1 **Effects of extrusion cooking on the chemical composition and**
2 **functional properties of dry **common** bean powders**

3 Yongfeng Ai¹, Karen A. Cichy^{2, 3}, Janice B. Harte¹, James D. Kelly³, and Perry K.W.
4 Ng^{1, *}

5 ¹ Department of Food Science and Human Nutrition, Michigan State University, East
6 Lansing, MI 48824

7 ² United States Department of Agriculture-Agricultural Research Service; Sugarbeet and
8 Bean Research Unit, East Lansing, MI 48824

9 ³ Department of Plant, Soil and Microbial Sciences, Michigan State University, East
10 Lansing, MI 48824

11 * Corresponding author. Tel.: +1 517 353 9605; Fax: +1 517 353 8963; E-mail address:
12 ngp@msu.edu.

13

Abstract

The impact of extrusion cooking on the chemical composition and functional properties of bean powders from four common bean varieties was investigated. The raw bean powders were extruded under eight different conditions, and the extrudates were then dried and ground (particle size ≤ 0.5 mm). Compared with corresponding non-extruded (raw) bean powders (particle size ≤ 0.5 mm), the extrusion treatments did not substantially change the protein and starch contents of the bean powders and showed inconsistent effects on the sucrose, raffinose and stachyose contents. The extrusion cooking did cause complete starch gelatinization and protein denaturation of the bean powders and thus changed their pasting properties and solvent-retention capacities. The starch digestibilities of the cooked non-extruded and cooked extruded bean powders were comparable. The extruded bean powders displayed functional properties similar to those of two commercial bean powders.

Keywords

Common beans; extrusion cooking; bean powder; chemical composition; functional properties; starch digestibility

1. Introduction

Common beans (*Phaseolus vulgaris* L.) are a group of plants that fix atmospheric nitrogen and are included among the pulses. Dry seeds of common beans are cooked and consumed as staples by large populations in Latin America, Africa and South Asia. Dry common beans have much higher contents of protein (20-22%) and dietary fiber (23-32%) than cereal grains (8-17% and 3-16%, respectively) (Costa, Queiroz-Monici, Reis, & de Oliveira, 2006; Oomah, Patras, Rawson, Singh, & Compos-Vega, 2011; Tacer-Caba, Nilufer-Erdil, & Ai, 2015). Dry common beans are also a good source of vitamins, minerals and phytochemicals (e.g., polyphenols) (Oomah, Patras, Rawson, Singh, & Compos-Vega, 2011). The consumption of beans is potentially beneficial for human health, including lowering postprandial glucose and insulin responses, preventing obesity, reducing the risk of cardiovascular diseases and preventing cancers (Hutchins, Winham, & Thompson, 2012; Leterme, 2002). The health benefits of beans have fostered growing interests in increasing the consumption of beans as a part of human diets (Leterme, 2002).

The consumption of beans in the United States is low, with only about 8% of the population consuming beans, peas or lentils daily (Mitchell, Lawrence, Hartman, & Curran, 2009). On average, about 3 kg beans/capita are consumed annually, which is much less than what is recommended (Lucier, Lin, Allshouse, & Kantor, 2000).

Important factors that hinder the utilization of beans in human diets include: (1) flatulence and general gastrointestinal discomfort associated with raffinose family oligosaccharides such as raffinose, stachyose and verbascose; (2) undesirable beany flavor; and (3) long cooking time. Research has been undertaken to use different methods, including soaking prior to cooking, dehulling, germination, fermentation and a

combination of different methods, to reduce the impacts of those adverse factors on the food applications of beans (Granito, Frias, Doblado, Guerra, Champ, & Vidal-Valverde, 2002; Sharma & Sehgal, 1992).

One effective approach to enhancing the food applications of beans is to process beans into various value-added food ingredients. Among all the processing technologies used to modify the functional properties of food ingredients, extrusion is one widely used method, particularly for cereal-based ingredients. Extrusion is a continuous process in which a material is cooked by a combination of heat, shear and pressure. Extrusion has been utilized to effectively alter the functional properties (Owusuansah, Vandervoort, & Stanley, 1983; Sarawong, Schoenlechner, Sekiguchi, Berghofer, & Ng, 2014) and improve the nutritional value (Batista, Prudencio, & Fernandes, 2010; Marzo, Milagro, Urdaneta, Barrenetxe, & Ibanez, 2011) of flours and starches from different botanical sources.

The objectives of the current study were to develop novel food ingredients from four varieties of common beans using extrusion technology and to examine how the extrusion cooking affected the chemical composition and functional properties of the bean powders. In this study, edible dry beans of four varieties were ground, extruded under eight different conditions, dried and ground again, and evaluative results were obtained and compared with those of non-extruded bean counterparts and two commercial bean powders. The information from the study would be valuable to understand how extrusion technology can be used to modify the functional properties of bean-based ingredients for value-added food applications.

2. Materials and Methods

2.1. Materials

Common beans of four distinct market classes were obtained from different sources: Zorro Black from Heritage Bean & Grain Inc. (Alma, MI, U.S.A.); Medalist Navy from Michigan Bean Commission (Frankenmuth, MI, U.S.A.); Merlot Small Red from Archer Daniels Midland Company (ADM, Chicago, IL, U.S.A.); and Fuji Otebo from Michigan State University Dry Bean Breeding and Genetics Program (East Lansing, MI, U.S.A.). Two commercial bean powders, ADM Navy (Product Code: 492001) and ADM Black (Product Code: 292001), were gifts from ADM (Chicago, IL, U.S.A.). Soft wheat flour (MSU Line F2019) was obtained from Michigan State University Wheat Testing Program (East Lansing, MI, U.S.A.). Total Starch Assay Kit and D-Glucose Assay Kit were purchased from Megazyme International Ireland Ltd. (Wicklow, Ireland). Vegetable oil (Wesson Brand) was from ConAgra Foods Inc. (Omaha, NE, U.S.A.). Other chemicals were obtained from Sigma-Aldrich Co. (St. Louis, MO, U.S.A.) or Thermo Fisher Scientific Inc. (Pittsburgh, PA, U.S.A.) and used as received.

2.2. Preparation of raw bean powders

Edible dry beans were ground using a Thomas Wiley[®] Mill (Model 4, Thomas Scientific Inc., Swedesboro, NJ, U.S.A.) to pass through a screen with 1.0- or 0.5-mm pore size to prepare coarse (particle size ≤ 1.0 mm) or fine (particle size ≤ 0.5 mm) raw (i.e., non-extruded) bean powders.

