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Application of Extrusion-Cooking for Processing of White and Red Bean to Create Specific Functional Properties

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Abstract: Extrusion-cooking, as a modern and versatile processing method, may be applied to create the properties of food ingredients and active components, especially beans and legumes. Two varieties of bean (red Toska and white Aura) were extruded with twin-screw extruder under various conditions (water dosing 0.8–2.4 $\mathrm{l\,h^{-1}}$, screw speed 300–700 rpm). Physical properties (energy consumption, expansion ratio, water absorption and solubility, viscosity, texture, color) and chemical characteristics (protein, fiber, reducing sugars, total phenols, anthocyanins, flavonoids, antioxidant activity and reducing power) were evaluated. Regardless of the bean cultivar, energy consumption significantly increased for about 60% with the extruder screw speed increase, and at the same time, the greater water addition reduced energy consumption by about 30%. The physical properties and texture of extruded bean were significantly connected with processing conditions for both bean varieties. Chemical composition and nutritional characteristics were different for red and white bean, especially phenols and anthocyanins levels were higher in red bean extrudates; significant effects of extrusion variable conditions were found in most characteristics. Nevertheless, the knowledge of the effect of red and white beans extrusion treatment on tested characteristics allows to select processing conditions to achieve ready-to-eat extrudates or functional additives with specific features.

Keywords: extrusion-cooking; bean; physical properties; chemical composition; nutritional value

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1. Introduction

Many cultivars of legumes are the basic source of food for the human population [1,2]. Soy, bean and other legumes are a rich source of protein, carbohydrates, fibre, vitamins and minerals. There big advantage is that they can form the basis of a gluten-free diet. In addition, bean and other legumes can help in the fight against civilization diseases such as diabetes, obesity, cardiovascular disease and colon cancer [3–6]. However, due to the presence of sugars which can cause bloating, these are still not very popular food products. However, insufficient knowledge about the changes occurring in the functional characteristics of bean during its processing is still an additional factor limiting the use of beans as a food raw material in Europe and developed countries [7].

Legumes, due to the chemical composition and high nutritional value, have an excellent potential to be used as extruded ready-to-eat foods or a product components by partial or total replacement of cereals, meat, fats, emulsifiers or other additives. In recent years many studies about the possibility to incorporate various legumes (such as bean, lentil, pea, chickpea and faba bean) to improve the nutritional value of extruded foods have been published. Extruded products based on legumes are nutrient dense, ready-to-eat, microbiologically safe and shelf-stable which make them excellent to mitigate malnutrition in developing countries [8,9]. Additionally, they can be easy supplemented with additional nutritional components (vitamins, minerals etc.) or developed as multi-legume or multi-grain compositions what made the possibility to be completed directly to the nutritional needs of consumers. Legumes play important role in regulating blood sugar and lipid level in diabetic patients and healthy people due to their very low glycaemic index [10]. They also stimulate greater weight loss and regulate body weight by improving satiety. Incorporation of legumes into food products such as snack bars [11], burgers and patties [12] and pasta [13] have also been studied.

The extrusion-cooking process as a HTST process is considered as a modern and versatile processing method of the vegetable raw materials for food purposes. Short processing at high temperature and high pressure has a positive effect on the properties of food ingredients and active components. At the same time, during the treatment, the reduction or even complete elimination of undesired anti-nutritious ingredients and microorganisms present in the processed raw material takes place. During the extrusion the water evaporates from products and, if it is insufficient, products are dried to the required moisture content. Thanks to this, the extruded products with low moisture content have a long shelf life, which is an additional advantage [14–17]. Due to the ease of adjustment, the extrusion-cooking process has found a wide range of applications, especially in the production of food and pet feed, in particular: breakfast cereals, pellets, pasta and flat bread [16,18–20].

The extrusion-cooking process is also used in legumes processing, especially soybean, with particular emphasis on the production on meat analogues. In recent years, interest in the possibility of using this method in the processing of other legumes, especially beans, has been growing. The extrusion-cooking allows to obtain products with addition of the beans, ingredients and food additives or even snacks from the beans themselves [14,21–24]. There is still insufficient information on the course of the extrusion-cooking process of the bean as well as on the properties of extrudates obtained from bean in different extrusion-cooking conditions.

The aim of this work was to investigate the effect of variable processing parameters of extrusion-cooking of two common bean cultivars (Toska and Aura) on selected physical, chemical and nutritional characteristics of extrudates.

2. Materials and Methods

2.1. Raw Materials

The Toska (red) and Aura (white) cultivars of common bean (*Phaseolus vulgaris* L.) were used in the experiment [2]. The moisture content of the bean seeds was about 8%. The seeds were ground using a hammer mill to pass the sieve with 1 mm diameter openings. Dry components were fed into the extruder feeder.

2.2. Extrusion-Cooking of Beans

Ground beans were extruded using a twin-screw extruder Evolum 25 (Clextral, Firminy, France) with L/D = 24. Standard elements supplied by Clextral were used in the experiment. Screws configuration was as follows, starting from feeding zone: 3 × 1.25D T2F elements, 4 × 1.25D C2F elements, 5 × 1D C2F elements, 3 × 0.75D C2F elements, 1 × 1D T1F elements, 2 × 0.75D T1F elements, 5 × 0.5D T1F elements, 1 × 1D T1F elements, 2 × 0.75D C2F elements, 1 × 0.5D C2F elements. A die hole diameter was 5 mm. The temperature of the barrel was set to 50/80/100/120/130 °C from the feeding to die section. The extrusion-cooking process was performed at five different screw speeds: 300, 400, 500, 600 and 700 rpm. The raw materials were fed by a screw feeder with a constant rate of 20 kg h^{-1}. During extrusion-cooking, 5 levels of water addition to the first barrel section

(0.8, 1.2, 1.6, 2.0 and 2.4 l h^{-1}) were used. The extrudates were collected and cooled down to ambient temperature. After cooling, the bean extrudates after the expansion ratio and the cutting force measurements were ground for further analyses using a hammer mill to pass through a 0.8 mm screen.

2.3. Physical Properties

The extrusion-cooking process energy consumption was calculated as specific mechanical energy (SME, kJ kg^{-1}) according to equation SME = $(T \cdot 2\pi f \cdot n)/(S + W)$ [25]. In this equation T is the screws torque in kJ (given in % by the software FITSYS Plus and converted to kJ multiplying to 0.1076 provided by the manufacturer), f is the screws rotation speed in s^{-1}, n is the number of screws, S is the dry feed rate in kg s^{-1} and W is the water feed rate in kg s^{-1} [25]. Results were calculated in triple and expressed as kWh kg^{-1}.

Expansion ratio of the extrudates was determined as the diameter of extrudates divided by the diameter of the matrix opening in 10 replications [20].

Water absorption index (WAI) was determined according to the method used by Estrada-Giron et al. [22] with our own modification in triplicate. A 0.7 g ground sample was suspended in 7 mL of distilled water in a 10 mL centrifuge tube and stirred intermittently over a 30 min period. The resulting suspension was centrifuged at 15,000 rpm for 10 min in T24D type centrifuge. The supernatant liquid was poured into a tared evaporating dish. The remaining gel was weighted and the WAI was calculated as WAI = w_g/w_s (g g^{-1}), where w_g is a weight of gel and w_s is the weight of dry sample.

Water solubility index (WSI) was determined from the amount of dried solids recovered during evaporation of supernatant obtained from the WAI analysis according to the method used by Estrada-Giron et al. [22] in triplicate. Results were calculated from formula WSI = $(w_{ds}/w_s) \times 100$ (%), where w_{ds} is the weight of dry solids of supernatant and w_s is the weight of dry sample.

The viscosity of the extruded beans pastes as a cold paste viscosity (cpv) was measured during the pasting properties of extruded beans using the Brabender Micro Visco-Amylo-Graph (Brabender, Germany). The suspensions of 10 g of the ground extrudate in 100 mL of distilled water were prepared. The measurements were performed with constant speed (250 rpm) within the following temperature profile: heating from 30 °C up to 93 °C with the temperature gradient of 7.5 °C min^{-1}, holding at 93 °C for 5 min, cooling from 93 °C to 50 °C with the temperature gradient of 7.5 °C min^{-1}, holding at 50 °C for 1 min [20]. The viscosity of the extruded beans pastes after cooling to 50 °C (cold paste viscosity) was measured in double.

