

Article

Extrusion of Rice and *Aronia melanocarpa* Pomace: Physical and Functional Characteristics of Extrudates

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Abstract: In this study, black chokeberry (*Aronia melanocarpa*) juice pomace was used to enrich the extrudates from rice in order to create a functional food. A response surface methodology was applied to optimize the physical (expansion ratio, bulk density, moisture content, hardness, pellet durability index, and color) and functional (water solubility index, water absorption index) characteristics of the extrudates. A laboratory single-screw extruder was used to produce the extrudates and a full factorial experimental design was applied ($N = 3^2$) to present the effect of the amount of chokeberry pomace (10 and 20%), the feed moisture content (14 and 20%) and the working screw speed (180 min^{-1} and 220 min^{-1}) of the extruder on the physical and functional characteristics. The results showed that the three factors influenced all studied characteristics. An exception with statistically insignificant effect was the amount of chokeberry pomace on the expansion ratio, pellet durability index, water adsorption index, lightness, redness, and yellowness, the feed moisture content on the water solubility, water adsorption index, redness and yellowness, and the working screw speed on the bulk density and hardness.

Keywords: rice; chokeberry pomace; extrusion; physical characteristics; functional characteristics



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1. Introduction

Intolerance to gliadin, which is the main component of wheat gluten, can lead to serious health problems, such as celiac disease and other forms of gluten intolerance [1]. In order to prevent such problems, it is advisable to consume gluten-free food products such as rice.

Rice (*Oryza sativa* L.) is one of the important crops that plays a role in providing food for the majority of the world's population. Rice is one of the main dietary staples of South Asians and the main food crop preferred by most people around the world [2]. It is one of the main forms of nutrition of people in many countries and it is the world's most important basic cereal [3]. Rice contains carbohydrates, fats, proteins (low concentrations) and B complex vitamins, including niacin, thiamine and riboflavin [4].

Black chokeberry (*Aronia melanocarpa*) is rich in polyphenols, vitamins, minerals and fiber. Polyphenols in chokeberry include anthocyanins, flavonols and proxianidines [5]. These compounds are responsible for the dark purple color of the grains and their antioxidant properties. Aronia berries have a very high antioxidant activity when compared to most fruits and vegetables. They also secrete free radicals, reduce oxidative stress and prevent cell damage [6]. Besides polyphenols, fruits are a good source of vitamins,

especially vitamin C and vitamin K. Aronia berries are also rich in minerals, including potassium, calcium, iron and manganese [7]. All these bioactive compounds explain their health benefits (antioxidative, anticancer, anti-inflammatory, hypotensive, antiviral, antidiabetic, antiplatelet, and anti-atherosclerotic), as well as their popularity and use in food and biotechnological production [8].

Pomace is a by-product of the fruit and vegetable industry. In order to reduce its detrimental effects on the environment and costs associated with the requirement for disposal, new opportunities for the use of pomace have recently been the subject of extensive research [9]. Bioactive compound-rich by-products have the potential to serve as useful ingredients in the food and pharmaceutical industries. Pomace can be used in many different ways, but extruded products appear to have great potential. The addition of fruit and vegetable by-products to cereal-based extrudates will enhance their nutritional value because they are high in easily digested carbohydrates [10].

Extrusion is a technological process used to develop new food products with special textures, shapes and functional properties. It is a combination of high temperature, pressure and moisture content applied to grain raw materials or mixtures of grain raw materials [11]. Extrusion technology is becoming popular in the global food industry, using mixing, shaping, texturing and cooking to create new food products. This process leads to gelatinization and heat treatment of ingredients, resulting in a change in the shape, texture, structure and nutritional value of the products [12]. This makes extrusion a useful and innovative technology for developing new food products, which meet the specific needs and preferences of consumers. The main advantage of extrusion in food production is the ability to create products with a longer shelf life, better stability and better functional properties. The extruded products increase the metabolic availability of proteins and starches, the retention of nutrients, digestibility, as well as the incorporation of various inexpensive bioactive compounds with health benefits located in fruit and vegetable by-products. Other advantages are diversity of textures, preservation of biologically active substances, inclusion of various additives and ingredients, better food safety, production optimization, standardization of products, possibility of innovative food products, etc. [13–15].

The aim of this study was to investigate the physicochemical and functional characteristics of the extrudates obtained from rice enriched with chokeberry pomace (a by-product of juice production) and to determine the optimal working conditions for production of quality products.

2. Materials and Methods

2.1. Materials

The flour used was obtained from rice from the company Familex Ltd. (Plovdiv, Bulgaria), purchased commercially. The chemical composition of the rice was as follows: proteins—7.1%; carbohydrates—76.5%, of which sugars—0.6%; fats—0.37%, of which saturated fatty acids—0.14%; fibers—1.32%; energy value—340 kcal/100 g. The rice was ground to flour using a laboratory stone mill BG Agro (Varna, Bulgaria).

The dried chokeberry pomace was delivered by the company VITANEA Ltd. (Plovdiv, Bulgaria). It was obtained as a byproduct from the production of chokeberry juice. The proximate composition of the pomace was as follows: proteins—3.9%, fibers—21.0%, polyphenols—6.4%.

The rice flour was mixed with the pomace in ratios of 90:10 and 80:20. These ratios were chosen on the basis of preliminary experiments described in Section 2.2.4. Statistical processing. The particle size of the mixed flours was below 450 µm. The moisture content of the mixtures was determined by drying at 105 °C for 24 h in a drying oven Labster 136N250 (Barcelona, Spain) [16]. The samples were moistened to reach a certain moisture content (14% or 20%), then homogenized and placed in polyethylene bags for storage at 5 °C in a refrigerator for 12 h. They were tempered for 2 h at a room temperature before extrusion. The moistening of the samples was made with drinking water, meeting the

requirements of Ordinance No. 9 of the Ministry of Health of Bulgaria from 16 March 2001 regarding the quality of water intended for drinking and household needs [17].

2.2. Methods

2.2.1. Extrusion

Extrusion was carried out using a single screw laboratory extruder Brabender 20DN (Brabender GmbH and Co KG, Duisburg, Germany). The extruder had the following parameters: nozzle diameter 3 mm, screw compression ratio 4:1, feeding screw speed 40 min^{−1}. The temperatures in the first, second and third zones of the extruder were 140 °C, 160 °C and 180 °C, respectively.

2.2.2. Determination of Physical Characteristics

The expansion ratio (*ER*) was represented by the ratio of the diameter of the extrudate and the die diameter (3 mm) and calculated by the following formula:

$$ER = \frac{\text{diameter of extrudate}}{\text{diameter of extruder die}} \quad (1)$$

The diameter of extrudate was measured with a digital vernier caliper.