2.3. Extrusion of coarse raw bean powders

The coarse raw bean powders were extruded using a co-rotating twin-screw extruder (Model MP19T2-25, APV Baker Inc., Grand Rapids, MI, U.S.A.) with a 19 mm barrel diameter, a L/D ratio of 25:1, and a 3 mm diameter exit die. The screw configuration was set the same as described by Kim, Tanhehco and Ng (2006), and the extrusion was carried out under eight different conditions as shown in **Table 1**. Two barrel temperature profiles were selected: 40, 60, 80, 120, 120°C or 40, 60, 80, 120, 140°C, from Zone 1 (feed port) to Zone 5 (exit die). Feed rate of the powder into the extruder was controlled at 2 kg/h (as-is weight) using a volumetric feeder (Model K2V-T20, Coperion K-Tron Pitman Inc., Sewell, NJ, U.S.A.). Screw speed of the extruder was set at 100 or 200 rpm. Total moisture content of the powder in the extruder was adjusted to 25 or 30% using a water pump (Brook Crompton E2 Metripump, Hudders Field, England). During the extrusion, percentage motor load and die pressure were recorded (**Table 1**). Specific mechanical energy (SME) was calculated as: $SME (Wh \cdot kg^{-1}) = [(test\ screw\ speed / rated\ screw\ speed) \times (\% \text{ motor load} \times rated\ motor\ power) / feed\ rate] / 100$, where rated screw speed is 500 rpm, rated motor power is 2.0 kW, and feed rate ($kg \cdot h^{-1}$) is the total mass input of feed and water (Koksel, Ryu, Basman, Demiralp, & Ng, 2004). The extrudates were manually cut (~4 cm length), cooled to room temperature, and dried at 50°C overnight. The dried extrudates were ground using the same mill to pass through a screen with 0.5-mm pore size to prepare extruded bean powders, which were stored in Ziplock bags at room temperature prior to analyses. The non-extruded (raw, as the control) and extruded bean powders passing through the same screen (0.5-

mm pore size) were used in the following analyses, and the two commercial bean powders (ADM Navy and ADM Black) were also included for comparison.

2.4. Proximate analyses

Total nitrogen contents of the bean powders were analyzed using the Dumas combustion method in accordance with AOAC Method 968.06 (AOAC, 2000). The protein content was calculated by multiplying the total nitrogen content by a conversion factor of 6.25. Starch contents of the bean powders were analyzed using the Megazyme Total Starch Assay Kit. Sugars of the bean powders were extracted using 80% (v/v) ethanol and then eluted and quantified using an HPLC method (Kuo, Vanmiddlesworth, & Wolf, 1988). The separation of sugars was achieved using a Sugar-Pak I Guard-Pak Insert and a Sugar-Pak I column (Waters Corporation, Milford, MA, U.S.A.) and the elution was monitored using a refractive index detector (Model 2414, Waters Corporation, Milford, MA, U.S.A.). Contents of sucrose, raffinose and stachyose were determined. All analyses were performed in duplicate, and the data were calculated on a dry basis (db).

2.5. Thermal properties

Thermal properties of the bean powders were analyzed using a differential scanning calorimeter (DSC, Model Q100, TA Instruments Inc., New Castle, DE, U.S.A.). The powder (~2 mg) was hydrated with distilled water (~3×, w/w) and sealed in an aluminum hermetic pan. After equilibrating at room temperature for at least 2 h, the sample was scanned from 10°C to 120°C at a rate of 10°C/min. A sealed empty aluminum hermetic pan was used as the reference. The onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy change (ΔH) of the thermal

transitions were determined using Universal Analysis 2000 Software (TA Instruments Inc., New Castle, DE, U.S.A.), and ΔH was calculated on a dry basis for each powder sample. The analysis was performed in duplicate.

2.6. Pasting properties

Pasting properties of the bean powders were analyzed using a Rapid Visco Analyzer (RVA, Model 4, Newport Scientific Pty. Ltd., Warriewood, NSW, Australia). The powder (3.01 g, db) was properly suspended in distilled water to reach a total weight of 28.5 g (10.6% dry solids content) and analyzed using Standard Method 2 (STD2) according to the Thermocline Software provided with the instrument. The analysis was performed in duplicate.

2.7. Water-holding, 5% lactic-acid-retention and oil-binding capacities

Water-holding capacity (WHC) and 5% lactic-acid-retention capacity (5% LARC) of the bean powders were analyzed following AACC Method 56-11 (AACC, 2000). Oil-binding capacity (OBC) was determined following a previously reported method (Ahn, Kim, & Ng, 2005) using vegetable oil (Wesson Brand). The analyses were performed in duplicate and the results were calculated on a dry basis.

2.8. Starch digestibility

Starch digestibility of non-extruded and extruded bean powders after cooking in boiling water was analyzed using the Englyst Method (Englyst, Kingman, & Cummings, 1992) with minor modifications. A calculated amount of bean powder containing 0.6 g starch (db) was precisely weighed into a 50-mL test tube, suspended in 15.0 mL of

distilled water, and cooked in a boiling-water bath for 15 min with magnetic stirring. After equilibrating the cooked sample in a shaking water-bath (Model SW22, Julabo Inc., Allentown, PA, U.S.A.) at 37°C and 160 rpm for 30 min, 5.0 mL of sodium acetate buffer (0.4 M, pH 5.2, containing 0.08% NaN₃) was added to the test tube, followed by the addition of 50.0 mg guar gum and 5 glass beads. A mixture of porcine pancreatic extract and amyloglucosidase was added to hydrolyze the cooked sample in the same shaking water-bath, and the concentrations of glucose released at time intervals of 20 and 120 min were determined using the Megazyme D-Glucose Assay Kit containing glucose oxidase and peroxidase (GOPOD) (Li, Jiang, Campbell, Blanco, & Jane, 2008). Rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) contents of the cooked non-extruded and cooked extruded bean powder samples were calculated on a dry basis of bean powder using the following equations (Englyst, Kingman, & Cummings, 1992):

$$\%RDS = (G_{20} \times 0.9) / (\text{dry mass of bean powder}) \times 100;$$

$$\%SDS = [(G_{120} - G_{20}) \times 0.9] / (\text{dry mass of bean powder}) \times 100;$$

$$\%RS = \%TS - (\%RDS + \%SDS)$$

G_{20} = total mass of glucose released at 20 min; G_{120} = total mass of glucose released at 120 min; %TS = total starch content as a percent of bean powder.

Soft wheat flour (MSU Line F2019, containing 75.5% starch) was analyzed following the same method for comparison. The analysis was performed in duplicate.

2.9. Statistical analysis

Statistical differences between the values of non-extruded and extruded bean powders of the same variety were evaluated using one-way ANOVA and multiple comparison test with Tukey's adjustment at $p < 0.05$. The statistical analyses were conducted using IBM SPSS Statistics (Version 21.0, IBM Corporation, Armonk, NY, U.S.A.)

