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Improvement of corn extruded snacks properties by incorporation of pulses

Mejora de las propiedades de snacks extrudidos de maíz mediante la incorporación de legumbres

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Abstract

Traditional extruded snacks are mainly made from cereal starch such as corn, rice, and wheat, being corn one of the most used, obtaining products with poor nutritional value. The search for new alternatives to improve the nutritional profile of these snacks involves, among other alternatives, the incorporation of pulses into corn-based extruded product formulations. Pulses provide an important content of protein, dietary fiber, minerals, and vitamins, as well as bioactive compounds such as polyphenols, and tannins, among others. The incorporation of pulses in corn extrudes is not only exempt from changes in its nutritional composition but also entails several changes in its technological and sensory attributes. Moreover, the evaluation of the health impact of these formulations still relies on *in vitro* studies. The objective of this review is to summarize the effect of the incorporation of pulses in corn-based extruded snacks on their physicochemical properties, sensory attributes, and their possible health impact.
Keywords: snack, extrusion, pulses, glycaemic index, protein, dietary fiber.

Resumen

Las botanas extrudidas tradicionales, están elaborados principalmente de almidón de cereales como el maíz, el arroz y el trigo, siendo el maíz el más usado dando lugar a productos con pobre valor nutricional. La búsqueda de nuevas alternativas que mejoren el perfil nutricional de este tipo de productos pasa entre otras alternativas, por la incorporación de legumbres a las formulaciones de productos extrudidos a base de maíz. Las legumbres pueden proveer un contenido importante de proteína, fibra dietética, minerales y vitaminas, además de compuestos bioactivos como son los polifenoles, taninos, entre otros. Esta incorporación junto al maíz no está exenta únicamente de cambios en su composición nutrimental, sino que además conlleva una serie de cambios en sus atributos tecnológicos y sensoriales. Además, la evaluación del impacto en la salud aun recae en la aplicación de estudios *in vitro*. El objetivo de esta revisión es resumir el efecto de la incorporación de legumbres en aperitivos extrudidos a base de maíz sobre sus propiedades fisicoquímicas, atributos sensoriales y su posible impacto en la salud.
Palabras clave: botana, extrusión, legumbres, índice glucémico, proteína, fibra dietética.

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1 Introduction

"Snacks" have been defined as light food consumed between regular meals, and suitable for snacking (Lusas *et al.,* 2001). Snacks are also easy to handle, ready to eat, small in size, whether solid or liquid, consisting of an individual portion, and, most importantly, temporarily satisfying hunger (Hurtado *et al.,* 2001). Currently, these foods are considered versatile and, often associated with entertainment activities, and their definition varies widely depending on the country in which they are consumed (McCarthy, 2001).

The snack market has presented a growing trend in recent decades and is expected to continue its increase in the coming years (Natabirwa *et al.,* 2020), including the demand for healthier products by consumers (Félix-Medina *et al.,* 2020). Many extruded or non-extruded snacks based on cereals are considered junk food, due to their low nutritional content, high amount of preservatives, and the presence of other ingredients that harm consumer health as salt or fat (Neder-Suárez *et al.,* 2021ab; Jensen & Schwartz., 2021). Corn-extruded cereal-based snacks do not fulfill the health needs of consumers due to their high glycaemic index because of the high starch content (Manosalvas *et al.,* 2019; Brennan *et al.,* 2013; Conti-Silva *et al.,* 2012), and the low nutritional value, which leads to increase consumer malnutrition (Freire, 2014). Their increasing consumption presents negative consequences and serious health concerns (Korkerd *et al.,* 2016). They are low in protein and deficient in certain amino acids such as lysine and tryptophan, demeriting the quality of their already low protein content (Félix-Medina *et al.,* 2021; Estrada-Girón *et al.,* 2015; Meng *et al.,* 2010; Pérez-Navarrete *et al.,* 2006). The content of other micronutrients such as iron, zinc, and vitamin A is also deficient (Korkerd et al. 2016). Moreover, snacks usually contain significant amounts of fat, thus increasing the caloric intake. Additionally, they often contain preservatives and other ingredients harmful to health (Neder-Suárez *et al.,* 2021b). In summary, traditional snacks are foods rich in sugars, carbohydrates, fat, and salt (Selvaprakash *et al.,* 2021; Jensen & Schwartz, 2021). Unfortunately, many of these snacks have become an integral part of daily food consumption of many people worldwide, especially children, due to their low cost and availability, as they are ready-to-consume products (Sebastian *et al.,* 2008). An example of the high consumption of snacks among the child population is what happens in the USA, where 28% of the daily energy intake in 2-5-year-old children comes from these products (Shriver *et al.,* 2018). Therefore, the nutritional improvement of these products is a challenge for the food industry, which intends to improve consumer health (Selvaprakash *et al.,* 2021; Tobias–Espinoza *et al.,* 2019; Gabr *et al.,* 2013; Seth & Rajamanickam, 2012; Meng *et al.,* 2010).

One of the leading methodologies in snack production is the extrusion process (Sebio & Chang, 2000). The goal of extrusion is to create products in which the starch expands, resulting in lightweight and voluminous products, namely high-quality extruded snacks (Neder-Suárez *et al.,* 2021b). This extrusion cooking is accompanied by the gelatinization of starch, which involves breaking intermolecular hydrogen bonds and allowing the increase in water absorption capacity (Gabr *et al.,* 2013). Gelatinized starch increases the viscosity of the dough and after leaving the extruder, the hot dough expands rapidly due to the immediate vaporization of water, providing a desirable porous structure to the product (Cheftel, 1986). The rapid cooling causes the dough to become rigid and lose its initial elasticity (Cheftel, 1986). Extrusion as a food technological process, based on high-temperature, short-time cooking (HTST), allows the preservation of essential nutrients, significantly reduces microbial loads, and the presence of antinutritional compounds (enzymes and non-nutritional factors), in addition to extending shelf life and enabling the development of higher-quality products (Delgado-Nieblas *et al.,* 2018; Mercier *et al.,* 2016; Obradovi *et al.,* 2014; Delgado *et al.,* 2012). Moreover, it is a versatile, cost-effective, and efficient food processing technology (Castro-Montoya *et al.*, 2024; Limón-Valenzuela *et al.,* 2017; Pansawat *et al.,* 2008; Shimelis & Rakshit, 2007; Rahman *et al.,* 2002; Alonso *et al.,* 2000).

Several strategies are being developed to increase the nutritional value of traditional snacks. Some of these are based on increasing the levels of macronutrients such as protein and dietary fiber, micronutrients such as vitamins (vitamins A or C) and minerals (iron, zinc), as well as increasing the presence of functional biomolecules such as antioxidants (Félix-Medina *et al.,* 2020; Bashir *et al.,* 2016; Pastor-Cavada *et al.,* 2011). Some of them are through the inclusion of other types of cereals, which provide a greater amount of these macronutrients, such as oats (Gopirajah & Muthukumarappan, 2018), or other types of plant foods such as legumes including soybeans, chickpeas and beans (Azima *et al.,* 2017). The incorporation of vegetables (carrots, cauliflower, spinach, broccoli) (Neder-Suárez *et al.,* 2021b; Shevkani *et al.,* 2019; Alam *et al.,* 2016; Bisharat *et al.,* 2014), algae such as spirulina (Bashir *et al.,* 2016), protein isolate from both animal (Kocherla *et al.,* 2012) and vegetable sources (Martin *et al.,* 2022; Chen *et al.,* 2017; Draganovic *et al.,* 2011) or fiber concentrate (Giannini *et al.,* 2013) are some other recent examples. Even foods of animal origin such as milk (Hegazy *et al.,* 2017; Gabr *et al.,* 2013), bovine lung (Moreira-Araujo *et al.,* 2008), or insects (García-Segovia *et al.,* 2020) have been proposed to improve this type of snack.

The incorporation of pulses into extruded snacks is an interesting alternative due to its nutritional profile, low in fat, rich in protein and complex carbohydrates where dietary fiber is included (Johnston *et al.,* 2021), in addition to its antioxidant content (Félix-Medina *et al.,* 2020). On the other hand, both the low costs are the same, as their contribution to the environment since they are considered a sustainable crop (Johnston *et al.,* 2021).

This study aimed to summarize the effect of incorporating pulses into corn-based extruded snacks on their physicochemical properties, sensory attributes, and their impact on human health.

2 Pulses in extruded corn snacks

Although cereals, especially corn, due to its high starch content, are ideal for the production of extruded snacks because of their excellent expansion and texture properties, the incorporation of pulses is an interesting alternative, especially from a nutritional point of view (Félix-Medina *et al.,* 2020).

Table 1: Summary nutritional characteristics of pulses.

Scientific name	Common name	Nutritional characteristics				References
		Protein (%)	Fat (%)	Carbohydrate (%)	Total dietary fiber (%)	
Phaseolus vulgaris L.	Black beans	19-20	2-3	63-74	18-26	Neder-Suarez *et al*. (2021b); Caprioli *et al*. (2016); Ambigaipalan *et al*. (2011); Sutivisedsak *et al*. (2011); Boschin & Arnoldi (2011); Silva-Cristobal *et al*. (2010); Hoover & Ratnayak (2002); Trugo *et al*. (2000); Garcia *et al*. (1997); Hoover & Sosulski (1985); deMoraes & Angelucci (1971)
	Navy beans	19-27	2	67-75	14-25	Caprioli *et al*. (2016); Soral-Smietana & Krupa (2005); Hoover & Ratnayak (2002); Su *et al*. (1998); Gujska & Khan (1991); Koehler *et al*. (1987); Sathe & Salunkhe (1984); Sathe & Salunkhe (1981); Naivikul & D'Appolonia (1979); Fordham *et al*. (1975)
	Pinto beans	18-25	1-2	70-76	14-26	Sutivisedsak *et al*. (2011); Wang *et al*. (2010); Silva-Cristobal *et al*. (2010); Oomah *et al*. (2008); Kutoš *et al*. (2003); Kahlon & Woodruff (2002); Hoover & Ratnayak (2002); Moraghan & Grafton (2002); Su *et al*. (1998); Koehler *et al*. (1987); Hoover & Sosulski (1985); Sathe & Salunkhe (1984); Marquez & Lajolo (1981); Pusztai *et al*. (1979); Naivikul & D'Appolonia (1979); Sgarbieri *et al*. (1979); Fordham *et al*. (1975)
	Kidney beans	17-27	1-5	63-74	18-30	Caprioli *et al*. (2016); Sutivisedsak *et al*. (2011); Wang *et al*. (2010); Ryan *et al*. (2007); Yoshida *et al*. (2005); El-Adawy (2002); Alonso *et al*. (2001); Su *et al*. (1998); Pérez-Hidalgo *et al*. (1997); Hoover & Sosulski (1985); Sathe & Salunkhe (1984); Koinov & Radkov (1981); Pusztai *et al*. (1979); Meiners *et al*. (1976)
	White beans	23	1	60	15	Lazou *et al*. (2007)
	Carioca beans	25	2	67	1-2	Moreira da Silva *et al*. (2014)
Cicer arietinum	Chickpeas	19-27	2-7	52-71	6-15	Masood *et al*. (2014); Sreerama *et al*. (2012); Karaca *et al*. (2011); Frimpong *et al*. (2009); Shad *et al*. (2009); Ryan *et al*. (2007); Zia-Ul-Haq (2007a,b); Kaur *et al*. (2005); El-Adawy (2002); Cai *et al*. (2002); Gopala Krishna *et al*. (1997); Dhawan *et al*. (1991); Singh & Jambunathan (1982)
	Bengal grams					
Vigna unguiculata	Cowpeas	24-28	2	42-63	11-34	Fan *et al*. (2015); Sreerama *et al*. (2012); Gupta *et al*. (2010); Mallillin *et al*. (2008); Martin-Cabrejas *et al*. (2008); Mwangwela *et al*. (2007); Nugdallah & El Tinay (1997); Ene-Obong & Carnovale (1992)
Lupinus mutabilis	Lupinus	32-44	5-15	47	31-34	Calabró *et al*. (2015); Rumiyati *et al*. (2012); Boschin & Arnoldi (2011); Chilomer *et al*. (2010); Gulewicz *et al*. (2008); Martinez-Villaluenga *et al*. (2006); Sujak *et al*. (2006); Erbas *et al*. (2005); Torres *et al*. (2005)
Lens culinaris	Lentils	23-31	1-3	42-72	7-23	Ghumman *et al*. (2016); Fouad & Rehab (2015); Zhang *et al*. (2014); Gharibzahedi *et al*. (2012); Zia-ul-Haq *et al*. (2011); Bamdad *et al*. (2009); Ryan *et al*. (2007); Wang & Daun (2006); de Almeida Costa *et al*. (2006); Frias *et al*. (2003); Cai *et al*. (2002); Carlsson *et al*. (1992)
Pisum sativum	Dry green peas	25	1-2	69-70	5	Wani & Kumar *et al*. (2016d)