The bulk density (*BD*) was calculated using the diameter and the length of the extruded sample measured by a digital vernier caliper, and the weight of the sample measured by an analytical balance (Kern ABS 220-4N with level of accuracy 0.1 mg):

$$BD = \frac{\text{weight of extrudate}}{\text{volume of extrudate}} \quad (2)$$

A TA-XT texture analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with 50 kg load cell and 2-bladed Kramar shear cell (distance 10 mm, speed 1.0 mm/s) was used to determine the hardness (*HD*). This was presented as the minimal force (N) necessary to crumb the sample.

The moisture content of the extrudates (*MC*) was determined by drying at 105 °C until a constant mass [13].

A standard methodology [18] was used to determine the pellet durability index (*PDI*, %) using a Procon tester (Voss, Hamburg, Germany).

The color characteristics were determined as follows: the extrudates were ground in a laboratory mill to a particle size of 200 µm, after which their color was instrumentally determined by a CIE Lab color system Colorgard 2000 (Pacific Scientific, Chandler, MD, USA), where: *L*—brightness (*L* = 0—black, *L* = 100—white), *+a*—red, *−a*—green, *+b*—yellow, *−b*—blue. The color coordinates of mixtures of rice and chokeberry pomace before extrusion are given in Table 1.

Table 1. Color coordinates of mixtures of rice and chokeberry pomace before extrusion.

Chokeberry Pomace, %	<i>L</i> ₀	<i>a</i> ₀	<i>b</i> ₀
10	72.62	6.13	6.73
20	64.58	8.43	5.69

*L*₀, *a*₀, *b*₀—brightness, redness and yellowness of mixtures of rice and chokeberry pomace before extrusion, respectively.

2.2.3. Determination of Functional Characteristics

The water solubility index (*WSI*, %) and water absorption index (*WAI*, g/g product) were determined by the method described in [19] using some modifications: the ground extrudate was put in falcon tubes (0.2 g) and then diluted with 5 mL of distilled water. The sample was held in a water bath at 30 °C for 30 min accompanied by gentle stirring, followed by centrifugation at 3000 min^{−1} for 20 min in a centrifuge CH 90-2A (Polypharma

Sarl, Douala, Cameroun). The supernatant was placed in an evaporating dish and dried at 105 °C in a drying oven until a constant weight was achieved.

The *WSI* was determined by the following equation:

$$WSI = \frac{m_{ds}}{m_s} 100 \quad (3)$$

The *WAI* was determined by the following equation:

$$WAI = \frac{m_g}{m_s} \quad (4)$$

where m_{ds} was weight of dry solids after evaporation of the supernatant, g ; m_s was weight of sample, g ; and m_g was weight of sediment, g .

2.2.4. Statistical Processing

The interaction between the amount of chokeberry pomace (X_1), feed moisture content (X_2) and working screw speed (X_3) was studied by a full factorial experiment ($N = 2^3$). Table 2 presents the experimental design with natural and coded values of three independent variables chosen on the basis of preliminary experiments. They showed that the decrease in the amount of chokeberry pomace below 10 led to a decrease in the expansion of the extrudates, as well their functional value, while the increase over 20% led to an increase in the redness of the extrudates. The decrease in the feed moisture content below 14% hindered the gelatinization and overall extrusion. The increase in the feed moisture over 20% led to a decrease in the expansion. The decrease in the working screw speed below 180 min^{-1} led to a decrease in the expansion and to an increase in the torque which would cause the extruder to block, while the increase over 220 min^{-1} led to an excessive increase in pressure, which resulted in extrudate breaking as it exited the die. Three batches of extrudates were prepared, and the physical and functional characteristics were determined with three replications.

Table 2. Experimental design with natural and coded values.

No.	Natural Values			Coded Values		
	Factor A—Amount of Chokeberry Pomace, %	Factor B—Feed Moisture Content, %	Factor C—Working Screw Speed, min^{-1}	X_1	X_2	X_3
1	10	14	180	−1	−1	−1
2	20	14	180	+1	−1	−1
3	10	20	180	−1	+1	−1
4	20	20	180	+1	+1	−1
5	10	14	220	−1	−1	+1
6	20	14	220	+1	−1	+1
7	10	20	220	−1	+1	+1
8	20	20	220	+1	+1	+1

The following linear regression equation was used to describe the experimental data:

$$y = b_0 + \sum_{i=1}^n b_i X_i + \sum_{i=1, j=1}^n b_{ij} X_i X_j \quad (5)$$

where b_0 ; b_i ; b_{ij} were coefficient for intercept, coefficient of linear effects and coefficients of interactions.

2.2.5. Optimization of Physical and Functional Characteristics

The optimization aims to improve the physical and functional characteristics of the extrudates from rice enriched with chokeberry pomace. The optimal working conditions were determined using a numerical multiple response optimization technique [19]. The aim was to create a product with maximum *ER*, *PDI*, lightness, and minimum *BD*, *MC*, *WAI*, *WSI*, *HD*.

3. Results and Discussion

3.1. Experimental Results

The mean values and the corresponding standard deviations of the studied characteristics are presented in Table 3. The experimental data showed that the *ER* changed from 1.51 to 2.74, the *BD*—from 0.111 to 0.186 g/cm³, the feed moisture content—from 5.84% to 9.32%, the *PDI*—from 66.11% to 97.36%, and the *HD*—from 18.99 N to 30.68 N. The color characteristics varied as follows: between 55.07 and 66.36 for lightness *L*, between 10.92 and 15.73 for redness *a*, between 9.75 and 16.67 for yellowness *b*. The *WSI* changed from 22.76% to 43.19%, and the *WAI* from 4.28 g/g to 6.53 g/g (Table 4).

Table 3. Experimental results for physical characteristics of extrudates.

No.	<i>ER</i>	<i>BD</i> , g/cm ³	<i>MC</i> , %	<i>PDI</i> , %	<i>HD</i> , N	<i>L</i>	<i>a</i>	<i>b</i>
1	2.74 ± 0.06	0.111 ± 0.013	8.37 ± 0.80	66.11 ± 1.15	18.99 ± 0.8	61.33 ± 2.3	13.16 ± 1.1	10.06 ± 0.9
2	2.67 ± 0.26	0.142 ± 0.008	6.03 ± 0.88	70.13 ± 2.35	19.16 ± 0.9	62.07 ± 1.5	10.92 ± 0.7	9.75 ± 0.8
3	1.90 ± 0.07	0.151 ± 0.009	9.32 ± 1.46	97.36 ± 1.67	30.68 ± 1.2	66.36 ± 2.1	12.38 ± 0.9	12.64 ± 1.1
4	1.81 ± 0.07	0.174 ± 0.012	8.17 ± 0.74	88.96 ± 1.19	24.72 ± 1.0	65.35 ± 2.2	12.47 ± 1.2	11.01 ± 0.9
5	2.64 ± 0.18	0.146 ± 0.028	6.85 ± 0.55	82.55 ± 1.19	22.77 ± 1.4	55.07 ± 1.1	13.22 ± 1.2	16.67 ± 1.2
6	2.48 ± 0.05	0.132 ± 0.010	5.84 ± 1.06	78.32 ± 2.54	26.96 ± 0.8	56.53 ± 1.0	15.73 ± 1.1	15.16 ± 1.1
7	1.59 ± 0.09	0.144 ± 0.015	8.36 ± 0.47	89.32 ± 2.67	24.43 ± 1.2	58.18 ± 1.1	15.18 ± 1.0	12.83 ± 1.0
8	1.51 ± 0.01	0.186 ± 0.015	6.67 ± 1.45	93.56 ± 2.17	21.68 ± 1.5	58.87 ± 1.6	15.00 ± 0.9	13.89 ± 1.0

Table 4. Experimental results for functional characteristics of extrudates.