3. Results and Discussion

3.1. Extrusion of coarse raw bean powders

Larger SME input was found with a lower feed moisture and a higher screw speed (**Table 1**), which is consistent with the data from other studies using twin-screw extrusion (Bhattacharya, Sudha, & Rahim, 1999; Koksel, Ryu, Basman, Demiralp, & Ng, 2004). A lower feed moisture could be responsible for a higher viscosity of the material in the barrel, which generally resulted in an increased percentage motor load (**Table 1**) and thus a larger SME. SME is proportional to the screw speed according to the equation used for the calculation (**Section 2.3**). In general, a higher die pressure was observed for a lower barrel temperature, a lower feed moisture and a lower screw speed (**Table 1**), all of which are in accordance with previous data (Hsieh, Grenus, Hu, & Huff, 1993; Koksel, Ryu, Basman, Demiralp, & Ng, 2004). Die pressure is a result of the constrained flow of the dough mass through the die opening and its consequent build-up behind the die (Hsieh, Grenus, Hu, & Huff, 1993). Die pressure tends to decrease with a less viscous dough because it can pass through the opening more easily. The viscosity of a dough usually decreases with a higher barrel temperature and feed moisture. The viscosity of a dough is

also reduced by a higher screw speed because a greater shearing force is imparted, causing more severe disintegration of starch granules and degradation of starch molecules (Cai, Diosady, & Rubin, 1995; Owusuansah, Vandervoort, & Stanley, 1983).

Consequently, the die pressure tends to be negatively associated with barrel temperature, feed moisture and screw speed, and results shown in **Table 1** are consistent with this.

3.2. Protein, starch and soluble sugar contents of non-extruded and extruded bean powders

Non-extruded Fuji Otebo powder had the highest protein content (28.1%), followed by Merlot Small Red (22.2%) and Medalist Navy (21.7%), and then Zorro Black powder, which displayed the smallest value (21.5%, **Table 2**). In general, the extrusion under different conditions slightly reduced the protein contents of the bean powders of all the four varieties. The protein content of ADM Navy powder (22.6%) was comparable to those of Medalist Navy (20.8-22.5%) and Merlot Small Red (20.7-22.2%) powders, and the value of ADM Black powder (24.8%) was slightly lower than those of Fuji Otebo powders (26.8-28.1%) but higher than those of the other three varieties.

Among the non-extruded bean powders, Merlot Small Red had the highest starch content (42.8%), followed by Medalist Navy (41.8%), Zorro Black (39.5%) and Fuji Otebo (39.3%) (**Table 2**). Compared with their respective non-extruded bean powders, extruded Merlot Small Red and Fuji Otebo powders had slightly lower starch contents. For Zorro Black and Medalist Navy, extrusion did not result in a clear trend in starch contents. The two commercial bean powders, ADM Navy (42.1%) and ADM Black (40.2%), displayed starch contents comparable to those of Zorro Black (37.6-42.6%),

Medalist Navy (41.1-44.0%) and Merlot Small Red (39.0-42.8%) powders, but greater than those of Fuji Otebo powders (35.3-39.3%).

Similar to the results of starch content, extrusion did not display substantial influence on the sucrose contents of Zorro Black, Merlot Small Red and Fuji Otebo powders. But the extrusion treatments appeared to increase the sucrose content of Medalist Navy powders. ADM Navy and ADM Black bean powders exhibited lower sucrose contents than most of the non-extruded and extruded bean powders.

Raffinose and stachyose are oligosaccharides commonly found in beans that cause flatulence and general gastrointestinal discomfort after consumption. For all four bean varieties, extrusion significantly reduced the raffinose contents but increased the stachyose contents. Extrusion cooking has been reported to decrease the concentrations of raffinose and/or stachyose in navy beans, pinto beans and peas (Borejszo & Khan, 1992; Frias, Giacomino, Penas, Pellegrino, Ferreyra, Apro, et al., 2011; Kelkar, Siddiq, Harte, Dolan, Nyombaire, & Suniaga, 2012). However, controversial results have been shown in another study and the effects appeared to be dependent upon the varieties of the pulse (Berrios, Morales, Camara, & Sanchez-Mata, 2010). The discrepancies in the data of different studies suggest that special attention should be paid to the processing conditions and the pulse varieties when extrusion cooking is utilized to decrease the contents of the flatulence-inducing raffinose family oligosaccharides. Furthermore, any pre-treatments, such as soaking prior to extrusion, could also play a role in decreasing these oligosaccharides in extruded samples (Kelkar, Siddiq, Harte, Dolan, Nyombaire, & Suniaga, 2012). The ADM Navy and ADM Black bean powders had raffinose contents much lower than those of the non-extruded samples but similar to those of the extruded

samples, whereas the stachyose contents of the two commercial bean powders were higher than those of the non-extruded samples but similar to or lower than those of the extruded samples.

3.3. Thermal properties of bean powders

DSC thermograms of non-extruded bean powders showed two endothermic peaks and the results are summarized in **Table 3**. The first peak (Peak I) mainly corresponds to starch gelatinization, and the second peak (Peak II) mainly corresponds to protein denaturation and amylose-lipid complex dissociation (Chung, Liu, Pauls, Fan, & Yada, 2008; Wright & Boulter, 1980). For Peak I, T_o of the four non-extruded bean powders varied between 69.6°C (Fuji Otebo) and 75.8°C (Zorro Black), whereas their T_p and T_c values were similar. The ΔH of Peak I ranged from 3.6 J/g (Fuji Otebo) to 5.6 J/g (Zorro Black). Following the same trend of T_o in Peak I, Zorro Black and Merlot Small Red powders displayed higher T_o values than the other two samples in Peak II. The conclusion of the endothermic transitions occurred in a temperature range of 104.6°C (Fuji Otebo) to 113.5°C (Merlot Small Red). Compared with Peak I, the ΔH values of Peak II were much smaller, varying between 0.5 J/g (Zorro Black) and 1.9 J/g (Merlot Small Red). The differences in the thermal properties of the raw bean powders suggest that different cooking conditions are needed in order to fully cook the bean powders during food processing.

For all the bean powders extruded under different conditions, both Peaks I and II disappeared for all the four varieties (data not shown), indicating that the extrusion cooking caused complete starch gelatinization and protein denaturation. The DSC

thermograms of ADM Navy and ADM Black bean powders did not show those two endothermic peaks (data not shown), which indicated that complete starch gelatinization and protein denaturation occurred during the processing of those two commercial samples.

3.4. Pasting properties of bean powders

The pasting profiles of the non-extruded and extruded bean powders did not show peak and breakdown viscosities (**Figure 1**), which is consistent with the results of other studies on bean powders (Chung, Liu, Pauls, Fan, & Yada, 2008) but different from those of cereal flours analyzed using RVA (Mira, Eliasson, & Persson, 2005; Xie, Chen, Duan, Zhu, & Liao, 2008). The differences could be attributed to the much lower starch contents (35.3-44.0%) and higher protein contents (19.6-28.1%) of the bean powders (**Table 2**) than cereal flours (~70% starch and 7-14% protein, db). The starch granules could be embedded in the protein matrices of the bean powders, which hindered the hydration and restricted the swelling of starch granules for viscosity development (Chung, Liu, Pauls, Fan, & Yada, 2008; Otto, Baik, & Czuchajowska, 1997).

