.; Šubarić, D.; Jozinović, A.; Ačkar, Đ.; Klarić, I. Influence of dried Hokkaido pumpkin and ascorbic acid addition on chemical properties and colour of corn extrudates. *Food Chem.* **2015**, *183*, 136–143. [CrossRef]
20. Chaovanalikit, A.; Dougherty, M.P.; Camire, M.E.; Briggs, J. Ascorbic acid fortification reduces anthocyanins in extruded blueberry-corn cereals. *J. Food Sci.* **2003**, *68*, 2136–2140. [CrossRef]
21. Altan, A.; McCarthy, K.L.; Maskan, M. Evaluation of snack foods from barley-tomato pomace blends by extrusion processing. *J. Food Eng.* **2008**, *84*, 231–242. [CrossRef]
22. International Standard Organization. *ISO 6492:2001: Animal Feeding Stuffs—Determination of Fat Content*; ISO: Geneva, Switzerland, 2001.
23. International Standard Organization. ISO 6865:2000: Animal Feeding Stuffs—Determination of Crude Fibre Content—Method with Intermediate Filtration. 2000. Available online: https://www.iso.org/standard/13377.html (accessed on 20 October 2020).
24. Sharma, P.; Gujral, H.S.; Singh, B. Antioxidant activity of barley as affected by extrusion cooking. *Food Chem.* **2012**, *131*, 1406–1413. [CrossRef]
25. Kljak, K.; Grbeša, D.; Karolyi, D. Estimation of carotenoid content from colour analysis of corn grits. *Stočarstva* **2009**, *63*, 65–73.
26. Plunkett, A.; Ainsworth, P. The influence of barrel temperature and screw speed on the retention of L-ascorbic acid in an extruded rice based snack product. *J. Food Eng.* **2007**, *78*, 1127–1133. [CrossRef]
27. Anuonye, J.C.; Onuh, J.O.; Egwim, E.; Adeyemo, S.O. Nutrient and antinutrient composition of extruded acha/soybean blends. *J. Food Process. Preserv.* **2010**, *34*, 680–691. [CrossRef]
28. Lin, S.; Hsieh, F.; Huff, H.E. Effects of lipids and processing conditions on lipid oxidation of extruded dry pet food during storage. *Anim. Feed Sci. Technol.* **1998**, *71*, 283–294. [CrossRef]
29. Sriburi, P.; Hill, S.E.; Mitchell, J.R. Effects of L-ascorbic acid on the conversion of cassava starch. *Food Hydrocoll.* **1999**, *13*, 177–183. [CrossRef]
30. Wang, Y.Y.; Ryu, G.H. Physicochemical and antioxidant properties of extruded corn grits with corn fiber by CO_2 injection extrusion process. *J. Cereal Sci.* **2013**, *58*, 110–116. [CrossRef]
31. Sarawong, C.; Schoenlechner, R.; Sekiguchi, K.; Berghofer, E.; Ng, P.K.W. Effect of extrusion cooking on the physicochemical properties, resistant starch, phenolic content and antioxidant capacities of green banana flour. *Food Chem.* **2014**, *143*, 33–39. [CrossRef]
32. Stojceska, V.; Ainsworth, P.; Plunkett, A.; Ibanoglu, S. The effect of extrusion cooking using different water feed rates on the quality of ready to eat snacks made from food by-products. *Food Chem.* **2009**, *114*, 226–232. [CrossRef]
33. Rodriguez Amado, I.; Franco, D.; Sanchez, M.; Zapata, C.; Vazquez, J.A. Optimisation of antioxidant extraction from Solanum tuberosum potato peel waste by surface response methodology. *Food Chem.* **2014**, *165*, 290–299. [CrossRef]
34. Yen, Y.H.; Shih, C.H.; Chang, C.H. Effect of adding ascorbic acid and glucose on the antioxidative properties during storage of dried carrot. *Food Chem.* **2008**, *107*, 265–272. [CrossRef]
35. Everette, J.D.; Bryant, Q.M.; Green, A.M.; Abbey, Y.A.; Wangila, G.W.; Walker, R.B. Through study of reactivity of various compound classes toward the Folin-Ciocalteu Reagent. *J. Agric. food Chem.* **2010**, *58*, 8139–8144. [CrossRef]
36. Obiang-Obounou, B.W.; Ryu, G.H. The effect of feed moisture and temperature on tannin content, antioxidant and antimicrobial activities of extruded chestnuts. *Food Chem.* **2013**, *141*, 4166–4170. [CrossRef]
37. Acosta-Estrada, B.A.; Gutierrez-Uribe, J.A.; Serna-Saldivar, S.O. Bound phenolics in foods, a review. *Food Chem.* **2014**, *152*, 46–55. [CrossRef]
38. Sensoy, I.; Rosen, R.T.; Ho, C.T.; Karwe, M.V. Effect of processing on buckwheat phenolics and antioxidant activity. *Food Chem.* **2006**, *99*, 388–393. [CrossRef]
39. Rodriguez-Amaya, D.B.; Regini Nutti, M.; de Carvahlo, J.L.V. Carotenoids of sweet potato, cassava, and maize and their use in bread and flour fortification. In *Flour and Breads and Their Fortification in Health and Disease Prevention*; Preedy, V.R., Watson, R.R., Patel, V.B., Eds.; Elsevier: Amsterdam, The Netherlands, 2011; pp. 301–311.

40. Viacava, F.; Santana-Gálveza, J.; Heredia-Oleab, E.; Pérez-Carrillo, E.; Nair, V.; Cisneros-Zevallos, L.; Jacobo-Velázque, 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]
41. Knoackert, G.; Lemmens, L.; Buggenhout, S.; Hendrickx, M.; Loey, A. Changes in β-carotene bioaccessibility and concentration during processing of carrot puree. *Food Chem.* **2012**, *133*, 60–67. [CrossRef]
42. Qiu, D.; Chen, Z.R.; Li, H.R. Effect of heating on solid β-carotene. *Food Chem.* **2009**, *112*, 344–349. [CrossRef]
43. Alam, M.S.; Pathania, S.; Sharma, A. Optimization of the extrusion process for development of high fibre soybean-rice ready-to-eat snacks using carrot pomace and cauliflower trimmings. *LWT Food Sci. Technol.* **2016**, *74*, 135–144. [CrossRef]
44. Hagenimana, A.; Ding, X.; Fang, T. Evaluation of rice flour modified by extrusion cooking. *J. Cereal Sci.* **2006**, *43*, 38–46. [CrossRef]
45. Maga, J.A.; Kim, C.H. Co-extrusion of rice flour with dried fruits and fruit juice concentrates. *Lebensm. Wiss. Technol.* **1989**, *22*, 182–187.
46. Bisharat, G.I.; Oikonomopoulou, V.P.; Panagiotou, N.M.; Krokida, M.K.; Maroulis, Z.B. Effect of extrusion conditions on the structural properties of corn extrudates enriched with dehydrated vegetables. *Food Res. Int.* **2013**, *53*, 1–14. [CrossRef]
47. Obradović, V.; Babić, J.; Šubarić, D.; Jozinović, A.; Ačkar, Đ. Physico-chemical Properties of Corn Extrudates Enriched with Tomato Powder and Ascorbic Acid. *Chem. Biochem. Eng. Q.* **2015**, *29*, 325–342. [CrossRef]