No.	<i>WSI</i> , %	<i>WAI</i> , g/g
1	31.88 ± 2.51	4.49 ± 0.27
2	31.21 ± 1.05	6.19 ± 0.18
3	31.21 ± 1.05	5.81 ± 0.24
4	28.61 ± 1.04	6.56 ± 0.05
5	22.76 ± 1.04	5.50 ± 0.06
6	41.61 ± 1.15	5.19 ± 0.78
7	31.35 ± 0.80	4.56 ± 0.45
8	43.19 ± 2.52	4.28 ± 0.21

The influence of each independent variable on the physical and functional characteristics is presented in the standardized Pareto charts (Figure 1). Feed moisture content had a primary effect on *ER*, *BD*, *PDI*, and *HD*. This is in agreement with the results in [20–22]. The amount of chokeberry pomace had a primary effect on *MC* and *WSI*. The working screw speed had the biggest effect on *WAI*, *L*, *a* and *b*. Insignificant was the effect of the amount of chokeberry pomace on *ER*, *PDI*, *L* and *a*; the feed moisture content on *WSI*, *WAI*, *a* and *b*; and the working screw speed on *BD*.

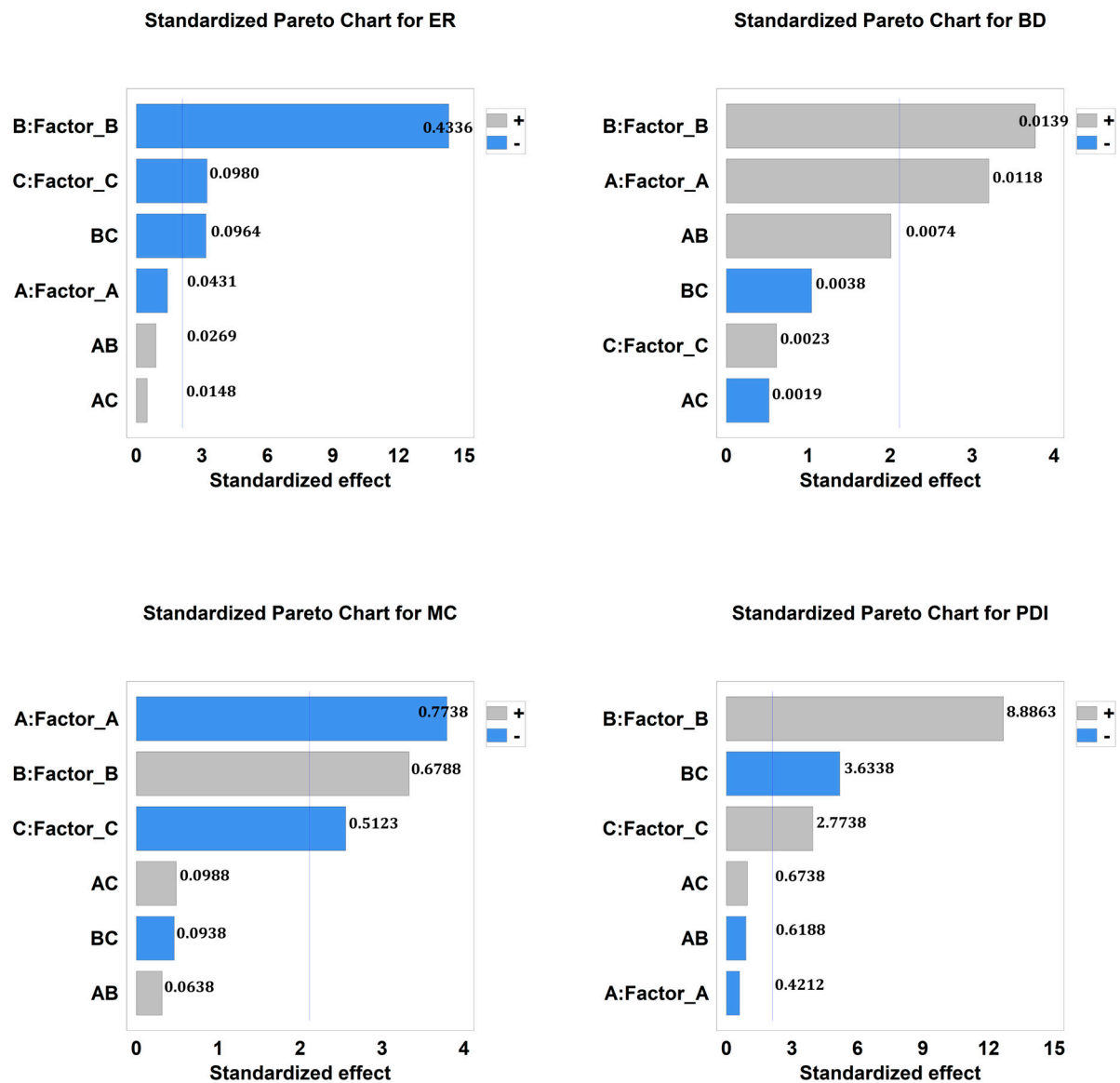


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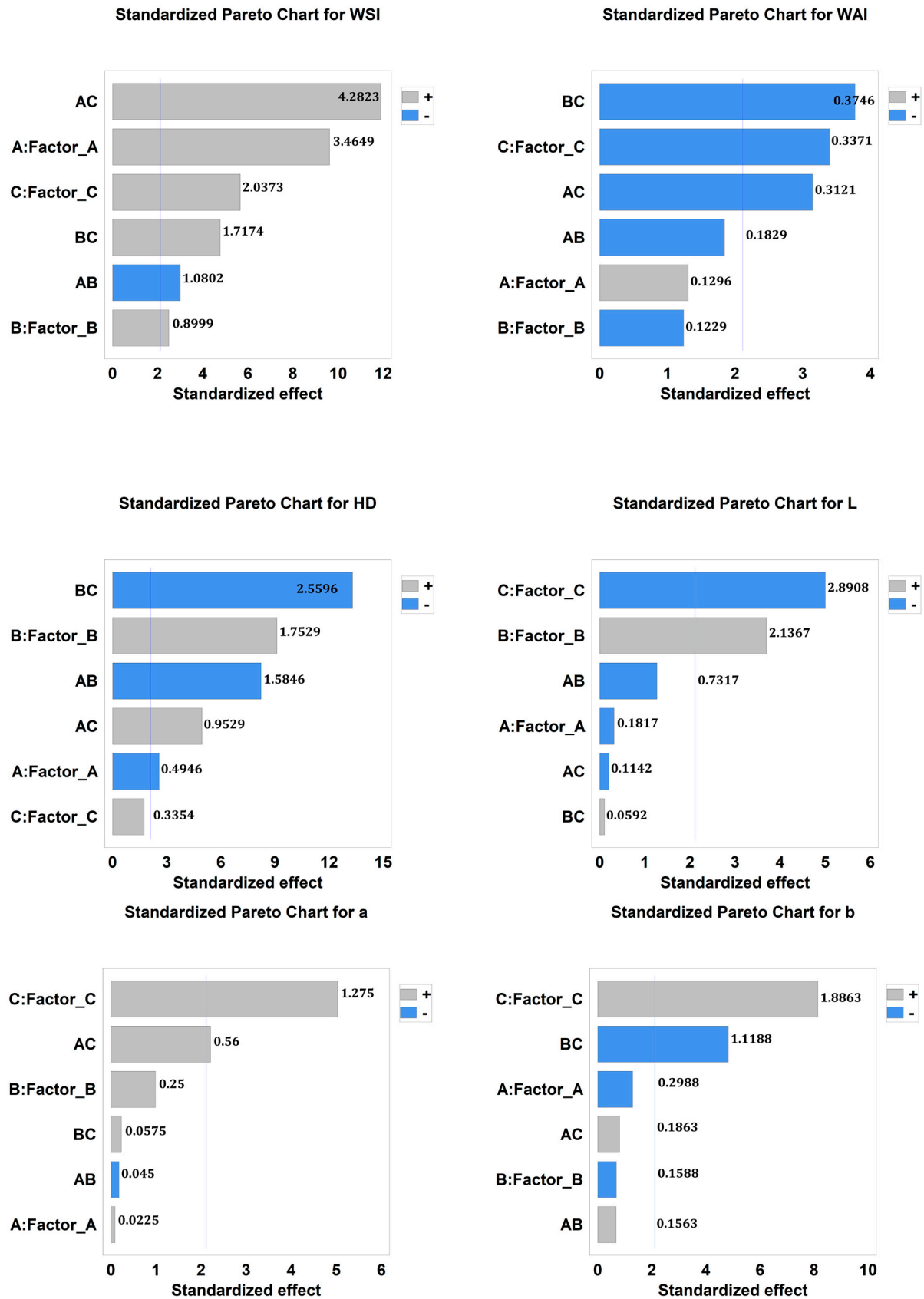


Figure 1. Pareto charts for the effect of the factors on the physical and functional characteristics of extrudates.

3.2. Expansion Ratio

Expansion is a main characteristic of extruded products, like those which are attractive to consumers as well puffed [23]. During extrusion, the effect of high expanded products with low density is looked for. The response surfaces (Figure 2) showed that the feed moisture content and working screw speed negatively influenced negatively the *ER*, and the feed moisture had the biggest effect among the three factors investigated. The amount of chokeberry pomace had an insignificant effect on the *ER* in this range of the change in amount (Figure 1). Schmid et al. [24] established a sectional extrusion ratio between 0.85 and 1.95 for pure chokeberry pomace with co-rotating twin screw extruder. Our experimental values are higher (between 1.51 and 2.74), which could be explained by the presence of rice in the raw material used for extrusion. The decrease in the feed moisture provokes a decrease in the level of starch gelatinization, and thus the expansion decreases [22]. Singh et al. [25] found that low feed moisture led to increased shearing rate and increased extrusion duration, thus leading to increased starch gelatinization and expansion. The increase in the working screw speed led to a reduction of the sectional expansion of pure chokeberry pomace [24]. Our experimental data are in accordance with these results, which could be explained by the reduced duration of the product in the extruder [26]. Schmid et al. [27] also established that the sectional expansion index decreased with increasing screw speed of the