For the non-extruded bean powders, Merlot Small Red and Medalist Navy powders had greater final viscosities than Zorro Black and Fuji Otebo powders, which could be partly explained by the higher starch contents of the former two bean samples (**Table 2**). Compared with the non-extruded bean counterparts, the extruded bean powders developed a higher viscosity in the initial low temperature range (< 80°C), which could result from the fact that the starch was already gelatinized and the protein denatured in the extruded bean powders (**Section 3.3.**). Thus, the extruded bean powders

could be more readily hydrated for viscosity development at a low temperature. The final viscosities of the extruded bean powders, however, were much lower than those of the corresponding non-extruded bean powders. The lower final viscosities of the extruded bean powders could be attributed to the loss of integrity of starch granules and the degradation of starch molecules during the extrusion cooking (Cai, Diosady, & Rubin, 1995; Owusuansah, Vandervoort, & Stanley, 1983). The decrease in the final viscosities of the bean powders after extrusion is in good agreement with previous studies (Koksel, Ryu, Ozboy-Ozbas, Basman, & Ng, 2003; Sarawong, Schoenlechner, Sekiguchi, Berghofer, & Ng, 2014). However, differences in the extrusion conditions did not result in any clear trends in the pasting properties of the bean powders. ADM Navy and ADM Black bean powders exhibited lower viscosities than the non-extruded and extruded bean powders of all the four varieties. The very low viscosities of those two commercial bean powders might be caused by the processing methods applied to manufacture the products. The low viscosities of the ADM Navy and ADM Black bean powders and the extruded samples suggest that they can be incorporated into food formulations at a relatively high percentage without substantially increasing the viscosity.

3.5. Water-holding, 5% lactic-acid-retention and oil-binding capacities of bean powders

In comparison with the non-extruded bean counterparts, the extruded bean powders exhibited significantly higher WHC and 5% LARC but lower OBC (**Figure 2**). This could partly be ascribed to the starch gelatinization caused by extrusion cooking (**Section 3.3.**), which led to the exposure of more hydroxyl groups and enhanced the hydrophilic properties of the extruded bean powders. The greater WHC of the extruded

bean powders could also explain their higher viscosities than the non-extruded bean counterparts in the initial low temperature range ($< 80^{\circ}\text{C}$) as shown in **Figure 1**.

Each of the bean powders possessed a WHC close to its respective 5% LARC (**Figure 2, A and B**), which is a different pattern than that found for WHC and 5% LARC of wheat flour. Wheat flour has a 5% LARC about 1.8-2.6 times that of WHC because the interactions between lactic acid and gluten facilitate the swelling of the gluten network (Guttieri, Bowen, Gannon, O'Brien, & Souza, 2001; Kweon, Slade, & Levine, 2011; Nishio, Oikawa, Haneda, Seki, Ito, Tabiki, et al., 2009). The similar values of WHC and 5% LARC for each of the bean powders suggest that the proteins in the bean powders do not have the same properties as gluten in terms of interacting with lactic acid. The two commercial bean powders, ADM Navy and ADM Black, possessed WHC, 5% LARC and OBC values closer to those of the extruded bean powders in the present study, which is in accordance with the complete starch gelatinization and protein denaturation of those bean powders as revealed by DSC (**Section 3.3**).

3.6. Starch digestibility of cooked bean powders

For the cooked non-extruded bean powders, Medalist Navy displayed a slightly larger RDS content (34.5%) and a smaller RS content (5.0%) than the other samples (**Table 4**), suggesting a greater susceptibility of the starch in that bean sample to the enzymatic hydrolysis. Fuji Otebo powder, containing 31.1% RDS and 6.9% RS, appeared to have the lowest starch digestibility. In comparison with the cooked non-extruded bean powders, starch digestibilities of the cooked extruded bean powders were not substantially altered. The results are in disagreement with those reported before, in which

extrusion considerably increased the starch digestibilities of bean powders (Alonso, Aguirre, & Marzo, 2000; Masoero, Pulimeno, & Rossi, 2005). The discrepancies in the findings could be explained by the fact that the non-extruded (raw) and extruded bean powder samples were cooked before starch hydrolysis in the current study, but were used for starch hydrolysis without cooking in previous studies (Alonso, Aguirre, & Marzo, 2000; Masoero, Pulimeno, & Rossi, 2005). When bean powders are utilized as ingredients to prepare food products, starch will probably be gelatinized during the processing. Therefore, the data obtained from our study should fairly accurately reflect the starch digestibility of the bean powders in food applications.

The cooked ADM Navy bean powder displayed a slightly lower RS content (3.8%) than most of the cooked extruded bean powders (3.7-6.6%), but the cooked ADM Black bean powder showed a value (5.5%) similar to those of the other samples. All the bean powders contained substantially less RDS and more RS than the soft wheat flour sample after cooking (**Table 4**). Because starchy foods with less RDS but more RS can provide health benefits to humans (Birt, Boylston, Hendrich, Jane, Hollis, Li, et al., 2013), bean powder could be a valuable food ingredient with respect to carbohydrate nutrition and human health.

4. Conclusions

The eight different extrusion treatments did not considerably alter the protein and starch contents of the bean powders and yielded inconsistent impacts on the sucrose, raffinose and stachyose contents. The extrusion cooking resulted in complete starch

gelatinization and protein denaturation of the bean powders, which caused changes in their pasting properties and solvent-retention capacities. The starch digestibilities of the cooked non-extruded and cooked extruded bean powders were similar, but all the bean samples had substantially lower RDS and higher RS contents than those of the cooked soft wheat flour. The chemical composition, physical properties and starch digestibilities of the two commercial bean powders were, in general, comparable to those of the extruded bean powders. Extrusion cooking can be used to prepare bean-based food ingredients with unique functional properties and a high nutritional value.

Acknowledgements

The authors are grateful for the financial support from the Michigan Department of Agriculture & Rural Development Strategic Growth Initiative and the Michigan Bean Commission.

References

- AACC. (2000). Approved Methods of the AACC, 10th Ed. *American Association of Cereal Chemists: St. Paul, Minnesota.*
- Ahn, H. J., Kim, J. H., & Ng, P. K. W. (2005). Functional and thermal properties of wheat, barley and soy flours and their blends treated with a microbial transglutaminase. *Journal of Food Science*, 70(6), C380-C386.
- Alonso, R., Aguirre, A., & Marzo, F. (2000). Effects of extrusion and traditional processing methods on antinutrients and in vitro digestibility of protein and starch in faba and kidney beans. *Food Chemistry*, 68(2), 159-165.
- AOAC. (2000). Official Methods of Analysis, 17th Ed. W. Horwitz, ed. *Association of Analytical Communities International: Gaithersburg, MD.*
- Batista, K. A., Prudencio, S. H., & Fernandes, K. F. (2010). Changes in the functional properties and antinutritional factors of extruded hard-to-cook common beans (*Phaseolus vulgaris*, L.). *Journal of Food Science*, 75(3), C286-C290.
- Berrios, J. D., Morales, P., Camara, M., & Sanchez-Mata, M. C. (2010). Carbohydrate composition of raw and extruded pulse flours. *Food Research International*, 43(2), 531-536.
- Bhattacharya, S., Sudha, M. L., & Rahim, A. (1999). Pasting characteristics of an extruded blend of potato and wheat flours. *Journal of Food Engineering*, 40(1-2), 107-111.
- Birt, D. F., Boylston, T., Hendrich, S., Jane, J. L., Hollis, J., Li, L., McClelland, J., Moore, S., Phillips, G. J., Rowling, M., Schalinske, K., Scott, M. P., & Whitley, E. M. (2013).

