ACS FOOD SCIENCE & TECHNOLOGY

Open Access

pubs.acs.org/acsfoodscitech

Article

Impact of Cooking and Extrusion Processing on Nutritional, Antinutritional, and Techno-Functional Characteristics of Indigenous Bean (*Phaseolus coccineus*)

Evelyn I. Osuna-Gallardo, Edith O. Cuevas-Rodríguez,* Carlos I. Sepúlveda-García, Cuauhtémoc Reyes-Moreno, Liliana León-López, Ruixian Han, and Alan J. Hernández-Álvarez*

Cite This: https://doi.org/10.1021/acsfoodscitech.2c00416

Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: Ayocote bean (*Phaseolus coccineus*) is an underutilized pulse rich in protein, lipids, and carbohydrates; however, the impact of thermal processing has not been studied. Thus, the objective of this research was to assess the nutritional, antinutritional, and techno-functional properties of ayocote beans processed by conventional cooking and extrusion. Thermal processing had a positive impact on total dietary fiber increasing after cooking (35.49%). Trypsin inhibitors were inactivated after processing; however, lectin activity was still observed after extrusion (0.2 mg/mL). Extrusion showed a higher impact on TPC (75% retention) and TFC (88% retention) than cooking (61 and 74% retention, respectively). Cooking and extrusion caused significant losses of antioxidant activity when compared to raw flour, though cooking showed higher AOX retention (ORAC = 88.5/ABTS = 87.3%) than extrusion (ORAC = 74.4/ABTS = 77.5%). The results suggest that ayocote bean is a legume that could be used to develop novel food formulations with improved health benefits for the wider population.

KEYWORDS: *Phaseolus coccineus, cooking, extrusion, antinutrients, lectins, antioxidant, techno-functional properties*

INTRODUCTION

Bean (*Phaseolus* spp) seeds are a family of legumes that play an important role in human nutrition, especially among low-income populations in developing countries including Mexico, which represents a rich and consuming tradition throughout history and has even become a staple food of cultural identification.[1,2] Although in Mexico there are about 70 species of *Phaseolus* reported in the country, only five have been domesticated, including *P. vulgaris* (common bean), *P. lunatus* (lima bean), *P. acutifolius* (tepary bean), *P. polyanthus* (year bean), and *P. coccineus* (ayocote bean).[3,4]

Ayocote bean (*Phaseolus coccineus* L.) (Figure 5) is an underutilized legume native from Mexico with great potential for a wide variety of food purposes by its foliage, flowers, pods, and seeds.[5] This legume is used as an ornamental plant in some parts of the world due to its large size and diverse colors (beige, brown, violet, and black). Likewise, ayocote bean can tolerate colder climates compared to other *Phaseolus* species. In Mexico, small growers and indigenous communities cultivate this species on a small scale and use it to prepare different soups, bean purees, and other dishes.[6−8]

On the other hand, colored raw beans have shown the presence of phytochemical compounds such as polyphenols, anthocyanins, carotenoids, and tannins. These compounds have been linked to their nutraceutical properties, mainly for the prevention of chronic diseases (cancer, diabetes, and cardiovascular diseases).[9] However, the bioactive compounds present in raw foods are modified during processing (dehulling, steeping, germination, domestic cooking, extrusion, among others).[10] Sometimes these changes improve palatability, nutritional value, and nutraceutical properties.[11]

Domestic cooking is one of the most traditional methods used for bean consumption. It is defined as the percentage of bean cooking required to reach an acceptable texture for the consumer, which has been subjected to a constant boiling temperature (100 °C) in water, at a ratio of 1:3 (w/v) each time.[12] Different processing methods have been used for cooking beans (steaming, boiling, pressure cooking, and microwave). Corzo-Ríos et al. (2020)[4] used a high-pressure cooking method for ten different bean varieties, reporting that, after cooking, an increase in the dietary fiber in all beans was observed; moreover, a decrease in non-nutritional compounds, particularly in trypsin inhibitor content (995−100%), was found; also total phenolic compounds exhibited a reduction between 3.2 and 40.9% after cooking. Hydrothermal heating causes gelatinization, thus increasing the starch digestibility, and upon cooling, retrograded starch (less digestible) is formed, thus affecting the nutritional composition of legumes.[13] Moreover, cooking can modify the composition of pulses, increasing the concentration of resistant starch and total dietary fiber (soluble and insoluble).[4,14,15] Also, a significant reduction in antinutritional compounds like phytic

Received: June 22, 2023
Revised: October 7, 2023
Accepted: October 10, 2023

acid, tannins, trypsin inhibitors, and saponins, among others, has been observed.[4,14,16] Luo and Xie (2013)[17] reported that cooking fava bean did not affect total phenolics, while phytic acid was increased. Phenolic compounds and anthocyanins have been reported to decrease after cooking by different processing methods.[18,19]

Extrusion is a high-temperature/short-time, simple, versatile, and modern method that has already been used to process legumes and cereals, obtaining favorable results for the generation of novel food formulations.[20] Extrusion seems to be suitable to produce ready to eat legume-based foods.[21] The temperature, pressure, and moisture conditions used during extrusion can cause changes at structural, nutritional, and functional levels, thus causing lipid oxidation, inactivation of antinutritional compounds, improvements of sensorial attributes, and modifications on the bioactive profile.[22] Furthermore, extrusion has been used to reduce antinutritional factors[23] and to increase the protein and carbohydrate digestibility.[24]

There is scarce information regarding ayocote bean properties, and furthermore, to our knowledge, any previous research on the changes that may occur during processing, as well as its potential to develop new food products for human consumption with enhanced health benefits, has been reported for this bean species. Thus, it is essential to study the impact of cooking and extrusion on the ayocote bean. The objective of this research was to assess the nutritional, antinutritional, and techno-functional properties of ayocote beans processed by conventional cooking and extrusion, to understand the impact that dry and wet heating may have on ayocote bean, and thus provide knowledge on the potential use of this underutilized pulse for human consumption.

MATERIALS AND METHODS

Chemicals. Folin−Ciocalteu reagent, gallic acid, fluorescein, 2,2′-azobis(2-methyl-propinamide) (AAPH), and Trolox were obtained from Sigma Chemical Co. Ethanol, sodium hydroxide, hydrochloric acid, boric acid, potassium sulfate, cupric sulfate, methyl red, petroleum ether, hexane, isopropanol, sodium carbonate, and potassium chloride were purchased from Sigma-Aldrich (St. Louis, MO, USA). The available carbohydrates dietary fiber assay kit, resistant starch rapid format, and damaged starch were purchased from Megazyme. The sheep hemagglutination kit was purchased from Rockland. All reagents used were of analytical grade.

Materials. For this study, black ayocote bean (*Phaseolus coccineus*) seeds were collected in 2019 from Teacapa Puebla, Mexico. The seeds were thoroughly cleaned and sorted to remove foreign materials; then, the seeds were stored in plastic bags until further use at 8 °C.

Methods. *Physical Characteristics of Ayocote Bean Seeds.* Physical characteristics of seeds were determined by using standard procedures: Physical dimensions were measured according to the methodology reported by Milán-Carrillo et al. (2000).[25] The weight of 1,000 seeds was determined by the international method of ISTA (1985)[26] (International Seed Testing Association). To determine the hectoliter weight, procedure 55-10.01 of the AACC (1995)[27] was used. The caliber and percent of testa determination was carried out according to Reyes-Moreno et al. (2000).[28]

Preparation of Processed Ayocote Bean Flours. Cooking Time (CT). A Mattson bean cooker was used to carry out the cooking process following the method by Reyes-Moreno et al. (2001),[29] with modifications. For each batch, 25 bean seeds (whole grains, cotyledons, and seed coats) were used at a time. Cooking time is in the meantime, when 15 bean seeds were cooked, as indicated by stainless steel plungers (weight 75 ± 0.5 g, point diameter 2 mm) dropping and penetrating individual samples. The 60% cooked point corresponded to the sensorial preferred degree of cooking. The determinations were made in triplicate.[29] Once the cooking time was obtained (2 h), the bean seeds were cooked in boiling water (100 °C) at a 1:3 (w/v) ratio, frozen overnight at −80 °C, then lyophilized (Freeze-Dry System Model 77520, LABCONCO) (including cooking liquor), and finally ground to obtain the cooked ayocote bean flour (CAF).

Extruded Ayocote Bean Flour. The extruded ayocote bean flour (EAF) was obtained following the procedure reported by Milán-Carrillo et al. (2012).[30] The bean seeds (1 kg batch) were ground (Thomas-Wiley laboratory Mill, Mod. 4) using a 2 mm sieve (particle size ∼1−2 mm) and conditioned with purified water to reach a moisture content of 24%. Each batch was packed in a polyethylene bag and stored at 4 °C for 12 h. Before extrusion, the grits were tempered at 25 °C for 2−4 h. A single screw laboratory extruded Model 20 DN (CW Brabender Instruments, Inc., NJ, USA) with a 19 mm screw diameter, length to diameter of 20:1, nominal compression ratio of 2:1, and die opening of 3 mm was used. The extrusion operation conditions were an extrusion barrel temperature (ET) of 137 °C and a screw speed (SS) of 220 rpm. After extrusion, the flours were cooled, equilibrated under environmental conditions (25 °C), milled (UD Cyclone Sample Mill, UD Corp, Boulder, CO, USA) to pass through an 80-US mesh (0.180 mm) screen, packed in plastic bags, and stored at −4 °C until further use.

Nutritional Properties. Proximate Composition. The proximate composition of unprocessed ayocote beans flour (AF), cooked ayocote flour (CAF), and extruded ayocote flour (EAF) was determined according to the official methods of the AOAC (1999);[31] moisture (44.15), protein (979.09), fats (920.39), ashes (923.03), total fiber, and available carbohydrates was determined according to the K-ACHDF (Megazyme) kit, resistant starch by the K-RAPRS (Megazyme) kit, and damaged starch by the K-SDABM (Megazyme) kit. The measurements were made in triplicate on a dry basis.

Fatty Acid Profile. 7 g of the samples was mixed with 15 mL of a hexane:isopropanol (3:2 v/v) solution. The mixture was stirred for 1 h in a rotator (300 rpm) (Thermolyne MIRAK). After that, it was centrifuged at 5000 rpm/10 min (Eppendorf brand centrifuge, Mod. 5804R), and the supernatant was collected. The precipitate was resuspended in 15 mL of hexane:isopropanol (3:2 v/v) and again stirred and centrifuged. The two supernatants were combined, and 2.5 mL of KCl 0.75% was added; after that, two phases appeared. The upper phase was collected and dried in a concentrator (50 °C/sample was protected from the light). Lipid transesterification was carried out by adding 0.0269 g of KOH and 500 μL of MeOH. Then, the samples were sonicated (Hielscher, Ultrasound Technology, UP200S, 200 W, 24 kHz) for 5 min at 65% amplitude during one cycle followed by centrifugation at 4000 rpm/5 min. The supernatant was analyzed using a gas chromatography (Agilent 6890N, NY, USA) device with an Agilent 5973 mass spectrometer (Agilent 5973N, USA), Omega Wax 250 column, Helio as a carrier, and injector gas series 7683. The operating conditions were the following: injection volume, 1 μL; flow, 1 mL/min; column temperature, 50−270 °C (10 min) with a heating rate of 5 °C/min. The samples were analyzed by gas chromatography-mass spectrometry (GC-MS).[32]

Amino Acid Analysis. Protein samples (2 mg) were hydrolyzed in 6 N HCl (4 mL) at 110 °C for 24 h in tubes sealed under nitrogen. Tryptophan was analyzed by HPLC after basic hydrolysis according to Yust et al. (2004).[33] Amino acids were determined after derivatization with diethyl ethoxymethylenemalonate by HPLC according to the method of Alaiz, Navarro, Girón, and Vioque (1992),[34] using D,L-α-aminobutyric acid as an internal standard and a 300 mm × 3.9 mm i.d. reversed-phase column (Novapack C18, 4 lm; Waters, Milford, MA, USA).

Mineral Content. 2 g of samples was cremated in a Phoenix microwave furnace overnight at 780 °C or until the sample did not present black spots. This was followed by cooling down the sample; then 1 mL of concentrated nitric acid/10 min incubation and 10 mL of Milli-Q water were added until a volume of 25 mL was reached. Finally, the samples were filtered through a 0.45 μm nylon syringe filter. Then the samples were analyzed by an ICP-OES iCAP 7600

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

DUO, Serial number: IC76DC151510, Model: Cetac ASX-520 autosampler.

Physicochemical Characteristics. Total Color Difference (ΔE). The surface color of the samples was measured using a Minolta color-difference meter Model CR-210 (Minolta LTD, Osaka, Japan). The parameters L (0 = black, 100 = white), a (+ value = red, − value = green), and b (+ value = yellow, − value = blue) were recorded. The L, a, and b values of a white standard (std) tile used as reference were 97.63, 0.78, and −2.85, respectively. ΔE was calculated (SI Formula 1) in triplicate for each sample.

Water Activity (a_w). The measurement of a_w was carried out using the methodology reported by Milán-Carrillo et al. (2002),[35] in a calibrated Aqualab instrument (Mod Series 3TE) (using distilled water). A sample of ayocote bean flour of approximately 2 g was placed in the sample cell of the equipment until equilibrium was reached (40−60 min). The measurements were made in triplicate.

pH. The pH was determined according to the methodology of the AOAC (1999)[31] (Association of Official Analytical Chemists). 5 g of flour was added to 50 mL of boiled and cooled distilled water; the suspension was stirred on an orbital shaker (Thermolyne, MIRAK, US) (10 min/240 rpm), and then the pH of the suspension was measured with a potentiometer (Hanna Instruments, Mod. HI3221). The measurements were made in triplicate on a dry basis.

Functional Properties. Water Absorption (WAI) and Solubility Index (WSI). For this determination, the method described by Anderson et al. (1969)[36] was used with some modifications.[37] A 2.5 g flour sample was suspended in 30 mL of water at 30 °C in a tube previously calibrated; the suspension was stirred in an orbital shaker (OVAN NR50-E brand) at 30 rpm for 30 min. The suspension was centrifuged at 3000g/30 °C/10 min (Eppendorf brand centrifuge, Mod. 5804R). The supernatant was poured into a calibrated evaporating dish. The WAI was calculated from the weight of the remaining gel and expressed as g of gel/g of solid. The WSI expressed as g of solids/g of original solids was calculated from the weight of dry solids recovered by evaporating the supernatant overnight at 110 °C. The measurements were made in triplicate on a dry basis.

Oil Absorption Capacity (OAC). The oil absorption capacity was determined according to the methodology reported by Marie et al. (2015)[38] with minor modifications. Samples of 0.5 g of flour with 3 mL of vegetable oil were placed in a graduated centrifuge tube, stirred for 1 min in a vortex, and allowed to stand for 30 min. Finally, they were centrifuged at 1600g/25 min (Eppendorf brand centrifuge, model 5804R), and the free oil volume was measured. The results were expressed as mL of absorbed oil/g of flour (SI Formula 2). The test was performed in triplicate.

Dispersibility Index (DI). The DI was determined according to the technique reported by Mora-Escobedo et al. (1991).[39] 1 g of flour samples was mixed in a conical graduated tube with 10 mL of distilled water. The samples were homogenized in an ultra Turrax (IKA brand, Mod. T18 basic) at 10,000 rpm/5 min. The phase separation (sediment and liquid) was measured after 30 min of rest. Samples were made in triplicate. The results were expressed as a percentage of dispersibility in triplicate (SI Formula 3).

Foaming Capacity (FC) and Foam Stability (FS). FC and FS were determined by the method of Huffman et al. (1975)[40] and Khattab et al. (2009),[41] respectively. In a 100 mL test tube, 0.5 g of the sample and 50 mL of distilled water were added. The mixture was stirred in an Ultraturrax (IKA bran, Mod. T18 Basic) at 12,000 rpm/1 min. Subsequently, the volume of the foam formed was measured. Foaming capacity was reported as a percentage (% FC) and carried out in triplicate (SI Formula 4.1). The material was allowed to stand for 30 min; at the end of this time, the volume of the residual foam was measured, and the foam stability was expressed as percent foam stability (% FS) (SI Formula 4.2).

Emulsifying Capacity (EC) and Emulsion Stability (ES). EC and ES were determined using the method described by Huffman et al. (1975)[40] and Butt and Batool (2010).[42] 0.7 g of samples was added to 10 mL of distilled water and 10 mL of vegetable oil. Subsequently, the samples were stirred in an Ultraturrax (IKA brand, Mod. T18 basic) homogenizer at 12,000 rpm for 1 min. The mixture was centrifuged at 1,300g for 5 min (Eppendorf brand centrifuge, Mod. 5804R). The EC (SI Formula 5.1) was calculated by dividing the height of the emulsion layer by the total height of the emulsion and multiplied by 100. ES was determined by heating the emulsion at 80 °C for 30 min in a water bath and then centrifuging (1300g/5 min). ES was measured and calculated (SI Formula 5.2), dividing the height of the emulsion layer after heating by the height of the emulsion before heating. Both results were expressed as a percentage (%).