co-rotating screw extruder, and an increase in chokeberry pomace in the mixture based on corn starch resulted in a decrease in the sectional expansion index. The decrease in the sectional expansion index with the increase in the amount of pomace was also established for other fruit pomaces [28–32]. Altan et al. [33] also found a decrease in the sectional expansion index when the barley-tomato pomace level increased. The high feed moisture content of the raw material limited the evaporation, which resulted in a product with a lower expansion and higher density [34]. Figure 2 also shows that, at a low level of feed moisture content, the effect of the working screw speed was insignificant, but at a high level of the same factor a clearly manifested decrease in the expansion was observed.

3.3. Bulk Density

The effect of the three independent variables on the density of the extrudates is presented in Figure 2. The response surfaces showed that the rise in the feed moisture content and the amount of chokeberry pomace led to an increase in the *BD*, as the effect of feed moisture was higher. The working screw speed had an insignificant effect on the *BD* (Figure 1). Figure 2 shows that the effect of the amount of chokeberry pomace was more pronounced at high level of feed moisture (20%) than at low level (14%). The feed moisture had more pronounced influence on the density when the amount of the chokeberry pomace was at high level (20%) than at low level (10%). It also can be seen that the effect of the investigated factors on the density was positive, while the effect of the same factors on the expansion was negative. This inversely proportional relationship between the expansion and the density is in agreement with the experimental data for other extruded products [35,36]. Feed moisture is a key factor in the bulk density of extrudate [37]. According to Ding et al. [34], the increased feed moisture during extrusion provokes molecular transformation of amylopectin leading to a less elastic melt, reduced expansion and increased density. According to Potter et al. [38], the addition of fruits affects the degree of gelatinization and therefore the degree of expansion and the bulk density. These authors related the increase in the *BD* of extrudates to the presence of sugar and soluble fiber absorbing more moisture, leading to a decrease in the expansion and increase in the density. Altan et al. [39] also found that the increase in the amount of grape pomace led to a rise in the *BD* of extrudates obtained with a twin-screw extruder. Similar results were obtained from Selani et al. [32] for pineapple pomace using a single screw extruder.