399 Resistant starch: Promise for improving human health. *Advances in Nutrition*, 4(6), 587-
400 601.

401 Borejszo, Z., & Khan, K. (1992). Reduction of flatulence-causing sugars by high
402 temperature extrusion of pinto bean high starch fractions. *Journal of Food Science*, 57(3),
403 771-777.

404 Cai, W., Diosady, L. L., & Rubin, L. J. (1995). Degradation of wheat starch in a twin-
405 screw extruder. *Journal of Food Engineering*, 26(3), 289-300.

406 Chung, H. J., Liu, Q., Pauls, K. P., Fan, M. Z., & Yada, R. (2008). In vitro starch
407 digestibility, expected glycemic index and some physicochemical properties of starch and
408 flour from common bean (*Phaseolus vulgaris* L.) varieties grown in Canada. *Food*
409 *Research International*, 41(9), 869-875.

410 Costa, G. E. D., Queiroz-Monici, K. D. S., Reis, S. M. P. M., & de Oliveira, A. C. (2006).
411 Chemical composition, dietary fibre and resistant starch contents of raw and cooked pea,
412 common bean, chickpea and lentil legumes. *Food Chemistry*, 94(3), 327-330.

413 Englyst, H. N., Kingman, S. M., & Cummings, J. H. (1992). Classification and
414 measurement of nutritionally important starch fractions. *European Journal of Clinical*
415 *Nutrition*, 46, S33-S50.

416 Frias, J., Giacomino, S., Penas, E., Pellegrino, N., Ferreyra, V., Apro, N., Carrion, M. O.,
417 & Vidal-Valverde, C. (2011). Assessment of the nutritional quality of raw and extruded
418 *Pisum sativum* L. var. laguna seeds. *Lwt-Food Science and Technology*, 44(5), 1303-
419 1308.

420 Granito, M., Frias, J., Doblado, R., Guerra, M., Champ, M., & Vidal-Valverde, C. (2002).
 421 Nutritional improvement of beans (*Phaseolus vulgaris*) by natural fermentation.
 422 *European Food Research and Technology*, 214(3), 226-231.

423 Guttieri, M. J., Bowen, D., Gannon, D., O'Brien, K., & Souza, E. (2001). Solvent
 424 retention capacities of irrigated soft white spring wheat flours. *Crop Science*, 41(4),
 425 1054-1061.

426 Hsieh, F., Grenus, K. M., Hu, L., & Huff, H. E. (1993). Twin-screw extrusion of rice
 427 flour with salt and sugar. *Cereal Chemistry*, 70(5), 493-498.

428 Hutchins, A. M., Winham, D. M., & Thompson, S. V. (2012). Phaseolus beans: impact
 429 on glycaemic response and chronic disease risk in human subjects. *British Journal of*
 430 *Nutrition*, 108, S52-S65.

431 Kelkar, S., Siddiq, M., Harte, J. B., Dolan, K. D., Nyomba, G., & Suniaga, H. (2012).
 432 Use of low-temperature extrusion for reducing phytohemagglutinin activity (PHA) and
 433 oligosaccharides in beans (*Phaseolus vulgaris*) cv. Navy and Pinto. *Food Chemistry*,
 434 134(4), 1636-1639.

435 Kim, J. H., Tanhehco, E. J., & Ng, P. K. W. (2006). Effect of extrusion conditions on
 436 resistant starch formation from pastry wheat flour. *Food Chemistry*, 99(4), 718-723.

437 Koksel, H., Ryu, G. H., Basman, A., Demiralp, H., & Ng, P. K. W. (2004). Effects of
 438 extrusion variables on the properties of waxy hulless barley extrudates. *Nahrung-Food*,
 439 48(1), 19-24.

440 Koksel, H., Ryu, G. H., Ozboy-Ozbas, B., Basman, A., & Ng, P. K. W. (2003).
 441 Development of a bulgur-like product using extrusion cooking. *Journal of the Science of*
 442 *Food and Agriculture*, 83(7), 630-636.

443 Kuo, T. M., Vanmiddlesworth, J. F., & Wolf, W. J. (1988). Content of raffinose
 444 oligosaccharides and sucrose in various plant seeds. *Journal of Agricultural and Food*
 445 *Chemistry*, 36(1), 32-36.

446 Kweon, M., Slade, L., & Levine, H. (2011). Solvent retention capacity (SRC) testing of
 447 wheat flour: Principles and value in predicting flour functionality in different wheat-
 448 based food processes and in wheat breeding-A review. *Cereal Chemistry*, 88(6), 537-552.

449 Leterme, P. (2002). Recommendations by health organizations for pulse consumption.
 450 *British Journal of Nutrition*, 88, S239-S242.

451 Li, L., Jiang, H. X., Campbell, M., Blanco, M., & Jane, J. L. (2008). Characterization of
 452 maize amylose-extender (ae) mutant starches. Part I: Relationship between resistant
 453 starch contents and molecular structures. *Carbohydrate Polymers*, 74(3), 396-404.

454 Lucier, G., Lin, B. H., Allshouse, J., & Kantor, L. S. (2000). Factors affecting dry bean
 455 consumption in the United States. *Small*, 19, 2-5.

456 Marzo, F., Milagro, F. I., Urdaneta, E., Barrenetxe, J., & Ibanez, F. C. (2011). Extrusion
 457 decreases the negative effects of kidney bean on enzyme and transport activities of the rat
 458 small intestine. *Journal of Animal Physiology and Animal Nutrition*, 95(5), 591-598.

459 Masoero, F., Pulimeno, A. M., & Rossi, F. (2005). Effect of extrusion, expansion and
 460 toasting on the nutritional value of peas, faba beans and lupins. *Italian Journal of Animal*
 461 *Science*, 4(2), 177-189.

462 Mira, I., Eliasson, A. C., & Persson, K. (2005). Effect of surfactant structure on the
 463 pasting properties of wheat flour and starch suspensions. *Cereal Chemistry*, 82(1), 44-52.

464 Mitchell, D. C., Lawrence, F. R., Hartman, T. J., & Curran, J. M. (2009). Consumption of
 465 dry beans, peas, and lentils could improve diet quality in the US population. *Journal of*
 466 *the American Dietetic Association*, 109(5), 909-913.

467 Nishio, Z., Oikawa, H., Haneda, T., Seki, M., Ito, M., Tabiki, T., Yamauchi, H., & Miura,
 468 H. (2009). Influence of amylose content on cookie and sponge cake quality and solvent
 469 retention capacities in wheat flour. *Cereal Chemistry*, 86(3), 313-318.

470 Oomah, B. D., Patras, A., Rawson, A., Singh, N., & Compos-Vega, R. (2011). Chemistry
 471 of Pulses. In B. K. Tiwari, A. Gowen & B. McKenna (Eds.), *Pulse Food: Processing,*
 472 *Quality and Nutraceutical Applications*, (pp. 9-55). Burlington, MA: Academic Press.