Elaborated with data from Hall *et al*. (2017).

Table 2. Summary of several studies focused in the modification of nutritional, technological and sensory properties because of the inclusion of pulses in corn extruded snack.

Pulse added to the mixture	Scientific name	Inclusion rate (%)	References
Common beans	*Phaseolus vulgaris* L., var. Higuera Azufrado	16, 30, 40	Félix-Medina *et al.* (2021)
Bengal gram	*Cicer arietinum* L.,	10, 20	Sawant *et al.* (2013)
Common beans	*Phaseolus vulgaris* L., var. Roba1 Beans	50-85	Natabirwa *et al.* (2020)
Black beans	*Phaseolus vulgaris* L.,	33	Neder-Suarez *et al.* (2021ab)
Cowpea	Vigna unguiculata	20	Sosa-Moguel *et al.* (2009)
Lupinus	*Lupinus mutabilis* Sweet., var. INIAP 450	15, 10	Manosalvas *et al.* (2019)
Navy bean and pinto bean	*Phaseolus vulgaris* L.,	Navy bean (50-40) Pinto bean (50-40)	Vadukapuram *et al.* (2014)
Lima bean	*Phaseolus lunatus* L.,	25-50-75	Pérez-Navarrete *et al.* (2006)
Red kidney bean Broad bean Green pea	*Phaseolus vulgaris Vicia faba Pisum sativum*	Red kidney bean flour (29.5) Broad bean flour (20.0) Green pea flour (5)	Limsangouan *et al.* (2010)
Chickpea	*Cicer arietinum* L.	72	Moreira-Araujo *et al.* (2008)
Dry green pea	*Pisum sativum*	9	Wani & Kumar (2019)
Lentil	*Lens culinaris Medik.*	0-10-30-50	Lazou *et al.* (2010)
Chickpea Mexican bean White bean Lentil	*Cicer arietinum* L., *Phaseolus vulgaris* L., *Phaseolus vulgaris* L., *Lens culinaris*	Chickpea (10, 50, 90) Mexican bean (10, 50, 90) White bean (10, 50, 90) Lentil (10, 50, 90)	Lazou *et al.* (2007)
Chickpea	*Cicer arietinum* L.	(10, 20, 30)	Selvaprakash *et al.* (2021)
Green gram	*Vigna radiata*	30	Thakur *et al.* (2020)
Carioca beans	*Phaseolus vulgaris* L.,	Carioca beans (4.8-55.2)	Moreira da Silva *et al.* (2014)

Pulses in general are edible seeds from leguminous crops. This term includes dry beans (*Phaseolus. vulgaris*, *Vigna angularis*), chickpeas (*Cicer arietinum*), lentils (*Lens culinaris*), dry peas (*Pisum sativum*), lupinus (*Lupinus mutabilis*) and cowpea (*Vigna unquiculata*) (Tosh & Yada, 2010) and excludes those with a high-fat content such as peanut (*Arachis hypogaea*) and soybean (*Glycine max*) (Singh & Muthukumarappan, 2017a) or fresh beans and peas (Graybosch, 2004; FAO, 2011). The content of macronutrients and amino acids will depend on the type of pulse, the variety, and the environment (Wang & Daun, 2006, 2004; Chauchan *et al.,* 1988). In general, pulses are low in fat, and rich in protein and complex carbohydrates, including a significant amount of soluble and insoluble dietary fiber. Its content will vary depending on the type of pulse. Pulses contain between 42-76% carbohydrates, and approximately 17-44% protein (Dahl *et al.,* 2012), being rich in amino acids such as lysine and tryptophan, while methionine and cysteine are the limiting amino acids (Mosibo *et al.,* 2022; Algarni *et al.,* 2019; Wang et al 2019; Shi *et al.,* 2017). Related to the dietary fiber content, they contain approximately 1-34 g/100 g raw pulse, being mostly insoluble fiber (10-34 g/100 g raw pulse), and less soluble fiber (1-9 g/100 g raw pulse) (Hall *et al.,* 2017; Kutos *et al.,* 2003; Dalgetty & Baik, 2003; Martín-Cabrejas *et al.,* 2003). Fat content is between (1-7 g/100 g pulse). They also contribute to the supply of B-complex vitamins and minerals such as potassium, iron, zinc, calcium, and magnesium (Simons *et al.,* 2017; Saha *et al.,* 2009).

There are differences in the nutritional composition of different pulses (Table 1). For example, the pulses with the highest protein content are lupinus, which can reach 44% protein, while Kidney bean and Pinto bean, have been reported with the lowest content (17-18%). Regarding the total dietary fiber content, those pulses with the highest content are lupine and cowpea, reaching a maximum of 34%, those with the lowest content are carioca beans (1-2%) and dry green pea (5%). In the case of fat content, excepting lupinus (5-15%) and chickpea (2-7%), the rest of the pulses have a rather modest fat content (1-5%) (Table 1).

In the last decade, several works have been published about the inclusion of pulses mixed with corn in extruded snacks (Table 2). The incorporation of pulses in extrudates varies from small amounts (5-10%) (Hegazy *et al.,* 2017; Limsangouan *et al.,* 2010) even combined with other types of food (Natabirwa *et al.,* 2020; Manosalvas *et al.,* 2019) to its elaboration close to 100% of pulse (Shevkani *et al.,* 2019; Ai *et al.,* 2016; Hardacre *et al.,* 2006). The most commonly used pulses include different varieties of bean, chickpea, lentil, dry green pea, lupinus, and even wild varieties such as *Vicia lutea* var. Hirta, *Vicia. sativa* subsp. Sativa, *Lathyrus annuus* and *Lathyrus* clymenum (Pastor-Cavada *et al.,* 2013, 2011).

Apart from the improvement of protein and some limiting amino acids in cereals, especially lysine (Hall *et al.,* 2017; Boye *et al.,* 2010; Iqbal *et al.,* 2006). Also, the starch from pulses can contribute to reducing the glycaemic index in expanded snacks because of its lower digestibility associated with the presence of resistant starch (Hoover *et al.,* 2010; Tosh & Yada, 2010). Furthermore, the presence of 2-3 times more protein than traditional cereal-based products can have a greater satiating effect, which has been observed in other protein products (Veldhorst *et al.,* 2012). Furthermore, the regular consumption of products made from a combination of whole grains and pulses has been associated with a reduced risk of developing certain chronic diseases and other conditions (e.g., diabetes, obesity, colon cancer, and cardiovascular diseases) (Das & Singh, 2016; Fan & Beta, 2016; Chen *et al.,* 2015; Reyes-Moreno *et al.,* 2012; Zilic *et al.,* 2012). The presence of other compounds in these combinations, such as dietary fiber, phenolic compounds, and other bioactive components from pulses, has been associated with certain health benefits (Félix-Medina *et al.,* 2020; Espinoza-Moreno *et al.,* 2016; Camacho-Hernandez *et al.,* 2014; Escalante-Aburto *et al.,* 2013; Limsangouan *et al.,* 2010). The reformulation of these products not only provides a benefit in nutritional quality, but also reduces the environmental impact of these foods (Chaudhary *et al.,* 2018).

3 Nutritional properties of pulses-corn extruded snacks

Due to the different composition of pulses, the nutritional content of extruded legume-corn snacks is positively favored in terms of the main macromolecules: proteins, lipids, and carbohydrates (Félix-Medina *et al.,* 2020; Natabirwa *et al.,* 2020; Shevkani *et al.,* 2019; Shah *et al.,* 2017). In terms of protein, the incorporation of pulses favors the increase of protein in the snack by 1.9-10.37%, some examples can be observed in Table 3, as they are richer in protein than the traditional raw material (Johnston *et al.,* 2021; Neder-Suárez *et al.,* 2021b; Rico *et al.,* 2021; Félix-Medina *et al.,* 2020; Natabirwa *et al.,* 2020; Manosalvas *et al.,* 2019; Hegazy *et al.,* 2017; Gabr *et al.,* 2013; Pastor-Cavada *et al.,* 2013, 2011; Hardacre *et al.,* 2006; Pérez-Navarrete *et al.,* 2006).

Extrusion usually does not affect the protein content of the snacks (Rico et al. 2021; Félix-Medina *et al.* 2020; Sosa-Moguel *et al.,* 2009; Alonso *et al.,* 2001). However, small decreases in protein content (1-3%) have been reported (Manosalvas *et al.,* 2019), in addition to the reduction of certain essential amino acids such as lysine during extrusion, by interacting with sugars during Maillard reactions (Sahoo *et al.,* 2021; Félix-Medina *et al.,* 2021; Pérez-Navarrete *et al.,* 2006).

Table 3. Summary of studies where chemical composition is determined.