The texture of extruded beans was evaluated with the universal testing machine Zwick BDO-FB0.5TH (Zwick GmbH & Co., Germany). Cutting force (F_{max}) was tested with a Warner-Bratzler steel blade. Test head speed was 500 mm/min. A measurement curves were recorded and analysed with testXpertII based on the data of 10 replications [20].

The colour of extruded bean was evaluated using Colour and Appearance Measurements System Lovibond CAM-System 500 (The Tintometer Ltd., Amesbury, UK). The CIE-Lab scale was used for the evaluation of L^* for brightness, a^* for redness and b^* for yellowness [20]. Measurements were performed in 20 replications for each sample.

2.4. Chemical and Nutritional Characteristics

Protein content in extruded samples was determined by using the Kjeldahl method [26].

Fibre determinations were conducted in three replications for the contents of neutral-detergent fibre (NDF) in extrudate samples according to the Van Soest et al. [27] method using filtration bags and Ankom apparatus (Ankom220, Macedon, NY, USA). The NDF content was determined using a solution of neutral detergent (sodium-lauryl sulfate, ethylenediamine tetra acetic disodium salt, sodium borate, di-basic sodium phosphate, triethylene glycol), alpha-amylase (17,400 liquid units/mL, FAA Ankom Technology) and sodium sulfite (FSS Ankom Technology).

Reducing sugar content was determined using the standard dinitrosalicylic acid (DNSA) method [28]. The contents of free reducing sugars and sucrose were determined as follows: the samples were dispersed in a sodium acetate buffer (pH 5.0) and then treated with 200 µL (10 mg in 1 mL of 0.4 M sodium acetate buffer, pH 5.0) of invertase (EC 3.2.1.26; 300 U mg^{-1}) at 37 °C for 30 min. After centrifugation, reducing sugars were analysed in the supernatants using the DNSA reagent.

Extrudate extracts were prepared to evaluate phenolics content and antioxidant activity following the methodology proposed by Świeca et al. [29]. Ground extrudates were extracted with a mixture of acetone, water and hydrochloric acid (70:29:1; *v*/*v*/*v*). Afterwards, the samples were centrifuged for 10 min and the resultant supernatant was collected and used for further analyses.

The content of total phenols was determined with the method of Singleton and Rossi [30] by using the Folin–Ciocalteau reagent. The absorbance of the samples was measured with a UV-vis spectrophotometer at the wavelength of 725 nm. Results was computed and expressed as gallic acid equivalents (GAE) in mg per g of dry matter (DM).

The content of anthocyanins in extruded beans was determined according to the method provided by Fuleki and Francis [31]. Determinations were carried out using solutions of potassium chloride and sodium acetate at two pH values, i.e., 1.0 and 4.5. The solutions were mixed with extrudate extract in a ratio of 20:1 (*v*/*v*). After 15 min, absorbance of the samples was measured at two wavelengths (520 nm and 700 nm). After absorbance value correction for various pH values, the content of anthocyanins was expressed in mg of cyanidin 3-glucoside equivalents (Cy3-GE) per g of dry matter (DM).

The total content of flavonoids was determined according to the method used by Szparaga et al. [32]. The prepared bean extract was mixed with a methanolic solution of $AlCl_3 \times 6H_2O$. After incubation, absorbance was measured with a UV-vis spectrophotometer at the wavelength of 430 nm. The total flavonoid content was expressed as quercetin equivalents (QE) in mg per g DM.

The antiradical activity of extrudate extracts was determined according to the method of Sancho et al. [33] with some modifications. A Trolox calibration solution (0, 25, 50, 75, 100, 150, 200, 300 µM/mL) was prepared in the extraction mixture. An $ABTS^+$ solution with the final concentration of 2.45 mM potassium persulfate and 7 mM $ABTS^+$ was diluted with an acetone solution to ensure the absorbance of 0.7 ± 0.02 at 734 nm. Then, 280 µL of $ABTS^+$ were transferred to a 96-well microplate and mixed with 20 µL of the sample. The result obtained was expressed as Trolox equivalent.

Reducing power was measured by following the method provided by Pulido et al. [34]. The extrudate extract was mixed with a phosphate buffer (200 mM, pH 6.6) and 1% solution of $K_3[Fe(CN_6)]$. Next, the samples were incubated at 50 °C for 20 min. The reaction was stopped with trichloroacetic acid, and the samples were centrifuged (6800× *g*, 10 min). The resultant supernatant was mixed with distilled water and $FeCl_3$. Then absorbance was measured at the wavelength of 700 nm. Reducing power was expressed as Trolox equivalents in mg per g DM.

2.5. Statistical Analysis

For each bean cultivar, a multifactorial experimental design of 5 × 5 (screw speed, water addition) with three replications was selected in this study. The effect of extrusion variables on selected physiochemical properties was tested with five different screw speeds (300, 400, 500, 600 and 700 rpm) and five levels of water addition (0.8, 1.2, 1.6, 2.0 and 2.4 l h^{-1}), for a total of 25 treatments combinations. The selection of these conditions, as well as the extrusion-cooking temperature profile, was based on preliminary runs and from published data reporting that die temperatures over 140 °C may damage the final extruded bean products [22]. Statistical analysis was conducted using the Statistica software version 13.3 (TIBCO 199 Software Inc., Palo Alto, CA, USA). Two-way ANOVA was used to evaluate the effect of various processing conditions on extrudates' characteristics with a significance level $\alpha = 0.05$.RSM with a square fit was used to evaluate combined effect of various processing conditions on extrudates' characteristics.

3. Results and Discussion

3.1. Physical Properties of Extruded Beans

3.1.1. SME and Expansion Ratio

Specific mechanical energy as well as expansion ratio of the extruded beans were significantly affected by the extrusion process parameters (Figure 1). As other research suggests [25,35], both SME and expansion index are related to the viscosity of the molten mass. A more intensive extrusion process may cause increased changes in the processed material (e.g., starch degradation) which can lead to the creation a less viscous slurry [36]. de Mesa et al. [37] indicated that greater protein content in processed material can also lead to increased energy consumption (SME) of the extrusion process due to changes in viscosity of the extruded material. SME during extrusion of beans varied within 0.184–0.489 kWh kg^{-1} (662.4–1760.4 kJ kg^{-1}) range for red bean Toska and within 0.228–0.480 kWh kg^{-1} (820.8–1728.0 kJ kg^{-1}) range for Aura white bean. The research has shown (Figure 1a,b) that, regardless of the bean cultivar, SME value significantly increased with the extruder screw speed increase ($p < 0.05$) for about 60%. SME value was directly proportional to screw speed in the equation used for SME calculations, therefore, the observed data can be found as experimental confirmation. At the same time, the greater water addition to the extruded material reduced for about 30% the energy consumption of the extrusion process ($p < 0.05$). Lower moisture content of the raw material may result in the formation of a more viscous dough inside the extruder, which results in a greater load of the engine [38]. The impact of both these parameters on SME changes during the extrusion-cooking process of the beans was similar to the effect observed by other researchers during the extrusion of legumes or other starch–protein raw materials [17,38]. SME during the extrusion-cooking of white beans was slightly larger than that the red ones. Probably the lower starch content in red Toska contributed to this causing the formation of a more viscous material due to less intensive starch gelatinization and thus increasing the energy consumption of the process.

The expansion ratio (ER) is one of the most important characteristics of the extruded products. Expansion occurs when the hot material is pushed through the extruder outlet die. At this point, the water contained in the material rapidly evaporates causing the expansion of the molten material and, as a result, a porous structure of the finished product is formed [35,36,39]. However, too high a water content in the processed material may limit the expansion. The expansion ratio of red beans Toska ranged from 2.20 to 4.48 while for white Aura beans higher ER values in range 2.94–5.25 were found (Figure 1c,d). The reason of these differences can be found in the chemical composition of both varieties of beans. Starch is a structure-forming component that determines the extent of expansion. The Aura cultivar (white) was characterised by higher content of the carbohydrates and lower content of the protein and fibre in comparison with Toska cultivar (red). These differences can lead to observed expansion results. The research showed that increase in screw speed had a positive effect on the expansion ratio of the obtained extrudates and increase of 26% ER was noted for the highest rpm used. The increase in the water addition during the extrusion process of beans had a negative effect on the ER of the obtained extrudates, reduction in ER was maximum 38% at the highest water dosing level. These changes were observed regardless of the type of beans used. About similar changes in ER values were reported by Cappa et al. [40] and Natabirwa et al. [41] in the case of the extrusion of bean as well as by Pasqualone et al. [42] in the case of the legume's extrusion.