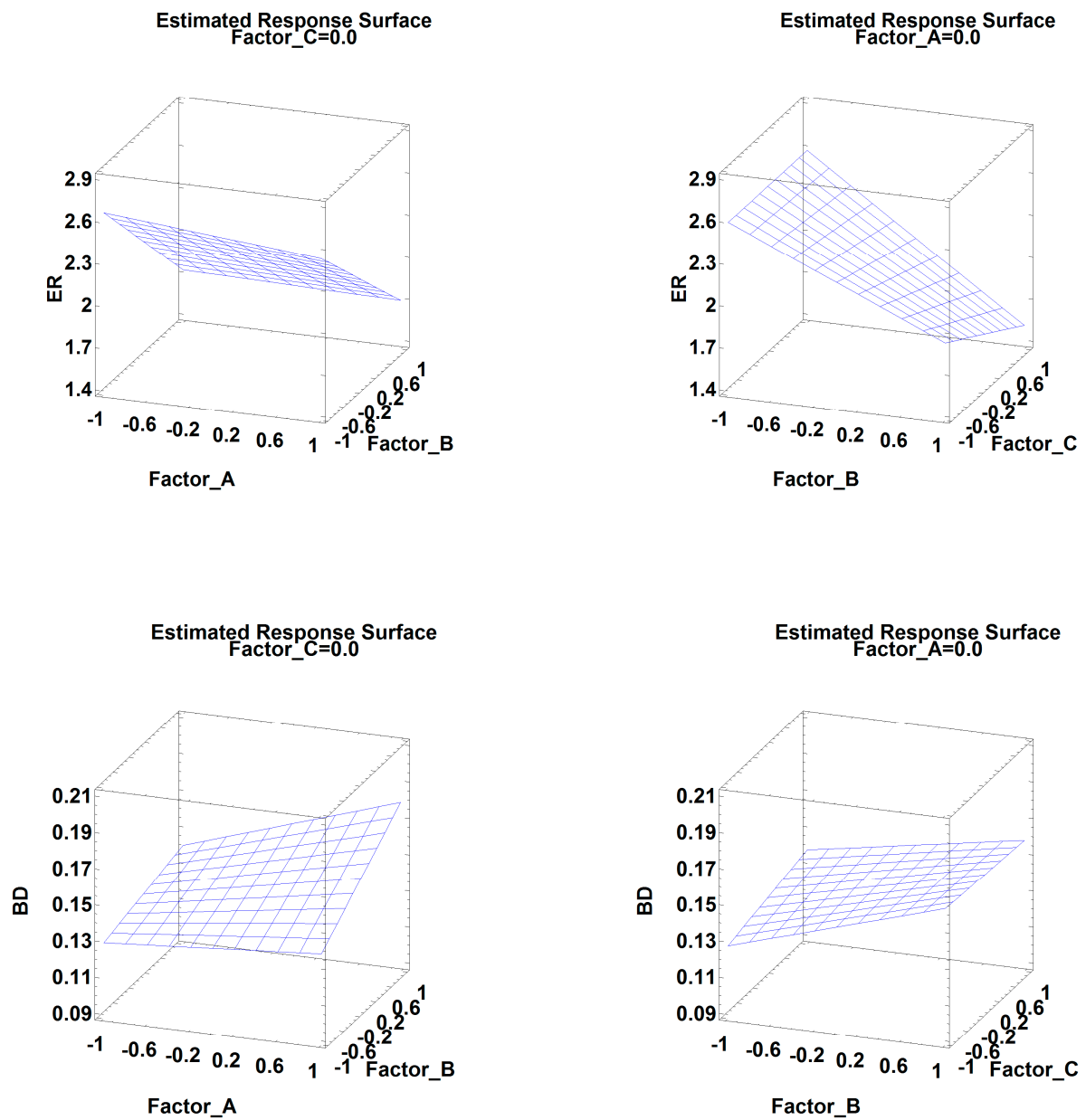


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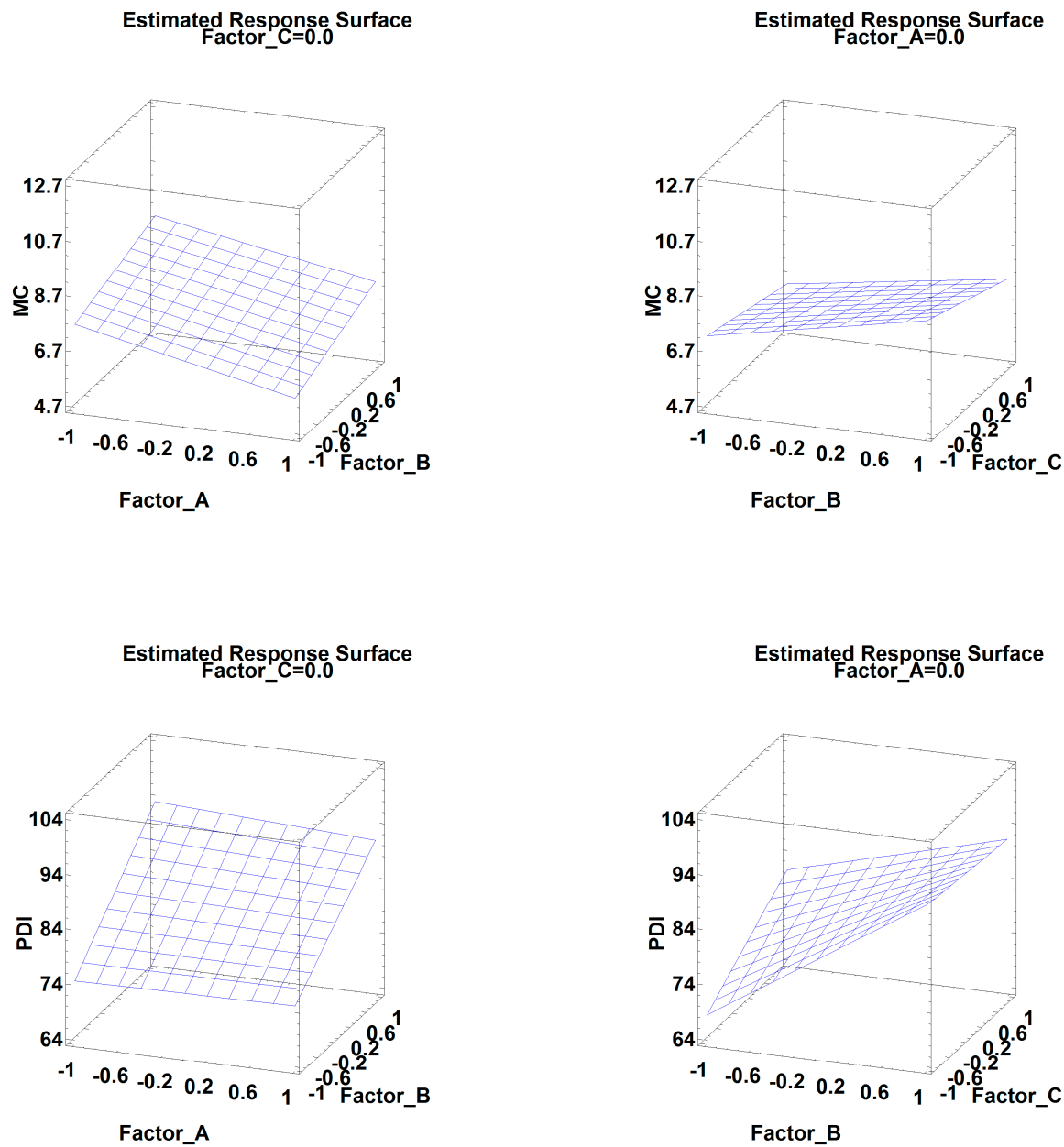