Pulse added to the mixture	Other ingredients	Extruder type	Extrusion parameters	Chemical composition	References
Bean (16%-30%-40%)	NA	Single screw Model 20 DN (CW Brabender Instruments, Inc., NJ, USA)	Moisture: 18% Barrel temperature (120-145 °C) Screw speed (50-240 rpm) Diameter screw (19 mm) Length/diameter ratio: 19	Increased protein (↑1.54-3.51%), lipids (↑0.15-0.44%), dietary fibre (↑1.65-2.1%) and ash (↑0.49-1.2%). Reduction of carbohydrates (↓1.56-4.6%)	Félix-Medina *et al.* (2020)
Chickpea (8.75 / 12.5%)	Rice (20/14%), what germ (10/7%), barley (5/3.5%), milk powder (2.5/1.75%)	Twin screw extruder (Clextral, Firminy Cedex, France)	Flow rate (12 Kgh) Diameter circular die (3 mm) Screw speed (400 rpm) Barrel temperature (150 °C)	Increased protein (↑0.4-1.2%), and carbohydrates (↑1.4-3.4%) Reduction of lipids (↓1.11-1.6%), dietay fibre (↓0.26-0.49%) and ash (↓0.1-0.2%)	Gabr *et al.* (2013)
Chickpea germinated and dehulled (10%-20%- 30%)	Tomato powder (5%), Skim milk powder (5%), salt (1%)	Single screw	Feeding screw (160 rpm) Barrel temperature (100-180 °C) Screw speed (250 rpm)	Increased protein (↑5.92-3.07%), fat (↑0.42-1.01%), dietary fibre (↑1.44-1.64%) and ash (↑1.85-2.41%) Reduced carbohydrate (↓6.27-10.89%) and caloric value (↓10.59-11.23%).	Hegazy *et al.* (2017)
Whole yellow pea (40%) Split yellow pea (40%) Green lentil (40%) Chickpea (40%) Pinto bean (40%)	NA	NA	NA	Increased protein (↑6.3-8%), fat (↑0.5-2%), soluble (↑0.8-2.6%) and insoluble dietary fibre (↑1.6-4.4%). Reduction of available carbohydrate (↓11.1-17.5%), starch damage (↓7.6-16.3%), energy (↓5-11 kcal).	Johnston *et al.* (2021)

Lupinus (10-15%)	Potatoes (10-15%)	Single screw (marca Sermaconi, Ecuador)	Barrel temperature (110-140 °C) Moisture (15-20%) Screw speed (300 rpm) Die diameter (2.50 mm.)	Increased protein (↑4.11-10.37%), fat (↑0.7-1.47%), fibre (↑0.25-1.73%), ash (↑0.25-0.43%). Reduction of carbohydrates (↓6.21-13.2%)	Manosalvas *et al.* (2019)
Lathyrus seeds (*L. annuus* and *L. clymenum*) (15%)	NA	Single screw extruder Brabender 20 DN (Brabender GmbH & Co. KG, Duisberg, Germany)	Screw compression ratio (4:1) Moisture (14%) Cylindrical die (diameter/length): 3/20-mm; Screw speed (150 rpm) Extrusion temperature: 175 °C (die and extruder barrel).	Increased protein (↑1.2-1.9%), dietary fibre(↑4.71-4.8%) ash (↑0.19-0.21%), Fe (↑7.2-12.3 ppm) and Zn (↑5.4-6ppm) Reduction carbohydrate (↓5.55-5.65%) and lipids (↓0.53-1.06%)	Pastor-Cavada *et al.* (2011)
Vicia lutea var. Hirta y Vicia. sativa subsp. Sativa (15%)	NA	Single screw extruder Brabender 20 DN (Brabender GmbH & Co. KG, Duisberg, Germany)	Screw compression ratio (4:1) Moisture (14%) Cylindrical die (diameter/length): 3/20-mm; Screw speed (150 rpm) Extrusion temperature: 175 °C (die and extruder barrel).	Increased protein (↑2.41-2.81%), dietary fibre (↑4.38-5.83%), ash (↑0.16-0.26%) Fe (↑6.2-9 ppm) and Zn (↑3.8-4.6 ppm) Reduction lipids (↓0.87-0.9%)	Pastor-Cavada *et al.* (2013)
Lentil (50%)	NA	Single-screw lab-scale extruder (Brabender mod.KE19 20 DN, Duisburg, Germany)	Feeding screw (150 rpm) Barrel temperature (110-130 °C) Moisture (20%) Screw diameter (19 mm) Length/diameter ratio: 25	Increased protein (↑6.5%), fibre (↑12.05%), ash (↑0.8%) and phytic acid (↑0.58%). Reduction of fat (↓0.65%), carbohydrates (↓10.07%)	Rico *et al.* (2021)

These Maillard reactions are proportional to the intensity of the thermo-mechanical process, by reducing the humidity, increasing the temperature, and increasing the screw speed. (Ruiz-Ruiz *et al.,* 2008; Ilo & Berghofer, 2003; Obatolu *et al.,* 2000). An example of this effect was reported by Wang *et al.* (2019) observing a change in the limiting amino acid from threonine in the raw dough to lysine in the snack because of the Maillard reactions during extrusion.

The addition of pulses usually alters the amino acid composition, with minor contents in cysteine, leucine and an increase in lysine content (Pastor-Cavada *et al.,* 2011, 2013). In Sahoo *et al.* (2021), tree bean (10%) was incorporated into a corn-chickpea mixture, and an increase a 1.9% in protein and lysine, leucine, isoleucine, cysteine, threonine, tyrosine and methionine contents were observed. Although extrusion reduces the content of some essential amino acids (Paes & Maga, 2004), the high protein content and some of these essential amino acids in the tree bean offset the effect of extrusion. Focusing on changes in protein digestibility, the extrusion process increases *in vitro* protein digestibility in extrudates with pulse when compared to raw doughs from 75.17 to 77.21% in Félix-Medina *et al.* (2021), increase from 81.40 to 87.57% in Hegazy *et al.* (2017), from 76.8 to 81.75% in Pérez-Navarrete *et al.* (2006), and from 74.11% to 80.91-82.43% in Wang *et al.* (2019). In Natabirwa *et al.* (2020), extrusion increased protein digestibility from 50.6-62.4% in the raw dough to levels above 71.5% in the extruded. In the same study it was observed that the high corn content of the formulations increased protein digestibility, this effect may be related to the protein-starch interaction that increases hydrophilic groups, facilitating protein solubility (Siddiq *et al.,* 2013). This increase in protein digestibility is also associated with the structural change caused by extrusion (shearing and temperature), leaving more exposed areas more susceptible to the action of proteolytic enzymes (Flores-Silva *et al*., 2022; Krupa-Kozak & Soral-Śmietana, 2010; Pérez-Navarrete *et al.,* 2006; Alonso *et al.,* 2000). As an exception in Pastor-Cavada *et al.* (2011) the incorporation of wild legumes *Lathyrus annuus* and *Lathyrus clymenum* compared to the maize-based control sample did not increase protein digestibility in the extrudates.

In summary, the incorporation of pulses into corn extrudates will increase both the protein content and the quality of this protein and the protein digestibility. Although the extrusion process will reduce the presence of certain essential amino acids, the increased digestibility and the additional supply of essential amino acids deficient in corn will enhance the protein quality (Félix-Medina *et al.,* 2021; Natabirwa *et al.,* 2020; Wang *et al.,* 2019; Hegazy *et al.,* 2017; Pastor-Cavada *et al.,* 2013; Pérez-Navarrete *et al.,* 2006).

Regarding lipids, in general, the higher lipid content of pulses (1-2%) compared to traditional raw materials increases the lipid content of snacks (Johnston *et al.,* 2021; Félix-Medina *et al.,* 2020; Manosalvas *et al.,* 2019; Hegazy *et al.,* 2017). There are exceptions whose possible causes are explained by the use of pulses with very low-fat content, such as wild legume (Pastor-Cavada *et al.,* 2011) and lentils (Rico *et al.,* 2021) and on the other hand the formation of amylose-lipid and protein-lipid complexes, which makes the quantification of the former difficult (Rico *et al.,* 2021; Natabirwa *et al.,* 2020; Félix-Medina *et al.,* 2020; Simons *et al.,* 2017; Espinoza-Moreno *et al.,* 2016). Sometimes pulses having a higher lipid content than cereals affect the quantification of fat content, due to the formation of these complexes, making it less apparent (Félix-Medina *et al.,* 2020). This phenomenon makes extraction, quantification (Bhatnagar & Hanna, 1994; Izzo & Ho, 1989), oxidation, and/or degradation difficult (Estrada-Girón *et al.,* 2015). However, this reduction of available lipids can reduce the oxidation potential of these compounds (Estrada-Girón *et al.,* 2015), and, therefore, this favors the shelf life of the final products (Simons *et al.,* 2015).

The carbohydrate content by including pulses as a raw material is reduced in the snack (4.6-17.5%) since the proportion of carbohydrates in pulses is lower than in maize (Sahoo *et al.,* 2021; Rico *et al.,* 2021; Félix-Medina *et al.,* 2020; Johnston *et al.,* 2021; Natabirwa *et al.,* 2020; Manosalvas *et al.,* 2019; Hegazy *et al.,* 2017; Pastor-Cavada *et al.,* 2011; Hardacre *et al.,* 2006; Pérez-Navarrete *et al.,* 2006).

In addition to increasing protein content by including legumes in snack formulations, dietary fiber content is also benefited by these ingredients increasing from 1.64% to 20.6% (Rico *et al.,* 2021; Félix-Medina *et al.,* 2020; Johnston *et al.,* 2021; Natabirwa *et al.,* 2020; Manosalvas *et al.,* 2019; Hegazy *et al.,* 2017; Pastor-Cavada *et al.,* 2011; Hardacre *et al.,* 2006; Perez-Navarrete *et al.,* 2006). It has also been observed that the characteristics of dietary fiber are affected by increasing the severity of the extrusion process since increasing barrel temperature, screw speed, pressure, and shear force in the extrusion process, increases the percentage of soluble dietary fiber to the detriment of insoluble dietary fiber (Félix-Medina *et al.,* 2020; Esposito *et al.,* 2005). This effect is caused by the break of the glycosidic bonds of polysaccharides by mechanical stress during the extrusion process which forms smaller molecular fragments favoring their solubility (Espinoza-Moreno *et al.,* 2016; Steel *et al.,* 2012; Singh *et al.,* 2007). Although after extrusion the insoluble dietary fiber content is reduced, it is still in the majority (Wani *et al.,* 2021; Pérez-Navarrete *et al.,* 2006).

Regarding ash content, the incorporation of legumes in the mixture resulted in an increase in ash compared to the traditional corn-based snack (0.21-2.41%) (Rico *et al.,* 2021; Félix-Medina *et al.,* 2020; Manosalvas *et al.,* 2019; Hegazy *et al.,* 2017; Pastor-Cavada *et al.,* 2011; Hardacre *et al.,* 2006; Pérez-Navarrete *et al.,* 2006). In terms of minerals, the incorporation of pulses generally increases the supply of major minerals (Na, Ca, K, and Mg) and trace minerals (Zn, Cu, Fe, F, Cr, Se, and Mo) (Shah *et al.,* 2017). Adding wild pulses (*Lathyrus annuus* and *Lathyrus clymenum*) to corn-based snacks increased the potential availability of iron (Pastor-Cavada *et al.,* 2011), as well as its iron content when compared to the extruded corn product by adding beans (Natabirwa *et al.,* 2020). An increase in calcium (55.4 ± 3.5 mg/100 g), zinc (0.72 ± 0.01 mg/100 g), and phosphorus (244 ± 12.3 mg/100 g) was also observed compared to the maize-based snack, respectively (2.4 ± 0.05 mg/100 g), (0.30 ± 0.04 mg/100 g), (34.1 ± 1.6 mg/100 g) (Natabirwa *et al.,* 2020; Pastor-Cavada *et al.,* 2011).