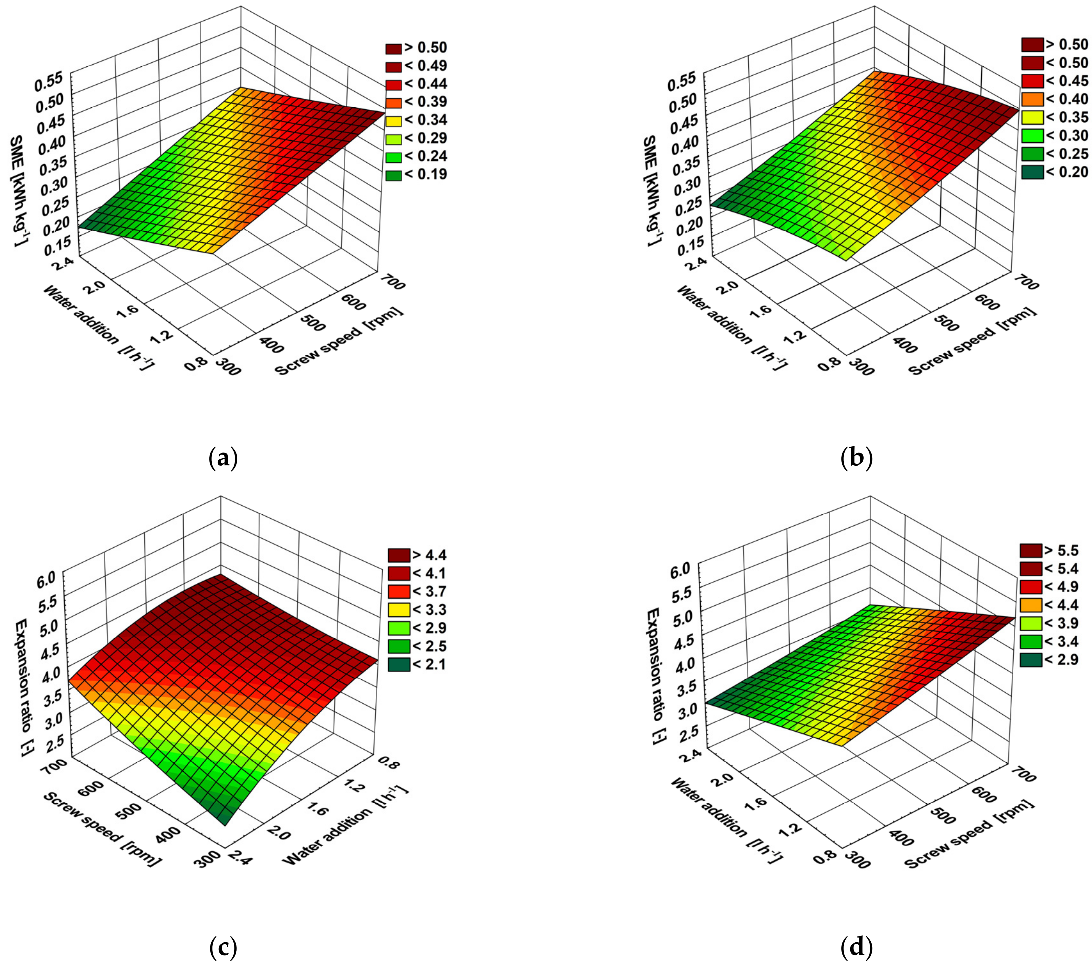
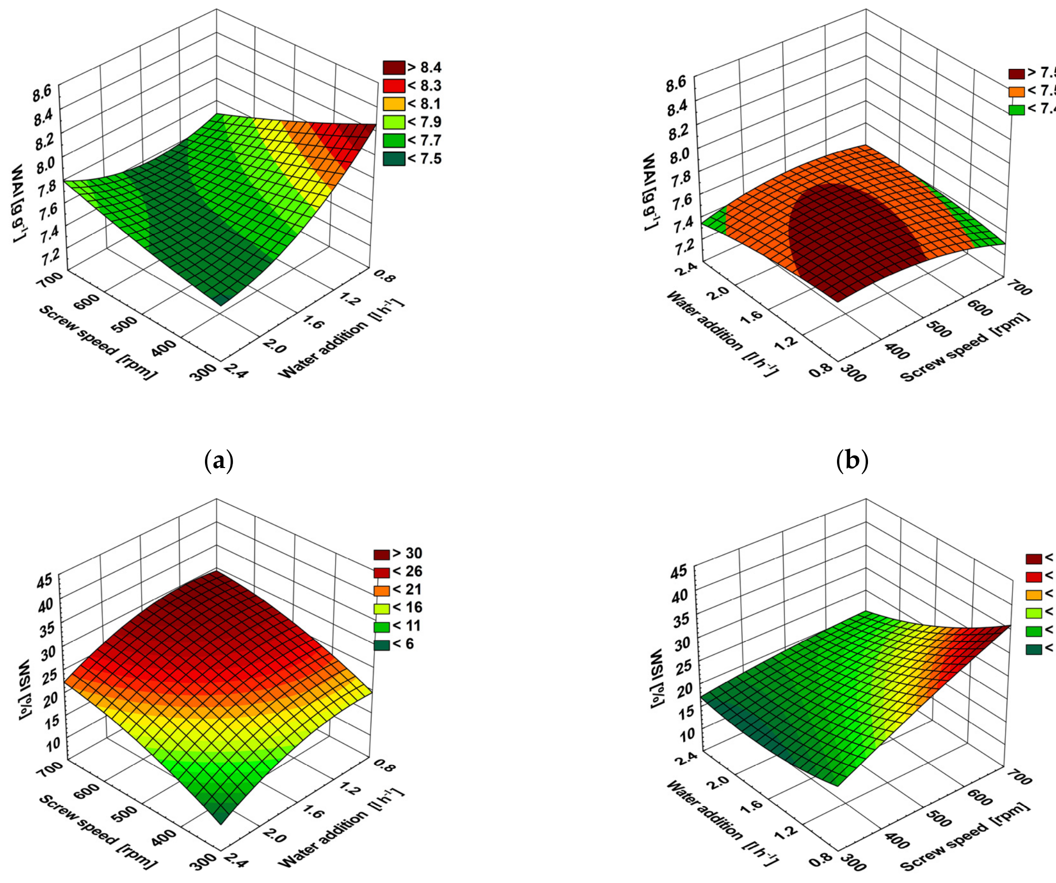


Figure 1. Effect of various extrusion parameters on SME and expansion ratio of extruded red beans (**a**,**c**) and white beans (**b**,**d**).

3.1.2. Water Absorption and Water Solubility

Water absorption index (WAI) and water solubility index (WSI) are important functional properties that can affect other extrudate properties and even applicability. In general, WAI reflects the changes in processed material, such as starch gelatinization and protein denaturation, affecting its water holding and binding capacity. WSI is often used as an indicator of molecular degradation of components. It indicates the degree of starch fragmentation during the extrusion-cooking process [43,44]. The influence of various extrusion parameters on WAI of red and white bean extrudates is presented in Figure 2a,b, respectively. During the research it was found that the extrudates made from both bean varieties were characterized by similar WAI values ranged 7.39–8.78 g g^{-1} for red Toska bean and 7.22–8.17 g g^{-1} for white Aura bean. The results showed that only the level of water addition had a significant negative impact (maximum decrease of 16%) on the WAI values of the red beans (Toska) extrudates (Supplementary Table S1). The changes in the extruder screw speed did not significantly affect the changes in WAI of the extruded Tosca variety. Similar WAI changes were observed by Sutividsedsak et al. [45] on four beans cultivars. They suggest that significant decrease in WAI when feed moisture (or water addition) increase is caused by less viscosity of the dough and reduction in energy provided to extruded mass resulting in less mechanical damage of starch and more compact internal structure. The opposite results were observed by Lopes et al. [43] for extruded bean cotyledons. They recorded that increase in raw material moisture content caused significant increase in WAI of the extrudates.