Antinutritional Factors. Phytic Acid Content (PAC). The PAC was determined according to the colorimetric procedure reported by Vaintraub and Lapteva (1988)[43] with some modifications. PAC was calculated (SI Formula 6) and expressed as mg equivalents of sodium phytate (ESP)/100 g of sample.

Saponins (SC). Saponins extraction was performed as follows: 0.5 g of sample flours was weighed into centrifuge tubes, and 10 mL of 80% methanol was added. The tubes were mixed for 16 h at room temperature on an orbital shaker, and then the extracts were recovered by centrifugation (10 min/5,000 g/25 °C) (Eppendorf, model 5804R). The remaining pellet was re-extracted twice by vortexing with 5 mL of 80% methanol and further centrifugation. The resulting supernatants were pooled together. The total saponins content (SC) was quantified based on the vanillin−sulfuric acid assay proposed by Hiai et al. (1976).[44] SC was expressed as mg of diosgenin equivalents/100 g of sample (SI Formula 7).

Condensed Tannins Content (CTC). This analysis was carried out according to the methodology reported by Xu and Chang (2007).[45] CTC was calculated (SI Formula 8) and expressed in mg equivalents of catechin (EC)/100 g db of sample.

Trypsin Inhibitor Activity (TIU). The trypsin inhibitor activity was determined according to the method reported by Welham and Domoney (2000).[46] The trypsin inhibitor activity was expressed in terms of trypsin units inhibited per milligram of sample, where one trypsin inhibitor unit (TIU) was defined as a decrease of 0.01 absorbance units at 410 nm in relation to the trypsin control reaction. The trypsin inhibitor activity was calculated (SI Formula 9) and expressed as trypsin inhibitor units (TIU)/mg of sample.

Hemagglutinin Activity. To detect lectin activity in samples, the sheep Hemagglutination Kit (KPA-39913) was used. Lectins were extracted according to De Mejía et al. (2005).[47] 1 g of sample was mixed with 10 mL of 10 mM phosphate buffered saline (PBS) pH 7.4 (1:10 w/v) and stirred overnight at 4 °C, and then the mixture was centrifuged at 12,000g/30 min/4 °C; supernatant was brought to 80% $(NH_4)_2SO_4$ saturation. Stirring was performed 1 h/4 °C, making sure salt was dissolved. The precipitate was recovered after centrifugation at 12,000g/30 min/4 °C, dissolved in PBS (1:10 w/v), dialyzed against distilled water for 1 h/5 times, and finally lyophilized.

Nutraceutical Properties. Free Phenolics Extract. Phenolic compounds in AF, CAF, and EAF were extracted as previously reported by Mora-Rochin et al. (2010).[48] Briefly, 5 g of ground samples was stirred with 20 mL of cold ethanol−water (80:20 v/v) for 10 min. After centrifugation at 3000g for 10 min, the supernatant was evaporated to dryness at 45 °C. The resulting extracts were frozen at −20 °C and stored until use.

Total Phenolic Content (TPC). Briefly, 20 μL of diluted extracts was oxidized with 180 μL of Folin−Ciocalteu reagent. After 3 min, 50 μL of 7% sodium carbonate was added and the mixture incubated for 90 min. Then, absorbance was measured at 750 nm (Microplate Reader, SynergyTM HT, BioTek, Inc., Winooski VT). Total phenolics were expressed as milligrams of gallic acid equivalents (mg of GAE)/100 g db of sample.[49]

Flavonoids. In a 96-well microplate, 20 μL of sample and standard were added with 100 μL of distilled water and 6 μL of $NaNO_2$ 5% and then incubated for 5 min, and after, 12 μL of $AlCl_3$ 10% was added. After 5 min of incubation, 40 μL of 1 M NaOH and 22 μL of distilled water were added and incubated for 30 min at 25 °C. Absorbance was measured at 510 nm (Synergy HT Multidetection, Biotek, Inc., Winooski, VT). The standard was catechin (CA), and the content of total flavonoids (TF) was expressed as mg equivalents of catechin/100 g of sample in dry basis (mg of ECA/100 g db). Determinations were made in triplicate.[50]

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

Anthocyanins. A 1 g sample was weighed, and 1 mL of cold acidified methanol was added (95% methanol/1 N HCl, 85:15 v/v). Subsequently, sample was centrifuged at 3,000 rpm/10 min, the supernatant was recovered, and the absorbance of the samples was read at 535 and 700 nm (SynergyTMHT Multidetection, Biotek, Inc., Winooski, VT). Anthocyanin content (AC) was calculated (SI Formula 10) following the formula by Abdel-Aal and Hucl (1999).[51] The determination was carried out in triplicate.

Antioxidant Capacity. Determination of Oxygen Radical Absorbance Capacity (ORAC) Assay. The ORAC method was determined by the assay described by Ou et al. (2001).[52] The assay was performed using fluorescein as the fluorescent probe, AAPH as a radical generating agent, and Trolox as the standard. Extracts, Trolox, and AAPH were diluted with sodium phosphate buffer (75 mM, pH 7.4). Extract aliquots (25 μL) were transferred into a 96-well plate, loaded into the plate holder on the Synergy Microplate Reader (SynergyTM HT Multi-Detection, BioTeK, Inc., Winooski, VT) for the kinetic reading. Results of the protective effects of the extracts and control were calculated based on the differences in the area under the sodium fluorescein decay curves (AUC) between the blank and the sample.[53] Results were expressed as micromoles of Trolox equivalents/100 g db.

Determination of ABTS Radical Scavenging. Antiradical activity by ABTS radical assay was determined by the method described previously by Re et al. (1999).[54] A stock solution of the ABTS radical cation was generated by reacting the ABTS solution with 2.45 mM potassium persulfate, and the mixture was allowed to stand in the dark for 12−16 h before use. An aliquot of the radical ABTS solution was diluted in PBS (pH 7.4) until an absorbance of 0.7 ± 0.02 at 734 nm was reached. 7.5 μL of the blank, extracts, and curve was transferred into a transparent 96-well plate; the test started when 292.5 μL of ABTS solution was added and then recorded after 10 min at 734 nm. The ABTS loss of absorbance was calculated against the blank. A calibration curve with Trolox was used, and the data were expressed as μmol equivalents of Trolox/100 g of sample on a dry basis (μmol of ET/100 g db of sample).

Statistical Analysis. Data were reported as the mean ± standard deviation (SD) in triplicate. A one-way analysis of variance (ANOVA) was used for statistical analysis of the experimental results. Differences among treatments were determined using Fisher's pairwise t test comparison. A p-value <0.05 was considered significant. All statistical analyses were performed with the use of Minitab 16 software.

RESULTS AND DISCUSSION

Physical Characteristics of the Seed. Table 1 shows the physical characteristics of black ayocote bean (*P. coccineus*) seeds. The results of the seed dimensions were registered as length = 16.21 mm, width = 10.21 mm, and thickness = 7.11 mm. Recently, Corzo-Ríos et al. (2020)[4] reported the following dimension range: length, 16.1−20.9 mm; width, 10.7−13.7 mm; thickness, 6.8−8.8 mm for ayocote bean varieties. The weight of 100 seeds was 78.59 g/100 seeds, hectoliter weight 75.69 kg/hL, and caliber 37.40 seeds/30 g, respectively. Ayala Garay et al. (2006)[55] reported values of hectoliter weight of 68−83 kg/hL for ayocote bean, similar to those obtained in this investigation. Considering the classification reported by Singh et al. (1991),[56] black ayocote beans could be classified as "large" seeds (large: >40 g/100 seeds). On the other hand, hectoliter weight is a useful value for pulse producers as large seeds make large holes during transportation or grain storage; thus, too many empty spaces will result in low hectoliter weight.[57] The importance of measuring physical attributes in bean seeds allows evaluating the commercial quality of varieties with potential to increase high yields during sowing, which are of interest both for the agriculture sector and the institutions responsible for seed certification, since they determine the value of the seeds therefore benefiting the farmer.[26]

Table 1. Physical Characteristics of Ayocote Bean[1]

Physical Characteristics	Ayocote Bean
Dimensions (mm)	
Length	16.21 ± 1.41
Width	10.21 ± 0.96
Thickness	7.11 ± 0.81
1,000 seeds weight (g)	785.96 ± 27.88
100 seeds weight (g)	78.59 ± 2.78
Hectoliter weight (kg/hL)	75.69 ± 0.58
Caliber	37.40 ± 0.89
Percent of testa (%)	11.50 ± 0.26

[1]Values represent the mean ± standard error of three determinations.

The percent of testa for ayocote beans was 11.5%; this is higher than values reported for different *P. vulgaris* varieties (9.2−9.7%)[58] and previous reports for ayocote bean seeds (8.7%).[59] The high content of testa has been related to the protection of the seed against different pathogens, higher cooking time, and water absorption capacity; it also contains fiber, phenolic compounds, and minerals.[60−62]

Nutritional Properties. *Proximate Composition of Raw, Cooked, and Extruded Flours.* The proximal composition of raw and processed ayocote beans is shown in Table 2. The protein contents for AF, CAF, and EAF flours were 18.82, 19.69, and 19.75%, respectively; these results were similar to those reported for different raw ayocote bean varieties (18.07−18.93%).[63] After processing, the protein content did not show significant differences ($p > 0.05$). Corzo-Ríos et al. (2020)[4] obtained an increase of protein content in some *P. vulgaris* beans (0.5−2.2%) after traditional cooking; this has been explained by different factors such as grain hardness, cooking time, and lixiviation of soluble solids during cooking similar to those obtained in this study. The fat content was 2.78, 2.50, and 1.74%, respectively, in the different flours. Corzo-Ríos et al. (2020)[4] reported a range of fat content between 1.7 and 4.3% for different varieties of beans, with similar results to this study. Nevertheless, a decrease after cooking was reported, attributing this to lipolysis which is catalyzed by the processing of food in the presence of water and high temperatures, where the ester linkages of triglycerides and phospholipids are hydrolyzed, thus releasing fatty acids.[64] Margier et al. (2018)[65] reported the content of fat for different pulses after household cooking and canning, observing that the method and the pulse used influenced the fat content; for instance, kidney beans had no changes in fat content after using both methods (0.28 and 0.29 g/100 g), while chickpeas showed a significant change between these (2.04 and 1.78 g/100 g); this could be related to differences in the lipid profile.

A decrease in fat content was found in the extruded flour; this could be the result of high temperature that can reduce the lipase and lipoxygenase activity and moisture level, thereby favoring free fatty acid development and fatty acid oxidation; extrusion can enhance the oxygen exposure, contributing to the oxidation of lipids; furthermore, fatty acids could form complexes with amylose and proteins.[66−68] Moreover, in instances where the extrusion duration is extended and/or the fat content of the samples exceeds 5%, the shear stress exerted upon the sample within the extrusion barrel leads to the depletion of fat from the vegetal tissues, consequently yielding

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

Table 2. Chemical Composition, Physicochemical, and Techno-Functional Properties of Raw, Cooked, and Extruded Ayocote Bean Flours

	Ayocote Bean[1]		
Proximate Composition (%, db[2])	AF	CAF	EAF
Protein	18.82 ± 0.69 a	19.69 ± 0.09 a	19.75 ± 0.30 a
Fat	2.78 ± 0.31 a	2.50 ± 0.00 a	1.47 ± 0.05 b
Ash	4.45 ± 0.07 a	4.51 ± 0.05 a	4.54 ± 0.05 a
Carbohydrates	73.93 ± 0.72 ab	73.27 ± 0.05 b	74.22 ± 0.37 a
Total dietary fiber	30.38 ± 0.17 b	35.49 ± 0.34 a	29.85 ± 1.15 b
Insoluble	30.31 ± 0.64 a	31.83 ± 0.07 a	25.87 ± 0.95 b
Soluble	0.07 ± 0.46 b	3.66 ± 0.26 a	4.66 ± 0.20 a
Available carbohydrates	35.47 ± 0.20 a	33.81 ± 0.10 b	36.11 ± 0.36 a
Total starch	33.24 ± 0.46 c	42.99 ± 0.31 a	39.49 ± 0.54 b
Resistant starch	8.53 ± 0.20 b	18.86 ± 0.06 a	3.97 ± 0.29 c
Non-resistant starch	24.71 ± 0.258 c	24.12 ± 0.25 b	35.52 ± 0.84 a
Damaged starch	0.94 ± 0.03 c	5.28 ± 0.17 b	16.76 ± 0.20 a
Physicochemical Properties			
Color			
Hunter value "*L*"	78.40 ± 0.64 a	46.72 ± 1.54 c	55.40 ± 0.90 b
Total color difference	19.42 ± 0.64 c	51.79 ± 1.50 a	42.81 ± 0.87 b
Aqueous activity (aW)	0.33 ± 0.00 b	0.07 ± 0.00 c	0.36 ± 0.00 a
pH	6.36 ± 0.00 b	6.28 ± 0.00 c	6.56 ± 0.00 a
Techno-Functional Properties			
Water absorption index[3]	2.87 ± 0.04 b	3.47 ± 0.39 a	3.46 ± 0.03 a
Water solubility index[4]	20.41 ± 0.15 b	23.07 ± 0.69 ab	27.45 ± 0.69 a
Oil absorption index[5]	1.60 ± 0.12 a	0.87 ± 0.11 b	0.78 ± 0.09 b
Dispersibility (%)	71.66 ± 2.88 b	100.00 ± 0.00 a	93.33 ± 5.77 a
Foaming (%)	8.08 ± 0.11 a	2.00 ± 0.04 b	ND
Foam stability (%)	4.04 ± 0.05 a	ND	ND
Emulsion capacity (%)	27.85 ± 2.57 a	27.04 ± 1.03 a	13.42 ± 0.76 b
Emulsion stability (%)	50.72 ± 1.25 a	50.00 ± 0.00 a	25.92 ± 1.60 b

[1]Results are expressed as mean ± standard deviation of three determinations; applying the Fisher multiple range test; different letters in the lines indicate statistically significant differences ($p < 0.05$). [2]db: dry basis. [3]g of gel/g of db. [4]g of solids/100 g of db. [5]g/g of db. AF = raw ayocote bean flour, CAF = cooked ayocote bean flour, EAF = extruded ayocote bean flour, ND = not detected.

fat loss and the manifestation of visible die drip fat on the end plate.[69]

No differences ($p > 0.05$) were found in the ash content of AF, CAF, and EAF flours (4.45, 4.51, and 4.54%, respectively), being similar to those reported by Sahasakul et al. (2022)[70] for 10 bean varieties from Thailand (3.51−5.13%). On the other hand, Corzo-Ríos et al. (2020)[4] reported a decrease in ash concentration after cooking, except for one bean variety, with no correlation between cooking time and the decrease in ash content. Changes in the ash content during thermal processing have been related to hardness of the bean and its composition.

The content of total dietary fiber (TDF) of AF, CAF, and EAF was 30.38, 35.49, and 29.85%, respectively, presenting an increase after cooking; this could be due to an increase of soluble fiber (3.59%), which is related to the formation of resistant starch or tannin−protein complexes, contributing to the increase of TDF.[71] Other studies have found similar behaviors in TDF after cooking; for instance, Corzo-Ríos et al. (2020)[4] obtained a TDF increase between 1 and 6.6% after cooking for 10 different bean varieties, while Bento et al. (2022)[72] also observed an increase of TDF (1.66%) in Dama bean after cooking.

Moreover, during extrusion, dietary fiber may be significantly modified; this is related mainly to the fiber content and solubility, depending on the extrusion conditions and composition of the material extruded.[73] In this study, we observed an increase in soluble fiber after extrusion around 66.5 times more than the AF sample. This effect could be related to different explanations, the use of high temperature, pressure, and shear force leads to a breakdown of glycosidic bonds of insoluble polysaccharides, converting them into smaller soluble units, and/or a release of the hemicellulose soluble fraction during the process.[68,74] Chen et al. (2014)[75] reported similar results where the soluble dietary fiber content of soybean increased after the extrusion process.

The content of available carbohydrates (CAC) in AF, CAF, and EAF was 35.47, 33.81, and 36.11%, respectively. A significant decrease was found in the CAC after cooking; this result could be due to an increase of resistant starch content in the flour after cooking, decreasing the amount of CAC. Nakitto et al. (2015)[76] reported an increase in the CAC after cooking for dry beans (3.19%); these differences could be because of the different methods used for cooking and the varieties of beans studied. Extrusion did not significantly ($p > 0.05$) affect the CAC content; similar results were reported by Ciudad-Mulero et al. (2022),[77] reporting the CAC content for chickpeas and lentils before and after extrusion without any significant effect. Kowalski et al. (2018)[78] reported a decrease in starch and available carbohydrates after extrusion in waxy wheat flour, due to high shear forces, heat, and pressure during extrusion, thus promoting a breakdown of starch resulting in dextrinization. Arribas et al. (2019)[79] described that the effect caused by extrusion treatment depends on the extrusion conditions as well as the food matrix.