4 Technological and sensorial modifications in extruded snacks

The acceptance of extruded snacks depends on the technological and sensorial properties of the extruded products. A properly expanded snack will exhibit high porosity and, a great expansion rate, but a low bulk density value (Neder-Suárez *et al.,* 2024; Pérez-Navarrete *et al.,* 2006). All these parameters are closely related to the amount and type of starch present in the raw materials, which will affect the expansion rate and the quantity and air cell size developed during extrusion (Gomes *et al.,* 2023; Dehghan-Shoar *et al.,* 2010). Changes in starch structure, such as fusion, gelatinization, and dextrinization, will be affected by factors such as starch source, particle size, amylose/amylopectin ratio, water/starch ratio in the mass (humidity), the type of extruder (single or double screw), screw configuration, barrel and die temperatures, screw speed (shear), and extruder fill rate (Singh & Muthukumarappan, 2017ab; Singh & Muthukumarappan, 2014a; Lai & Kokini, 1991). In this sense, extrusion conditions as well as the composition of the mass will determine the sensorial characteristics and acceptance of the snack.

Viscosity is one of the important rheological properties to understand the behavior of the dough and the changes that occur during extrusion (Lam & Flores, 2003). The study of pasting properties by Rapid Visco Analyzer (RVA) helps to evaluate the texture and quality of extrudates (Wani & Kumar, 2016a). Products with a higher degree of cooking have lower pasting properties than the raw mix (Wani *et al.,* 2021). Extrusion conditions such as reduced humidity and increased screw speed favor dextrinization and gelation, reducing the pasting properties and consequently obtaining a more cooked and more expanded extrudate (Neder-Suárez *et al.,* 2021b), and with lower bulk density (Félix-Medina *et al.,* 2020). High viscosity during extrusion and low final viscosity in RVA tests on already extruded products is associated with high gelatinization, level of starch cooking during extrusion, and therefore more expanded products with lower bulk density (Félix-Medina *et al.,* 2020; Wang *et al.,* 2019). On the contrary, an excess of humidity reduces expansion rates and increases the bulk density of expanded products since the water provokes a reduction in viscosity on the starch matrix and a decrease in energy dissipation in the extruder (Ali *et al.,* 2017; Sosa-Moguel *et al.,* 2009).

In fact, the Specific Mechanical Energy (SME), an indicator of the amount of mechanical energy applied per unit mass during extrusion, represents the breakdown of macromolecules such as starch granules and depends on the viscosity of the mass (Shevkani *et al.,* 2019). SME is positively correlated with expansion because higher SME values, are associated with a greater degree of dextrinization and starch gelatinization, promoting the breaking of intermolecular hydrogen bonds, and giving more air bubbles and therefore, more expanded snacks (Shevkani *et al.,* 2019; Pastor-Cavada *et al.,* 2013). In this context, SME values will be higher in the presence of increased starch concentrations, and higher barrel temperatures and screw speeds. While higher humidity masses and oil contents will reduce SME (Wang *et al.,* 2019; Pastor-Cavada *et al.,* 2013). The presence of humidity and oil enhances the lubricating effect, reducing the viscosity and friction of the dough, and resulting in a less cooked extrudate. As mentioned earlier, this is associated with less expansion, higher density, and greater hardness (Shevkani *et al.,* 2019; Wang *et al.,* 2019; Pastor-Cavada *et al.,* 2013).

Increasing the barrel temperatures during extrusion allows the generation of small and fine air cells, resulting in crunchier, lighter, and less dense products. The higher barrel-temperatures promote the overheating of water, causing it to evaporate more rapidly as it exits the die, contributing to the expansion and lightness of the extrudates (Singha *et al.,* 2018a, Wani & Kumar, 2016b; Gomez & Aguilera, 1984). However, excessive barrel temperatures could lead to a reduced viscosity and lower SME negatively affecting the snack expansion (Singha *et al.,* 2018b). The screw speed has a positive correlation with expansion and a negative correlation with bulk density, since it promotes shear effects on starch, increasing its hydration (Moreira da Silva *et al.,* 2014). In general terms, during extrusion, excess humidity reduces the expansion rates, while higher barrel temperatures favor it (Gomez & Aguilera, 1984). The presence of pulses in the mixtures reduces the SME, possibly due to the lower hardness of pulse cotyledons (Pérez-Navarrete *et al.,* 2006). This decrease can also be attributed to higher protein, fat, and fiber content, which interact with the starch and water, preventing water and starch interaction and affecting starch gelatinization (Gomes *et al.,* 2023; Shevkani *et al.,* 2019).

The inclusion of pulses in the snack formulation will affect to extrusion process and inevitably technological and sensorial snack characteristics will be modified, although the manipulation of the extrusion parameters can somehow reverse the effects.

4.1 Technological properties

As it was said in the previous section, bulk density, expansion, and porosity of an extrudate are important correlated physical characteristics related to the quality of a snack.

Bulk density is negatively correlated with the expansion, porosity, elasticity, and viscosity of the mix during extrusion (Gomes *et al.,* 2023; Singha *et al.,* 2018a; Pathania *et al.,* 2013; Hardacre *et al.,* 2006). The inclusion of pulses generally results in higher bulk density values and consequently lower expansion rates (Félix-Medina *et al.,* 2020; Hegazy *et al.,* 2017; Rodríguez-Miranda *et al.,* 2014; Gabr *et al.,* 2013; Sawant *et al.,* 2013; Pastor-Cavada *et al.,* 2011; Hardacre *et al.,* 2006; Pérez-Navarrete *et al.,* 2006). The higher presence of proteins provided by pulses keeps the mass more plastic during extrusion, leading to the collapse of foam structures and the breaking of cell walls as steam expands due to pressure, preventing air bubbles from growing and resulting in harder, denser extrudates and less expanded (Neder-Suárez *et al.,* 2024; Félix-Medina *et al.,* 2020; Hardacre *et al.,* 2006). Also, the protein interacts with water through hydrophilic interactions, slowing down the loss of expansion in the extruded (Wani *et al.,* 2021). The presence of fiber also has a similar effect on expansion and bulk density (Hegazy *et al.,* 2017). Proteins and fibers compete with starch for available water, reducing the gelation capacity of starch and, therefore, its expansion (Wani *et al.,* 2021; Félix-Medina *et al.,* 2020; Hegazy *et al.,* 2017). The fiber also promotes the rupture of air cells during extrusion (Gomes *et al.,* 2023; Wani *et al.,* 2021; Vadukapuram *et al.,* 2014; Pérez-Navarrete *et al.,* 2006). Moreover, increasing the proportion of other compounds such as protein and fiber reduces the amount of starch in the raw materials, which is responsible for the lower expansion and porosity properties of flours like corn (Neder-Suárez *et al.,* 2024). The effect of lipids on expansion also depends on the type of lipid. Lipids, like proteins, can interact with starch, interfering with gelation and the expansion of the mass (Pérez-Navarrete *et al.,* 2006). They act as a lubricant, reducing cooking and shear effects in the extruder, and leading to lower expansion values (Pastor-Cavada *et al.,* 2013; Lazou *et al.,* 2007).

Furthermore, in the presence of proteins, increasing screw speed when pulses are added to the formulation will promote more protein stretching, weakening bonds, resulting in a fluffier product. This effect is enhanced when starch is affected by shear, promoting its gelatinization and therefore expansion (Wani & Kumar, 2016b). So, an increase in barrel temperature and screw speed can overcome the reduction in the expansion rate, lowering the bulk density values of the extrudates (Kothakota *et al.,* 2013).

Other technological parameters affected by the presence of pulses in extruded snack formulations include the Water Absorption Index (WAI), Water Solubility Index (WSI), and Oil Absorption Index (OIA). WAI measures the amount of water absorbed by starch and serves as an indicator of the degree of gelatinization since starch does not absorb water at room temperature (Nongmaithem *et al.,* 2024; Gomes *et al.,* 2023; Lazou & Krokida, 2010). There is a positive correlation between gelatinized starch and WAI (Nongmaithem *et al.,* 2024).

Increasing the proportion of pulses in mixtures with corn usually results in lower WAI values (Nongmaithem *et al.,* 2024; Shevkani *et al.,* 2019; Singha *et al.,* 2018a; Wani & Kumar, 2016c). This reduction in WAI may be favored by the increased proportion of proteins provided by the pulses which provoke a reduction in starch content in the mixtures (Wani & Kumar, 2016c) and promotes the formation of intermolecular and intramolecular protein-starch bonds with amylose and amylopectin, reducing the availability of starch for gelatinization and, therefore, reducing WAI (Shevkani *et al.,* 2019). Although the presence of proteins should favor the absorption of water due to their hydrophilic groups, during the extrusion process, these proteins denature, losing their ability to hydrate and form gels (Lazou & Krokida, 2010). It can also be explained that the presence of pulse proteins in mixtures with cereal starch increases the gelatinization temperature (Singh & Muthukumarappan 2014; Shevkani *et al.,* 2014). However, some studies have reported that increasing the amount of pulses led to an increase in WAI (Hegazy *et al.,* 2017; Rzedzicki *et al.,* 1994).

WSI measures the amount of soluble components released during extrusion from both starch and protein degradation (Neder-Suárez *et al.,* 2024; Hegazy *et al.,* 2017). The inclusion of pulses, such as increasing the humidity of the mass, increases the WSI (Nongmaithem *et al.,* 2024; Neder-Suárez *et al.,* 2021b; Wani & Kumar, 2016c; Pastor-Cavada *et al.,* 2013).

On the other hand, OIA represents the extrudate's capacity to retain oil and functions as an indicator of its hydrophobic nature. The inclusion of pulses has been shown to diminish OIA (Lazou & Krokida, 2010). The inclusion of pulse proteins (Gujska & Khan, 1991) should favor OIA, as it also increases the presence of nonpolar amino acids and augments the side chains of proteins. However, these proteins interact with each other during extrusion, as well as with starch and lipids, thereby altering their oil absorption capacity. It is crucial to note that a greater presence of proteins fosters interactions between proteins, starch, and lipids, thereby altering the extrudate's oil retention capacity. For instance, when incorporating lentil flour (10-30-50%) into a mixture with corn flour (0.91–4.49 mL/g), as compared to a control extrudate comprising 100% corn flour (1.48 to 5.45 mL/g), notable changes in OIA were observed, as detailed in Lazou & Krokida (2010). In the same study, the impact of extrusion parameters on OIA was explored. It was noted that OIA increased with the extrusion temperature increase. This effect could be attributed to the heightened degree of cooking in the extrudates (Drago *et al.,* 2007), resulting in the formation of smaller starch molecules through dextrinization, thereby favoring increased OIA (Lazou & Krokida, 2010). Conversely, humidity was found to diminish the degree of cooking consequently reducing OIA, as fewer small starch molecules are produced. Another influential parameter affecting OIA is the extruder feed speed, which reduces the residence time of the dough within the equipment, thereby decreasing the degree of cooking and dextrinization, and ultimately lowering OIA (Lazou & Krokida, 2010).