(**a**) (**b**)

(**c**) (**d**)

Figure 2. Effect of various extrusion parameters on WAI and WSI changes of extruded red beans (**a**,**c**) and white beans (**b**,**d**).

In case of white beans (Aura) extrusion-cooking parameters had no significant influence on water absorption of the obtained extrudates. Moreover, Nyombaire et al. [46] discovered that extrusion process parameters had no significant effect on extruded bean WAI changes. However, it was observed that the combined interactions of water addition and extruder screw speed had a significant effect on the changes in WAI for both tested beans varieties (Supplementary Table S2).

A significant effect of extrusion-cooking parameters on the water solubility index values was found. WSI ranged from 10.43 to 45.43% for red Toska cultivar and from 12.43 to 39.43% for white Aura cultivar (Figure 2c,d). For both beans cultivars a significant negative effect of water addition on WSI was observed. WSI is a parameter that can indicate the degradation extend of the molecular components, in particular starch granules disintegration. A larger amount of water can act in a protective way during the extrusion-cooking of beans, limiting both fragmentation and thermal or mechanical degradation of individual components in the processed material. Similar effect of water level on WSI changes was observed by Sutivisedsak et al. [45] and Natabirwa et al. [41]. Studies have shown that an increase in extruder screw speed caused a significant increase in WSI of the extruded beans, regardless of its cultivar for a maximum 90% if 1.2 l h^{-1} was applied. With the higher screw speed, the greater shear forces are generated due to the friction and greater heat is generated. As a result, increased degradation and fragmentation of ingredients in the extruded beans can be noted. WAI and WSI ranged from 2.04 g g^{-1} to 5.01 g g^{-1} and 20.80% to 46.80%, respectively, for the whole legume flours of kidney bean, mung bean, pigeon pea, soybean and black soybean [47].

Cold paste viscosity (cpv) of extruded materials reflects a retrogradation tendency of the starchy component present in a processed material. Generally, extrusion-cooking parameters have a significant influence on pasting properties of the extruded bean [48]. The cpv values expressed as viscosity of extruded bean ranged between 47–104 mPas for red Toska bean and 31–63 mPas for white Aura bean extrudates. It was observed that increase in screw speed during processing had a negative influence reducing the cold paste viscosity of extruded bean (for a maximum 26%), regardless of cultivar. This can be connected with weakened gel formation ability due to a higher shear forces generated during the extrusion-cooking under higher screw speed. The increase in water addition during the extrusion-cooking caused an increase in cold paste viscosity for a maximum 57% for Aura bean cultivar. It may reflect the better gel formation ability of the extruded beans, but due to protein and fibre content this ability is lower than pure starch extrudates [49].

Various texture parameters, especially hardness, are often related to the acceptability of the final extruded product. Usually, less hard and more expanded extrudates are more appreciated for direct consumption. If extruded plant material is used as functional ingredient this feature is less important than viscosity or water binding capacity. The results showed the effect of various screw speed and water addition level on the cutting force (hardness) of the obtained extrudates for both bean cultivars (Figure 3c,d). The values of this parameters were within the range 12.09–61.43 N for Toska cultivar and 10.90–93.63 N for Aura cultivar.

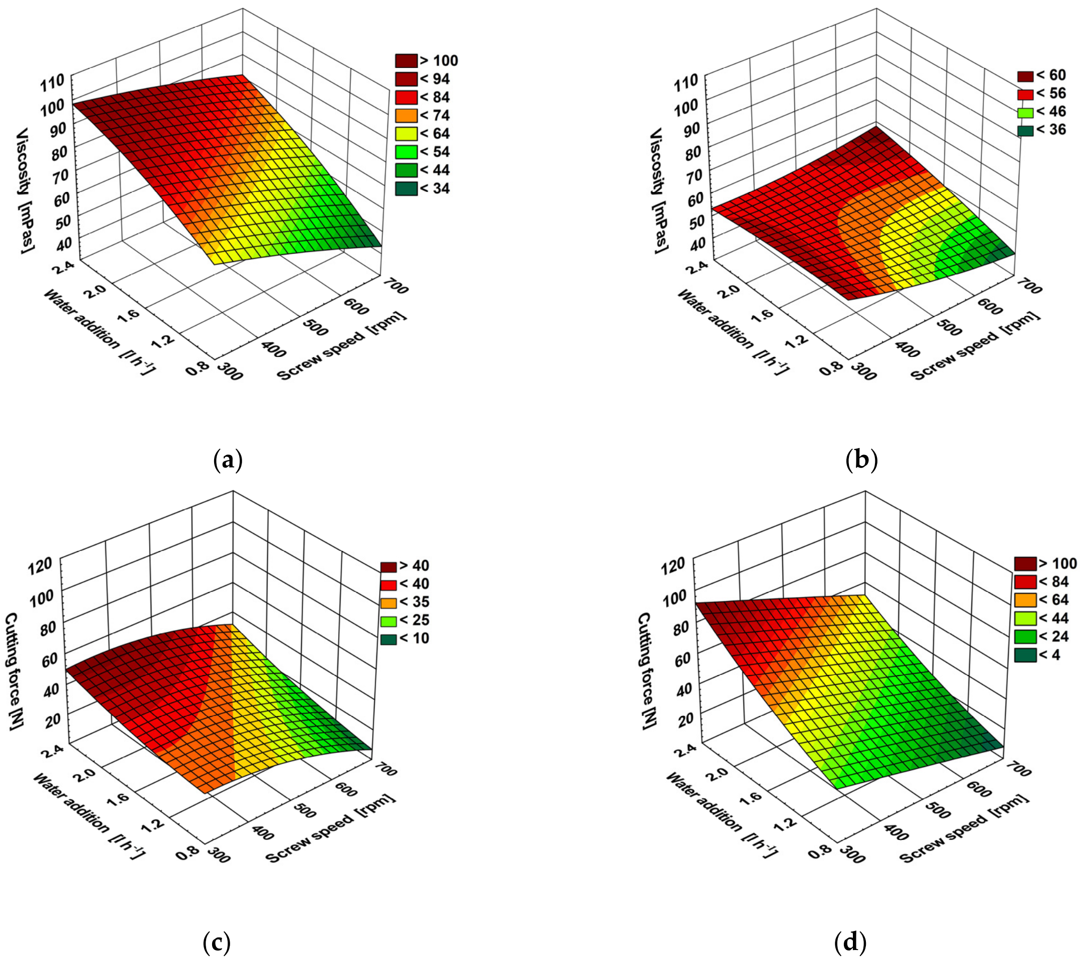


Figure 3. Effect of various extrusion parameters on viscosity and cutting force changes of extruded red beans (**a**,**c**) and white beans (**b**,**d**).

Increase in screw speed had a significant influence on extrudates hardness for both bean cultivars, but greater effect was observed for a white bean. Extrudates produced with higher screw speeds were characterised by lower cutting force for about 71% due to a greater expansion. The higher rate of water addition resulted in higher cutting force of bean extrudates, maximum increase in hardness (348%) was observed if water addition increased for Aura bean extrudates. These results were correlated with lower expansion of the extrudates produced with a higher water addition. This effect was more significant for Aura bean. Such influence of the extrusion-cooking parameters on product hardness was commonly observed for different kinds of starchy extrudates, including bean and legume extrudates [41].

The tested bean cultivars showed significant differences in the colour profile (Figure 4).