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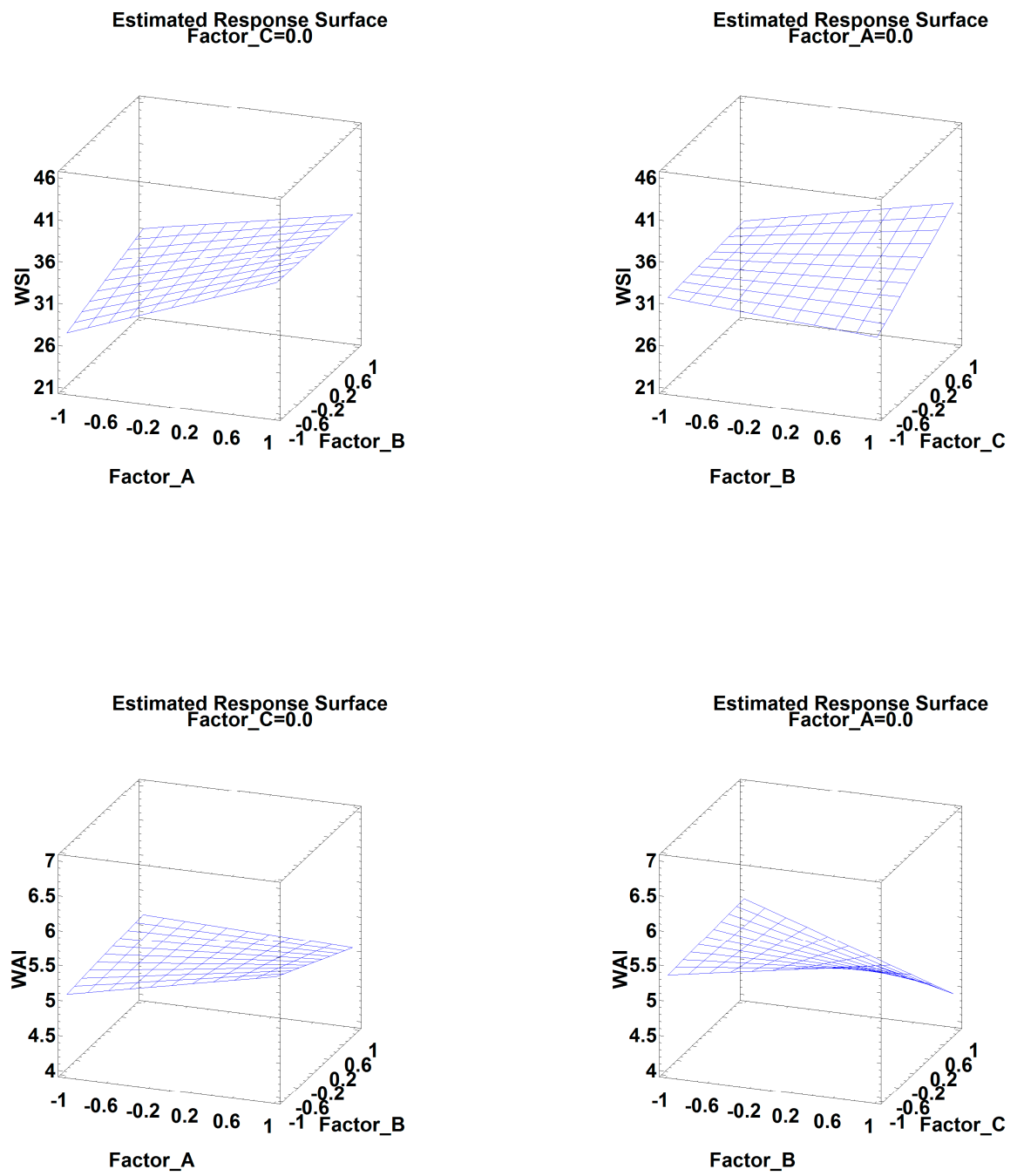


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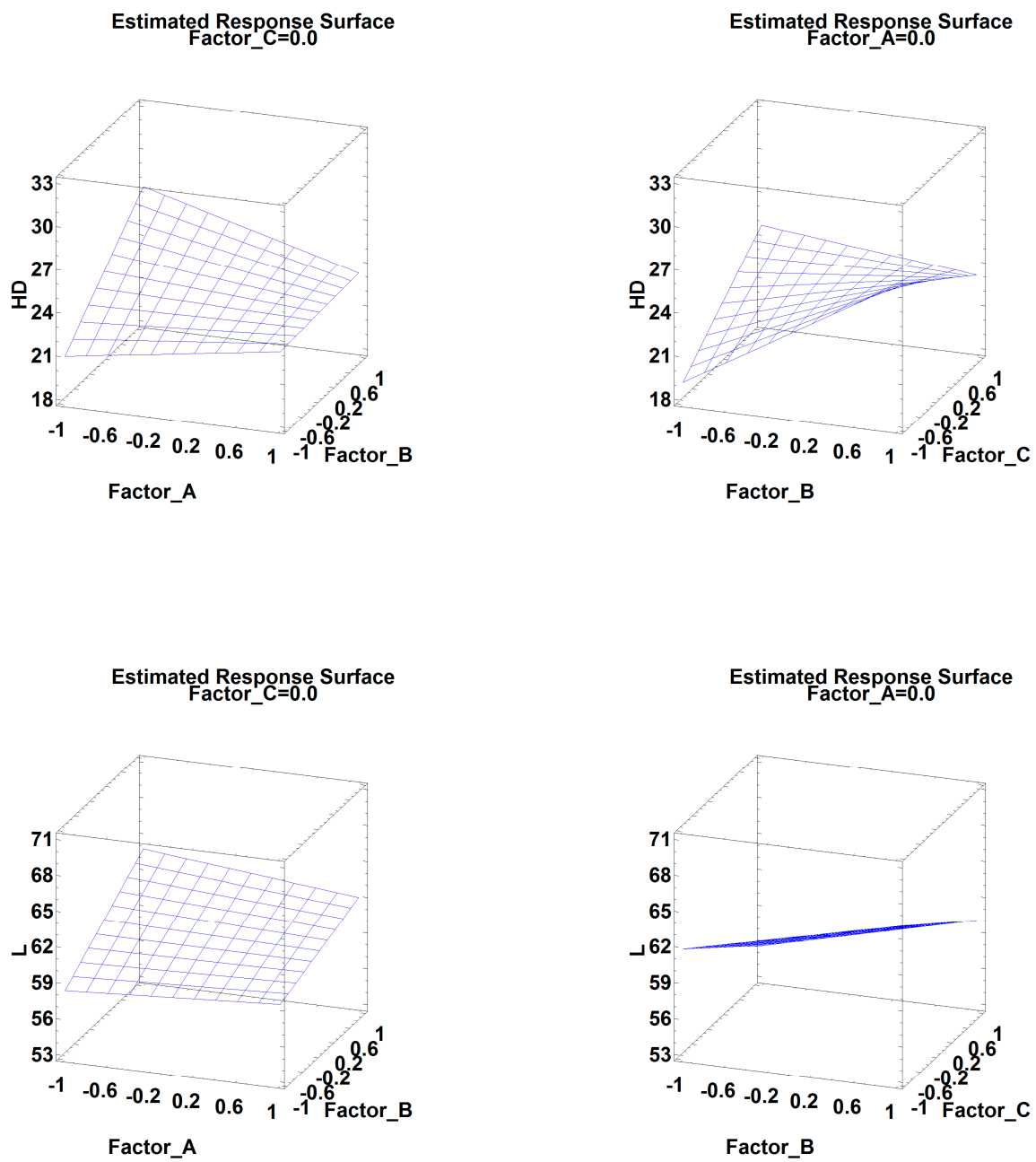