4.2 Sensory properties

The evaluation of sensory properties in extruded products is one of the parameters studied to know the level of acceptability by the consumer, especially in the development of new food products or the modification of some of the characteristics of products already on the market (Wani & Kumar, 2016a; Sawant *et al.,* 2013).

Color is one of the most important attributes that affect snack acceptability. It is one of the parameters studied when obtaining pulse-extruded products since the color of many of these pulses is different from the traditional ingredients of these products, such as cereals. An example is the natural green color of the green pea compared to the yellow color of corn (Wani & Kumar, 2016c). Color changes can provide information about the extent of browning reactions, such as caramelization, the Maillard reaction, the degree of cooking, and pigment degradation which take place during the extrusion process (Ilo & Berghofer, 1999). In general, incorporating pulses into the extrudate will result in snack darkening reflected in lower L^* values as the values of a^* and b^* increase (Rico *et al.,* 2021; Félix-Medina *et al.,* 2020; Singha *et al.,* 2018a; Sawant *et al.,* 2013). However, there are examples where the luminosity (L^*) of the raw pulse is greater than that of the corn flour, such as in Neder-Suárez *et al.* (2021a) (where blue corn and black beans were used), the L^* value was higher in the beans than in the corn. The same occurred with chickpeas which exhibited a higher L^* value than corn (Shevkani *et al.,* 2019). In general a^* increases with the incorporation of pulses and with increasing extrusion temperature and humidity (Singha *et al.,* 2018a; Sawant *et al.,* 2013). As for b^*, it typically increases due to non-enzymatic browning reactions (Rico *et al.,* 2021). Sometimes b^* decreases due to the loss of carotenoids from corn (Cueto *et al.,* 2017), and it increases with an increase in screw speed (Neder-Suárez *et al.,* 2021a).

The other most affected parameter by incorporating pulses into corn extrudates is hardness. Hardness is defined as the maximum force required to overcome the resistance of the extrudate's cell or alveolus walls to break. The more the snack expands the less hard the product is because of the more fragile the cell walls are (Félix-Medina *et al.,* 2020). So, all parameters which limit the snack expansion will increase the product's hardness (Wani *et al.,* 2021; Félix-Medina *et al.,* 2020; Shevkani *et al.,* 2019; Ruiz-Armenta *et al.,* 2018; Tovar-Jiménez *et al.,* 2016; Limón-Valenzuela *et al.,* 2010; Pérez Navarrete *et al.,* 2006). Since pulses incorporation in extruded snacks results in less expanded products, hardness inevitably increases as several studies have shown with chickpeas (Shevkani *et al.,* 2019; Shah *et al.,* 2017), green peas (Wani & Kumar, 2016c), beans (Neder-Suárez *et al.,* 2024; Félix-Medina *et al.* 2020; Pérez-Navarrete *et al.,* 2006) and lentil (Nongmaithem *et al.,* 2024; Gomes *et al.,* 2023).

The inclusion of pulses in the extrudates enhances the protein content, thereby contributing to heightened crispiness. This phenomenon can be elucidated by the intricate interactions between starch and proteins, resulting in the formation of small air bubbles (Natabirwa *et al.,* 2020). Furthermore, the existence of these starch-protein interactions has been linked to an augmentation in the crunchiness and crispiness of the extrudates (Onwulata *et al.,* 2001).

Cohesiveness, another parameter in evaluating extruded products, mirrors the behavior of hardness and increases with the presence of pulses (Paula & Conti-Silva, 2014; Parada *et al.,* 2011). Springiness, indicating the ability of an extrudate to return to its initial height after the first compression, serves as a reliable descriptor for crispy products versus non-crispy ones. In simpler terms, products deemed crispy, like those composed of 100% corn, exhibit very low springiness, whereas the addition of pulses enhances springiness.

Gumminess, chewiness, and resilience exhibit similar trends to hardness. Chewiness assesses bite behavior, with products containing more pulses requiring more bites than those consisting solely of corn. Resilience measures a product's capacity to regain its initial height after undergoing pressure (Shah *et al.,* 2017).

The darkening of the snacks as well as the increase in hardness has been also detected when pulses added to snacks are sensorially evaluated (Shevkani *et al.,* 2019; Hardacre *et al.,* 2006; Rzedzicki *et al.,* 1994). Color changes are also typically observed, with snacks generally darker (Félix-Medina *et al.,* 2020). The flavor of snacks can be also modified (Hardacre *et al.,* 2006). However, not all these changes are necessarily perceived as negative by the panelists (Natabirwa *et al.,* 2020). In general, the most affected parameter is hardness, considering that excessive hardness usually is negatively perceived by the panelists (Shah *et al.,* 2017; Wani & Kumar, 2016a). The addition of pulses to the extrudates causes the traditional yellow color of corn to be penalized, darkening the snacks. There are more discrepancies regarding flavor. The presence of a high percentage of pulses has been sometimes seen as positive, while in other cases, it was negatively scored (Natabirwa *et al.,* 2020; Gabr *et al.,* 2013; Hardacre *et al.,* 2006). For instance, in Hardacre *et al.* (2006) the presence of lentils negatively impacted flavor, while in Natabirwa *et al.* (2020), the snack formulation with 85% pulses received the highest score for taste among adults but was penalized by schoolchildren. In terms of overall acceptability, formulations with moderate proportions of pulses have been better-scored by the panelists, such as 15% pulses chickpea (Shah *et al.,* 2017), 20% pulses chickpea (Selvaprakash *et al.,* 2021), 25% pulses dry green pea (Wani & Kumar, 2016a), and 35% raw materials (rice, chickpea, wheat germ, barley, milk powder) in the study of Gabr *et al.* (2013). However, in some studies such as Natabirwa *et al.* (2020), the highest-rated formulation was the one containing the most pulse (85%).

5 Health impact

It is well-known that snacking, or eating between meals, along with healthy habits, is beneficial for appetite control, weight management, and improved blood glucose control ultimately contributing to maintaining or enhancing the overall health of the population (Kaneko *et al.,* 2021; Arora *et al.,* 2020; Hess *et al.,* 2016). However, controversy arises as current snacks, particularly those categorized as savory, often present large portions, high energy density, and high palatability (Almoraie *et al.,* 2021). These snacks are rich in additives, fats, and salt, categorizing them as junk food (Dunford *et al.,* 2020).

It is the nutritional characteristics of these snacks that make them detrimental to health (Morris *et al.,* 2019). They may increase the risk of developing conditions such as obesity, diabetes, hypertension, and dental issues in the population (Almoraie *et al.,* 2021). Therefore, reducing their nutritional deficiencies and mitigating the negative impact on consumers sounds as a strategy to ameliorate the bad press.

The incorporation of pulses into traditional extruded snacks made mainly from cereals such as corn (Félix-Medina *et al.,* 2020) has been attributed to certain beneficial health-related effects such as reducing the risk of developing certain diseases such as diabetes, obesity, cardiovascular disease and colon cancer by mixing pulses-corn, for example with regular consumption of corn-beans-rich products (Das & Singh, 2016; Fan & Beta, 2016; Chen *et al.,* 2015; Zillic *et al.,* 2012; Reyes-Moreno *et al.,* 2012). These beneficial effects have been associated with several bioactive components present in pulses (polyphenols, polyunsaturated fatty acids, flavonoids, proteins, dietary fiber, minerals, and vitamins) (Félix-Medina *et al.,* 2020; Saha *et al.,* 2009). In addition to the composition of macronutrients, in particular, the higher protein content of pulses along with the amino acid supplementation by the conjugate pulse-corn, increases both the quantity and quality of the protein in the extruded products, as indicated by various studies (Wang *et al.,* 2019; Simons *et al.,* 2015; Estrada-Girón *et al.,* 2015; Sosa-Moguel *et al.,* 2009). On the other hand, as also mentioned earlier, extrusion favors that the food is not excessively altered when it is subjected to a thermal process. They also preserve or in some cases improve aspects associated with health. (Hegazy *et al.,* 2017; Espinoza-Moreno *et al.,* 2016; Delgado *et al.,* 2012). However, it can also cause certain disturbances in the characteristics of macronutrients, such as starch, proteins (Gilani *et al.,* 2012; Huber *et al.,* 2001, Mitchell & Areas, 1991), and dietary fiber. (Lue *et al.,* 1991).

There are few studies on corn-pulse extruded products that focus on health aspects, and most of them rely on *in vitro* tests (antioxidant content, antioxidant activity, glycaemic index, etc.) with only a few involving *in vivo* assessments (serum insulin, glycaemic index, satiety).

Although the consumption of pulses brings benefits as already discussed earlier, on the other hand, it provides antinutrients such as the inhibitors of digestive enzymes such as tripsin, quimotripsine, amylase, tannins, saponins, which are less common and are found in a lower proportion in cereals such as maize. The presence of antinutrient compounds, such as phytic acid, tannic acid, and trypsin inhibitors, can diminish the digestibility of proteins, carbohydrates, fats, and minerals (Wani & Kumar, 2016d). In general, extrusion has been found to increase mineral absorption by reducing anti-nutritional factors like phytates (5.02 mg/g extruded sample) and tannins (0.38 mg/g extruded sample) comparing it with the unextruded mixture (Wani & Kumar, 2016d).

In the study by Hegazy *et al.* (2017), where different chickpea proportions were used (10%, 20%, 30%), the extrusion process reduced the phytic acid content of extrudes by 43.30-46,51% from 1.86 mg/g to 1.00 mg/g in the case of extruded with 30% chickpea by comparing it to the raw mixture. As for tannic acid, the reduction was between 40.46-43.61%, passing from 1.05 to 0.62 mg/g tannic acids in the same previous mixture, this reduction of tannin content due to the heat treatment in extrusion favors the mineral absorption (Wani & Kumar, 2016d). Similar results were reported by Wani & Kumar (2016b), Anton *et al.* (2009), and Hussein (2000). Rico *et al.* (2021) worked with extruded lentil-maize mixtures at different temperatures (110 to 130°C), without obtaining important differences in the content of phytic acid, possibly due to hydrolysis and the action of phytase with an optimal temperature in the range of 48 to 55 °C.

Another parameter studied in this type of product is the content of antioxidants and antioxidant activity. In general, according to the antioxidant activity tests used in several studies, the antioxidant activity (DPPH, ABTS, FRAP and ORAC) in corn blends and pulses increases after the extrusion process (Rico *et al.,* 2021; Félix-Medina *et al.,* 2020; Hegazy *et al.,* 2017; Wani & Kumar, 2016a) and the inclusion of pulses (Nongmaithem *et al.,* 2024; Sahoo *et al.,* 2021; Gómez-Favela *et al.,* 2021; Hegazy *et al.,* 2017).