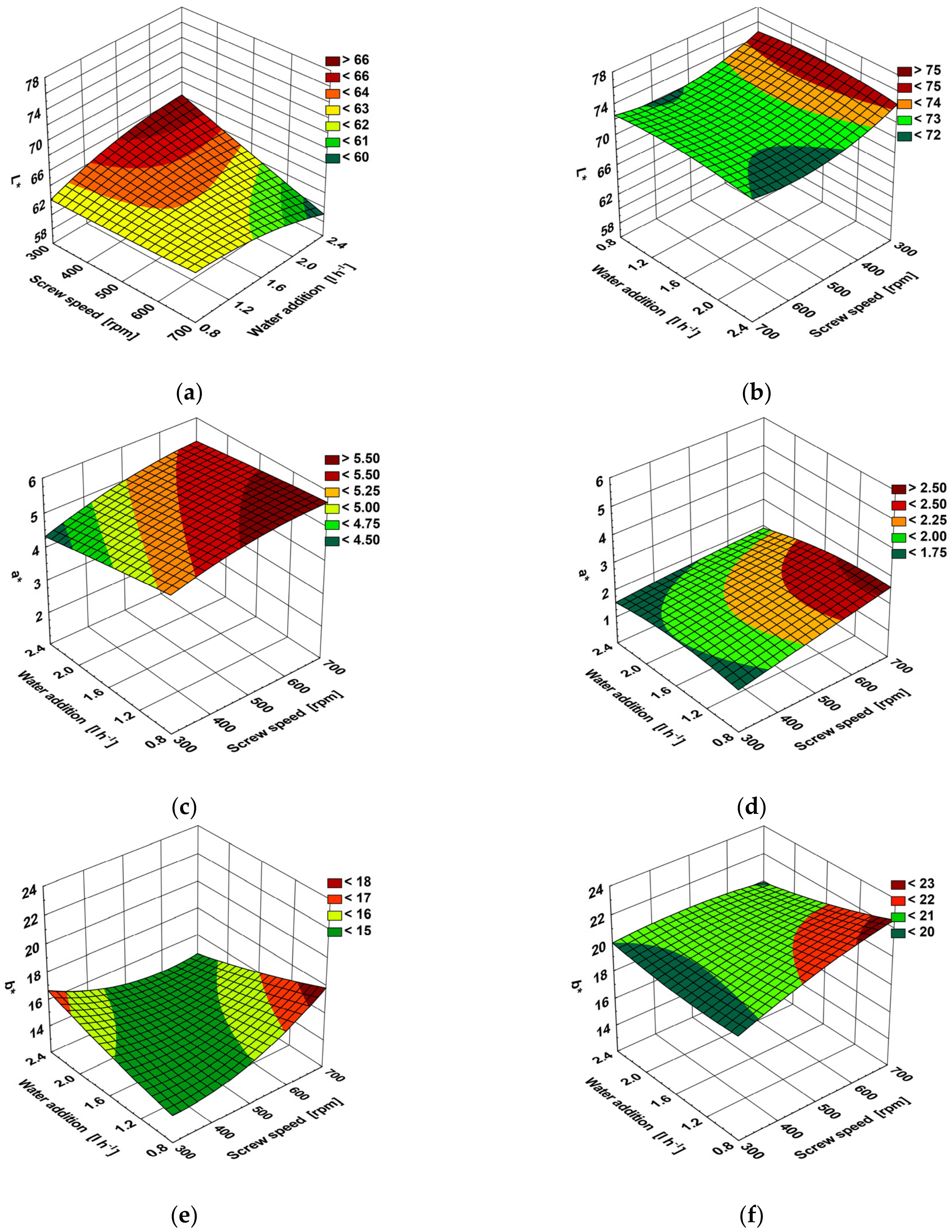


Figure 4. Effect of various extrusion parameters on lightness (L^*) and colour components (redness a^* and yellowness b^*) of the extruded red beans (**a**,**c**,**e**) and white beans (**b**,**d**,**f**).

Aura bean was the brighter with the higher L^* values in comparison with Toska bean. This effect a result of much darker colour of the red bean seeds cover. Toska cultivar showed also a higher redness (a^* value) and lower yellowness (b^* value) than Aura cultivar, mainly due to the seed cover colour. The extrusion-cooking conditions changed the colour of the processed beans. After the extrusion processing obtained extrudates were darker, more red and more yellow than unprocessed beans. Process parameters significantly affected lightness of both tested beans. Extrudates obtained with higher screw speeds were characterised by lower L^* value for about 16% in red bean extrudates. In contrast, water addition increase had a negative effect on L^* value, probably due to the lower expansion causing the extrudates to become darker. This effect was especially evident when tested red bean Toska. Process parameters had a significant influence on a^* and b^* components in white bean extrudates. Results revealed that extrudates obtained at higher screw speed were more red and yellow. Water addition increase caused a decrease in a^* and b^* colour components intensity. The only significant effect of the screw speed on extrudate redness was observed in extruded red bean. Similarly, in white (Aura) bean extrudates increase in screw speed caused an increase in redness. A yellow tint (b^*) was much lower in red bean than in white one, but the trends to intensify yellow colour was similar when increased screw speed was applied during processing and increase for about 23% was noted for red bean and for about 21% for white bean extrudates.

3.2. Chemical and Nutritional Characteristics of Bean Extrudates

3.2.1. Proximate Chemical Composition

Information about food composition is necessary to assess the diet quality or to develop and apply of food products in sustainability with dietary guidelines and human nutrition [50]. Moreover, in the case of legumes treatment, the extrusion-cooking process has a positive effect on nutritional characteristics due to significant modifications to starch and proteins, enhancing their digestibility, but at the same time reducing antinutritional substances content, such as trypsin inhibitors, lectins, phytic acid and tannins, commonly present in legume or bean seeds [51–54]. Extrusion cooking results in starch gelatinization, partial or total, at much lower moisture levels (12–22%) than is needed by other processing technologies [55]. The digestibility of starch may be about 90% depend on the extrusion temperature and water content, which enhance starch gelatinization level. Therefore, extrusion-cooking of legumes is sufficient way to improve the nutritional features and additionally due to the significant effect of HTST treatment extruded products became RTE what is minimizing home preparation time and may induce the consumption of these sustainable crops [42]. Extrusion-cooking seems to be suitable for producing wide range of ready-to-eat legume-added foods or may be useful in the development of functional foods by blending diverse ingredients into novel food products [56].

Protein contents in legumes (17 to 40%) are comparable with animal protein, and they are 2–3 times higher than cereal grains (3–7%). The amino acid profile provides essential nutrient compositions even though most legumes lack sulphur-containing amino acids. They also provide complex carbohydrates, dietary fibre, vitamins and minerals. Many studies reported that application of legumes as food additives improves overall nutritional quality [13]. After the extrusion-cooking of red and white bean the content of protein in extrudates seemed to be stable and varied from 27.04 to 30.20% of DM in Toska bean (Table 1) and 26.04 to 28.80% in Aura bean extrudates (Table 2). A little higher protein content was observed after the extrusion-cooking in red Toska cultivar extrudate because of higher initial protein content in seeds. Slight differences were noted depend on the processing conditions due to possible formation of complexes between protein and starch or protein and other components [16,57]. In most cases, increasing the amount of water during the extrusion of beans caused higher levels of protein in extrudates because the water acted as a lubricant and lowered the shear forces responsible for protein hydrolysis. Similar observation was according to neutral detergent fibre level, slight differences were observed between cultivars; due to the higher content of fibre in red beans a little higher

NDF content was evaluated in red Toska extrudates ranged 7.194–9.322%, while the white Aura extrudates showed level of NDF ranged 6.83–9.086%. These levels differ significantly if various processing conditions were applied during processing (Supplementary Table S3).

Table 1. Chemical and nutritional characteristics of red bean Toska extrudates processed at various conditions.