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

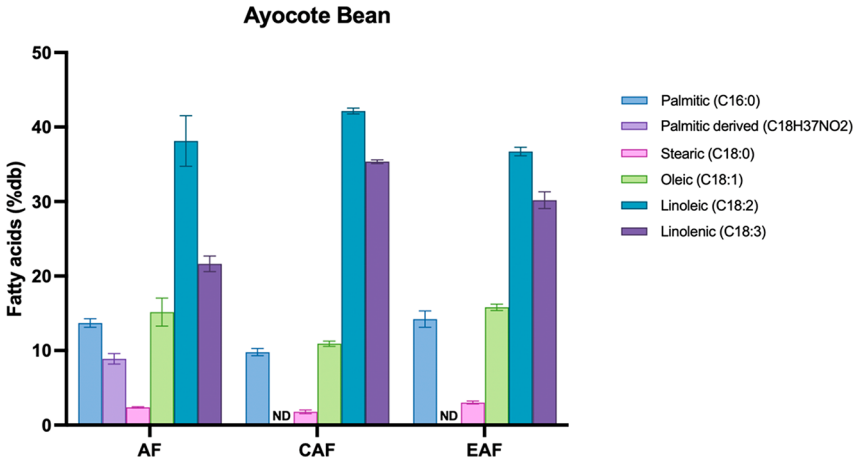

Figure 1. Fatty acids content of raw, cooked, and extruded ayocote bean flours. AF = raw ayocote bean flour, CAF = cooked ayocote bean flour, EAF = extruded ayocote bean flour, ND = not detected.

Starch is a polymeric carbohydrate that serves as the major source of energy in the human diet, which is composed of amylose and amylopectin.[80] Starch can be classified by its time of digestion, as rapidly digestible (20 min), slowly digestible (>2 h), and resistant starch that generally remains undigested by the small intestine; this last one needs to be fermented by the microbiota in the large intestine.[81] Since starch can be modified during processing, the content of total starch (resistant and non-resistant) and damaged starch in raw and processed ayocote bean is shown in Table 2. Resistant starch (RS) is the portion of starch that is not broken down by human enzymes in the small intestine. The measurement of RS can provide information about starch reorganization; high values of RS might indicate a retrogradation. Besides, damaged starch (DS) is related to the susceptibility of starch to α-amylase hydrolysis; high values of DS in processed foods indicate starch gelatinization and/or disintegration.[82]

The resistant starch (RS) contents in AF, CAF, and EAF were 8.53, 18.86, and 3.97%, respectively. The content of RS had a significant increase ($p \leq 0.05$) after cooking (10.33%). During cooking, starch gelatinization can be produced, thus increasing starch digestibility, and upon cooling, retrograded starch can be formed (less digestible); this could be due to RS increase after cooking, as samples were freeze-dried. However, the formation of RS is dependent on the starch composition.[72] Bento et al. (2022)[72] reported the content of RS in raw (9.0−29.0%) and cooked (31.1−8.3%) carioca bean flours. The RS results for raw beans were higher than the ones obtained in this study, and for processed bean flours, some of them increased (2.11%) while others decreased (0.8%). However, the content of RS could be influenced by different factors, like composition (fiber), starch characteristics (crystallinity of starch), and high content of amylose, which tend to make the major amount of RS related to the chain length.[83]

The content of RS decreased significantly after extrusion (4.56%). Escobedo et al. (2020)[84] reported a reduction of RS in black beans after extrusion, attributing that this could correspond to the destruction of RS1 and RS2 (native RS); besides during thermal treatments, protein amino groups could interact with starch carbonyl groups through hydrogen and covalent bonds, thus hindering complete starch retrogradation, because of the protein−starch interactions, resulting in reduction of RS content. Gulzar et al. (2021)[85] studied how the extrusion process and parameters used during extrusion could affect the RS content in rice-flour-based extruded snacks, finding that the different parameters used during extrusion affected differently the RS content; for instance, the increase of temperature from 130 to 180 °C increased significantly from 6.84% to 7.78%, while the RS content decreased from 6.40 to 6.21% with an increase in screw speed from 50 to 150 rpm. Furthermore, during extrusion starch gelatinization can be generated, resulting in an increase in starch digestibility (90%); in addition, extrusion can cause a cleavage of amylose and particularly of amylopectin molecules induced by the shear, resulting in smaller and more digestible fragments (dextrins and reducing sugars).[21] The interest in RS is growing because of its potential role as a protective factor against colon cancer and its capability to reduce the rate of glucose release into the bloodstream.[81]

Present findings in this research showed differences in DS in unprocessed sample (AF) and processed ones (CAF and EAF) with a content of 0.94, 5.28, and 16.76%, respectively. The content of DS in raw flour is similar to those reported by Blandino et al. (2023)[82] in three different flour pulses of 0.99−1.8% (chickpeas, red lentils, and green field peas). DS content in raw flours can be due to the effect of milling on starch granules; the final product provides information about relevant changes to starch; the higher value, the greater the degree of gelatinization.[86] Both processes increased DS, cooking increased DS 4.6 times compared to raw sample, while extrusion was increased 16.8 times. It is known that during extrusion cooking can cause a complete breakdown of the starch structure due the high shear forces and high temperatures, thus promoting almost complete gelatinization of starch, leading to a decrease in RS.[87] This is in accordance with the results obtained in this research where an increase in DS and a decrease in RS were observed after extrusion processing. On the other hand, the increase of DS in CAF was lower than that in EAF because, even though gelatinization occurs during cooking, a retrogradation of starch can take place after cooking and during freeze-drying processes and most of the starch fraction can change into RS.

Fatty Acid Content. The fatty acid content in AF, CAF, and EAF is shown in Figure 1. For AF the values of palmitic acid 13.71%, stearic acid 2.38%, oleic acid 15.16%, linoleic acid 38.12%, and linolenic acid 21.64% were close to the values that have been reported previously by Grela and Günter (1995)[88] for ayocote beans (16.40, 3.30, 13.30, 31.40, and 21.80%,

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

respectively). However, linoleic acid values are higher than those reported by other researchers for other bean varieties (15−33.7%).[89,90] Linoleic acid is known for its potential beneficial properties for human health, such as prevention of atherosclerosis, cancer, and hypertension and improvement of bone mineralization, insulin sensitivity, and immune response.[91] Furthermore, linoleic and linolenic acids increased after cooking processing. Heat processes can cause cell membrane disruption, thus releasing of pro-oxidant, and/or isomerization reactions that produce small amounts of trans fatty acids, particularly linoleic and linolenic acids.[92] On the other hand, significant ($p \leq 0.05$) differences were found in CAF; a decrease in palmitic, stearic, and oleic fatty acids was observed. This behavior was reported by De La Cruz Garcia and Simal Lozano (2000),[93] in which processed beans by different cooking methods (pressure-cooking, steaming, boiling, and microwave) showed slight decreases in palmitic acid (3.6, 4.8, 5.2, and 4.2%, respectively) after processing. Also, the compound palmidrol, also known as palmitoylethanolamide ($C_{18}H_{37}NO_2$), was found in AF. This compound is present as well in egg yolk, peanuts, and soy seeds, being an endogenous lipid chemically related to endocannabinoid anandamide.[94] Palmitoylethanolamide (PEA) is a saturated fatty acid amide derived from the naturally occurring N-acylethanolamine (NAE) in which the carboxylate group is amidated by the primary amine of ethanolamine. PEA is recognized for its extensive effects, believed to play protective and homeostatic roles across both animal and plant domains. This compound is present in a variety of organisms, from animals to plants, and is linked to a host of beneficial functions.[95] No significant differences ($p > 0.05$) were found for EAF, except for a decrease in palmidrol and an increase of linoleic acid. This behavior could be explained by the absence of palmidrol in the flour processed by extrusion. There was a change in the proportion of linoleic acid. Ushakumari et al. (2004)[96] found an increase in unsaturated fatty acids in a foxtail millet based extruded product. This could be as a result of lipids released from cells due to high temperature and physical disruption of plant cell walls owing to severe shear actions, as discussed above.[97]

Amino Acids Content. The amino acid (AA) contents of AF, CAF, and EAF flours are summarized in Table 3. Overall, Leu, Lys, and Phe were found to be the major essential AAs, while Asp and Glu were the two most abundant nonessential AAs. On the contrary, Met, Trp, and Cys were the less abundant AAs. These results were similar to those reported by Alvarado-López et al. (2019)[63] for 4 different varieties of ayocote bean, with Leu (1.74−1.84 g/100 g) being the most abundant essential AAs, followed by Glu (nonessential AAs, 3.22−3.58 g/100 g), while the limiting AAs were the sulfur-containing AAs (Cys and Met, 0.23 and 0.28 g/100 g, respectively).

Cooking changed the AA content, with an increase in Glu (3.70%), Ala (3.47%), Val (3.03%), Ile (6.42%), and Leu (2.4%). On the other hand, a decrease in Tyr (17.18%), Cys (66.66%), and Met (56.25%.) was observed. The reason for an increase in some AAs could be attributed to the breakdown and degradation of some other AAs.[98] On the other hand, proteins not only exist alone but also form complexes with carbohydrates and lipids; for instance, AAs with a side chain can be associated with reducing substances and form complexes with phytates; nevertheless, these compounds are partially or completely destroyed during hydrothermal treatment, which is likely to increase the amino acid content of boiled beans compared with the raw ones.[99,100] Shamkova et al. (2022)[100] studied the effect of cooking of beans (*P. vulgaris* L.) using three different solutions (water, 0.25% whey solution, and 0.25% calcium bicarbonate solution), observing that after cooking mainly with water a significant increase in total AA content was obtained, similar to our results. This may be related to the loss of carbohydrates (oligosaccharides) during heat treatment; these oligosaccharides could form bonds with other macromolecules such as proteins or polysaccharides, and these bonds may get affected during the cooking process, resulting in leaching of the oligosaccharides into the cooking medium.[100] However, the available data about changes in AA content of beans during processing is contradictory; some studies found that most of the processing methods have a little effect on protein quality, while others found that even under gentle technological processes the proteins are easily damaged.[100,101] For example, Aremu et al. (2010)[102] reported a reduction in all essential AAs in cranberry bean (*Phaseolus coccineus* L.) after cooking, attributing this effect to transamination and deamination reactions that might be responsible for the changes in the amino acid profile of this bean after cooking. Heat treatment can cause considerable nutritional damage, particularly in methionine and cysteine because these are heat sensitive; thus, prolonged cooking times in legumes may result in destruction and/or racemization of amino acids.[103]

Extrusion of the ayocote bean significantly reduced the concentration of Glu (5.5%), Ala (4.3%), Tyr (10.9%), Cys (38.0%), Met (87.5%), and Lys (3.52%), respectively. The relation between AAs and temperature in Maillard's reaction is considered the principal reason for the reduction of AA concentration observed in grain legume extrudates.[104] Free sugars might be produced from starch during extrusion and

Table 3. Amino Acid Profile (g/100 g of Protein) of Raw, Cooked, and Extruded Ayocote Bean Flours[1]

	Ayocote Bean (g/100 g of Protein)		
Amino Acid	AF	CAF	EAF
Asp	2.75 ± 0.03 a	2.83 ± 0.03 a	2.75 ± 0.00 a
Glu	3.24 ± 0.04 b	3.36 ± 0.01 a	3.06 ± 0.00 c
Ser	1.49 ± 0.01 a	1.51 ± 0.00 a	1.49 ± 0.00 a
His*	0.65 ± 0.00 a	0.64 ± 0.03 a	0.65 ± 0.01 a
Gly	1.03 ± 0.01 a	1.08 ± 0.05 a	1.12 ± 0.04 a
Thr*	1.30 ± 0.00 a	1.31 ± 0.01 a	1.29 ± 0.00 a
Arg	1.47 ± 0.04 a	1.44 ± 0.00 a	1.43 ± 0.02 a
Ala	1.15 ± 0.00 b	1.19 ± 0.00 a	1.10 ± 0.00 c
Pro	0.96 ± 0.00 a	0.92 ± 0.04 a	0.86 ± 0.06 a
Tyr	0.64 ± 0.00 a	0.53 ± 0.00 c	0.57 ± 0.00 b
Cys	0.21 ± 0.00 a	0.07 ± 0.00 c	0.13 ± 0.00 b
Val*	1.32 ± 0.00 ab	1.36 ± 0.01 a	1.30 ± 0.01 b
Met*	0.16 ± 0.00 a	0.07 ± 0.00 b	0.02 ± 0.00 c
Phe*	1.48 ± 0.00 a	1.50 ± 0.00 a	1.47 ± 0.01 a
Ile*	1.09 ± 0.01 b	1.16 ± 0.01 a	1.08 ± 0.00 b
Leu*	2.08 ± 0.00 b	2.13 ± 0.01 a	2.05 ± 0.01 b
Lys*	1.70 ± 0.01 a	1.70 ± 0.01 a	1.64 ± 0.00 b
Trp*	0.19 ± 0.01 a	0.18 ± 0.00 a	0.18 ± 0.01 a

[1]Results are expressed as mean ± standard deviation of three determinations; applying the Fisher multiple range test; different letters in the lines indicate statistically significant differences ($p < 0.05$). *Essential amino acids. AF = raw ayocote bean flour, CAF = cooked ayocote bean flour, EAF = extruded ayocote bean flour.

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

Table 4. Composition of Minerals of Raw, Cooked, and Extruded Ayocote Bean Flours[1]

Minerals (mg/kg)	Ayocote Bean		
	AF	CAF	EAF
Macrominerals			
K	8420.94 ± 224.48 a	7755.20 ± 133.45 a	8285.48 ± 789.74 a
Mg	1673.28 ± 73.94 a	1708.58 ± 5.42 a	1694.96 ± 9.33 a
Na	29.17 ± 10.65 b	64.42 ± 10.56 a	29.16 ± 3.24 b
Ca	1169.00 ± 61.25 b	1253.68 ± 22.54 a	1290.16 ± 0.75 a
Trace Minerals			
Cu	5.08 ± 0.10 b	4.95 ± 0.23 b	6.59 ± 0.12 a
Fe	55.24 ± 0.04 c	57.46 ± 1.44 b	83.51 ± 0.01 a
Mn	14.91 ± 0.13 b	16.63 ± 0.37 a	16.88 ± 0.12 a
Zn	26.14 ± 1.25 b	27.92 ± 0.46 a	28.76 ± 0.20 a
Se	0.010 ± 0.00 a	0.016 ± 0.00 a	0.003 ± 0.00 a

[1]Results are expressed as mean ± standard deviation of three determinations; applying the Fisher multiple range tests; different letters in the lines indicate statistically significant differences ($p < 0.05$). AF = raw ayocote bean flour, CAF = cooked ayocote bean flour, EAF = extruded ayocote bean flour.

react with amino groups of AAs, starch, and dietary fiber fragments, as well as with sucrose hydrolysis products, which are available for Maillard reaction.[105] The loss of AAs depends mainly on the extrusion conditions; for instance, some studies have shown that higher temperatures than 100 °C during extrusion increase the loss of most AAs in three different legumes (Bambara groundnut, pigeon pea, and African yam pea).[104] These results are similar to this study considering that the extrusion process used a temperature of 137 °C. Marsolais et al. (2010)[106] investigated the AA profile of different storage proteins (globulins, albumins, glutelins, and prolamins) in *Phaseolus* spp. demonstrating that the modification of the ratio of these protein fractions altered the AA composition; this is why it is possible that during thermal processing (baking/cooking/extrusion) the protein fractions ratio can result in different AA profiles in the final product, and the use of different varieties of beans, cropping years, and environmental conditions can alter the AA profile.[101]

Minerals. The mineral contents of AF, CAF, and EAF samples are shown in Table 4. Minerals have a key role in our body for vital functions, from building strong bones to transmitting nerve pulses. For example, trace minerals (Cu, Fe, Mn, Mg, Se, and Zn) play a vital role as a structural part in many enzymes, while macrominerals (Ca, Mg, P, Na, and K) have a lot more considerable functions in nerve cells.[107]