Extrusion parameters such as barrel temperature, humidity, screw speed, and feed rate affect the antioxidant activity of extrudates. In general, increasing screw speed decreases the antioxidant activity, especially at lower humidity conditions and especially when it is accompanied by lower feed rates. In the case of increased humidity in the mixture, it favors antioxidant activity due to the lubricating effect, since the shear effect is more aggressive for antioxidants at lower humidity. Regarding the barrel temperature, its increase favors antioxidant activity (Neder-Suarez *et al.*, 2021a; Wani & Kumar, 2019; Ozer *et al.,* 2006; Delgado-Andrade *et al.,* 2005; Cämmerer *et al.,* 2002). An increase in antioxidant activity has been observed as a consequence of extrusion, increasing from 8.1 to 20.90% in the DPPH technique (Wani & Kumar, 2019, 2016a). As for the incorporation of pulses into corn extrudates, it has been observed that the antioxidant activity increases (Rico *et al.,* 2021; Ciudad-Mulero *et al.,* 2018; Espinoza-Moreno *et al.,* 2016). An exception is observed by Felix-Medina *et al.* (2020), who observed that by increasing the proportion of pulses, the antioxidant activity decreased.

On the other hand, the antioxidant activity is given by certain antioxidant compounds such as different types of polyphenols. Polyphenols are substances that contain an aromatic ring possessing hydroxyl groups (Zielinski *et al.,* 2001). These compounds are thermosensitive at temperatures above 80 °C, therefore increasing the barrel temperature and screw speed causes a reduction in the content of these compounds (Wani *et al.,* 2021; Wani & Kumar, 2019, 2016a; Sharma *et al.,* 2012; Altan *et al.,* 2009). Polyphenols can be found in two states, free or bound to the cell wall of the raw material. In the study by Félix-Medina *et al.* (2021), it was observed that free phenolic compounds have a lower antioxidant activity than those bound to the cell wall. The latter remains present after extrusion.

The incorporation of corn pulses in snacks usually provokes an increase in overall polyphenols when compared with a product obtained from 100% corn, as occurred in Sahoo *et al.* (2021) and Shevkani *et al.* (2019) with chickpea, in Gómez-Favela *et al.* (2021) and Neder-Suarez *et al.* (2024) with bean, in Nongmaithem *et al.* (2024) with lentils. For example, Hegazy *et al.* (2017) saw an increase in total phenols (1.92-7.94%) and antioxidant activity respectively, but the antioxidant increased ratio decreased from 5.94 to 1.94% as the proportion of chickpeas increased (10-30%). On the other hand, the results obtained by Rico *et al.* (2021) showed that both polyphenol content and antioxidant activity increased with both pulse incorporation and with increasing extrusion temperature (110-130 °C). A possible explanation offered for this effect was the release of bioactive components from the cell wall matrix (Wang & Ryu, 2013; Zielinski *et al.,* 2006). However, a reduction in both phenolic compounds and antioxidant activity was observed when beans were included (Félix-Medina *et al.,* 2020). In the results provided by Pastor-Cavada *et al.* (2011, 2013), the incorporation of wild vegetables neither meant an increase nor a decrease in the content of polyphenols. The discrepancies found could be explained as follows. On the one hand, it has been observed that there is a release of polyphenols due to the destruction of the cell walls of the raw materials after applying the extrusion process in pulse-corn mixtures (Sahoo *et al.,* 2021; Gómez-Favela *et al.,* 2021; Félix-Medina *et al.,* 2020). It has also been reported that the presence of free amino acids, the reduction of sugars and proteins, and the use of high temperatures and low humidity, favor the Maillard reactions forming melanoidins, which although they are degradation products of phenolic acids (Bartel *et al.,* 2015) also it presented antioxidant activity (Félix-Medina *et al.,* 2020; Wani & Kumar, 2016a). In addition to these compounds, other high molecular weight compounds are also formed that absorb in the same wavelength range, so this polyphenol content might be overestimated (Félix-Medina *et al.,* 2020; Thanuja *et al.,* 2020). On the other hand, the reported reduction of total polyphenols in pulse-corn snacks has been attributed to the high temperatures reached during extrusion, which alter or degrade the molecular structure of phenolic compounds (Nongmaithem *et al.,* 2024; Neder-Suarez *et al.,* 2024; Wani *et al.,* 2021; Wani & Kumar, 2016a).

In summary, most studies support that the incorporation of pulses favors antioxidant activity (Rico *et al.,* 2021; Félix-Medina *et al.,* 2020; Hegazy *et al.,* 2017; Wani & Kumar, 2016a), and that extrusion under conditions of high humidity, low screw speed, and high barrel temperature increases antioxidant activity (Neder-Suarez *et al.,* 2021a; Wani & Kumar, 2019; Ozer *et al.,* 2006; Delgado-Andrade *et al.,* 2005; Cämmerer *et al.,* 2002). As for the polyphenol content, the incorporation of pulses increases its content (Neder-Suarez *et al.,* 2024; Nongmaithem *et al.,* 2024; Sahoo *et al.,* 2021; Gómez-Favela *et al.,* 2021; Shevkani *et al.,* 2019; Hegazy *et al.,* 2017) but concerning extrusion, there are discrepancies between whether it increases or decreases its content.

One of the most studied health parameters, especially at the *in vitro* level, has been the glycaemic index (GI), which is defined as the elevation of blood glucose concentrations after consumption of a food or a meal. Glycemia after food (glycaemic postprandial) consumption is a normal physiological response whose intensity and duration will depend, among other factors, on the characteristics of the food intake. The concept of GI categorizes food based on its proposed effect on postprandial blood glucose compared to a reference food, or more recently, to pure glucose. GI can be influenced not only by the chemical and physical nature of the food or meal consumed but also by individual factors (Venn *et al.,* 2007). Some of these factors include certain types of dietary fiber, starch structures, types of sugar, fat, protein content, water content, cellular structure, particle distribution, and the presence of organic acids and enzymatic inhibitors (Thorsdottir *et al.,* 2005). It is of interest to know the GI of foods, since it has been associated with the consumption of foods with a low GI, with a reduced risk of type 2 diabetes (Hodge., 2004).

Several articles have studied *in vitro* GI in snacks combining pulses and corn (Nongmaithem *et al.,* 2024; Rico *et al.,* 2021; Wani *et al.,* 2021; Hardacre *et al.,* 2006) and very few have studied it *in vivo* (Johnston *et al.,* 2021). Both the effect of the combination of these ingredients and the effect of the extrusion itself have been studied. In the case of the incorporation of pulses, Hardacre *et al.* (2006) worked with lentils, showing that products with a higher proportion of corn released more glucose than those with a higher proportion of lentils. As a curiosity, the lowest glucose release was not obtained in the formulation with 100% lentils but in the combination of 40-60 corn-lentils, so the combination of both might have a better effect on glycemia. The same conclusions were provided by Rico *et al.* (2021) where the combination of 50-50 corn-lentils portion, showed a reduction of GI at extrusion temperatures of

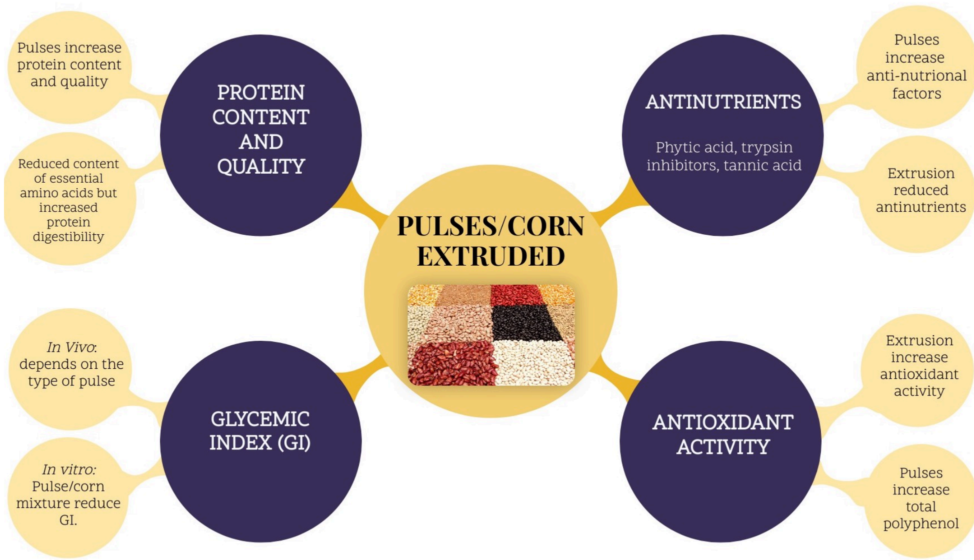

Figure 1. Effects of including pulse in corn extrudates.

110-120 °C concerning the original product (100% corn). In Wani *et al.* (2021), similar results were obtained with the green bean (9%), reducing GI from 73± 3 to 47± 1.2 mmol·min/L of glucose.

Regarding the effects of extrusion parameters, the effect of temperature was studied as mentioned above (Rico *et al.,* 2021) when combining corn-lentils, obtaining the lowest GI at an extrusion temperature of 130 °C, when compared with lower extrusion temperatures (110-120 °C). The possible explanation offered was the formation of a crust at high temperatures that reduces the gelatinization of starch, i.e. the formation of resistant starch that limits the access of the digestive enzymes and the liberation of the starch.

As for the IG *in vivo* studies, the results are disparate and there are differences about the original product, depending on which click let's talk (Johnston *et al.,* 2021). Corn-pulse was combined in proposition 60-40, obtaining IG differences concerning the control with 100% corn (142.0 mmol·min/L of blood glucose) in the mixtures with chickpea (110.0 mmol·min/L of blood glucose) and pinto bean (102.0 mmol·min/L of blood glucose). Nevertheless, no significant differences were appreciated between whole yellow pea (148.0 mmol·min/L of blood glucose), and green lentil (140.0 mmol·min/L of blood glucose) as well as the control. The same study also analyzed postprandial insulin after the consumption of the product, obtaining differences only in the mixture of pinto bean and corn. Another parameter that was determined was satiety after the consumption of the different formulations, without finding significant differences.

In short, the combination of pulses-corn in *in vitro* studies has been observed to reduce the release of glucose (Rico *et al.,* 2021; Wani *et al.,* 2021; Hardacre *et al.,* 2006). Extrusion at high temperatures (130 °C) also reduces IG (Rico *et al.,* 2021). And in *in vivo* studies, only the chickpea and pinto bean have reduced glucose levels. In conclusion, there are few *in vitro* IG studies, such as *in vivo*. Therefore, it is necessary to study further the effect of the incorporation of pulses in combination with corn in extruded snacks.

Natabirwa *et al.* (2020) studied how an optimized snack containing 82.03% beans, 10% corn, and 2.97% OFSP (orange-fleshed sweet potato) contributed to the recommended daily intake of protein, fiber, and iron for children aged 4 to 8 years, reaching 42.9, 19.3 and 12.1% of the RDI for protein, iron, and zinc, respectively.

Conclusion

The incorporation of pulses is a good option to improve the nutritional profile of puff snacks as reviewed in this article, due to the increase of protein, fiber, minerals, and the reduction of carbohydrates. At the same time, it notoriously affects the technological and sensory characteristics of the product, which can be minimized by adjusting certain parameters during extrusion, but it may still affect the acceptability of the product to consumers. As far as health studies are concerned, most of them use *in vitro* methodologies, which suggest certain benefits associated with the reduction of anti-nutritional compounds, antioxidant activity, and glycaemic index, but which need to be confirmed by *in vivo* studies.