Screw Speed [rpm]	Water [l h^{-1}]	Protein [%]	Neutral Detergent Fiber [%]	Reducing Sugars [%g glucose/100 g]	Total Phenols [mg/g]	Anthocyanin [mg/g]	Total Flavonoids [mg/g]	Antiradical Activity [mgTE/g]	Reducing Power [mgTE/g]
300	0.8	29.04 ± 0.04 ^{fgh}	8.220 ± 0.010 ^{s}	5.693 ± 0.325 ^{efg}	13.23 ± 0.65 ^{p}	0.090 ± 0.02 ^{kl}	1.054 ± 0.001 ^{h}	2.91 ± 0.04 ^{fg}	1.200 ± 0.001 ^{a}
	1.2	29.39 ± 0.37 ^{h}	8.306 ± 0.000 ^{t}	7.213 ± 0.266 ^{gh}	10.35 ± 0.05 ^{o}	0.078 ± 0.004 ^{j}	0.949 ± 0.003 ^{c}	2.12 ± 0.02 ^{ab}	1.202 ± 0.002 ^{a}
	1.6	28.76 ± 0.24 ^{ab}	7.903 ± 0.000 ^{q}	4.106 ± 0.106 ^{bcdef}	7.13 ± 0.71 ^{ijklm}	0.054 ± 0.003 ^{g}	1.066 ± 0.002 ^{i}	2.38 ± 0.10 ^{d}	3.040 ± 0.070 ^{f}
	2.0	29.23 ± 0.19 ^{gh}	7.723 ± 0.000 ^{j}	7.734 ± 0.366 ^{h}	3.66 ± 0.42 ^{abcd}	0.083 ± 0.001 ^{jk}	1.080 ± 0.001 ^{j}	2.50 ± 0.01 ^{de}	1.083 ± 0.003 ^{a}
	2.4	29.21 ± 0.40 ^{gh}	8.657 ± 0.001 ^{x}	9.600 ± 0.547 ^{ij}	2.77 ± 0.32 ^{ab}	0.088 ± 0.002 ^{kl}	1.012 ± 0.001 ^{de}	2.99 ± 0.02 ^{fg}	2.485 ± 0.006 ^{e}
400	0.8	27.93 ± 0.18 ^{de}	7.931 ± 0.000 ^{p}	6.818 ± 0.397 ^{gh}	13.87 ± 0.14 ^{p}	0.020 ± 0.002 ^{cd}	1.042 ± 0.002 ^{g}	3.03 ± 0.02 ^{g}	1.279 ± 0.002 ^{a}
	1.2	28.09 ± 0.27 ^{de}	8.384 ± 0.000 ^{u}	2.615 ± 0.018 ^{ab}	10.60 ± 0.47 ^{o}	0.066 ± 0.005 ^{hi}	1.043 ± 0.003 ^{g}	2.59 ± 0.08 ^{e}	1.605 ± 0.411 ^{b}
	1.6	28.26 ± 0.17 ^{de}	7.858 ± 0.000 ^{n}	5.739 ± 0.261 ^{efg}	7.92 ± 0.27 ^{lm}	0.013 ± 0.001 ^{ab}	0.906 ± 0.006 ^{b}	2.46 ± 0.04 ^{d}	1.213 ± 0.003 ^{a}
	2.0	28.49 ± 0.45 ^{ab}	7.643 ± 0.000 ^{h}	5.047 ± 0.100 ^{def}	4.66 ± 0.19 ^{def}	0.025 ± 0.003 ^{de}	1.031 ± 0.000 ^{f}	2.96 ± 0.05 ^{fg}	2.138 ± 0.002 ^{cd}
	2.4	27.99 ± 0.29 ^{de}	8.418 ± 0.002 ^{v}	8.413 ± 0.834 ^{hi}	3.26 ± 0.51 ^{abcd}	0.081 ± 0.001 ^{j}	1.042 ± 0.002 ^{g}	3.62 ± 0.05 ^{l}	2.038 ± 0.002 ^{a}
500	0.8	27.67 ± 0.33 ^{cd}	9.322 ± 0.000 ^{y}	4.652 ± 0.336 ^{cdef}	8.52 ± 0.43 ^{mn}	0.027 ± 0.003 ^{e}	1.030 ± 0.001 ^{f}	3.29 ± 0.02 ^{jk}	1.057 ± 0.003 ^{a}
	1.2	28.70 ± 0.27 ^{efgh}	7.374 ± 0.001 ^{d}	11.528 ± 0.686 ^{k}	8.26 ± 0.33 ^{mn}	0.062 ± 0.001 ^{h}	0.921 ± 0.001 ^{a}	2.22 ± 0.03 ^{bc}	1.946 ± 0.004 ^{c}
	1.6	28.12 ± 0.12 ^{de}	7.359 ± 0.001 ^{b}	10.403 ± 1.245 ^{jk}	6.07 ± 0.82 ^{ghij}	0.051 ± 0.001 ^{fg}	1.131 ± 0.001 ^{l}	3.03 ± 0.02 ^{g}	1.084 ± 0.005 ^{a}
	2.0	27.04 ± 0.04 ^{bc}	7.665 ± 0.002 ^{i}	3.989 ± 0.117 ^{bcde}	4.37 ± 0.57 ^{cde}	0.067 ± 0.003 ^{hi}	1.028 ± 0.001 ^{f}	2.16 ± 0.03 ^{abc}	1.038 ± 0.005 ^{a}
	2.4	28.17 ± 0.19 ^{de}	7.853 ± 0.000 ^{m}	2.081 ± 0.397 ^{a}	2.19 ± 0.10 ^{a}	0.049 ± 0.002 ^{fg}	1.062 ± 0.002 ^{i}	3.16 ± 0.02 ^{hi}	3.200 ± 0.014 ^{f}
600	0.8	28.31 ± 0.18 ^{def}	8.051 ± 0.001 ^{r}	7.046 ± 0.941 ^{gh}	7.48 ± 0.72 ^{jklm}	0.031 ± 0.004 ^{e}	1.337 ± 0.007 ^{m}	2.26 ± 0.01 ^{c}	2.223 ± 0.011 ^{d}
	1.2	28.28 ± 0.28 ^{def}	8.535 ± 0.000 ^{w}	8.027 ± 0.238 ^{hi}	7.65 ± 0.09 ^{klm}	0.046 ± 0.002 ^{f}	1.010 ± 0.001 ^{de}	2.89 ± 0.03 ^{f}	1.242 ± 0.002 ^{a}
	1.6	28.75 ± 0.26 ^{ab}	7.786 ± 0.002 ^{l}	3.008 ± 1.113 ^{abc}	6.45 ± 0.60 ^{hijkl}	0.011 ± 0.001 ^{a}	1.069 ± 0.002 ^{i}	2.08 ± 0.03 ^{a}	2.134 ± 0.004 ^{cd}
	2.0	28.06 ± 0.05 ^{de}	7.510 ± 0.000 ^{f}	4.845 ± 0.634 ^{def}	2.81 ± 0.36 ^{abc}	0.069 ± 0.001 ^{i}	1.078 ± 0.001 ^{j}	3.02 ± 0.04 ^{fg}	1.047 ± 0.004 ^{a}
	2.4	30.20 ± 0.20 ^{i}	7.381 ± 0.001 ^{e}	5.864 ± 0.285 ^{fg}	5.20 ± 0.62 ^{fgh}	0.030 ± 0.000 ^{e}	1.094 ± 0.003 ^{k}	3.53 ± 0.03 ^{l}	1.135 ± 0.003 ^{a}
700	0.8	28.24 ± 0.23 ^{de}	7.575 ± 0.001 ^{g}	3.741 ± 0.154 ^{abcd}	6.36 ± 0.33 ^{hijk}	0.093 ± 0.003 ^{l}	1.007 ± 0.002 ^{d}	3.18 ± 0.03 ^{ij}	1.183 ± 0.003 ^{a}
	1.2	28.01 ± 0.01 ^{de}	7.194 ± 0.001 ^{a}	4.086 ± 0.612 ^{bcdef}	3.30 ± 0.13 ^{abcd}	0.071 ± 0.000 ^{i}	1.053 ± 0.003 ^{h}	3.33 ± 0.05 ^{k}	1.099 ± 0.002 ^{a}
	1.6	28.53 ± 0.06 ^{efg}	7.747 ± 0.000 ^{k}	3.029 ± 0.024 ^{abc}	3.15 ± 0.24 ^{abcd}	0.010 ± 0.001 ^{a}	1.017 ± 0.000 ^{e}	3.04 ± 0.03 ^{gh}	1.121 ± 0.001 ^{a}
	2.0	28.58 ± 0.10 ^{efg}	7.889 ± 0.000 ^{o}	2.538 ± 0.433 ^{ab}	4.18 ± 0.74 ^{bcde}	0.017 ± 0.001 ^{bc}	1.050 ± 0.001 ^{gh}	2.45 ± 0.03 ^{d}	1.002 ± 0.002 ^{a}
	2.4	28.23 ± 0.20 ^{a}	7.370 ± 0.000 ^{c}	3.239 ± 0.502 ^{abcd}	9.47 ± 0.63 ^{no}	0.079 ± 0.002 ^{j}	1.049 ± 0.001 ^{gh}	3.04 ± 0.04 ^{g}	1.029 ± 0.003 ^{a}

Data are expressed as mean values ± standard deviation; $^{a–y}$—values in columns with the same letter were not significantly different (p < 0.05).