The most abundant macrominerals in AF were K, Mg, and Ca, while the highest trace minerals were Fe and Zn. These results were lower for K, higher for Mg, and similar to Ca (12,834−14,433, 1,467−1563, and 1205−1229 mg/kg, respectively) than those reported by Alvarado-López et al. (2019)[63] for four varieties of ayocote bean; these differences might be attributed to the genetic composition of varieties, different soil conditions at different habitats during growth, etc. Despite this, similar studies have reported that major minerals present in beans are K, Mg, and Ca.[70] Redondo-Cuenca et al. (2022)[108] reported contents of macro and micro minerals of three different colors of ayocote bean, with higher results in Na (400−300 mg/kg) and K (14,000−13,000 mg/kg), lower results in Mn (12.8−10.7 mg/kg), and similar values for Mg (1,900−1,600 mg/kg), Ca (1,100−900 mg/kg), Cu (6.9−6.1 mg/kg), Fe (53.6−52.5 mg/kg), and Zn (26.4−24.7 mg/kg). It has been reported that the variation in mineral composition may be related to pedoclimatic conditions, genotypic characteristics, plant maturity, and analytical techniques used in the analysis.[109]

The mineral content in CAF had a minor effect (with the exception of Na), with an increase in Na (120.84%), Ca (7.24%), Fe (4.01%), Mn (11.53%), Zn (6.80%), and Se (60%) and a decrease in K (8%). The augmentation in mineral content may arise as a consequence of the retention of cooking water and subsequent freeze-drying thereof in conjunction with the cooked beans. This process results in the incorporation of minerals that were originally dissolved in the water, which become concentrated post freeze-drying. Moreover, the observed reduction in potassium (K) levels may be attributed to the concomitant increase in the relative proportion of other minerals. In this study, there was a notable increase in mineral content after the cooking process. The potential reasons for this phenomenon could be attributed to the reduction of phytic acid upon heating, which might result in enhanced mineral extractability and bioavailability. Alternatively, this could be due to modifications in the food matrix, such as the disruption of plant cell walls.[110,111] In this study, the cooking liquor was retained. Consequently, it is plausible that certain minerals might have been introduced via the cooking water, leading to the final concentrations described above. On the other hand, some studies have observed that mineral loss can occur due to minerals leaching into soaking and/or cooking water.[108] Additionally, some losses can be related to mineral binding to proteins causing less extractability[110]

Extrusion increased Ca (10.36%), Cu (29.72%), Fe (51.17%), Mn (13.2%), and Zn (10.0%) and decreased K (2.0%) and Mg (1.29%). The main mineral that changed was Fe, which is most likely a result of wear of metallic pieces, mainly screws, and the barrel of the extrusion equipment.[112] Minerals are heat stable and unlikely to be lost in the steam-distillate at the die.[105] Even though the content of minerals is not significantly affected, other studies have shown that extrusion can improve the absorption of minerals by reducing other factors like antinutritional factors that inhibit absorption; further research in this area is necessary.[105]

Physicochemical Properties. Table 2 shows the physicochemical properties of raw and processed ayocote bean flours. The raw and processed flours showed significant differences ($p \leq 0.05$). The results for total color difference (ΔE) in AF, CAF, and EAF were 19.42, 51.79, and 42.81,

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

respectively. Cooking and extrusion caused an increase ($p \leq 0.05$) in ΔE of raw ayocote bean flour. Furthermore, a decrease in the hunter L value from 78.4 to 46.72 (CAF) and 55.40 (EAF) was observed. Higher ΔE and lower L values mean darker flours. During the extrusion process, the color changed; this has been related to Maillard reactions, where sugar reacts with proteins, thus producing melanoidins and making extrudates turn dark brown.[113] These changes could be a result of the drive power or the specific mechanical energy as the source for the changes in extrusion due to heating and shear forces produced. CAF color was darker than EAF; this may be because traditional cooking had a longer reaction time compared to the extruded one.[114]

Water activity (a_w) from 2 g of AF, CAF, and EAF samples was 0.33, 0.07, and 0.36, respectively. Borijindakul and Phimolsiripol (2013)[115] reported similar values for lablab (*Dolichos lablab*) beans (0.24−0.58); values below 0.6 reduce the growth probability of harmful microorganisms. The lowest water activity observed was 0.07 for CAF. This result may be due to the drying method used, as CAF was lyophilized, while EAF was dried at room temperature (25 °C).

Regarding pH, AF, CAF, and EAF were 6.36, 6.28, and 6.56, respectively. Dzudie et al. (1996)[116] reported acidity values in raw black and white bean flours grown in France, with values of 5.9 and 6.2, respectively. A pH increase ($p \leq 0.05$) in EAF was observed; this may be due to the solubilization of basic amino acids during extrusion.[117] The determination of pH in flours has been associated with some functional properties such as solubility and emulsion properties, which are extremely affected by pH fluctuations.[116]

Functional Properties. The functional properties of raw and processed ayocote beans are shown in Table 2. The water absorption index (WAI) for CAF and EAF was higher ($p \leq 0.05$) than that of AF, 3.47, 3.46, and 2.87, respectively. Other studies have found an increase in WAI for beans subjected to cooking[117] and extrusion processing.[118] Researchers argue that the cooking temperature increases the WAI of different pulses. During extrusion, protein denaturation (mainly globulins as the major protein fraction present in beans)[119] increases the surface area to mass ration and exposes some previously hidden peptide bonds and pole side chains which leads to increased ability to entrap and retain water molecules; starch gelatinization could also increase the WAI due the large loss of crystalline structure and molecular order, and swelling of raw fiber occurs. This behavior could be responsible for the increased WAI in extruded products.[67,119]

Significant differences ($p \leq 0.05$) were found regarding WSI results; the increase for processed samples was noticeable, and even more for EAF, findings are consistent with those reported by other authors[120] for raw and extruded bean (*P. acutifolius*) flours (20.21 and 27.45 g of solids/100 g of dry sample). It is suggested that this behavior is caused by starch degradation due to the cutting pressure and thermal process during extrusion.[67] Water solubility index (WSI) indicates the number of solids dissolved in water when a flour sample is subjected to an excess of liquid and shows the degree of cooking. WSI is associated with the presence of soluble starch molecules, which is related to dextrinization.[67]

In this study, OAI results obtained for AF were 1.60 g/g (25.5%) of dry sample; on the other hand, a decrease ($p \leq 0.05$) was found in processed flours (CAF = 0.87 (14.4%) g/g of dry sample and EAF = 0.78 (12.4%) g/g of dry sample, respectively). These results agree with those reported by Granito et al. (2007),[121] observing a reduction of OAI during cooking. The OAI is related to the number of hydrophobic groups present in the proteins, thus increasing the fat bonding interactions. When the cooking process is applied, protein denaturation and aggregation are produced, which causes interactions among hydrophobic groups, decreasing the free hydrophobic groups exposed to oil bonding.[121] Oil absorption index (OAI) is the mechanism of this property due to the physical retention of oil by capillary attraction. Additionally, our results agree with Lazou and Krokida (2010);[122] in this study, a decrease in OAI after extrusion in a sample of corn/lentils was reported, with increasing feed moisture (6, 13, 19%); in this study, a 24% feed moisture was used. The rise of feed moisture content decreases the degree of cooking, and the OAI of extrudates should be lower because small amounts of molecules of starch are present, which favor OAI. On the other hand, it has been reported that OAI can vary depending on the extrusion conditions used; for example, high temperatures increase the degree of cooking of extrudates, resulting in a formation of smaller molecules due to starch dextrinization; the presence of these molecules may be responsible for the increased OAI.[123] The increase of protein content present in extrudates can decrease the OAI and could be related to the increased presence of nonpolar amino acids, thus conferring different conformational features and that starch−protein−lipid complexes could all be in some or less extent related to different oil retaining capabilities.[124]

The percentages of dispersibility for AF, CAF, and EAF were 71.66, 100, and 93.33%, respectively. CAF and EAF had higher values ($p \leq 0.05$) than AF. Milán-Carrillo et al. (2000)[25] found an increase (38.7−145%) in dispersibility values in extruded chickpea flours. The increase in dispersibility could be attributed to the degree of damaged starch due to gelatinization during thermal processing, extrusion induced fragmentation, and thus a molecular weight reduction of amylose and amylopectin molecules.[125] Other authors have attributed that cooking and extrusion processing slightly increased the protein denaturation, meaning the more denaturation, the higher the dispersibility.[67] Dispersibility is a useful property for the formulation of beverages, since it is a means of comparing the solubility of the protein in water.

AF and CAF presented foaming percentages (F) of 8.08 and 2.00 and foam stability (FS) of 4.04 and ND (not detected), respectively, while EAF showed non-foaming capacities (Table 2). For both parameters, a significant decrease ($p \leq 0.05$) was observed after both processes were applied. The effect of temperature on the reduction of F and FS has been reported for other bean varieties (Tepary bean).[126] This effect is attributed to the fact that high temperatures used in both processes (cooking and extruding) probably affected the molecular and physicochemical characteristics of the components responsible for foam formation[127] and extrusion is the one that has mostly reduced both parameters. Batista et al. (2010)[127] evaluated the percentage of foam formation in raw and extruded cowpea beans (51.16 to 0.00%), finding no foam formation after extrusion (ET = 150 °C, SS = 150 rpm), which corresponds to the results obtained. Potentially, proteins may be unfolded by share forces during extrusion, while the high temperature could generate protein cross-links into macromolecular aggregates reducing F and FS.[128] Foaming percentage (F) is a measure of the maximum level of foam generated by a solution, while foam stability (FS) provides a measure of the foam's resistance to destabilization.

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

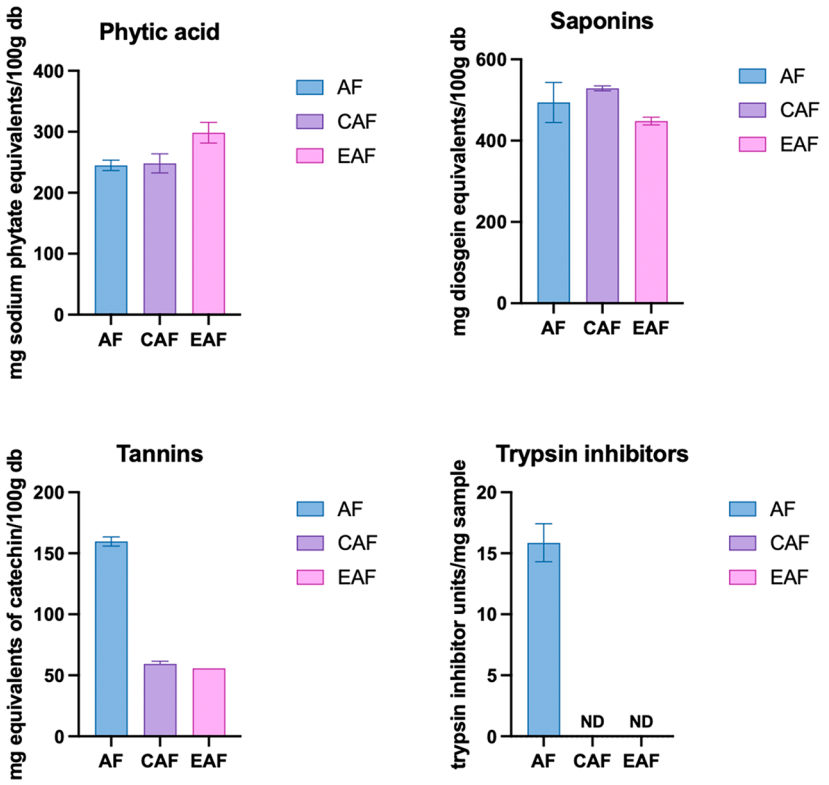

Figure 2. Antinutritional factors content of raw, cooked, and extruded ayocote bean flours. AF = raw ayocote bean flour, CAF = cooked ayocote bean flour, EAF = extruded ayocote bean flour, ND = not detected.

AF, CAF, and EAF showed emulsion capacity (EC) values of 27.85, 27.04, and 13.45% as well as emulsion stability (ES) values of 50.72, 50.00, and 25.92%, respectively. The extrusion process causes a decrease ($p \leq 0.05$) in the pH levels in EC and ES. The emulsifying properties of flours are known to be influenced by the quality and quantity of soluble proteins.[20] Lin et al. (2020)[119] reported a decrease in EC of common bean flours after heat treatments, attributing this behavior to a reduced ability of processed bean protein to rapidly absorb, unfold, and reorient at the interface; this may be due to a change in the distribution pattern of hydrophilic/hydrophobic residues on the protein surface, favoring a higher proportion of hydrophilic groups on the surface. Singh (2007)[105] reports that heat treatment causes marked reductions in emulsifying capacity in processed legume flours. Emulsion capacity (EC) is a measure of the interface area that stabilizes per unit weight of protein. In contrast, emulsion stability (ES) is a measure of the resistance of the emulsion to decompose.[129]

Functional properties are physicochemical properties that provide information on how a particular ingredient (compound) in particular (protein, carbohydrate, etc.) could behave in a complex or simple food matrix. These properties are established by the composition and molecular structure of the individual components and the interactions established between them.[117]

Antinutritional Factors. Antinutritional compounds are secondary metabolites that act as the opposite of nutrient functions.[130] These are synthesized during plant growth, playing a protecting role in the plant from diseases and pests. Nevertheless, these compounds mainly interfere with the release or absorption of nutrients, reducing the bioavailability of nutrients.[131]

The PAC in AF sample ayocote bean (244.91 mg of ESP/100 g) was similar to the results reported by Shang et al. (2016)[132] (200−500 mg of ESP/100 g) in 56 bean varieties (Figure 2). However, these were lower than those reported by Corzo-Ríos et al. (2020)[4] in two different varieties of ayocote bean, 1035 and 1038 mg of ESP/100 g samples.

The PAC was not affected after cooking; phytates are relatively heat stable. Corzo-Ríos et al. (2020)[4] reported that PAC after cooking for eight varieties of *P. vulgaris* and two *P. coccineus* decreased for some varieties, while in others it was not significantly affected; this could be attributed to the food matrix microstructure, as the formation of insoluble phytic acid can form complexes with proteins and minerals, thus reducing the probability of phytic acid loss during hydrothermal processing.

On the other hand, extrusion significantly increases PAC (21.9%) in ayocote bean (Figure 2); it could be due to a release of these compounds during the extrusion process, which make it more detectable. Rathod and Annapure (2016)[133] reported that extrusion can affect PAC mainly by the processing conditions such as moisture, temperature, and pressure in different pulses.

Saponins (SC) are compounds present in legumes as amphiphilic glycosides of steroids and triterpenes, playing a protective role against insects.[134] SC in AF was 494.19 mg of diosgenin equivalents/100 g (mg of DE/100 g) (Figure 2). Corzo-Ríos et al. (2020)[4] reported similar results in eight varieties of *P. vulgaris* and two *P. coccineus*, 279−482 and 477−514 mg of DE/100 g, respectively.

After cooking, saponins were not significantly affected ($p \leq 0.05$). Sánchez-Velázquez et al. (2021)[10] reported a decrease in SC after cooking in 10 different pulses, attributing this effect to the migration and/or solubilization of these into the soaking/

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

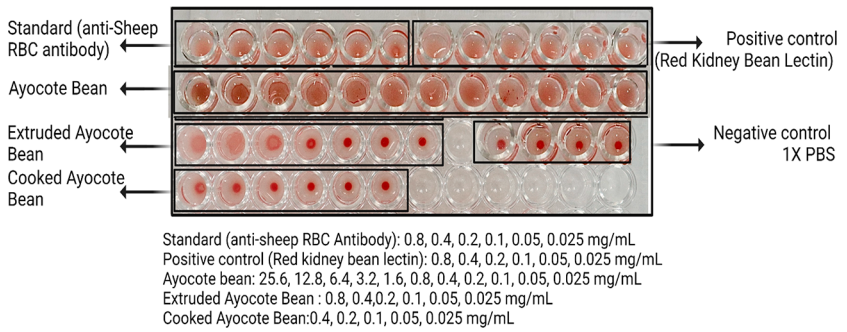

Figure 3. Hemagglutinin activity of raw, cooked, and extruded ayocote bean flours.