References

Ai, Y., Cichy, K. A., Harte, J. B., Kelly, J. D. and Ng, P. K. (2016). Effects of extrusion cooking on the chemical composition and functional properties of dry common bean powders. *Food Chemistry 211*, 538-545. https://doi.org/10.1016/j.foodchem.2016.05.095

Alam, M. S., Kaur, J., Khaira, H. and Gupta, K. (2016). Extrusion and extruded products: changes in quality attributes as affected by extrusion process parameters: a review. *Critical Reviews in Food Science and Nutrition 56*(3), 445-473. https://doi.org/10.1080/10408398.2013.779568

Algarni, E. H., Hussien, H. A. and Salem, E. M. (2019). Development of nutritious extruded snacks. *Life Science Journal 16*(9), 23-31. http://www.lifesciencesite.com/lsj/lsj160919/03_35203lsj160919_23_31.pdf

Ali, S., Singh, B. and Sharma, S. (2017). Development of high-quality weaning food based on maize and chickpea by twin-screw extrusion process for low-income populations. *Journal of Food Process Engineering 40*(3), e12500. https://doi.org/10.1111/jfpe.12500

Almoraie, N. M., Saqaan, R., Alharthi, R., Alamoudi, A., Badh, L. and Shatwan, I. M. (2021). Snacking patterns throughout the life span: potential implications on health. *Nutrition Research 91*, 81-94.

Alonso, R., Aguirre, A. and 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. https://doi.org/10.1016/S0308-8146(99)00169-7

Alonso, R., Rubio, L. A., Muzquiz, M. and Marzo, F. (2001). The effect of extrusion cooking on mineral bioavailability in pea and kidney bean seed meals. *Animal Feed Science and Technology 94*(1-2), 1-13. https://doi.org/10.1016/S0377-8401(01)00302-9

Altan, A., McCarthy, K. L. and Maskan, M. (2009). Effect of extrusion process on antioxidant activity, total phenolics and β-glucan content of extrudates developed from barley-fruit and vegetable by-products. *International Journal of Food Science and Technology 44*(6), 1263-1271. https://doi.org/10.1111/j.1365-2621.2009.01956.x

Ambigaipalan, P., Hoover, R., Donner, E., Liu, Q., Jaiswal, S., Chibbar, R., Nantanga, K.K.M. and Seetharaman, K. (2011). Structure of faba bean, black bean and pinto bean starches at different levels of granule organization and their physicochemical properties. *Food Research International 44*(9), 2962-2974. https://doi.org/10.1016/j.foodres.2011.07.006

Anton, A. A., Fulcher, R. G. and Arntfield, S. D. (2009). 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 Chemistry 113*(4), 989-996. https://doi.org/10.3390/foods9111593

Arora, M., Singhal, S., Rasane, P., Singh, J., Kaur, S., Kumar, V., Kumar, A. and Mishra, A. (2020). Snacks and Snacking: Impact on Health of the Consumers and Opportunities for its Improvement. *Current Nutrition & Food Science 16*(7), 1028-1043. https://doi.org/10.2174/1573401316666200130110357

Azima, F., Anggraini, T., Syukri, D. and Septia, R. A. (2017). Research Article Effects of Sodium Bisulfite Soaking on the Quality of Durian Seed Flour and its Application to Dakak-dakak Production (West Sumatra's Traditional Snack). *Pakistan Journal of Nutrition 6* (3): 175-178. https://doi.org/10.3923/pjn.2017.175.178

Bamdad, F., Dokhani, S. and Keramat, J. (2009). Functional assessment and subunit constitution of Lentil (*lens culinaris*) proteins during Germination. *International Journal of Agriculture and Biology 11*(6), 690-694.

Bartel, C., Mesías, M. and Morales, F. J. (2015). Investigation on the extractability of melanoidins in portioned espresso coffee. *Food Research International 67*, 356-365. https://doi.org/10.1016/j.foodres.2014.11.053

Bashir, S., Sharif, M. K., Butt, M. S. and Shahid, M. (2016). Functional properties and amino acid profile of *Spirulina platensis* protein isolates. *Pakistan Journal of Scientific and Industrial Research 59*(1), 12-19. http://dx.doi.org/10.52763/PJSIR.BIOL.SCI.59.1.2016.12.19

Bhatnagar, S. and Hanna, M. A. (1994). Extrusion processing conditions for amylose-lipid complexing. *Cereal Chemistry 35*, 340-347.

Bisharat, G. I., Eleni, P. N., Panagiotou, N. M., Krokida, M. K. and Maroulis, Z. B. (2014). Thermal, textural, and physicochemical analysis of corn extrudates enriched with broccoli or olive paste. *International Journal of Food Properties 17*(9), 2100-2116. https://doi.org/10.1080/10942912.2013.785560

Boschin, G. and Arnoldi, A. (2011). Legumes are valuable sources of tocopherols. *Food Chemistry 127*(3), 1199-1203. https://doi.org/10.1016/j.foodchem.2011.01.124

Boye, J., Zare, F., and Pletch, A. (2010). Pulse proteins: Processing, characterization, functional properties and applications in food and feed. *Food Research International 43*(2), 414-431. https://doi.org/10.1016/j.foodres.2009.09.003

Brennan, M. A., Derbyshire, E., Tiwari, B. K. and Brennan, C. S. (2013). Ready-to-eat snack products: the role of extrusion technology in developing consumer acceptable and nutritious snacks. *International Journal of Food Science & Technology 48*(5), 893-902. https://doi.org/10.1111/ijfs.12055

Cai, R., McCurdy, A. and Baik, B. K. (2002). Textural property of 6 legume curds in relation to their protein constituents. *Journal of Food Science 67*(5), 1725-1730. https://doi.org/10.1111/j.1365-2621.2002.tb08713.x

Calabrò, S., Cutrignelli, M. I., Lo Presti, V., Tudisco, R., Chiofalo, V., Grossi, M., Infascelli, F. and Chiofalo, B. (2015). Characterization and effect of year of harvest on the nutritional properties of three varieties of white lupine (*Lupinus albus* L.). *Journal of the Science of Food and Agriculture 95*(15), 3127-3136. https://doi.org/10.1002/jsfa.7049

Camacho-Hernández, I. L., Zazueta-Morales, J. J., Gallegos-Infante, J. A., Aguilar-Palazuelos, E., Rocha-Guzmán, N. E., Navarro-Cortez, R. O., Jacobo-Valenzuela, N. and Gómez-Aldapa, C. A. (2014). Effect of extrusion conditions on physicochemical characteristics and anthocyanin content of blue corn third-generation snacks. *CyTA-Journal of Food*, *12*(4), 320-330. https://doi.org/10.1080/19476337.2013.861517

Cämmerer, B., Jalyschko, W. and Kroh, L. W. (2002). Intact carbohydrate structures as part of the melanoidin skeleton. *Journal of Agricultural and Food Chemistry 50*(7), 2083-2087. https://doi.org/10.1021/jf011106w

Caprioli, G., Giusti, F., Ballini, R., Sagratini, G., Vila-Donat, P., Vittori, S. and Fiorini, D. (2016). Lipid nutritional value of pulses: Evaluation of different extraction methods and determination of fatty acid composition. *Food Chemistry 192*, 965-971. https://doi.org/10.1016/j.foodchem.2015.07.102

Carlsson, N. G., Karlsson, H. and Sandberg, A. S. (1992). Determination of oligosaccharides in foods, diets, and intestinal contents by high-temperature gas chromatography and gas chromatography/mass spectrometry. *Journal of Agricultural and Food Chemistry 40*(12), 2404-2412. https://doi.org/10.1021/jf00024a015

Castro-Montoya, Y. A., Jacobo-Valenzuela, N., Delgado-Nieblas, C. I., Ruiz-Armenta, X. A., Heredia, J. B., Delgado-Murillo, S. A., Calderón-Castro, J.J. and Zazueta-Morales, J. J. (2024). Effect of the extrusion process on phytochemical, antioxidant, and cooking properties of gluten-free pasta made from broken rice and nopal. *Revista Mexicana de Ingeniería Química 23*(1), Alim24149. https://doi.org/10.24275/rmiq/Alim24149

Chaudhary, A., Marinangeli, C. P., Tremorin, D. and Mathys, A. (2018). Nutritional combined greenhouse gas life cycle analysis for incorporating canadian yellow pea into cereal-based food products. *Nutrients 10*(4), 490. https://doi.org/10.3390/nu10040490

Chauhan, G. S. and Bains, G. S. (1988). Effect of some extruder variables on physico-chemical properties of extruded rice-Legume blends. *Food Chemistry 27*(3), 213-224. https://doi.org/10.1016/0308-8146(88)90064-7

Cheftel, J. C. (1986). Nutritional effects of extrusion-cooking. *Food Chemistry 20*(4), 263-283. https://doi.org/10.1016/0308-8146(86)90096-8

Chen, B., Yu, C., Liu, J., Yang, Y., Shen, X., Liu, S. and Tang, X. (2017). Physical properties and chemical forces of extruded corn starch fortified with soy protein isolate. *International Journal of Food Science & Technology 52*(12), 2604-2613. https://doi.org/10.1111/ijfs.13547

Chen, P. X., Bozzo, G. G., Freixas-Coutin, J. A., Marcone, M. F., Pauls, P. K., Tang, Y., Zhang, B., Liu, R. and Tsao, R. (2015). Free and conjugated phenolic compounds and their antioxidant activities in regular and non-darkening cranberry bean (*Phaseolus vulgaris* L.) seed coats. *Journal of Functional Foods 18*, 1047-1056. https://doi.org/10.1016/j.jff.2014.10.032

Chilomer, K., Zaleska, K., Ciesiolka, D., Gulewicz, P., Frankiewicz, A., and Gulewicz, K. (2010). Changes in the alkaloid, alpha-galactoside and protein fractions content during germination of different lupin species. *Acta Societatis Botanicorum Poloniae 79*(1), 11-20. http://dx.doi.org/10.5586/asbp.2010.002

Ciudad-Mulero, M., Barros, L., Fernandes, Â., Berrios, J. D. J., Cámara, M., Morales, P., Fernández-Ruiz, V. and Ferreira, I. C. (2018). Bioactive compounds and antioxidant capacity of extruded snack-type products developed from novel formulations of lentil and nutritional yeast flours. *Food & Function 9*(2), 819-829. https://doi.org/10.1039/C7FO01730H

Conti-Silva, A. C., Bastos, D. H. and Arêas, J. A. (2012). The effects of extrusion conditions and the addition of volatile compounds and flavour enhancers to corn grits on the retention of the volatile compounds and texture of the extrudates. *International Journal of Food Science & Technology 47*(9), 1896-1902. https://doi.org/10.1111/j.1365-2621.2012.03047.x