473 Otto, T., Baik, B. K., & Czuchajowska, Z. (1997). Microstructure of seeds, flours, and
 474 starches of legumes. *Cereal Chemistry*, 74(4), 445-451.

475 Owusuansah, J., Vandervoort, F. R., & Stanley, D. W. (1983). Physicochemical changes
 476 in cornstarch as a function of extrusion variables. *Cereal Chemistry*, 60(4), 319-324.

477 Sarawong, C., Schoenlechner, R., Sekiguchi, K., Berghofer, E., & Ng, P. K. W. (2014).
 478 Effect of extrusion cooking on the physicochemical properties, resistant starch, phenolic
 479 content and antioxidant capacities of green banana flour. *Food Chemistry*, 143, 33-39.

480 Sharma, A., & Sehgal, S. (1992). Effect of processing and cooking on the antinutritional
 481 factors of faba bean (*Vicia faba*). *Food Chemistry*, 43(5), 383-385.

482 Tacer-Caba, Z., Nilufer-Erdil, D., & Ai, Y. (2015). Chemical Composition of Cereals and
 483 Their Products. In P. C. K. Cheung & B. M. Mehta (Eds.), *Handbook of Food Chemistry*).
 484 Berlin Heidelberg: Springer-Verlag. DOI: 10.1007/978-3-642-41609-5_33-1.

485 Wright, D. J., & Boulter, D. (1980). Differential scanning calorimetric study of meals and
486 constituents of some food grain Legumes. *Journal of the Science of Food and Agriculture*,
487 31(12), 1231-1241.

488 Xie, L. H., Chen, N., Duan, B. W., Zhu, Z. W., & Liao, X. Y. (2008). Impact of proteins
489 on pasting and cooking properties of waxy and non-waxy rice. *Journal of Cereal Science*,
490 47(2), 372-379.

491

Table 1. Conditions used to extrude coarse raw bean powders (particle size ≤ 1.0 mm)

Condition	Barrel temperature profile ($^{\circ}\text{C}$) ^a	Feed rate (kg/h)	Feed moisture (%)	Screw speed (rpm)	Motor load (%)	SME ($\text{Wh}\cdot\text{kg}^{-1}$) ^b	Die pressure (psi)
<i><u>Zorro Black</u></i>							
Treatment 1	40, 60, 80, 120, 140	2	30	200	30.5	97.0	45
Treatment 2	40, 60, 80, 120, 140	2	25	200	35.0	119.3	85
Treatment 3	40, 60, 80, 120, 140	2	30	100	41.0	65.2	65
Treatment 4	40, 60, 80, 120, 140	2	25	100	50.0	85.2	105
Treatment 5	40, 60, 80, 120, 120	2	30	200	34.0	108.2	105
Treatment 6	40, 60, 80, 120, 120	2	25	200	40.0	136.4	150
Treatment 7	40, 60, 80, 120, 120	2	30	100	41.5	66.0	115
Treatment 8	40, 60, 80, 120, 120	2	25	100	48.5	82.7	155
<i><u>Medalist Navy</u></i>							
Treatment 1	40, 60, 80, 120, 140	2	30	200	31.5	99.9	75
Treatment 2	40, 60, 80, 120, 140	2	25	200	32.5	110.4	85
Treatment 3	40, 60, 80, 120, 140	2	30	100	37.5	59.5	85
Treatment 4	40, 60, 80, 120, 140	2	25	100	42.5	72.2	115
Treatment 5	40, 60, 80, 120, 120	2	30	200	31.5	99.9	85
Treatment 6	40, 60, 80, 120, 120	2	25	200	33.5	113.8	110
Treatment 7	40, 60, 80, 120, 120	2	30	100	38.5	61.0	95
Treatment 8	40, 60, 80, 120, 120	2	25	100	37.5	63.7	115
<i><u>Merlot Small Red</u></i>							
Treatment 1	40, 60, 80, 120, 140	2	30	200	30.5	96.3	55
Treatment 2	40, 60, 80, 120, 140	2	25	200	35.0	118.3	85
Treatment 3	40, 60, 80, 120, 140	2	30	100	37.5	59.2	55
Treatment 4	40, 60, 80, 120, 140	2	25	100	53.5	90.4	115
Treatment 5	40, 60, 80, 120, 120	2	30	200	37.5	118.3	95
Treatment 6	40, 60, 80, 120, 120	2	25	200	39.5	133.6	130
Treatment 7	40, 60, 80, 120, 120	2	30	100	38.5	60.8	105
Treatment 8	40, 60, 80, 120, 120	2	25	100	49.5	83.7	145
<i><u>Fuji Otebo</u></i>							
Treatment 1	40, 60, 80, 120, 140	2	30	200	34.5	109.8	65

Treatment 2	40, 60, 80, 120, 140	2	25	200	42.5	145.0	115
Treatment 3	40, 60, 80, 120, 140	2	30	100	47.5	75.6	115
Treatment 4	40, 60, 80, 120, 140	2	25	100	45.5	77.6	105
Treatment 5	40, 60, 80, 120, 120	2	30	200	40.5	128.9	125
Treatment 6	40, 60, 80, 120, 120	2	25	200	50.5	172.3	175
Treatment 7	40, 60, 80, 120, 120	2	30	100	50.5	80.4	145
Treatment 8	40, 60, 80, 120, 120	2	25	100	59.0	100.6	170

^aTemperatures in the five barrel zones from the feed port to the exit die.

^bSpecific mechanical energy ($\text{Wh} \cdot \text{kg}^{-1}$) = [(test screw speed / rated screw speed) $\times$ (% motor load $\times$ rated motor power) / feed rate] / 100, where rated screw speed is 500 rpm, rated motor power is 2.0 kW, and feed rate ($\text{kg} \cdot \text{h}^{-1}$) is the total mass input of feed and water.

Table 2. Protein, starch, sucrose, raffinose, and stachyose contents (on a dry basis) of non-extruded (raw) and extruded bean powders^a