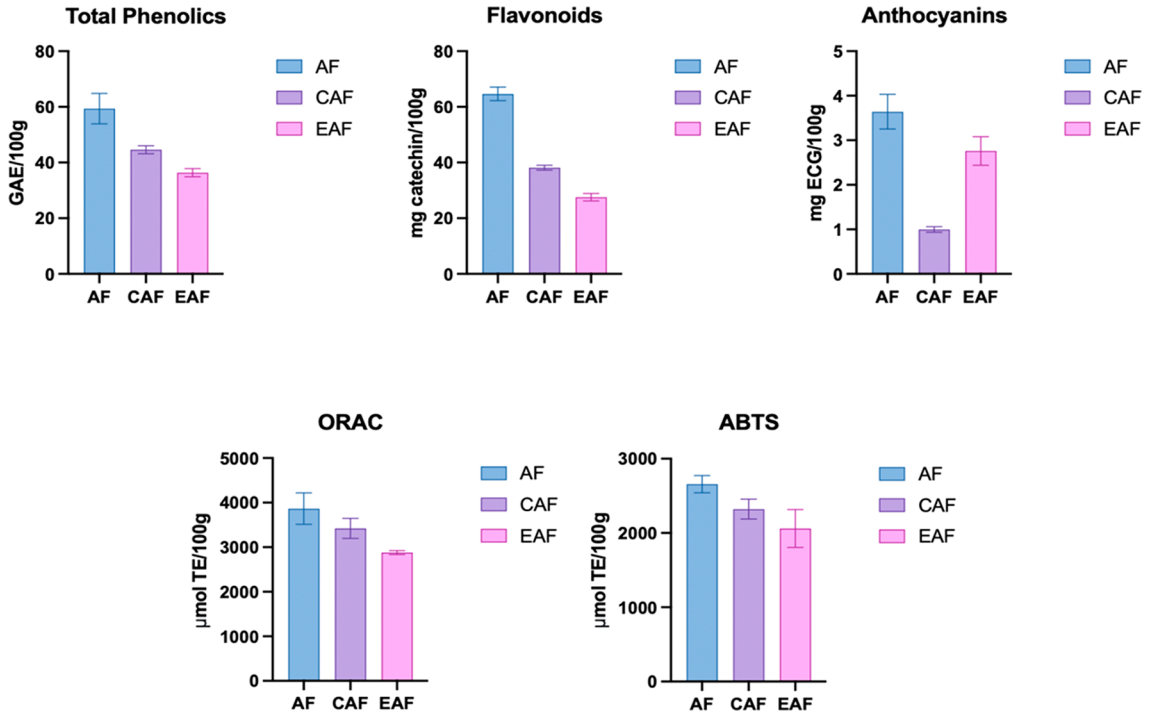

Figure 4. Phenolic compounds and antioxidant activity of raw, cooked, and extruded ayocote bean flours.

cooking water. However, some researchers reported that saponins are relatively heat-stable components.[135] Barakat and Rohn (2015)[136] reported that different cooking conditions differently affected the saponin content in chickpea, soy, and fava beans. Furthermore, saponins were identified; particularly saponin B increased after cooking; therefore, the type of saponin could have an impact on the concentration and types of saponins that could be found in different legumes. Also, hydrothermal processing can destroy and/or change the original structure of saponins into smaller fragments.[137]

Meanwhile, extrusion generated a decrease in SC (9.31%). Barakat and Rohn (2015)[136] reported SC in quinoa was subjected to different parameters of extrusion, demonstrating that moisture, temperature, and screw speed had significant linear effects in SC; for example, increased heat decreased SC, and lower moisture content also decreased SC. On the other hand, Sánchez-Velázquez et al. (2021)[138] reported that the impact of the extrusion process on saponins did not show a clear pattern, stating that this effect will depend on different factors such as pulse type, saponins location in the seed, processing conditions, etc. However, the shear and thermal energy present during extrusion may be sufficient to destroy the original structure of saponins, resulting in the formation of smaller chemical fragments.[137]

Additionally, as saponins are mainly found in the testa, milling and/or decortication before extrusion could be used as pretreatment methods to reduce SC, due to the remotion of the testa and particle size reduction during the milling process.

Tannins are antioxidant compounds in foods with multifunctional properties related to health benefits, but these also exhibit antinutritional properties decreasing the digestion of various nutrients.[139] The tanin content (TC) in AF was 159.69 mg of EC/100 g (Figure 2); these results are within the range reported by Wang et al. (2010)[14] for seven different varieties of beans (3.00−1,990.00 mg of EC/100 g). Cooking significantly ($p \leq 0.05$) reduced TC (62.82%); other studies reported a decrease in TC after cooking in beans and pulses.[14,72,140] Corzo-Ríos et al. (2020)[4] reported a decrease in TC after cooking processing in two species of *Phaseolus* (*P. vulgaris* and *P. coccineus*), attributing the reduction to the high temperatures that alter the chemical structure of polyphenols, promoting polymerization and/or decomposition of their aromatic structure. Reduction in TC could also be explained by the thermolability of tannins; besides the variation in TC reduction

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

rates depends on the plant material and the cooking time and temperature used.[141] TC was reduced after the extrusion process (65.06%); this could be a result of decarboxylation that promotes polymerization, leading to declined extractability.[72]

In the case of the trypsin inhibitor activity, AF presented 15.86 TIU/mg (Figure 2); this result is higher than that reported by Corzo-Ríos et al. (2020)[4] for eight varieties of *Phaseolus vulgaris* and two *P. coccineus*, i.e., 5.97−8.40 and 6.70−6.90 TIU/mg, respectively. The TIU in common beans is related to seed protein content, planting year, and genotypes; this could be the reason for the differences between studies.[142] Cooking and extrusion caused a 100% loss of the activity of TIU; these are thermolabile proteins that undergo denaturation during thermal processing, which causes a loss of activity due to protein denaturation and unfolding.[4]

Hemagglutinin Activity. Hemagglutinin or lectins are glycoproteins that have been found in more than 600 genus of legumes; the total protein of pulse seeds contains around 2−10% lectins, and these can inhibit digestive enzymes.[143,144] Figure 3 shows the presence of hemagglutinin activity in AF, CAF, and EAF samples. Wells with uniform red color or diffuse suspension are positive to hemagglutinin activity, while those with a red button or dot shape at the bottom of the well are negative. Different concentrations of lectin extracts were assayed to determine the dose-dependent activity. AF showed hemagglutinin activity at all concentrations tested, while CAF showed no activity at all concentrations and EAF showed minor activity after 0.2 mg/mL of protein. Therefore, the cooking process was the most effective in eliminating hemagglutinin activity.

González-Cruz et al. (2022)[8] reported that, in extracts of lectins from two varieties of *P. coccineus* treated at different temperatures (12−95 °C) for 30 min, the hemagglutination activity was lost up to 90 °C. Changes in hemagglutination activity by thermal treatment are associated with modifications in the secondary structure of lectins,[145] which occurred by the conditions used during the cooking and extrusion processes, time of exposure, water/substrate ratio, pressure, temperature applied, and shear rate.

Nutraceutical Properties. *Total Phenolic Content.* The total phenolic compound content for the raw and processed beans is shown in Figure 4. AF, CAF, and EAF showed total phenolic compounds of 59.3, 44.6, and 36.3 mg of GAE/100 g, respectively. Both cooking and extrusion processes caused significant ($p \leq 0.05$) losses of phenolics when compared to AF. However, a higher percentage of retention was observed in CAF (75.2%) than in EAF (61.7%). Corzo-Ríos et al. (2020)[4] evaluated the content of phenolic compounds in raw and cooked common bean (*P. vulgaris*) and ayocote bean (*P. coccineus*), reporting a decrease in these compounds after cooking and similar retention percentages for common (59.1−96.6%) and ayocote (66.4−74.7%) beans. The results after the cooking process could be due to the high heating temperatures that altered the chemical structure of polyphenols, promoting polymerization or decomposition of their aromatic structures.[146] Abd El-Hady and Habiba (2003)[147] studied the effects of extrusion processing variables such as barrel temperature and feed moisture in total phenolics content of whole meal peas, chickpeas, faba, and kidney bean flours. A significant decrease was observed in total phenolics for extruded products, and these behaviors were attributed mainly to the individual effect of both temperature and moisture content. Other authors mentioned that this decrease may be due to the decarboxylation of phenolic acids during extrusion.[68]

Flavonoids. FC is shown in Figure 4. AF, CAF, and EAF showed 64.65, 38.14, and 27.57 mg of CA/100 g of sample, respectively. The FCs of AF were lower than those reported by Alvarado-López et al. (2019)[63] in four varieties of ayocote bean, 108.4−161.2 mg of CA/100 g. In general, the content of flavonoids was impacted by the thermal process; after cooking and extrusion, a significant ($p \leq 0.05$) decrease (41% and 57.35%, respectively) of FC was found. Flavonoids are secondary metabolites from plants that are present in legumes; they are water-soluble compounds, and during cooking, these phenolics can be lixiviated and degraded, depending on the chemical structure, time, and temperature used during the processing applied.[148] In this study, extrusion generated a significant ($p \leq 0.05$) decrease (57.35%) in FC; this could be due to the high content of starch in the sample produced after extrusion; additionally gelatinized starch can form complexes with lipids, thus trapping phenolics and reducing the extraction efficiency.[149] Moreover, high temperature and pressure in extrusion may result in decarboxylation of phenolics, promoting polymerization.[150]

Anthocyanins. Anthocyanin content (AC) is shown in Figure 4. Anthocyanins are an important type of flavonoids in pigmented common beans; the AC in AF was 3.64 mg equivalents of cyanidin-3-glucoside/100 g (mg of ECG/100 g); this result is lower than those reported by Alvarado-López et al. (2019)[63] for black and purple ayocote bean varieties (108.2 and 119.3 mg of ECG/100 g, respectively).[151]

Cooking caused a significant reduction ($p \leq 0.05$) in anthocyanin content (72.58%); the loss of anthocyanins could be due to different factors. Anthocyanins are highly water-soluble; therefore, boiling could increase leaching; also these are sensitive to high temperatures, thus causing their rapid degradation.[152] On the other hand, extrusion caused a loss of anthocyanins (24.17%) but not as noticeable as cooking, even though anthocyanins are thermally sensitive; during extrusion, starch is affected due to interactions between starch and nonstarch components like lipids, proteins, and phenolics including anthocyanins, causing prevention of the degradation and/or a reduced impact to these complexations.[153]

Antioxidant Activity. Antioxidant activity for the raw and processed bean samples is shown in Figure 4. Antioxidant capacity was determined using the ORAC and ABTS methodologies, obtaining values for AF of 3,866.37 and 2,657.94 μmol of TE/100 g, respectively. The antioxidant capacity for CAF was 3,422.02 (ORAC) and 2,321.84 (ABTS) μmol of TE/100 g, while the antioxidant capacity of EAF was 2,879.72 (ORAC) and 2,062.09 μmol of TE/100 g, respectively. The cooking process generated a retention percentage of antioxidant capacity of 88.50% (ORAC) and 87.35% (ABTS) for CAF. EAF flours showed retention percentages of 74.48% (ORAC) and 77.58% (ABTS), respectively. However, a higher percentage of retention was observed in CAF than EAF; this could be explained because, during the cooking process, the cooking liquor was freeze-dried with cooked beans, avoiding the loss of compounds that may have been leached during cooking. Korus et al. (2007)[154] evaluated the antioxidant activity in raw and extruded common beans, reporting a decrease in antioxidant activity (1−43% loss of antioxidant activity) once processed by extrusion, presenting the same behavior as the present study. However, Anton et al. (2009)[155] reported an increase in antioxidant activity (DPPH)

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

for cornstarch/common bean extrudates. Alam et al. (2016)[68] concluded that the antioxidant capacity is dependent not only on the amount of bioactive compounds but also on their bioactives composition.

To evaluate a possible association between changes in phenolic compounds and antioxidant capacity, a correlation analysis was performed. A significant correlation was found between phenolic compounds and ORAC (r^2 = 0.925; $p \leq 0.05$) and between phenolic compounds and ABTS (r^2 = 0.909; $p \leq 0.05$). These findings suggest that phenolic compound content is a positive predictor for *in vitro* antioxidant activity. Salas-López et al. (2018)[156] reported a simultaneous relationship between total phenolic content and antioxidant capacity (DPPH, ABTS) in sorghum after extrusion. Cooking and extrusion processes caused significant ($p \leq 0.05$) losses of antioxidant activity when compared to that of raw AF.

This study elucidates the modifications in various aspects of ayocote beans (*Phaseolus coccineus* L.), an indigenous and underutilized pulse, concerning nutritional, antinutritional, and techno-functional characteristics following traditional (cooking) and alternative (extrusion) processing methods, as illustrated in Figure 6. Notably, carbohydrates emerged as the primary macronutrient subject to modification during processing, with each method inducing distinct changes: a notable increase in resistant starch (RS) was observed in the cooked sample, whereas the extruded sample exhibited an opposing trend. Moreover, mineral and amino acid contents exhibited notable variations between both processing methods. Techno-functional properties, for the most part, displayed similar trends in response to both processes, with the exception of emulsion capacity and stability, which were exclusively influenced by extrusion. It is noteworthy that thermal processing resulted in a reduction of antinutritional factors, as evidenced by a decrease in tannin and trypsin inhibitor levels in both processed samples. Conversely, cooking proved to be the more efficient method for eliminating the presence of hemagglutinins. Furthermore, cooking exhibited a more pronounced impact on anthocyanins content, whereas extrusion exerted a greater influence on flavonoids content. Nevertheless, ayocote beans showed high antioxidant activity retention following both processing techniques. This suggests that ayocote beans represent a promising legume source for the development of novel food formulations that offer enhanced health benefits.

Figure 5. Flower and seeds of ayocote bean (*Phaseolus coccineus*).

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsfoodscitech.2c00416.

Formulas used to calculate physicochemical properties (total color difference), oil absorption capacity, dispersibility index, foaming capacity and foam stability, emulsifying capacity and emulsion stability, antinutritional (phytic acid content, saponins, condensed tannins content, trypsin inhibitor activity), and anthocyanin content in ayocote bean flours (PDF)

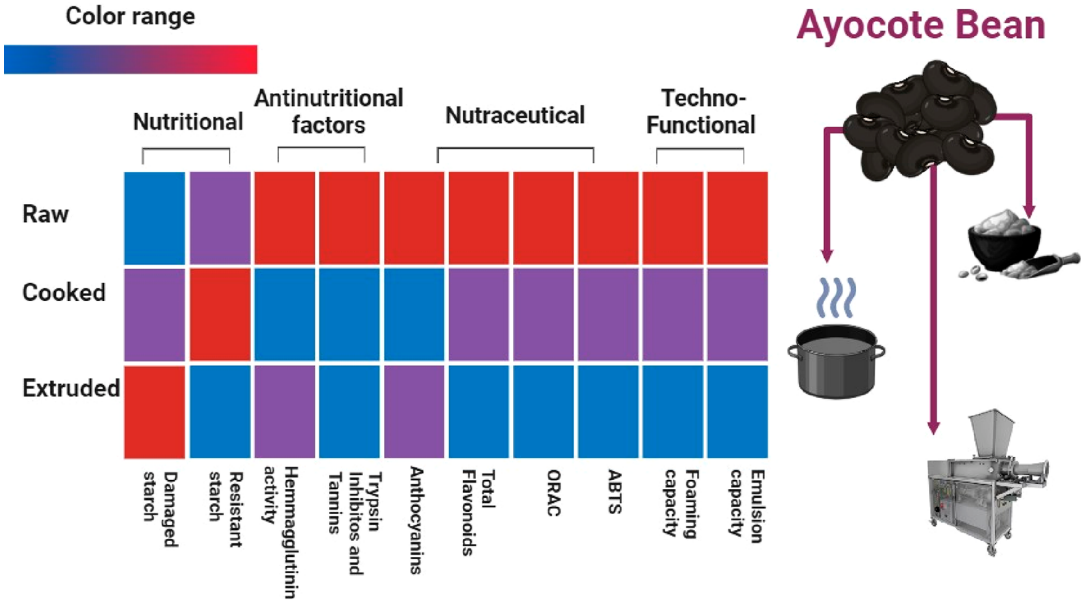

Figure 6. Overview heatmap of the different nutritional, antinutritional, nutraceutical, and techno-functional properties of raw, cooked, and extruded ayocote bean flours.