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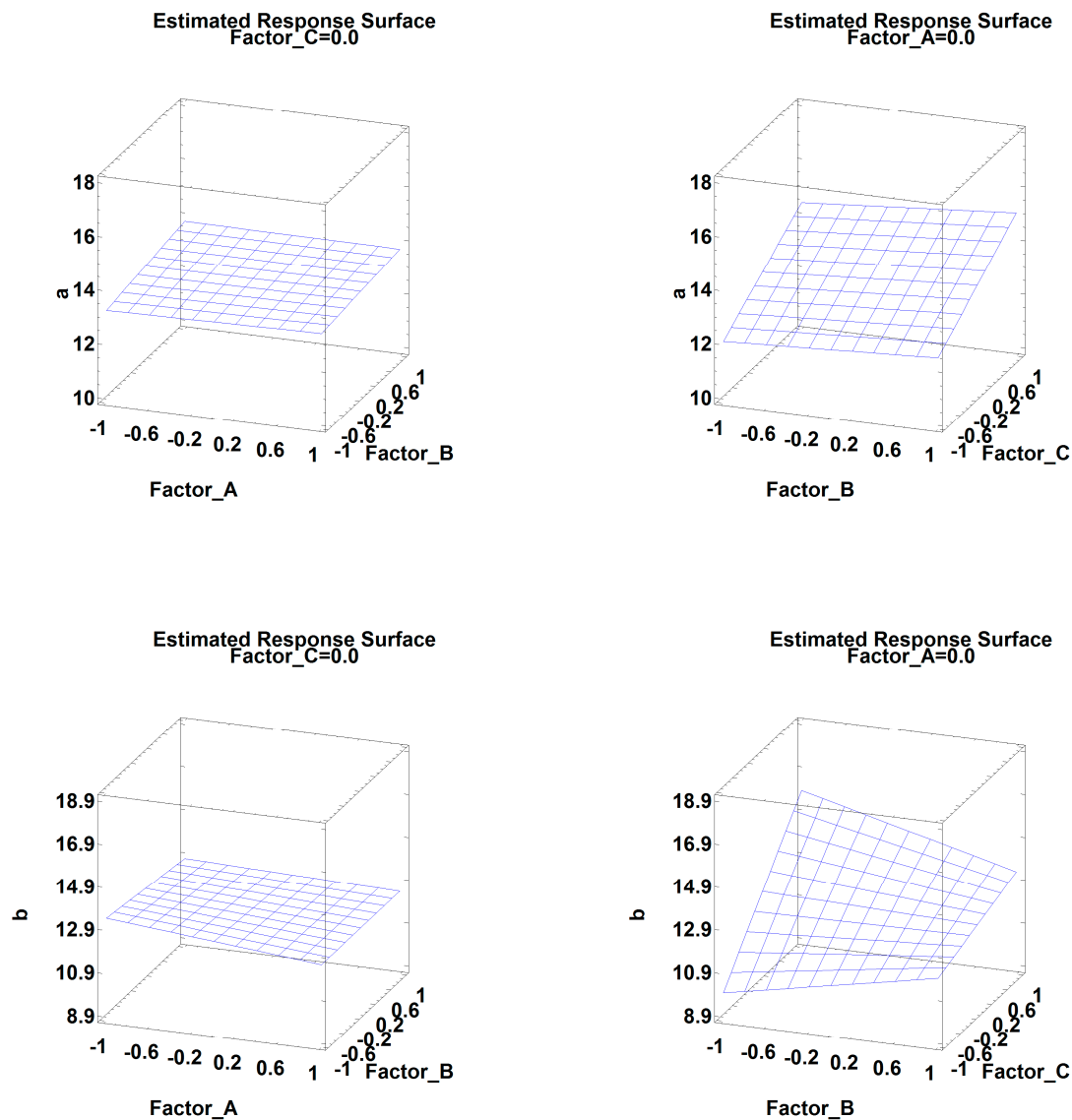


Figure 2. Response surfaces for physical and functional characteristics (Part I, Part II).

3.4. Moisture Content of Extrudates

Figure 1 shows that all investigated factors significantly influenced the moisture content of the extrudates. The biggest effect was from the amount of chokeberry pomace, followed by the feed moisture and the working screw speed. It can be seen in Figure 2 that, when the amount of pomace and the working screw speed increased, the moisture content of extrudates decreased. The feed moisture had a positive effect on the moisture content of extrudates, as it is clear that the relationship between two moisture contents was directly proportional. Figure 1 also shows that, on increasing the working screw speed, the expansion of extrudates decreased, leading to a reduced moisture content of extrudates. The response surfaces (Figure 2) give us information that the rate of decrease of moisture content of extrudates was equal at low and high levels of feed moisture content. An identical rate of increase of feed moisture content was observed at both levels of working screw speed (180 and 220 min^{-1}).

3.5. Pellet Durability Index

The pellet durability index (PDI) is the evaluation of pellet integrity using a pellet durability tester after the pellets have been shaken for ten minutes [40]. The experimental results showed that the effect of the amount of chokeberry pomace was insignificant, while

the effect of the other two factors (feed moisture and working screw speed) was positive. The *PDI* is directly related to the *BD* [41]. When the extrudate has higher density, it can be expected to be more durable. This was confirmed by our data—when the density increased, the *PDI* also increased (Figure 1). The effect of the feed moisture was equal at low and high levels of the amount of chokeberry pomace (Figure 2). Concerning the effect of the working screw speed, it can be seen that this effect was more pronounced at low level of feed moisture (14%) than at high level (20%). According to Sazzhetti et al. [34], the higher feed moisture of the grits limited the evaporation, leading to a product with higher density and thus higher durability. Similar results were obtained by Schmid et al. [24], who established a reduction in the sectional expansion of pure chokeberry pomace when the working screw speed increased, which is related to higher density and durability. This is probably due to the reduced residence time in the extruder which leads to lower expansion and higher density. All this statements are confirmed by our data.