Bean powder	Protein (%) ^b	Starch (%) ^c	Sucrose (mg/g) ^d	Raffinose (mg/g) ^d	Stachyose (mg/g) ^d
<i><u>Zorro Black</u></i>					
Non-extruded	21.5 ± 0.2 a	39.5 ± 0.0 de	25.1 ± 0.4 a	9.9 ± 1.2 a	18.0 ± 0.9 b
Treatment 1	19.6 ± 0.1 d	37.6 ± 0.1 f	26.0 ± 2.4 a	3.9 ± 0.1 b	31.4 ± 2.2 a
Treatment 2	20.2 ± 0.2 bc	40.0 ± 0.0 cd	25.6 ± 0.3 a	4.2 ± 0.0 b	34.8 ± 0.3 a
Treatment 3	20.5 ± 0.2 b	42.6 ± 0.1 a	27.1 ± 1.2 a	3.9 ± 0.2 b	30.9 ± 2.4 a
Treatment 4	19.7 ± 0.1 cd	41.9 ± 0.2 ab	26.5 ± 1.9 a	4.0 ± 0.1 b	33.6 ± 0.5 a
Treatment 5	20.2 ± 0.1 bc	40.4 ± 0.7 cd	24.9 ± 0.8 a	3.9 ± 0.3 b	31.9 ± 3.9 a
Treatment 6	19.7 ± 0.0 cd	41.0 ± 0.2 bc	27.0 ± 0.2 a	3.7 ± 0.0 b	33.4 ± 0.7 a
Treatment 7	20.2 ± 0.1 bc	38.6 ± 0.3 ef	26.1 ± 1.6 a	3.6 ± 0.1 b	29.2 ± 1.7 a
Treatment 8	20.4 ± 0.2 b	40.3 ± 0.3 cd	28.0 ± 0.3 a	3.9 ± 0.0 b	33.4 ± 1.7 a
<i><u>Medalist Navy</u></i>					
Non-extruded	21.7 ± 0.3 a	41.8 ± 0.5 c	19.9 ± 0.0 c	7.4 ± 0.0 a	15.7 ± 0.0 b
Treatment 1	20.8 ± 0.7 a	44.0 ± 0.4 a	31.0 ± 0.7 a	2.8 ± 0.1 b	31.1 ± 5.3 a
Treatment 2	21.9 ± 0.1 a	42.7 ± 0.1 abc	26.8 ± 0.5 b	2.5 ± 0.5 b	32.2 ± 1.9 a
Treatment 3	21.5 ± 0.0 a	43.6 ± 0.1 ab	29.6 ± 2.3 ab	2.9 ± 0.0 b	29.6 ± 0.9 a
Treatment 4	22.5 ± 0.3 a	42.1 ± 0.2 bc	30.5 ± 0.6 ab	2.9 ± 0.0 b	31.2 ± 1.3 a
Treatment 5	22.4 ± 0.9 a	41.3 ± 0.3 c	28.7 ± 1.0 ab	2.8 ± 0.0 b	31.5 ± 0.9 a
Treatment 6	21.4 ± 1.1 a	41.1 ± 0.1 c	31.8 ± 0.7 a	2.9 ± 0.1 b	34.4 ± 1.5 a
Treatment 7	21.6 ± 0.2 a	41.1 ± 0.7 c	29.0 ± 0.2 ab	3.0 ± 0.0 b	31.9 ± 1.0 a
Treatment 8	21.4 ± 0.6 a	42.4 ± 0.7 bc	29.0 ± 1.2 ab	2.7 ± 0.2 b	31.5 ± 0.3 a
<i><u>Merlot Small Red</u></i>					
Non-extruded	22.2 ± 0.4 a	42.8 ± 0.8 a	30.2 ± 0.3 a	7.4 ± 0.1 a	12.6 ± 1.0 b
Treatment 1	20.8 ± 0.1 b	39.1 ± 0.1 b	32.5 ± 0.3 a	2.6 ± 0.1 b	22.0 ± 1.9 ab
Treatment 2	20.8 ± 0.3 b	40.6 ± 0.3 b	33.0 ± 2.1 a	2.8 ± 0.3 b	25.7 ± 4.2 a
Treatment 3	20.9 ± 0.2 b	40.5 ± 0.8 b	33.2 ± 1.5 a	2.9 ± 0.3 b	24.2 ± 4.1 a
Treatment 4	20.7 ± 0.6 b	40.5 ± 0.6 b	31.7 ± 1.9 a	2.7 ± 0.1 b	22.6 ± 1.3 a
Treatment 5	21.0 ± 0.1 b	40.6 ± 0.1 b	31.4 ± 0.6 a	2.4 ± 0.6 b	25.1 ± 2.6 a
Treatment 6	21.2 ± 0.0 ab	40.4 ± 0.2 b	36.7 ± 3.8 a	2.9 ± 0.1 b	27.8 ± 0.8 a
Treatment 7	21.2 ± 0.0 ab	40.2 ± 0.3 b	35.1 ± 2.4 a	2.8 ± 0.0 b	25.6 ± 2.1 a
Treatment 8	21.6 ± 0.3 ab	39.0 ± 0.4 b	33.3 ± 0.8 a	2.8 ± 0.1 b	27.1 ± 0.2 a
<i><u>Fuji Otebo</u></i>					
Non-extruded	28.1 ± 0.2 a	39.3 ± 0.2 a	24.2 ± 1.0 bc	7.4 ± 1.0 a	19.7 ± 0.9 b
Treatment 1	27.1 ± 0.4 ab	38.3 ± 0.2 ab	28.5 ± 0.5 a	1.9 ± 0.3 b	32.4 ± 0.8 a
Treatment 2	27.4 ± 0.1 ab	38.4 ± 0.1 ab	24.0 ± 0.4 c	1.3 ± 0.0 b	28.5 ± 0.7 a
Treatment 3	27.4 ± 0.1 ab	37.1 ± 0.1 b	26.7 ± 0.3 abc	1.6 ± 0.1 b	29.7 ± 2.6 a
Treatment 4	27.7 ± 0.0 ab	36.9 ± 0.5 bc	28.2 ± 1.4 a	1.8 ± 0.3 b	28.2 ± 1.3 a
Treatment 5	27.0 ± 0.6 ab	35.3 ± 1.0 c	26.9 ± 1.2 abc	1.9 ± 0.3 b	32.3 ± 0.2 a
Treatment 6	26.8 ± 0.3 b	38.2 ± 0.4 ab	26.8 ± 1.9 abc	1.8 ± 0.2 b	27.2 ± 3.1 ab
Treatment 7	27.1 ± 0.2 ab	37.9 ± 0.3 ab	28.1 ± 0.5 ab	1.7 ± 0.1 b	28.2 ± 1.3 a
Treatment 8	27.3 ± 0.4 ab	37.5 ± 0.4 b	27.2 ± 0.4 abc	1.8 ± 0.3 b	29.7 ± 3.4 a
ADM Navy	22.6 ± 0.2	42.1 ± 0.4	19.1 ± 0.5	2.3 ± 0.3	22.5 ± 0.4
ADM Black	24.8 ± 0.4	40.2 ± 0.1	24.7 ± 3.0	3.2 ± 0.2	24.5 ± 2.4

^a For the same bean variety, values with the same letter in a column are not significantly different at $p < 0.05$.

^b Determined using the Dumas combustion method in accordance with AOAC Method 968.06 (AOAC, 2000).

^c Determined using the Megazyme Total Starch Assay Kit.

^d Determined using an HPLC method (Kuo, Vanmiddlesworth, & Wolf, 1988).