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

AUTHOR INFORMATION

Corresponding Authors

Alan J. Hernández-Álvarez − *School of Food Science & Nutrition, University of Leeds, LS2 9JT Leeds, United Kingdom*; Email: A.J.HernandezAlvarez@leeds.ac.uk

Edith O. Cuevas-Rodríguez − *Programa de Posgrado Integral en Biotecnología and Programa de Posgrado en Ciencia y Tecnología de Alimentos, Facultad de Ciencias Químico-Biológicas, Universidad Autónoma de Sinaloa, Ciudad Universitaria, PC 80030 Culiacán, Sinaloa, México*; Email: edith.cuevas.r@uas.edu.mx

Authors

Evelyn I. Osuna-Gallardo − *Programa de Posgrado Integral en Biotecnología, Ciudad Universitaria, PC 80030 Culiacán, Sinaloa, México*

Carlos I. Sepúlveda-García − *Programa de Posgrado en Ciencia y Tecnología de Alimentos, Facultad de Ciencias Químico-Biológicas, Universidad Autónoma de Sinaloa, Ciudad Universitaria, PC 80030 Culiacán, Sinaloa, México*

Cuauhtémoc Reyes-Moreno − *Programa de Posgrado Integral en Biotecnología and Programa de Posgrado en Ciencia y Tecnología de Alimentos, Facultad de Ciencias Químico-Biológicas, Universidad Autónoma de Sinaloa, Ciudad Universitaria, PC 80030 Culiacán, Sinaloa, México*

Liliana León-López − *Programa de Posgrado Integral en Biotecnología, Ciudad Universitaria, PC 80030 Culiacán, Sinaloa, México*

Ruixian Han − *School of Food Science & Nutrition, University of Leeds, LS2 9JT Leeds, United Kingdom*

Complete contact information is available at: https://pubs.acs.org/10.1021/acsfoodscitech.2c00416

Author Contributions

E.I.O.-G. performed bean processing (cooking and extrusion), nutritional composition (proximate analysis, fatty acid content, mineral content), physicochemical characteristics (total color difference ΔE, water activity, pH), functional properties (water absorption and solubility index, oil absorption capacity, dispersibility index, foaming capacity and foam stability, emulsifying capacity, and emulsion stability), hemagglutinin activity, nutraceutical properties (total phenolic content, ORAC, and ABTS), test data, interpreted results, and drafted the manuscript; E.O.C.-R. participated in the general design of the study and supervision and helped on the manuscript drafting and reviewing; C.I.S.-G. performed antinutritional tests (phytic acid content, saponins, condensed tannin content, trypsin inhibitor activity) and anthocyanins and flavonoids tests; C.R.-M. contributed with the sample (ayocote bean) and helped on the manuscript; L.L.-L. designed the antinutritional test and helped on the manuscript drafting; R.H. participated in the damaged starch determination and helped on the manuscript; A.J.H.-A. participated in the general design of the study and supervision and helped on the manuscript drafting and reviewing.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

Scholarships for E.I.O.-G. and C.I.S.-G. were provided by Consejo Nacional de Ciencia y Tecnología (CONACYT), through doctoral scholarship 666706 and master scholarship 923415, respectively.

ABBREVIATIONS USED

AAs, amino acids; AAPH, 2,2′-azobis(2-methyl-propinamide); AC, anthocyanin content; AF, ayocote beans flour; AUC, area under the sodium fluorescein decay curves; a_w, water activity; BAPNA, Nα-benzoyl-DL-arginine *p*-nitroanilide hydrochloride; CA, catechin; CAC, content of available carbohydrates; CAF, cooked ayocote bean flour; CT, cooking time; CTC, condensed tannins content; DI, dispersibility index; EAF, extruded ayocote bean flour; EC, emulsifying capacity; ECA, equivalents of catechin; ES, emulsion stability; ESP, equivalents of sodium phytate; ET, extrusion temperature; F, foaming percentage; FC, foaming capacity; FS, foam stability; GAE, gallic acid equivalents; NAE, *N*-acylethanolamine; OAC, oil absorption capacity; ORAC, determination of oxygen radical absorbance capacity; PAC, phytic acid content; PAE, palmitoylethanolamide; RS, resistant starch; SC, saponins content; SS, screw speed; TDF, total dietary fiber; TE, Trolox equivalents; TF, total flavonoids; TIU, trypsin inhibitor activity; TPC, total phenolic content; WAI, water absorption; WSI, solubility index; ΔE, total color difference

REFERENCES

(1) Teniente-Martínez, G.; Cruz-González, L.; Cariño -Cortés, R.; Bernardinonicanor, A. CARACTERIZACIÓN DE LAS PROTEÍNAS DEL FRIJOL AYOCOTE (Phaseolus Coccineus L.). *Investigación y Desarrollo en Ciencia y Tecnología de Alimentos* **2016**, *1* (1), 1−6.

(2) Perera, T.; Russo, C.; Takata, Y.; Bobe, G. Legume Consumption Patterns in US Adults: National Health and Nutrition Examination Survey (NHANES) 2011−2014 and Beans, Lentils, Peas (BLP) 2017 Survey. *Nutrients 2020, Vol. 12, Page 1237* **2020**, *12* (5), 1237.

(3) Méndez-Aguilar, R.; Reyes-Valdés, M.; Mayek-Pérez, N. Avances y Perspectivas Sobre El Mapeo Genético de La Resistencia a Las Pudriciones de La Raíz En Frijol Común. *Phyton (Buenos Aires)* **2013**, *82* (2), 215−226.

(4) Corzo-Ríos, L. J.; Sánchez-Chino, X. M.; Cardador-Martínez, A.; Martínez-Herrera, J.; Jiménez-Martínez, C. Effect of Cooking on Nutritional and Non-Nutritional Compounds in Two Species of Phaseolus (P. Vulgaris and P. Coccineus) Cultivated in Mexico. *Int. J. Gastron Food Sci.* **2020**, *20*, 100206.

(5) Basurto, F.; Martínez, D.; Castellanos, A.; Martínez, M. A. Ciclo Agricola y Fenologia de Phaseolus Coccineus L. En Sistemas de Agricultura Tradicional En La Sierra Norte de Puebla, México. *Etnoecológica* **1996**, *3*, 71−82.

(6) Vargas-Vázquez, P.; Muruaga-Martínez, J. S.; Martínez-Villarreal, S. E.; Ruiz-Salazar, R.; Hernández-Delgado, S.; Mayek-Pérez, N. Diversidad Morfológica Del Frijol Ayocote Del Carso Huasteco de México Morphologic Diversity of Ayocote Beans from Huasteco Karst of Mexico. *Rev. Mex Biodivers* **2011**, *82* (3), 767−775.

(7) Guerra-García, A.; Suárez-Atilano, M.; Mastretta-Yanes, A.; Delgado-Salinas, A.; Piñero, D. Domestication Genomics of the Open-Pollinated Scarlet Runner Bean (Phaseolus Coccineus L.). *Front Plant Sci.* **2017**, *8*, 299557.

(8) González-Cruz, L.; Valadez-Vega, C.; Juárez-Goiz, J. M. S.; Flores-Martínez, N. L.; Montañez-Soto, J. L.; Bernardino-Nicanor, A. Partial Purification and Characterization of the Lectins of Two Varieties of Phaseolus Coccineus (Ayocote Bean). *Agronomy 2022, Vol. 12, Page 716* **2022**, *12* (3), 716.

(9) Bedoya, R. A.; Maldonado, M. E. Características Nutricionales y Antioxidantes de La Especie de Frijol Petaco (Phaseolus Coccineus). *Revista chilena de nutrición* **2022**, *49* (1), 34−42.

(10) Sánchez-Velázquez, O. A.; Cuevas-Rodríguez, E. O.; Mondor, M.; Ribéreau, S.; Arcand, Y.; Mackie, A.; Hernández-Álvarez, A. J.

Impact of in Vitro Gastrointestinal Digestion on Peptide Profile and Bioactivity of Cooked and Non-Cooked Oat Protein Concentrates. *Curr. Res. Food Sci.* **2021**, *4*, 93−104.
(11) Milán-Noris, A. K.; Gutiérrez-Uribe, J. A.; Santacruz, A.; Serna-Saldívar, S. O.; Martínez-Villaluenga, C. Peptides and Isoflavones in Gastrointestinal Digests Contribute to the Anti-Inflammatory Potential of Cooked or Germinated Desi and Kabuli Chickpea (Cicer Arietinum L.). *Food Chem.* **2018**, *268*, 66−76.
(12) Sevilla, V.; Carolina, B. Determinación Del Tiempo de Cocción En Variedades Comerciales de Frijol Rojo; 1996; https://bdigital.zamorano.edu/handle/11036/3037 (accessed September 24, 2023).
(13) Liu, Y.; Ragaee, S.; Marcone, M. F.; Abdel-Aal, E. S. M. Effect of Different Cooking Methods and Heating Solutions on Nutritionally-Important Starch Fractions and Flatus Oligosaccharides in Selected Pulses. *Cereal Chem.* **2020**, *97* (6), 1216−1226.
(14) Wang, N.; Hatcher, D. W.; Tyler, R. T.; Toews, R.; Gawalko, E. J. Effect of Cooking on the Composition of Beans (Phaseolus Vulgaris L.) and Chickpeas (Cicer Arietinum L.). *Food Research International* **2010**, *43* (2), 589−594.
(15) Kumari, M.; Urooj, A.; Prasad, N. N. Effect of Storage on Resistant Starch and Amylose Content of Cereal−Pulse Based Ready-to-Eat Commercial Products. *Food Chem.* **2007**, *102* (4), 1425−1430.
(16) Wang, N.; Hatcher, D. W.; Gawalko, E. J. Effect of Variety and Processing on Nutrients and Certain Anti-Nutrients in Field Peas (Pisum Sativum). *Food Chem.* **2008**, *111* (1), 132−138.
(17) Luo, Y. W.; Xie, W. H. Effect of Different Processing Methods on Certain Antinutritional Factors and Protein Digestibility in Green and White Faba Bean (Vicia Faba L.). *http://mc.manuscriptcentral.com/tcyt* **2013**, *11* (1), 43−49.
(18) Boukhanouf, R.; Louaileche, H.; Perrin, D. Phytochemical Content and in Vitro Antioxidant Activity of Faba Bean as Affected by Maturity Stage and Cooking Practice. *Int. Food Res. J.* **2016**, *23* (3), 954−961.
(19) López-Cobo, A.; Gómez-Caravaca, A. M.; Švarc-Gajić, J.; Segura-Carretero, A.; Fernández-Gutiérrez, A. Determination of Phenolic Compounds and Antioxidant Activity of a Mediterranean Plant: The Case of Satureja Montana Subsp. Kitaibelii. *J. Funct Foods* **2015**, *18*, 1167−1178.
(20) Siddiq, M.; Ravi, R.; Harte, J. B.; Dolan, K. D. Physical and Functional Characteristics of Selected Dry Bean (Phaseolus Vulgaris L.) Flours. *LWT* **2010**, *43* (2), 232−237.
(21) Pasqualone, A.; Costantini, M.; Coldea, T. E.; Summo, C. Use of Legumes in Extrusion Cooking: A Review. *Foods* **2020**, *9* (7), 958.
(22) Arribas, C.; Cabellos, B.; Cuadrado, C.; Guillamón, E.; Pedrosa, M. M. Extrusion Effect on Proximate Composition, Starch and Dietary Fibre of Ready-to-Eat Products Based on Rice Fortified with Carob Fruit and Bean. *LWT* **2019**, *111*, 387−393.
(23) Alonso, R.; Aguirre, A.; Marzo, F. Effects of Extrusion and Traditional Processing Methods on Antinutrients and in Vitro Digestibility of Protein and Starch in Faba and Kidney Beans. *Food Chem.* **2000**, *68* (2), 159−165.
(24) Patil, S. S.; Brennan, M. A.; Mason, S. L.; Brennan, C. S. The Effects of Fortification of Legumes and Extrusion on the Protein Digestibility of Wheat Based Snack. *Foods 2016, Vol. 5, Page 26* **2016**, *5* (2), 26.
(25) Milán-Carrillo, J.; Reyes-Moreno, C.; Armienta-Rodelo, E.; Carábez-Trejo, A.; Mora-Escobedo, R. Physicochemical and Nutritional Characteristics of Extruded Flours from Fresh and Hardened Chickpeas (Cicer Arietinum L). *LWT - Food Science and Technology* **2000**, *33* (2), 117−123.
(26) ISTA.. International Rules for Seed Testing. Rules 1985. *Seed Science and Technology* **1985**, *13* (2), 299−513.
(27) AACC. *Approved Methods of the American Association of Cereal Chemists*; AACC International: 1995.
(28) Reyes-Moreno, C.; Romero-Urías, C. A.; Milan-Carrillo, J.; Gomez-Garza, R. M. Composición Química y Calidad Nutritiva de Garbanzo (Cicer Arietinum L.) Fresco y Endurecido Después de La Fermentación En Estado Sólido (FES)/Chemical Composition and Nutritional Quality of Fresh and Hardened Chickpea (Cicer Arietinum L) after the Solid State Fermentation (SSF). *http://dx.doi.org/10.1177/108201320000600308* **2000**, *6* (3), 251−258.
(29) Reyes-Moreno, C.; Rouzaud-Sandez, O.; Milán-Carrillo, J.; Garzón-Tiznado, J. A.; Camacho-Hernández, L. Hard-to-Cook Tendency of Chickpea (Cicer Arietinum L) Varieties. *J. Sci. Food Agric* **2001**, *81* (10), 1008−1012.
(30) Milán-Carrillo, J.; Montoya-Rodríguez, A.; Gutiérrez-Dorado, R.; Perales-Sánchez, X.; Reyes-Moreno, C. Optimization of Extrusion Process for Producing High Antioxidant Instant Amaranth (*Amaranthus Hypochondriacus* L.) Flour Using Response Surface Methodology. *Appl. Math (Irvine)* **2012**, *03* (10), 1516−1525.
(31) Horwitz, W.; Chichilo, P.; Reynolds, H. *Official methods of analysis of the Association of Official Analytical Chemists*; 1970.
(32) Soto-León, S.; Zazueta-Patrón, I. E.; Piña-Valdez, P.; Nieves-Soto, M.; Reyes-Moreno, C.; Contreras-Andrade, I. Extracción de Lípidos de Tetraselmis Suecica: Proceso Asistido Por Ultrasonido y Solventes. *Rev. Mex. Ing. Quim.* **2014**, *13* (3), 723−737.
(33) Yust, M. M.; Pedroche, J.; Girón-Calle, J.; Vioque, J.; Millán, F.; Alaiz, M. Determination of Tryptophan by High-Performance Liquid Chromatography of Alkaline Hydrolysates with Spectrophotometric Detection. *Food Chem.* **2004**, *85* (2), 317−320.
(34) Alaiz, M.; Navarro, J. L.; Girón, J.; Vioque, E. Amino Acid Analysis by High-Performance Liquid Chromatography after Derivatization with Diethyl Ethoxymethylenemalonate. *J. Chromatogr A* **1992**, *591* (1−2), 181−186.
(35) Milán-Carrillo, J.; Reyes-Moreno, C.; Camacho-Hernández, I. L.; Rouzaud-Sandez, O. Optimisation of Extrusion Process to Transform Hardened Chickpeas (Cicer Arietinum L) into a Useful Product. *J. Sci. Food Agric* **2002**, *82* (14), 1718−1728.
(36) Anderson, R. A.; Sivri, D.; Yildirim, Z.; Koksel, H. Gelatinization of Corn Grits by Roll- and Extrusion-Cooking. *J. Cereal. Sci.* **1969**, *14* (1), 4−7.
(37) Wodajo, D.; Emire, S. A. Haricot Beans (Phaseolus Vulgaris L.) Flour: Effect of Varieties and Processing Methods to Favor the Utilization of Underconsumed Common Beans. *https://doi.org/10.1080/10942912.2022.2074029* **2022**, *25* (1), 1186−1202.
(38) N'guetta, N.; Marie, A.; Ahipo Edmond, D.; Koné, F. M. T.; Patrice, K. L. Functional Properties of Seed Flours from Different Cultivars of Citrullus Lanatus (Cucurbitaceae) Cultivated in Côte d'Ivoire. *International Journal of Research Studies in Agricultural Sciences (IJRSAS)* **2015**, *1* (5), 32−48.
(39) Mora-Escobedo, R.; Paredes-Lopez, O.; Dominguez, J. Optimization of a Germination Procedure by Response Surface Methodology. *Lebensmittel - Wissenschaft + Technologie* **1991**, *24* (6), 518−522.
(40) Huffman, V. L.; Lee, C. K.; Burns, E. E. Selected Functional Properties of Sunflower Meal (Helianthus annuus). *J. Food Sci.* **1975**, *40* (1), 70−74.
(41) Khattab, R. Y.; Arntfield, S. D. Nutritional Quality of Legume Seeds as Affected by Some Physical Treatments 2. Antinutritional Factors. *LWT - Food Science and Technology* **2009**, *42* (6), 1113−1118.
(42) Butt, M. S.; Batool, R. Nutritional and Functional Properties of Some Promising Legumes Protein Isolates. *Pakistan Journal of Nutrition* **2010**, *9* (4), 373−379.
(43) Vaintraub, I. A.; Lapteva, N. A. Colorimetric Determination of Phytate in Unpurified Extracts of Seeds and the Products of Their Processing. *Anal. Biochem.* **1988**, *175* (1), 227−230.
(44) Hiai, S.; Oura, H.; Nakajima, T. Color Reaction of Some Sapogenins and Saponins with Vanillin and Sulfuric Acid. *Planta Med.* **1976**, *29* (2), 116−122.
(45) Xu, B. J.; Chang, S. K. C. A Comparative Study on Phenolic Profiles and Antioxidant Activities of Legumes as Affected by Extraction Solvents. *J. Food Sci.* **2007**, *72* (2), S159−S166.
(46) Welham, T.; Domoney, C. Temporal and Spatial Activity of a Promoter from a Pea Enzyme Inhibitor Gene and Its Exploitation for Seed Quality Improvement. *Plant Science* **2000**, *159* (2), 289−299.