3.6. Water Solubility Index

The *WSI* characterizes the amount of the mixture of soluble components after extrusion [42]. It can be seen from Figure 1 that the *WSI* increased when the amount of chokeberry pomace and working screw speed raised. The effect of the feed moisture was insignificant. Figure 2 shows that the effect of the amount of chokeberry pomace was more pronounced at low level of feed moisture (14%) than at high level (20%). The effect of working screw speed on the *WSI* was clearly expressed at high level of feed moisture than at low level, where the effect was invisible. The increase in the screw speed led to stronger shear forces during the extrusion process, thus making the processed components more fragmented and much easier to elute [7]. The *WSI* varied from 22.3 to 26.4% of extrudates from chokeberry pomace with the twin screw extruder [24]. The authors established that, at low feed moisture (13%), the screw speed had a positive effect on the *WSI* while this effect was only slightly expressed at high feed moisture (23%). Our results for *WSI* are higher than their results, i.e., from 22.76% to 43.19%, which can be explained by different extruder (single-screw), different working conditions and the rice used for extrusion (not only chokeberry pomace). The increase in the *WSI* with the rise in the amount of chokeberry pomace could be explained by the availability of soluble carbohydrates and dietary fibers in the pomace [43]. According to other researchers [32], when the *WSI* was studied, the presence of pineapple pomace at both tested levels provoked less solubilization of the matrix components during extrusion when compared to the control.

3.7. Water Absorption Index

The *WAI* characterizes the amount of water absorbed by the material [27]. It can be seen from Figure 1 that the *WAI* increased when the working screw speed decreased, and the effect of the amount of chokeberry pomace and the feed moisture were insignificant in the investigated range. Figure 2 shows that the effect of the amount of chokeberry pomace was higher at low level of feed moisture than at high level. The screw speed influenced the process strongly at high level of feed moisture (20%), and slightly at low level (14%). Schmid et al. [24] established values of *WAI* from 1.6 g/g to 2.9 g/g during extrusion of chokeberry pomace with a twin-screw extruder. Our values were higher, from 4.28 g/g to 6.56 g/g, which can be explained by the use of rice as main raw material for extrusion in our study. Wójtowicz et al. [7] found that the increase in chokeberry amount in the initial mixture increased the water absorption of the snack pellets. This is in accordance with our results and can probably be explained by the increase in the number of components able to absorb water, like fibers and proteins [43]. Altan et al. [33] established that the *WAI* decreased significantly ($p < 0.01$) as the percentage of tomato pomace increased. This means that the relationship between the pomace level and *WAI* depends on the type and composition of pomace.

3.8. Hardness

The *HD* of extruded product describes the minimal force necessary to break the sample. The expansion, bulk density and hardness are closely related—a product with poor expansion and high density possesses high hardness [37]. Our experimental data showed that a rise in the feed moisture led to a decrease in the expansion, and an increase in the *BD* and *HD* of the extruded product (Figure 1). The effect of the feed moisture on the *HD* was more pronounced at low amount of chokeberry pomace (10%) and low level of feed moisture (14%) than at 20% chokeberry pomace and 20% feed moisture (Figure 2). A weaker effect than the feed moisture came from the amount of pomace and screw speed. When the amount of chokeberry pomace increased and the working screw speed decreased, the *HD* decreased. This is probably related to the *WAI*, as the higher amount of chokeberry pomace led to an increase in the number of components able to absorb water (like fibers and proteins), thus the *WAI* increased and the *HD* decreased, i.e., the extruded product is softer. Increased screw speed led to a reduction in the duration in the extruder leading to lower expansion, and higher density and hardness. The reduced duration hinders the complete gelatinization of the starch [26]. Meng et al. [35] also found that increase in the feed moisture led to an increase in the *HD* of the chickpea flour-based snack. According to Altan et al. [33], the response surface plot demonstrated that the decrease in die temperature and level of tomato pomace led to a rise in product hardness. This probably means that the relationship between hardness and the added amount of pomace depends on the type and composition of the pomace.

3.9. Lightness

During extrusion, non-enzymatic darkening reactions occurs, leading to extrudates with a darker color than the raw material before extrusion [44]. Comparing the data in Table 1 for L_0 and Table 3 for L , it can be seen that the L values for the extruded products were lower than the L_0 values of raw mixtures before extrusion. The lowest value for L was obtained at an amount of chokeberry pomace of 10%, feed moisture of 14% and working screw speed of 220 min^{-1} . The highest value was obtained at an amount of chokeberry pomace of 10%, feed moisture of 20% and working screw speed of 180 min^{-1} . Figure 1 shows that the amount of chokeberry pomace in the range from 10 to 20% had insignificant effect on lightness. When the feed moisture and working screw speed decreased, the lightness increased (Figure 2). Altan et al. [33] and Selani et al. [32] established that, when the amount of barley-tomato and pineapple pomace increased, the lightness increased. Our study showed that the amount of chokeberry pomace had an insignificant effect on the lightness in the investigated range from 10 to 20%.

3.10. Redness and Yellowness

Figure 1 shows that increasing the feed moisture and working screw speed led to an increase in redness a . The amount of chokeberry pomace had an insignificant effect. Concerning the yellowness b , the decrease in the amount of chokeberry pomace and the increase in the working screw speed led to an increase in the value of the yellowness (Figure 2). This could be probably explained by the dark blue color of the chokeberry pomace due to the anthocyanins [44].

3.11. Optimization

The results from the response optimization showed that the amount of chokeberry pomace of 10%, the feed moisture content of 15.2% and working screw speed of 191.4 min^{-1} were the optimal working conditions for production of quality extrudates. The optimization showed that it is possible to use values of independent variables close to the minimum (10% for amount of chokeberry pomace, 14% for feed moisture content, 180 min^{-1} for working screw speed) to produce enriched extrudates. The values of the response variables at the optimal working conditions are shown in Table 5.

Table 5. Physical and functional characteristics of extrudates at the optimal working conditions.

Response Variable	Value
ER	2.96
BD	0.128
PDI	76.23
MC	8.10
HD	21.80
L	60.55
WAI	5.00
WSI	29.53

4. Conclusions

Physical and functional characteristics of extrudates from rice and *Aronia melanocarpa* (chokeberry) pomace depend on the process conditions. The results showed that the three factors influenced all studied characteristics. The response optimization showed that the amount of chokeberry pomace at 10%, the feed moisture content at 15.2% and working screw speed of 191.4 min^{−1} were the optimal working conditions during the extrusion process. These established working conditions can be used in the production of quality extrudates with good expansion, minimal feed moisture and energy consumed. Further investigations could be made to establish the working conditions if a twin-screw extruder is used.

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