Table 3. Thermal properties^a of non-extruded (raw) bean powders analyzed using differential scanning calorimetry

Non-extruded bean powder	Peak I				Peak II			
	T _o (°C)	T _p (°C)	T _c (°C)	ΔH (J/g)	T _o (°C)	T _p (°C)	T _c (°C)	ΔH (J/g)
Zorro Black	75.8 ± 0.1	82.1 ± 0.1	90.5 ± 0.2	5.6 ± 0.3	98.3 ± 1.1	101.8 ± 2.3	109.3 ± 1.5	0.5 ± 0.2
Medalist Navy	71.8 ± 1.0	80.9 ± 0.4	89.4 ± 0.8	4.7 ± 0.3	92.8 ± 0.1	98.6 ± 0.3	105.3 ± 1.1	1.0 ± 0.1
Merlot Small Red	74.3 ± 0.2	81.9 ± 0.5	90.3 ± 0.5	5.2 ± 0.2	94.7 ± 0.3	102.8 ± 0.1	113.5 ± 0.7	1.9 ± 0.1
Fuji Otebo	69.6 ± 0.0	81.3 ± 0.2	90.3 ± 0.0	3.6 ± 0.3	92.9 ± 0.4	97.6 ± 0.7	104.6 ± 0.8	1.5 ± 0.0

^a T_o: onset temperature; T_p: peak temperature; T_c: conclusion temperature; ΔH: enthalpy change.

Table 4. Starch digestibility (on a dry basis) of cooked non-extruded and cooked extruded bean powders^{a, b}

Bean powder	Starch fraction ^c		
	RDS (%)	SDS (%)	RS (%)
<i><u>Zorro Black</u></i>			
Non-extruded	32.5 ± 0.2 de	1.8 ± 0.2 abc	5.3 ± 0.4 abc
Treatment 1	28.7 ± 0.6 f	3.2 ± 0.3 a	5.7 ± 0.3 ab
Treatment 2	33.2 ± 0.1 cd	2.7 ± 0.5 a	4.1 ± 0.5 bc
Treatment 3	35.2 ± 0.4 a	2.2 ± 0.1 ab	5.2 ± 0.3 abc
Treatment 4	35.9 ± 0.3 a	2.3 ± 0.1 ab	3.7 ± 0.4 c
Treatment 5	33.1 ± 0.2 cd	2.7 ± 0.1 a	4.5 ± 0.2 abc
Treatment 6	34.8 ± 0.2 ab	0.3 ± 0.2 c	5.9 ± 0.4 a
Treatment 7	31.6 ± 0.3 e	0.8 ± 0.8 bc	6.1 ± 0.5 a
Treatment 8	33.9 ± 0.3 bc	1.1 ± 0.4 bc	5.3 ± 0.7 abc
<i><u>Medalist Navy</u></i>			
Non-extruded	34.5 ± 0.3 cd	2.4 ± 0.0 ab	5.0 ± 0.3 a
Treatment 1	35.1 ± 0.1 bc	2.5 ± 0.2 a	6.4 ± 0.3 a
Treatment 2	36.1 ± 0.3 ab	1.2 ± 0.0 ab	5.4 ± 0.3 a
Treatment 3	36.5 ± 0.4 a	0.6 ± 0.9 b	6.5 ± 0.5 a
Treatment 4	34.4 ± 0.3 cd	1.4 ± 0.1 ab	6.3 ± 0.5 a
Treatment 5	33.5 ± 0.3 de	1.6 ± 0.0 ab	6.3 ± 0.4 a
Treatment 6	32.9 ± 0.2 e	2.7 ± 0.9 a	5.4 ± 0.7 a
Treatment 7	33.0 ± 0.3 e	2.5 ± 0.6 a	5.5 ± 0.9 a
Treatment 8	34.7 ± 0.4 c	2.4 ± 0.0 ab	5.3 ± 0.4 a
<i><u>Merlot Small Red</u></i>			
Non-extruded	33.2 ± 0.2 abc	2.7 ± 0.4 a	6.9 ± 0.2 a
Treatment 1	30.5 ± 0.2 d	2.3 ± 0.3 ab	6.3 ± 0.5 ab
Treatment 2	32.4 ± 0.6 c	2.8 ± 0.3 a	5.5 ± 0.3 b
Treatment 3	33.0 ± 0.4 bc	1.7 ± 0.9 ab	5.9 ± 0.5 ab
Treatment 4	34.8 ± 0.3 a	0.6 ± 0.1 b	5.2 ± 0.4 b
Treatment 5	33.8 ± 0.6 abc	1.4 ± 0.4 ab	5.4 ± 0.2 b
Treatment 6	34.4 ± 0.2 ab	0.3 ± 0.1 b	5.6 ± 0.3 ab
Treatment 7	32.6 ± 0.5 c	2.2 ± 0.9 ab	5.5 ± 0.4 b
Treatment 8	33.0 ± 0.5 bc	0.7 ± 0.6 ab	5.3 ± 0.0 b
<i><u>Fuji Otebo</u></i>			
Non-extruded	31.1 ± 0.2 b	1.3 ± 0.2 ab	6.9 ± 0.4 a
Treatment 1	31.6 ± 0.3 ab	1.0 ± 0.0 ab	5.7 ± 0.3 ab
Treatment 2	31.4 ± 0.2 ab	1.3 ± 0.5 ab	5.7 ± 0.2 ab
Treatment 3	29.3 ± 0.3 c	1.8 ± 0.1 a	6.0 ± 0.2 ab
Treatment 4	29.5 ± 0.6 c	0.9 ± 0.3 ab	6.6 ± 0.3 ab
Treatment 5	27.9 ± 0.4 d	0.8 ± 0.6 ab	6.6 ± 0.2 ab
Treatment 6	32.3 ± 0.0 a	0.3 ± 0.2 b	5.6 ± 0.2 b
Treatment 7	31.3 ± 0.2 ab	1.0 ± 0.2 ab	5.6 ± 0.3 b
Treatment 8	31.2 ± 0.0 ab	0.6 ± 0.4 ab	5.7 ± 0.4 ab
ADM Navy	35.6 ± 0.5	2.7 ± 0.4	3.8 ± 0.0
ADM Black	32.8 ± 0.2	1.9 ± 0.5	5.5 ± 0.3
Soft wheat flour ^d	74.3 ± 0.4	0.6 ± 0.2	0.6 ± 0.2

^a Determined following the Englyst Method (Englyst, Kingman, & Cummings, 1992) with minor modifications.

^b For the same bean variety, values with the same letter in a column are not significantly different at $p < 0.05$.

^c RDS: rapidly digestible starch; SDS: slowly digestible starch; RS: resistant starch; [see text for details about calculations](#).

^d Soft wheat flour (MSU Line F2019, containing 75.5% starch) obtained from Michigan State University Wheat Testing Program.

Figure(s)

Figure 1. Pasting properties of non-extruded (raw) and extruded bean powders analyzed using Rapid Visco Analyzer at 10.6% dry solids content. A: Zorro Black; B: Medalist Navy; C: Merlot Small Red; D: Fuji Otebo. Trt: Extrusion Treatment.

Figure 2. Water-holding (A), 5% lactic-acid-retention (B), and oil-binding (C) capacities of non-extruded (raw) and extruded bean powders on a dry basis (db). +: ADM Navy; #: ADM Black. *: Within each variety, the data of the extruded bean powders were significantly different ($p < 0.05$) from that of the corresponding non-extruded bean powder. Trt: Extrusion Treatment.