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

(47) De Mejía, E. G.; Prisecaru, V. I. Lectins as Bioactive Plant Proteins: A Potential in Cancer Treatment. *Crit Rev. Food Sci. Nutr* **2005**, *45* (6), 425−445.
(48) Mora-Rochin, S.; Gutiérrez-Uribe, J. A.; Serna-Saldivar, S. O.; Sánchez-Peña, P.; Reyes-Moreno, C.; Milán-Carrillo, J. Phenolic Content and Antioxidant Activity of Tortillas Produced from Pigmented Maize Processed by Conventional Nixtamalization or Extrusion Cooking. *J. Cereal Sci.* **2010**, *52* (3), 502−508.
(49) Singleton, V. L.; Orthofer, R.; Lamuela-Raventós, R. M. Analysis of Total Phenols and Other Oxidation Substrates and Antioxidants by Means of Folin-Ciocalteu Reagent. *Methods Enzymol* **1999**, *299*, 152−178.
(50) Heimler, D.; Vignolini, P.; Dini, M. G.; Romani, A. Rapid Tests to Assess the Antioxidant Activity of Phaseolus Vulgaris L. Dry Beans. *J. Agric. Food Chem.* **2005**, *53* (8), 3053−3056.
(51) Abdel-Aal, E. S. M.; Hucl, P. A Rapid Method for Quantifying Total Anthocyanins in Blue Aleurone and Purple Pericarp Wheats. *Cereal Chem.* **1999**, *76* (3), 350−354.
(52) Ou, B.; Hampsch-Woodill, M.; Prior, R. L. Development and Validation of an Improved Oxygen Radical Absorbance Capacity Assay Using Fluorescein as the Fluorescent Probe. *J. Agric. Food Chem.* **2001**, *49* (10), 4619−4626.
(53) Roy, M. K.; Koide, M.; Rao, T. P.; Okubo, T.; Ogasawara, Y.; Juneja, L. R. ORAC and DPPH Assay Comparison to Assess Antioxidant Capacity of Tea Infusions: Relationship between Total Polyphenol and Individual Catechin Content. *Int. J. Food Sci. Nutr* **2010**, *61* (2), 109−124.
(54) Re, R.; Pellegrini, N.; Proteggente, A.; Pannala, A.; Yang, M.; Rice-Evans, C. Antioxidant Activity Applying an Improved ABTS Radical Cation Decolorization Assay. *Free Radic Biol. Med.* **1999**, *26* (9−10), 1231−1237.
(55) Ayala Garay, O. J.; Pichardo González, J. M.; Estrada Gómez, J. A.; Carrillo Salazar, J. A.; Hernández Livera, A. Rendimiento y Calidad de Semilla del Frijol Ayocote en Yield and Seed Quality of Ayocote Bean at the Valley of Mexico. *Agricultura Técnica en México* **2006**, *32* (3), 313−321.
(56) Singh, S. P.; Gepts, P.; Debouck, D. G. Races of Common Bean (Phaseolus Vulgaris, Fabaceae). *Econ Bot* **1991**, *45* (3), 379−396.
(57) Peña-Valdivia, C. B.; García-Nava, J. R.; Aguirrer, J. R.; Ybarra-Moncada, M. C.; Lõpezh, M. Variation in Physical and Chemical Characteristics of Common Bean (Phaseolus Vulgaris L.) Grain along a Domestication Gradient. *Chem. Biodivers* **2011**, *8* (12), 2211−2225.
(58) Wani, I. A.; Sogi, D. S.; Wani, A. A.; Gill, B. S. Physical and Cooking Characteristics of Some Indian Kidney Bean (Phaseolus Vulgaris L.) Cultivars. *Journal of the Saudi Society of Agricultural Sciences* **2017**, *16* (1), 7−15.
(59) Herrera, P. P.; Esquivel, G. E.; Serna, R. R.; Acosta-Gallegos, J. A. Caracterización Física, Culinaria y Nutricional de Frijol Del Altiplano Subhúmedo de México. *Arch. Latinoam. Nutr.* **2002**, *52* (2), 172−180.
(60) Maderos, Y.; Reynaldo, I. M. Determinación de Indicadores de Calidad En 11 Genotipos de La Especie Phaseolus Vulgaris, L. *Cultivos Tropicales* **2007**, *28* (4), 51−56.
(61) Dhull, S. B.; Kidwai, M. K.; Noor, R.; Chawla, P.; Rose, P. K. A Review of Nutritional Profile and Processing of Faba Bean (Vicia Faba L.). *Legume Science* **2022**, *4* (3), No. e129.
(62) Ibarra-Perez, F. J.; Tosquy-Valle, O. H.; Rodríguez-Rodríguez, J. R.; Villar-Sánchez, B.; López-Salinas, E.; Anaya-López, J. L.; Ibarra-Perez, F. J.; Tosquy-Valle, O. H.; Rodríguez-Rodríguez, J. R.; Villar-Sánchez, B.; López-Salinas, E.; Anaya-López, J. L. Rubí: Nueva Variedad Mejorada de Frijol Negro Para Las Áreas Tropicales de Veracruz y Chiapas. *Rev. Mex De Cienc Agric* **2022**, *13* (3), 577−587.
(63) Alvarado-López, A. N.; Gómez-Oliván, L. M.; Heredia, J. B.; Baeza-Jiménez, R.; Garcia-Galindo, H. S.; Lopez-Martinez, L. X. Nutritional and Bioactive Characteristics of Ayocote Bean (Phaseolus Coccienus L.): An Underutilized Legume Harvested in Mexico. *CYTA - Journal of Food* **2019**, *17* (1), 199−206.
(64) Boye, J.; Zare, F.; Pletch, A. Pulse Proteins: Processing, Characterization, Functional Properties and Applications in Food and Feed. *Food Research International* **2010**, *43* (2), 414−431.
(65) Margier, M.; Georgé, S.; Hafnaoui, N.; Remond, D.; Nowicki, M.; Du Chaffaut, L.; Amiot, M. J.; Reboul, E. Nutritional Composition and Bioactive Content of Legumes: Characterization of Pulses Frequently Consumed in France and Effect of the Cooking Method. *Nutrients 2018, Vol. 10, Page 1668* **2018**, *10* (11), 1668.
(66) De Pilli, T.; Giuliani, R.; Buléon, A.; Pontoire, B.; Legrand, J. Effects of Protein-Lipid and Starch-Lipid Complexes on Textural Characteristics of Extrudates Based on Wheat Flour with the Addition of Oleic Acid. *Int. J. Food Sci. Technol.* **2016**, *51* (5), 1063−1074.
(67) Tovar Hernández, C. E.; Perafan Gil, E. A.; Enriquez Collazos, M. G.; Ceron Fernandez, L.; Pismag Portilla, Y. Evaluación Del Efecto Del Proceso de Extrusión En Harina de Quinua (Chenopodium Quinoa Willd) Normal y Germinada. *Biotecnologia en el Sector Agropecuario y Agroindustrial* **2017**, *15* (2), 30−38.
(68) Alam, M. S.; Kaur, J.; Khaira, H.; Gupta, K. Extrusion and Extruded Products: Changes in Quality Attributes as Affected by Extrusion Process Parameters: A Review. *Crit Rev. Food Sci. Nutr* **2016**, *56* (3), 445−473.
(69) Singh, S.; Gamlath, S.; Wakeling, L. Nutritional Aspects of Food Extrusion: A Review. *Int. J. Food Sci. Technol.* **2007**, *42* (8), 916−929.
(70) Sahasakul, Y.; Aursalung, A.; Thangsiri, S.; Wongchang, P.; Sangkasa-ad, P.; Wongpia, A.; Polpanit, A.; Inthachat, W.; Temviriyanukul, P.; Suttisansanee, U. Nutritional Compositions, Phenolic Contents, and Antioxidant Potentials of Ten Original Lineage Beans in Thailand. *Foods* **2022**, *11* (14), 2062−2062.
(71) Sánchez-Arteaga, H. M.; Urías-Silvas, J. E.; Espinosa-Andrews, H.; García-Márquez, E. Effect of Chemical Composition and Thermal Properties on the Cooking Quality of Common Beans (Phaseolus Vulgaris). *http://mc.manuscriptcentral.com/tcyt* **2015**, *13* (3), 385−391.
(72) Bento, J. A. C.; Morais, D. K.; de Berse, R. S.; Bassinello, P. Z.; Caliari, M.; Soares Júnior, M. S. Functional, Thermal, and Pasting Properties of Cooked Carioca Bean (Phaseolus Vulgaris L.) Flours. *Applied Food Research* **2022**, *2* (1), 100027.
(73) Pérez-Navarrete, C.; González, R.; Chel-Guerrero, L.; Betancur-Ancona, D. Effect of Extrusion on Nutritional Quality of Maize and Lima Bean Flour Blends. *J. Sci. Food Agric* **2006**, *86* (14), 2477−2484.
(74) Orozco-Angelino, X.; Espinosa-Ramírez, J.; Serna-Saldívar, S. O. Extrusion as a Tool to Enhance the Nutritional and Bioactive Potential of Cereal and Legume By-Products. *Food Research International* **2023**, *169*, 112889.
(75) Chen, Y.; Ye, R.; Yin, L.; Zhang, N. Novel Blasting Extrusion Processing Improved the Physicochemical Properties of Soluble Dietary Fiber from Soybean Residue and in Vivo Evaluation. *J. Food Eng.* **2014**, *120* (1), 1−8.
(76) Nakitto, A. M.; Muyonga, J. H.; Nakimbugwe, D. Effects of Combined Traditional Processing Methods on the Nutritional Quality of Beans. *Food Sci. Nutr* **2015**, *3* (3), 233−241.
(77) Ciudad-Mulero, M.; Vega, E. N.; García-Herrera, P.; Pedrosa, M. M.; Arribas, C.; Berrios, J. D. J.; Cámara, M.; Fernández-Ruiz, V.; Morales, P. Extrusion Cooking Effect on Carbohydrate Fraction in Novel Gluten-Free Flours Based on Chickpea and Rice. *Molecules* **2022**, *27* (3), 1143.
(78) Kowalski, R. J.; Hause, J. P.; Joyner, H.; Ganjyal, G. M. Waxy Flour Degradation − Impact of Screw Geometry and Specific Mechanical Energy in a Co-Rotating Twin Screw Extruder. *Food Chem.* **2018**, *239*, 688−696.
(79) Arribas, C.; Pereira, E.; Barros, L.; Alves, M. J.; Calhelha, R. C.; Guillamón, E.; Pedrosa, M. M.; Ferreira, I. C. F. R. Healthy Novel Gluten-Free Formulations Based on Beans, Carob Fruit and Rice: Extrusion Effect on Organic Acids, Tocopherols, Phenolic Compounds and Bioactivity. *Food Chem.* **2019**, *292*, 304−313.
(80) Fabbri, A. D. T.; Schacht, R. W.; Crosby, G. A. Evaluation of Resistant Starch Content of Cooked Black Beans, Pinto Beans, and Chickpeas. *NFS Journal* **2016**, *3*, 8−12.

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

(81) Nadeesha Dilrukshi, H. N.; Torrico, D. D.; Brennan, M. A.; Brennan, C. S. Effects of Extrusion Processing on the Bioactive Constituents, in Vitro Digestibility, Amino Acid Composition, and Antioxidant Potential of Novel Gluten-Free Extruded Snacks Fortified with Cowpea and Whey Protein Concentrate. *Food Chem.* **2022**, *389*, 133107.
(82) Blandino, M.; Bresciani, A.; Locatelli, M.; Loscalzo, M.; Travaglia, F.; Vanara, F.; Marti, A. Pulse Type and Extrusion Conditions Affect Phenolic Profile and Physical Properties of Extruded Products. *Food Chem.* **2023**, *403*, 134369.
(83) Van Hung, P.; Vien, N. L.; Lan Phi, N. T. Resistant Starch Improvement of Rice Starches under a Combination of Acid and Heat-Moisture Treatments. *Food Chem.* **2016**, *191*, 67−73.
(84) Escobedo, A.; Loarca-Piña, G.; Gaytan-Martínez, M.; Orozco-Avila, I.; Mojica, L. Autoclaving and Extrusion Improve the Functional Properties and Chemical Composition of Black Bean Carbohydrate Extracts. *J. Food Sci.* **2020**, *85* (9), 2783−2791.
(85) Gulzar, B.; Zameer Hussain, S.; Naseer, B.; Bashir Shikari, A.; Nazir, N.; Gani, G. Investigation of Process and Product Parameters on Physical Attributes, Resistant Starch, and in Vitro Starch Digestibility of Modified Rice Flour-Based Extruded Snacks. *J. Food Process Preserv* **2021**, *45* (11), No. e15953.
(86) Bresciani, A.; Giordano, D.; Vanara, F.; Blandino, M.; Marti, A. The Effect of the Amylose Content and Milling Fractions on the Physico-Chemical Features of Co-Extruded Snacks from Corn. *Food Chem.* **2021**, *343*, 128503.
(87) Simons, C. W.; Hall, C.; Tulbek, M.; Mendis, M.; Heck, T.; Ogunyemi, S. Acceptability and Characterization of Extruded Pinto, Navy and Black Beans. *J. Sci. Food Agric* **2015**, *95* (11), 2287−2291.
(88) Grela, E. R.; Günter, K. D. Fatty Acid Composition and Tocopherol Content of Some Legume Seeds. *Anim Feed Sci. Technol.* **1995**, *52* (3−4), 325−331.
(89) Bhardwaj, H. L.; Hamama, A. A. Oil and Fatty Acid Composition of Tepary Bean Seed. *HortScience* **2005**, *40* (5), 1436−1438.
(90) Lo Turco, V.; Potortì, A. G.; Rando, R.; Ravenda, P.; Dugo, G.; Di Bella, G. Functional Properties and Fatty Acids Profile of Different Beans Varieties. *Nat. Prod Res.* **2016**, *30* (19), 2243−2248.
(91) Borraz, A. M.; Borraz, A. M.; Camarena, S. Y. M.; Ríos, H. G.; Hernández, J.; Saavedra, A. P. Contenido de Ácido Linoleico Conjugado (CLA) En Leche de Ganado Lechero Holstein Estabulado En El Noroeste de México. *Rev. Mex. Cienc. Pecu.* **2012**, *1* (3), 221−235.
(92) Tsuzuki, W. *Formation of Trans Fatty Acids in Heated Triacylglycerols*; 2012.
(93) De La Cruz Garcia, C.; Lopez Hernandez, J.; Simal Lozano, J. Gas Chromatographic Determination of the Fatty-Acid Content of Heat-Treated Green Beans. *J. Chromatogr A* **2000**, *891* (2), 367−370.
(94) Pessina, F.; Capasso, R.; Borrelli, F.; Aveta, T.; Buono, L.; Valacchi, G.; Fiorenzani, P.; Di Marzo, V.; Orlando, P.; Izzo, A. A. Protective Effect of Palmitoylethanolamide in a Rat Model of Cystitis. *J. Urol* **2015**, *193* (4), 1401−1408.
(95) Esposito, E.; Cuzzocrea, S. Palmitoylethanolamide in Homeostatic and Traumatic Central Nervous System Injuries. *CNS Neurol Disord Drug Targets* **2013**, *12* (1), 55−61.
(96) Ushakumari, S. R.; Latha, S.; Malleshi, N. G. The Functional Properties of Popped, Flaked, Extruded and Roller-Dried Foxtail Millet (Setaria Italica). *Int. J. Food Sci. Technol.* **2004**, *39* (9), 907−915.
(97) Yadav, G. P.; Dalbhagat, C. G.; Mishra, H. N. Effects of Extrusion Process Parameters on Cooking Characteristics and Physicochemical, Textural, Thermal, Pasting, Microstructure, and Nutritional Properties of Millet-Based Extruded Products: A Review. *Journal of Food Process Engineering* **2022**, *45*, e14106.
(98) Khattab, R. Y.; Arntfield, S. D.; Nyachoti, C. M. Nutritional Quality of Legume Seeds as Affected by Some Physical Treatments, Part 1: Protein Quality Evaluation. *LWT* **2009**, *42* (6), 1107−1112.
(99) Caballero, B.; Trugo, L.; Finglas, P. Encyclopedia of Food Sciences and Nutrition. *Academic* **2003**, 1498−1506.
(100) Shamkova, N. T.; Abdulhamid, A. M.; Aleshkevich, J. S. Change in the Amino Acid Composition of Bean Proteins during Hydrothermal Treatment. *AIP Conf Proc.* **2022**, *2467* (1), 070007.
(101) Nosworthy, M. G.; Medina, G.; Franczyk, A. J.; Neufeld, J.; Appah, P.; Utioh, A.; Frohlich, P.; House, J. D. Effect of Processing on the In Vitro and In Vivo Protein Quality of Beans (Phaseolus Vulgaris and Vicia Faba). *Nutrients 2018, Vol. 10, Page 671* **2018**, *10* (6), 671.
(102) Aremu, M. O.; Olaofe, O.; Basu, S. K.; Abdulazeez, G.; Acharya, S. N. *Processed Cranberry Bean (Phaseolus Coccineus L.) Seed Flour for the African Diet* **2010**, *90*, 719.
(103) Clemente, A.; Sanchez-Vioque, R.; Vioque, J.; Bautista, J.; Millan, F. *Effect of Cooking on Protein Quality of Chickpea (Cicer Arietinrcm) Seeds* **1998**, *62*, 1.
(104) Adeleye, O. O.; Awodiran, S. T.; Ajayi, A. O.; Ogunmoyela, T. F. Effect of High-Temperature, Short-Time Cooking Conditions on in Vitro Protein Digestibility, Enzyme Inhibitor Activity and Amino Acid Profile of Selected Legume Grains. *Heliyon* **2020**, *6* (11), No. e05419.
(105) Singh, S.; Gamlath, S.; Wakeling, L. Nutritional Aspects of Food Extrusion: A Review. *Int. J. Food Sci. Technol.* **2007**, *42* (8), 916−929.
(106) Marsolais, F.; Pajak, A.; Yin, F.; Taylor, M.; Gabriel, M.; Merino, D. M.; Ma, V.; Kameka, A.; Vijayan, P.; Pham, H.; Huang, S.; Rivoal, J.; Bett, K.; Hernández-Sebastià, C.; Liu, Q.; Bertrand, A.; Chapman, R. Proteomic Analysis of Common Bean Seed with Storage Protein Deficiency Reveals Up-Regulation of Sulfur-Rich Proteins and Starch and Raffinose Metabolic Enzymes, and down-Regulation of the Secretory Pathway. *J. Proteomics* **2010**, *73* (8), 1587−1600.
(107) Gharibzahedi, S. M. T.; Jafari, S. M. The Importance of Minerals in Human Nutrition: Bioavailability, Food Fortification, Processing Effects and Nanoencapsulation. *Trends Food Sci. Technol.* **2017**, *62*, 119−132.
(108) Redondo-Cuenca, A.; Pedrosa, M. M.; Sanz, M. D. T.; Alvarado López, A. N.; Garcia-Alonso, A. Influence of High-Pressure Processing on Nutritional Composition and Bioactive Compounds of Phaseolus Coccineus L. *J. Food Sci.* **2022**, *87* (12), 5289−5302.
(109) Lopez-Martinez, L. X. Bioactive Compounds of Runner Bean (Phaseolus Coccineus L.). In *Reference Series in Phytochemistry*; Springer Science and Business Media B.V.: 2021; pp 565−581. DOI: 10.1007/978-3-030-57415-4_31.
(110) Suárez Martínez, S. E.; Ferriz Martínez, R. A.; Campos Vega, R.; Elton Puente, J. E.; Torre Carbot, K. de la; García Gasca, T. Bean Seeds: Leading Nutraceutical Source for Human Health. *CyTA: Journal of food* **2016**, *14* (1), 131−137.
(111) Briones-Labarca, V.; Muñoz, C.; Maureira, H. Effect of High Hydrostatic Pressure on Antioxidant Capacity, Mineral and Starch Bioaccessibility of a Non Conventional Food: Prosopis Chilensis Seed. *Food Research International* **2011**, *44* (4), 875−883.
(112) Alonso, R.; Rubio, L. A.; Muzquiz, M.; Marzo, F. The Effect of Extrusion Cooking on Mineral Bioavailability in Pea and Kidney Bean Seed Meals. *Anim Feed Sci. Technol.* **2001**, *94* (1−2), 1−13.
(113) Rodríguez-Miranda, J.; Ramírez-Wong, B.; Vivar-Vera, M. A.; Solís-Soto, A.; Gómez-Aldapa, C. A.; Castro-Rosas, J.; Medrano-Roldan, H.; Delgado-Licon, E. Effect of Bean Flour Concentration (Phaseolus Vulgaris L.), Moisture Content and Extrusion Temperature on the Fuctional Properties of Aquafeeds. *Rev. Mex. Ing. Quim.* **2014**, *13* (3), 649−663.
(114) Arribas, C.; Cabellos, B.; Cuadrado, C.; Guillamón, E.; Pedrosa, M. M. Cooking Effect on the Bioactive Compounds, Texture, and Color Properties of Cold-Extruded Rice/Bean-Based Pasta Supplemented with Whole Carob Fruit. *Foods* **2020**, *9* (4), 415.
(115) Borijindakul, L.; Phimolsiripol, Y. Physicochemical and Functional Properties of Starch and Germinated Flours from Dolichos Lablab. *Food and Applied Bioscience Journal* **2013**, *1* (2), 69−80.
(116) Dzudie, T.; Hardy, J. Physicochemical and Functional Properties of Flours Prepared from Common Beans and Green Mung Beans. *J. Agric. Food Chem.* **1996**, *44* (10), 3029−3032.
(117) Aguilera Gutiérrez, Y. Harinas de Leguminosas Deshidratadas Caracterización Nutricional y Valoración de Sus Propiedades Tecnofuncionales; 2010.