Table 2. Chemical and nutritional characteristics of white bean Aura extrudates processed at various conditions.

Screw Speed [rpm]	Water [l h^{-1}]	Protein [%]	Neutral Detergent Fiber [%]	Reducing Sugars [%g glucose/100 g]	Total Phenols [mg/g]	Total Flavonoids [mg/g]	Antiradical Activity [mgTE/g]	Reducing Power [mgTE/g]
300	0.8	27.82 ± 0.19 ^{gh}	7.626 ± 0.001 ^{o}	9.518 ± 0.271 ^{j}	1.28 ± 0.26 ^{abc}	0.008 ± 0.001 ^{a}	0.065 ± 0.0054 ^{ab}	0.157 ± 0.003 ^{kl}
	1.2	27.20 ± 0.21 ^{ef}	7.115 ± 0.000 ^{e}	6.812 ± 0.812 ^{fghi}	2.67 ± 0.34 ^{fg}	0.026 ± 0.001 ^{ab}	0.110 ± 0.010 ^{abcd}	0.051 ± 0.002 ^{de}
	1.6	27.61 ± 0.37 ^{fg}	7.760 ± 0.000 ^{p}	5.519 ± 0.466 ^{def}	2.21 ± 0.23 ^{cdefg}	0.019 ± 0.002 ^{a}	0.085 ± 0.005 ^{abc}	0.035 ± 0.003 ^{c}
	2.0	26.94 ± 0.06 ^{d}	8.058 ± 0.000 ^{s}	15.703 ± 0.545 ^{l}	1.69 ± 0.29 ^{abcde}	0.104 ± 0.004 ^{efg}	0.075 ± 0.005 ^{ab}	0.088 ± 0.004 ^{f}
	2.4	26.53 ± 0.26 ^{cd}	7.328 ± 0.001 ^{i}	11.390 ± 0.864 ^{k}	2.46 ± 0.46 ^{defg}	0.204 ± 0.003 ^{j}	0.200 ± 0.010 ^{defgh}	0.160 ± 0.002 ^{l}
400	0.8	28.80 ± 0.29 ^{j}	7.534 ± 0.001 ^{l}	3.652 ± 0.138 ^{abc}	1.21 ± 0.37 ^{ab}	0.119 ± 0.001 ^{fgh}	0.235 ± 0.015 ^{fgh}	0.109 ± 0.002 ^{g}
	1.2	26.50 ± 0.49 ^{cd}	7.254 ± 0.000 ^{g}	5.846 ± 0.372 ^{efg}	1.47 ± 0.47 ^{abc}	0.029 ± 0.002 ^{ab}	0.140 ± 0.010 ^{abcdef}	0.046 ± 0.001 ^{cde}
	1.6	27.91 ± 0.20 ^{gh}	7.559 ± 0.000 ^{m}	4.335 ± 0.651 ^{bcd}	1.80 ± 0.22 ^{bcdef}	0.066 ± 0.002 ^{cd}	0.125 ± 0.015 ^{abcde}	0.206 ± 0.005 ^{m}
	2.0	27.27 ± 0.25 ^{ef}	7.427 ± 0.000 ^{jk}	4.038 ± 0.249 ^{bc}	1.93 ± 0.11 ^{bcdef}	0.071 ± 0.001 ^{cde}	0.075 ± 0.015 ^{ab}	0.038 ± 0.002 ^{cd}
	2.4	26.14 ± 0.24 ^{abc}	8.421 ± 0.002	5.686 ± 0.318 ^{def}	1.34 ± 0.06 ^{abc}	0.122 ± 0.002 ^{fgh}	0.235 ± 0.025 ^{fgh}	0.218 ± 0.003 ^{n}
500	0.8	26.89 ± 0.16 ^{de}	8.013 ± 0.000 ^{r}	4.922 ± 0.080 ^{cde}	1.83 ± 0.23 ^{bcdef}	0.067 ± 0.001 ^{cd}	0.185 ± 0.015 ^{cdefg}	0.003 ± 0.002 ^{a}
	1.2	28.11 ± 0.37 ^{hi}	7.138 ± 0.000 ^{f}	2.502 ± 0.024 ^{a}	1.00 ± 0.03 ^{ab}	0.122 ± 0.002 ^{fgh}	0.250 ± 0.030 ^{gh}	0.010 ± 0.001 ^{ab}
	1.6	26.85 ± 0.30 ^{de}	7.049 ± 0.001 ^{c}	3.923 ± 0.182 ^{abc}	1.62 ± 0.08 ^{abcd}	0.164 ± 0.004 ^{i}	0.295 ± 0.015 ^{gh}	0.050 ± 0.003 ^{de}
	2.0	26.04 ± 0.11 ^{ab}	7.431 ± 0.002 ^{k}	8.160 ± 0.156 ^{i}	1.28 ± 0.41 ^{abc}	0.078 ± 0.003 ^{de}	0.215 ± 0.005 ^{defgh}	0.057 ± 0.003 ^{e}
	2.4	26.09 ± 0.06 ^{ab}	8.894 ± 0.005 ^{v}	7.808 ± 0.650 ^{hi}	1.55 ± 0.24 ^{abcd}	0.012 ± 0.001 ^{a}	0.051 ± 0.040 ^{a}	0.142 ± 0.009 ^{ij}
600	0.8	28.16 ± 0.33 ^{hi}	7.285 ± 0.001 ^{h}	4.923 ± 0.291 ^{cde}	1.22 ± 0.17 ^{ab}	0.082 ± 0.002 ^{de}	0.110 ± 0.010 ^{abcd}	0.121 ± 0.001 ^{h}
	1.2	27.82 ± 0.15 ^{gh}	9.068 ± 0.003 ^{u}	9.583 ± 0.425 ^{j}	0.81 ± 0.21 ^{a}	0.092 ± 0.002 ^{def}	0.1360 ± 0.010 ^{abcdef}	0.131 ± 0.007 ^{hi}
	1.6	26.92 ± 0.08 ^{de}	7.054 ± 0.004 ^{d}	6.264 ± 0.263 ^{efg}	1.28 ± 0.24 ^{abc}	0.077 ± 0.003 ^{de}	0.125 ± 0.015 ^{abcde}	0.047 ± 0.011 ^{cde}
	2.0	26.93 ± 0.14 ^{de}	7.739 ± 0.001 ^{q}	2.868 ± 0.973 ^{ab}	1.61 ± 0.36 ^{abcd}	0.069 ± 0.051 ^{cd}	0.160 ± 0.020 ^{bcdefg}	0.145 ± 0.002 ^{jk}
	2.4	28.46 ± 0.33 ^{ij}	7.601 ± 0.001 ^{n}	7.458 ± 0.331 ^{ghi}	2.94 ± 0.21 ^{g}	0.132 ± 0.002 ^{ghi}	0.165 ± 0.135 ^{bcdefg}	0.040 ± 0.001 ^{cd}
700	0.8	26.53 ± 0.32 ^{d}	6.839 ± 0.001 ^{a}	3.263 ± 0.000 ^{ab}	3.79 ± 0.32 ^{h}	0.149 ± 0.002 ^{hi}	0.265 ± 0.025 ^{gh}	0.196 ± 0.005 ^{m}
	1.2	27.27 ± 0.26 ^{ef}	7.323 ± 0.001 ^{g}	3.352 ± 0.227 ^{ab}	2.60 ± 0.45 ^{efg}	0.058 ± 0.002 ^{bcd}	0.200 ± 0.020 ^{defgh}	0.013 ± 0.001 ^{ab}
	1.6	27.95 ± 0.29 ^{gh}	7.422 ± 0.000 ^{j}	6.493 ± 0.493 ^{fgh}	1.69 ± 0.09 ^{abcde}	0.041 ± 0.001 ^{abc}	0.135 ± 0.025 ^{abcdef}	0.049 ± 0.002 ^{cde}
	2.0	26.56 ± 0.16 ^{d}	6.949 ± 0.000 ^{b}	7.759 ± 0.241 ^{hi}	1.05 ± 0.14 ^{ab}	0.163 ± 0.003 ^{i}	0.230 ± 0.010 ^{efgh}	0.020 ± 0.002 ^{b}
	2.4	27.08 ± 0.08 ^{e}	8.525 ± 0.001 ^{t}	6.771 ± 0.282 ^{fghi}	2.59 ± 0.39 ^{efg}	0.007 ± 0.001 ^{a}	0.045 ± 0.005 ^{a}	0.221 ± 0.009 ^{n}

Data are expressed as mean values ± standard deviation; $^{a–v}$—values in columns with the same letter were not significantly different ($p < 0.05$).

Red Toska cultivar is characterized by lower carbohydrates levels than Aura bean. It may have an effect on changes in starchy components and also in simple sugar content. The presence of reducing sugars in extruded products may be the effect of starchy components hydrolysis into simple sugars from complex carbohydrates. Reducing sugars are responsible for the darkening of extruded products under high temperature due to their function in the Maillard reaction undergoing during thermal treatment. The level of sugar reduction was generally higher in white bean extrudates than red ones due to higher total carbohydrate content in raw Aura bean seeds [2]. The content of reducing sugars in extruded Toska bean varied from 2.08 to 11.53% (Table 1) whereas Aura bean extrudates showed reducing sugars ranged from 2.50 to 15.7% after extrusion (Table 2). Unclear dependencies were found between processing conditions, so general conclusions cannot be gathered from the results achieved. However, a significant effect of variable processing conditions was found, except for the effect of screw speed on total flavonoid content and the effect of water on antioxidant activity of the Aura extrudates (Supplementary Table S4).

3.2.2. Nutritional Components in Extruded Beans

Extraction of phenolic compounds from extruded samples is easier than in untreated been seeds so the results of phenolics content clearly differentiate bean cultivars used in the experiment. With red Toska bean, if more water was applied, the results of total phenols content lowered significantly. The highest phenols content was found in Toska extrudates processed at 0.8 and 1.2 $l\,h^{-1}$ of water and with low screw speeds of 300 and 400 rpm (Table 1). These conditions seem to be the most efficient to make an easy extraction procedure with functional components due to intensive shearing in the presence of very low water in the processed material. This generates an intensive mechanical treatment and thus a higher amount of extractable phenolic compounds may be reached. Patil et al. [58] confirmed that high feed moisture protects phenolics from degradation, thus maintaining their stability especially at low temperature extrusion. They reported increased TPC at increased screw speed as a result of dual effect of high shear and low residence time at high screw speeds. High shearing and friction may cause degradation of cell walls, breakdown of conjugated or bound phenols and much easier release of free phenolic acids as well as minimizing thermal degradation by reduction of the residence time and thus high retention of phenolics [58]. A few times, lower results were found in Aura bean extrudates, total phenols content varied from 0.81 to 2.94% and here the effect of processing variables was not so evident (Table 2).

Anthocyanins are red colorants naturally present if plants and food containing dark plant additives. Anthocyanins are water-soluble vacuolar pigments that, depending on their pH, may appear red, purple, blue or black. They are responsible for most of the red, purple and blue colours exhibited by flowers, fruits and other plant tissues and have found application in the food industry as natural colorants [59]. Antioxidants, which can neutralize free radicals, may be important in the prevention of a number of diseases including cancer and atherosclerosis. Anthocyanin pigments may be used for colouring foodstuffs and snack food, beverages, pharmaceutical and cosmetic products, etc. The level of anthocyanin pigments may depend on plant cultivar, growing conditions, storage conditions or processing parameters. Red pigments due to the presence of many unsaturated are also sensitive to light so naturally red in colour products, should be protected from direct sunlight during storage by dark package. In the present study the level of anthocyanins in extruded red Toska bean varied from 0.010 to 0.093 mg/g and it was clearly visible that at high water content in material processed at low screw speed the content was much higher than at increased screw speed (Table 1). So, mechanical effects seem to be more important in red pigment degradation than water in the feed material. In the Aura bean cultivar, after extrusion anthocyanin pigments were not present because of the white colour of Aura seeds. Go and co-workers [60] investigated whether mulberry-extrudate solid formulations had a positive impact on the stability of anthocyanins. Mulberry fruits are rich sources of anthocyanins that exhibit beneficial biological activity. They found the mulberry-extrudate solid formulations extruded in the presence of an ionization agent and sodium alginate contained a large number of available anthocyanins even after being incubated for 180 min in the intestinal fluid system. Thus, hot-melt extrusion enhanced the water solubility and stability of anthocyanins with prolonged release. So, it can be stated that even under extrusion conditions anthocyanins could be stable. Durge et al. [61] tested the suitability of anthocyanin during pre-extrusion of coloured rice as a function of extrusion parameters: moisture content, screw speed and temperature of extrusion. They found the retention of anthocyanin increased with an increase in the moisture content of feed material and screw speed, but decreased with an increase in the die temperature.

The total flavonoids level in extruded bean was also the most connected with bean variety. Red Toska bean, after extrusion-cooking, showed at least 10 times more content of flavonoids (Table 1) than extruded Aura bean (Table 2). Total flavonoids varied from 0.906 to 1.337 mg/g DM in Toska extrudates and from 0.007 to 0.204 mg/g in Aura extrudates. This causes the red bean to be more favourable for extrusion due to its better nutritional profile after HTST treatment. Usually, the flavonoids remain stable during extrusion cooking [58]. High retention of bioactive components in extruded millet and sorghum flours proved their potential for the development of phenolic and antioxidant rich ready-to-eat snacks. They reported retention from 51–73% in extruded finger millet and 41–89% in extruded sorghum so plant materials after the extrusion cooking demonstrate good thermostability of flavonoids. Nayak et al. [62] confirmed the extruded products had significantly higher content of total phenolics, antioxidant activity and flavonoids, compared to the raw formulations if extruded purple potato and pea flours.

The presence of phenolic compounds or other biologically active substances is crucial for an antioxidant activity of food products. Extruded red Toska bean, which was characterized by the presence of both phenols, anthocyanins and flavonoids, showed a few times more antiradical activity and reducing power, as expressed in the Trolox equivalent in extrudates extracts, than white Aura bean (Tables 1 and 2, respectively). There was no clear tendency in the effects of both screw speed and water amount on antioxidant characteristics of bean extrudates. However, also in this case it could be noted that slightly higher antioxidant activity and reducing power were found at the highest water addition during the extrusion at a low screw speed up to 600 rpm. At the highest speed, 700 rpm, applied differences were insignificant due to very intensive shearing during treatment. Significant antioxidant activity and presence of free phytochemicals may be attributed to the breaking of conjugated phytochemicals by extrusion of shearing forces to release free phytochemicals but also darker colours of the extruded products both containing anthocyanins and undergoing Maillard reaction with products having antioxidant properties [63]. During the extrusion-cooking some changes in individual phenolics occur (phenolic acids, flavonoids, flavonols, proanthocyanidins, flavanones, flavones, isoflavons and 3-deoxyanthocyanidins) and these changes are related to the choice or raw materials, the configuration of the extruder and the setting the technological parameters [64].

4. Conclusions

The current focus is shifted towards the possibility of utilizing nutritionally valuable seeds and plants for enhancing the nutritional and functional quality of ready-to-eat products, especially extruded ones, for consumers preferring a healthy life-style and foods with extra nutritious properties. At the same time, this food must have proper quality and physical properties, especially texture, responsible for mouth filling and shelf stability. The functional properties of native bean flours can be improved by hydrothermal treatments such as extrusion, without using any additional chemical substances. By modifying extrusion-cooking processing conditions, it is possible to create specific properties, such as water absorption and solubility, viscosity, expansion, texture and colour, as well as the nutritional potential of extruded food, especially due to the content of biologically active substances. The knowledge of the effect of red and white beans' extrusion treatment on these characteristics allows to select the proper raw materials and processing conditions for direct applications as ready-to-eat extrudates or as functional additive with specific features.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app13031671/s1, Table S1: Two-way ANOVA for physical properties of extruded red Toska beans; Table S2: Two-way ANOVA for physical properties of extruded white Aura beans; Table S3: Two-way ANOVA for nutritional properties of extruded red Toska bea ns; Table S4: Two-way ANOVA for nutritional properties of extruded white Aura beans.

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