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

(118) de la Rosa-Millán, J.; Heredia-Olea, E.; Perez-Carrillo, E.; Guajardo-Flores, D.; Serna-Saldívar, S. R. O. Effect of Decortication, Germination and Extrusion on Physicochemical and in Vitro Protein and Starch Digestion Characteristics of Black Beans (Phaseolus Vulgaris L.). *LWT* **2019**, *102*, 330−337.
(119) Lin, T.; Fernández-Fraguas, C. Effect of Thermal and High-Pressure Processing on the Thermo-Rheological and Functional Properties of Common Bean (Phaseolus Vulgaris L.) Flours. *LWT* **2020**, *127*, 109325.
(120) Aliette, G. Á. Procesamiento de Extrusión Para Obtener Harina Funcional de Frijol Tépari (Phaseolus Acutifolius) Con Valor Nutricional/Nutracéutico Alto. Optimización Del Proceso; Universidad Autónoma de Sinaloa: Culiacán, Sinaloa, 2019.
(121) Granito, M.; Brito, Y.; Torres, A. Chemical Composition, Antioxidant Capacity and Functionality of Raw and Processed Phaseolus Lunatus. *J. Sci. Food Agric* **2007**, *87* (15), 2801−2809.
(122) Lazou, A.; Krokida, M. Functional Properties of Corn and Corn-Lentil Extrudates. *Food Research International* **2010**, *43* (2), 609−616.
(123) Kadan, R. S.; Bryant, R. J.; Pepperman, A. B. Functional Properties of Extruded Rice Flours. *J. Food Sci.* **2003**, *68* (5), 1669−1672.
(124) Gujska, E.; Khan, K. Functional Properties of Extrudates from High Starch Fractions of Navy and Pinto Beans and Corn Meal Blended with Legume High Protein Fractions. *J. Food Sci.* **1991**, *56*, 431.
(125) Altan, A.; McCarthy, K. L.; Maskan, M. Effect of Extrusion Cooking on Functional Properties and in Vitro Starch Digestibility of Barley-Based Extrudates from Fruit and Vegetable by-Products. *J. Food Sci.* **2009**, *74* (2), E77−E86.
(126) Obatolu, V. A.; Cole, A. H. Functional Property of Complementary Blends of Soybean and Cowpea with Malted or Unmalted Maize. *Food Chem.* **2000**, *70* (2), 147−153.
(127) Batista, K. A.; Prudêncio, S. H.; Fernandes, K. F. Changes in the Biochemical and Functional Properties of the Extruded Hard-to-Cook Cowpea (Vigna Unguiculata L. Walp). *Int. J. Food Sci. Technol.* **2010**, *45* (4), 794−799.
(128) Jiang, Z.; Meng, Y.; Hou, C.; Gantumur, M. A.; Gao, Y.; Huang, Y.; Zhang, S.; Sun, Y.; Narantuya, S.; Mu, Z.; Hou, J. Extrusion for Reducing Malondialdehyde-Induced Whey Protein Isolate Oxidation in Relation with Its Physicochemical, Functional and Intro Digestive Properties. *Food Hydrocoll* **2023**, *142*, 108730.
(129) Heywood, A. A.; Myers, D. J.; Bailey, T. B.; Johnson, L. A. Functional Properties of Low-Fat Soy Flour Produced by an Extrusion-Expelling System. *J. Am. Oil Chem. Soc.* **2002**, *79* (12), 1249−1253.
(130) Farinon, B.; Molinari, R.; Costantini, L.; Merendino, N. The Seed of Industrial Hemp (Cannabis Sativa L.): Nutritional Quality and Potential Functionality for Human Health and Nutrition. *Nutrients 2020, Vol. 12, Page 1935* **2020**, *12* (7), 1935.
(131) Kong, X.; Li, Y.; Liu, X. A Review of Thermosensitive Antinutritional Factors in Plant-Based Foods. *J. Food Biochem* **2022**, *46* (9), No. e14199.
(132) Shang, R.; Wu, H.; Guo, R.; Liu, Q.; Pan, L.; Li, J.; Hu, Z.; Chen, C. The Diversity of Four Anti-Nutritional Factors in Common Bean. *Hortic Plant J.* **2016**, *2* (2), 97−104.
(133) Rathod, R. P.; Annapure, U. S. Effect of Extrusion Process on Antinutritional Factors and Protein and Starch Digestibility of Lentil Splits. *LWT - Food Science and Technology* **2016**, *66*, 114−123.
(134) Chaieb, I. Saponins as Insecticides: A Review. *Tunisian Journal of Plant Protection* **2010**, *5*, 39−50.
(135) Chaturvedi, S.; Hemamalini, R.; Khare, S. K. Effect of Processing Conditions on Saponin Content and Antioxidant Activity of Indian Varieties of Soybean (Glycine Max Linn.). *Ann. Phytomed.* **2012**, *1* (1), 62−68.
(136) Barakat, H.; Reim, V.; Rohn, S. Stability of Saponins from Chickpea, Soy and Faba Beans in Vegetarian, Broccoli-Based Bars Subjected to Different Cooking Techniques. *Food Research International* **2015**, *76* (P1), 142−149.
(137) Kowalski, R. J.; Medina-Meza, I. G.; Thapa, B. B.; Murphy, K. M.; Ganjyal, G. M. Extrusion Processing Characteristics of Quinoa (Chenopodium Quinoa Willd.) Var. Cherry Vanilla. *J. Cereal Sci.* **2016**, *70*, 91−98.
(138) Sánchez-Velázquez, O. A.; Ribéreau, S.; Mondor, M.; Cuevas-Rodríguez, E. O.; Arcand, Y.; Hernández-Alvarez, Á. J. Impact of Processing on the in Vitro Protein Quality, Bioactive Compounds, and Antioxidant Potential of 10 Selected Pulses. *Legume Science* **2021**, *3* (2), e88.
(139) Boua Boua, B.; Clinnanga Ouattara, D.; Traoré, L.; Akhanovna Mamyrbekova-Békro, J.; Békro, Y.-A. Effect of Domestic Cooking on the Total Phenolic, Flavonoid and Condensed Tannin Content from Plantain of Côte d'Ivoire. *Journal of Materials and Environmental Sciences* **2020**, *2020* (3), 396−403.
(140) Yasmin, A.; Zeb, A.; Khalil, A. W.; Paracha, G. M. U. D.; Khattak, A. B. Effect of Processing on Anti-Nutritional Factors of Red Kidney Bean (Phaseolus Vulgaris) Grains. *Food Bioproc Tech* **2008**, *1* (4), 415−419.
(141) Tchumou, M.; Kouangbe, M. A.; Goly, K. C.; Tano, K. Effect of Cooking Time on the Nutritional and Anti-Nutritional Properties of Red and Black Beans of Phaseolus Lunatus (L.) Consumed in South and East of Côte d'Ivoire. *GSC Biological and Pharmaceutical Sciences* **2023**, *22* (1), 269−281.
(142) Piergiovanni, A. R.; Pignone, D. Effect of Year-to-Year Variation and Genotype on Trypsin Inhibitor Level in Common Bean (Phaseolus Vulgaris L) Seeds. *J. Sci. Food Agric* **2003**, *83* (5), 473−476.
(143) Abbas, Y.; Ahmad, A. Impact of Processing on Nutritional and Antinutritional Factors of Legumes: A Review. *Annals. Food Science and Technology* **2018**, *19* (2), 199−215.
(144) Nikmaram, N.; Leong, S. Y.; Koubaa, M.; Zhu, Z.; Barba, F. J.; Greiner, R.; Oey, I.; Roohinejad, S. Effect of Extrusion on the Anti-Nutritional Factors of Food Products: An Overview. *Food Control* **2017**, *79*, 62−73.
(145) Sun, L.; Zhang, S.; Ju, H.; Bao, Z.; Lin, S. Tryptophan Targeted Pulsed Electric Field Treatment for Enhanced Immune Activity in Pine Nut Peptides. *J. Food Biochem* **2020**, *44* (6), No. e13224.
(146) Granito, M.; Paolini, M.; Pérez, S. Polyphenols and Antioxidant Capacity of Phaseolus Vulgaris Stored under Extreme Conditions and Processed. *LWT - Food Science and Technology* **2008**, *41* (6), 994−999.
(147) Abd El-Hady, E.A; Habiba, R.A Effect of Soaking and Extrusion Conditions on Antinutrients and Protein Digestibility of Legume Seeds. *LWT - Food Science and Technology* **2003**, *36* (3), 285−293.
(148) Sharma, K.; Ko, E. Y.; Assefa, A. D.; Ha, S.; Nile, S. H.; Lee, E. T.; Park, S. W. Temperature-Dependent Studies on the Total Phenolics, Flavonoids, Antioxidant Activities, and Sugar Content in Six Onion Varieties. *J. Food Drug Anal* **2015**, *23* (2), 243−252.
(149) Xu, E.; Wu, Z.; Jiao, A.; Long, J.; Li, J.; Jin, Z. Dynamics of Rapid Starch Gelatinization and Total Phenolic Thermomechanical Destruction Moderated via Rice Bio-Extrusion with Alpha-Amylase Activation. *RSC Adv.* **2017**, *7* (32), 19464−19478.
(150) Ragaee, S.; Seetharaman, K.; Abdel-Aal, E. S. M. The Impact of Milling and Thermal Processing on Phenolic Compounds in Cereal Grains. *Crit Rev. Food Sci. Nutr* **2014**, *54* (7), 837−849.
(151) Aquino-Bolaños, E. N.; García-Díaz, Y. D.; Chavez-Servia, J. L.; Carrillo-Rodríguez, J. C.; Vera-Guzmán, A. M.; Heredia-García, E. Anthocyanins, Polyphenols, Flavonoids and Antioxidant Activity in Common Bean (Phaseolus vulgaris L.) Landraces. *Emir J. Food Agric* **2016**, *28* (8), 581−588.
(152) Murador, D. C.; da Cunha, D. T.; de Rosso, V. V. Effects of Cooking Techniques on Vegetable Pigments: A Meta-Analytic Approach to Carotenoid and Anthocyanin Levels. *Food Research International* **2014**, *65* (PB), 177−183.
(153) Hu, Z.; Tang, X.; Zhang, M.; Hu, X.; Yu, C.; Zhu, Z.; Shao, Y. Effects of Different Extrusion Temperatures on Extrusion Behavior,

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX

Phenolic Acids, Antioxidant Activity, Anthocyanins and Phytosterols of Black Rice. *RSC Adv.* **2018**, *8* (13), 7123−7132.
(154) Korus, J.; Gumul, D.; Folta, M.; Barton, H. Antioxidant and Antiradical Activity of Raw and Extruded Common Beans. *Electronic Journal of Polish Agricultural Universities. Series Food Science and Technology* **2007**, *4* (10), 1−10.
(155) Anton, A. A.; Gary Fulcher, R.; 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* (4), 989−996.
(156) Salas-López, F.; Gutierrez-Dorado, R.; Milan-Carrillo, J.; Cuevas-Rodriguez, E. O.; Canizalez-Roman, V. A.; Leon-Sicairos, C. d. R.; Reyes-Moreno, C. Nutritional and Antioxidant Potential of a Desert Underutilized Legume - Tepary Bean (Phaseolus Acutifolius). Optimization of Germination Bioprocess. *Food Science and Technology (Brazil)* **2018**, *38*, 254−262.

https://doi.org/10.1021/acsfoodscitech.2c00416
ACS Food Sci. Technol. XXXX, XXX, XXX−XXX