Cueto, M., Perez Burillo, S., Rufián-Henares, J. Á., Farroni, A. E. and Buera, M. D. P. (2017). Toasting time and cooking formulation affect browning reaction products development in corn flakes. *Cereal Chemistry 94*(3), 380-384. https://doi.org/10.1094/CCHEM-03-16-0053-R

da Silva, E. M. M., Ascheri, J. L. R., de Carvalho, C. W. P., Takeiti, C. Y. and Berrios, J. D. J. (2014). Physical characteristics of extrudates from corn flour and dehulled carioca bean flour blend. *LWT-Food Science and Technology 58*(2), 620-626. https://doi.org/10.1016/j.lwt.2014.03.031

Dahl, W. J., Foster, L. M. and Tyler, R. T. (2012). Review of the health benefits of peas (*Pisum sativum* L.). *British Journal of Nutrition 108*(S1), S3-S10. https://doi.org/10.1017/S0007114512000852

Dalgetty, D. D. and Baik, B. K. (2003). Isolation and characterization of cotyledon fibers from peas, lentils, and chickpeas. *Cereal Chemistry 80*(3), 310-315. https://doi.org/10.1094/CCHEM.2003.80.3.310

Das, A. K. and Singh, V. (2016). Antioxidative free and bound phenolic constituents in botanical fractions of Indian specialty maize (*Zea mays* L.) genotypes. *Food Chemistry 201*, 298-306. https://doi.org/10.1016/j.foodchem.2016.01.099

de Almeida Costa, G. E., da Silva Queiroz-Monici, K., Reis, S. M. P. M. and de Oliveira, A. C. (2006). Chemical composition, dietary fibre and resistant starch contents of raw and cooked pea, common bean, chickpea and lentil legumes. *Food Chemistry* 94(3), 327-330. https://doi.org/10.1016/j.foodchem.2004.11.020

de Moraes, R. M. and Angelucci, E. (1971). Chemical composition and amino acid contents of Brazilian beans (*Phaseolus vulgaris*). *Journal of Food Science 36*(3), 493-494 https://doi.org/10.1111/j.1365-2621.1971.tb06396.x

Dehghan-Shoar, Z., Hardacre, A. K., and Brennan, C. S. (2010). The physico-chemical characteristics of extruded snacks enriched with tomato lycopene. *Food Chemistry 123*(4), 1117-1122.

Delgado, E., Rodríguez, J. H., Rocha-Guzman, N., Rodriguez-Vidal, A., Herrera-Gonzalez, S. M., Medrano-Roldan, H., Solis-Soto, A. and Ibarra-Perez, F. (2012). Inhibition of the growth of rats by extruded snacks from beans (*Phaseolus vulgaris*) and corn (*Zea mays*). *Emirates Journal of Food and Agriculture 24*(3), 255-263.

Delgado-Andrade, C., Rufián-Henares, J. A. and Morales, F. J. (2005). Assessing the antioxidant activity of melanoidins from coffee brews by different antioxidant methods. *Journal of Agricultural and Food Chemistry 53*(20), 7832-7836. https://doi.org/10.1021/jf0512353

Delgado-Nieblas, C. I., Zazueta-Morales, J. J., Aguilar-Palazuelos, E., Jacobo-Valenzuela, N., Aguirre-Tostado, F. S., Carrillo-López, A., Ruiz-Armenta, X.A. and Telis-Romero, J. (2018). Physical, microstructural and sensory characteristics of extruded and microwave-expanded snacks added with dehydrated squash. *Revista Mexicana de Ingeniería Química 17* (3) 805-821 file:///D:/Descargas/10.24275/uam/izt/dcbi/revmexingquim/2018v17n3/Delgadoissn-e:%202395-8472

Dhawan, K., Malhotra, S., Dahiya, B. S. and Singh, D. (1991). Seed protein fractions and amino acid composition in gram (*Cicer arietinum*). *Plant Foods for Human Nutrition 41*, 225-232. https://doi.org/10.1007/BF02196390

Draganovic, V., van der Goot, A. J., Boom, R. and Jonkers, J. (2011). Assessment of the effects of fish meal, wheat gluten, soy protein concentrate and feed moisture on extruder system parameters and the technical quality of fish feed. *Animal Feed Science and Technology 165*(3-4), 238-250. https://doi.org/10.1016/j.anifeedsci.2011.03.004

Drago, S. R., Velasco-González, O. H., Torres, R. L., González, R. J. and Valencia, M. E. (2007). Effect of the extrusion on functional properties and mineral dialyzability from *Phaseolus vulgaris* bean flour. *Plant Foods for Human Nutrition 62*, 43-48. https://doi.org/10.1007/s11130-006-0033-5

Dunford, E. K., Popkin, B. M. and Ng, S. W. (2020). Recent trends in junk food intake in US children and adolescents, 2003–2016. *American Journal of Preventive Medicine 59*(1), 49-58. https://doi.org/10.1016/j.amepre.2020.01.023

El-Adawy, T. A. (2002). Nutritional composition and antinutritional factors of chickpeas (*Cicer arietinum* L.) undergoing different cooking methods and germination. *Plant Foods for Human Nutrition 57*, 83-97. https://doi.org/10.1023/A:1013189620528

Elkowicz, K. and Sosulski, F. W. (1982). Antinutritive factors in eleven legumes and their air-classified protein and starch fractions. *Journal of Food Science 47*(4), 1301-1304.

Ene-Obong, H. N. and Carnovale, E. (1992). A comparison of the proximate, mineral and amino acid composition of some known and lesser known legumes in Nigeria. *Food Chemistry 43*(3), 169-175. https://doi.org/10.1016/0308-8146(92)90169-3

Erbaş, M., Certel, M. and Uslu, M. K. (2005). Some chemical properties of white lupin seeds (*Lupinus albus L.*). *Food Chemistry 89*(3), 341-345. https://doi.org/10.1016/j.foodchem.2004.02.040

Escalante-Aburto, A., Ramírez-Wong, B., Torres-Chávez, P. I., Figueroa-Cárdenas, J. D., López-Cervantes, J., Barrón-Hoyos, J. M. and Morales-Rosas, I. (2013). Effect of extrusion processing parameters on anthocyanin content and physicochemical properties of nixtamalized blue corn expanded extrudates. *CyTA-Journal of Food 11*:sup1, 29-37. https://doi.org/10.1080/19476337.2013.764929

Espinoza-Moreno, R. J., Reyes-Moreno, C., Milán-Carrillo, J., López-Valenzuela, J. A., Paredes-López, O. and Gutiérrez-Dorado, R. (2016). Healthy ready-to-eat expanded snack with high nutritional and antioxidant value produced from whole amarantin transgenic maize and black common bean. *Plant Foods for Human Nutrition 71*, 218-224. https://doi.org/%2010.1007/s11130-016-0551-8

Esposito, F., Arlotti, G., Bonifati, A. M., Napolitano, A., Vitale, D. and Fogliano, V. (2005). Antioxidant activity and dietary fibre in durum wheat bran by-products. *Food Research International 38*(10), 1167-1173. https://doi.org/10.1016/j.foodres.2005.05.002

Estrada-Girón, Y., Martínez-Preciado, A. H., Michel, C. R. and Soltero, J. F. A. (2015). Characterization of extruded blends of corn and beans (*Phaseolus vulgaris*) cultivars: Peruano and Black-Queretaro under different extrusion conditions. *International Journal of Food Properties 18*(12), 2638-2651. https://doi.org/10.1080/10942912.2014.999862

Fan, G. and Beta, T. (2016). Proximate composition, phenolic profiles and antioxidant capacity of three common bean varieties (*Phaseolus vulgaris* L.). *Journal of Food Chemistry & Nanotechnology 2*(3), 147–152. http://dx.doi.org/10.17756/jfcn.2016-023

Fan, P. H., Zang, M. T. and Xing, J. (2015). Oligosaccharides composition in eight food legumes species as detected by high-resolution mass spectrometry. *Journal of the Science of Food and Agriculture 95*(11), 2228-2236. https://doi.org/10.1002/jsfa.6940

Félix-Medina, J. V., Gutiérrez-Dorado, R., López-Valenzuela, J. A., López-Ángulo, G., Quintero-Soto, M. F., Perales-Sánchez, J. X. K. and Montes-Ávila, J. (2021). Nutritional, antioxidant and phytochemical characterization of healthy ready-to-eat expanded snack produced from maize/common bean mixture by extrusion. *LWT – Food Science and Techonology 142*, 111053. https://doi.org/10.1016/j.lwt.2021.111053

Félix-Medina, J. V., Montes-Ávila, J., Reyes-Moreno, C., Perales-Sánchez, J. X. K., Gómez-Favela, M. A., Aguilar-Palazuelos, E.

and Gutiérrez-Dorado, R. (2020). Second-generation snacks with high nutritional and antioxidant value produced by an optimized extrusion process from corn/common bean flours mixtures. *LWT – Food Science and Techonology 124*, 109172. https://doi.org/10.1016/j.lwt.2020.109172

Flores-Silva, P., Martínez-Yañez, R. C., Rodríguez-Huezo, M. E. and Alvarez-Ramirez, J. (2022). Nutritional protein quality and digestibility changes during food processing. *Revista Mexicana de Ingeniería Química 21*(1), Alim2748. https://doi.org/10.24275/rmiq/Alim2917

Food and Agriculture Organization of the United Nations. (2011). Crops Statistics-Concepts, Definitions and Classifications. Available: https://www.fao.org/3/cb2462en/cb2462en.pdf. Accessed: April 21, 2024.

Fordham, J. R., Wells, C. E. and Chen, L. H. (1975). Sprouting of seeds and nutrient composition of seeds and sprouts. *Journal of Food Science 40*(3), 552-556. https://doi.org/10.1111/j.1365-2621.1975.tb12526.x

Fouad, A. A. and Rehab, F. M. (2015). Effect of germination time on proximate analysis, bioactive compounds and antioxidant activity of lentil (*Lens culinaris* Medik.) sprouts. *Acta Scientiarum Polonorum Technologia Alimentaria 14*(3), 233-246. https://doi.org/10.17306/j.afs.2015.3.25

Freire, V. (2014). La nueva situación epidemiológica de Ecuador. *Revista Informativa-Ops/Oms Representacion Ecuador 32*, 1-100.

Frias, J., Doblado, R. and Vidal-Valverde, C. (2003). Kinetics of soluble carbohydrates by action of endo/exo α-galactosidase enzyme in lentils and peas. *European Food Research and Technology 216*, 199-203. https://doi.org/10.1007/s00217-002-0638-3

Frimpong, A., Sinha, A., Tar'an, B., Warkentin, T. D., Gossen, B. D. and Chibbar, R. N. (2009). Genotype and growing environment influence chickpea (*Cicer arietinum* L.) seed composition. *Journal of the Science of Food and Agriculture 89*(12), 2052-2063. https://doi.org/10.1002/jsfa.3690

Gabr, A. M., Mahgoub, S. A. and Shehata, W. M. (2013). Production of high nutritional value snack foods for children from grains and legumes. *Journal of Food and Dairy Sciences*,*4*(9), 455-464. https://dx.doi.org/10.21608/jfds.2013.72085

Garcia, O. E., Infante, R. B. and Rivera, C. J. (1997). Determination of total, soluble and insoluble dietary fibre in two new varieties of *Phaseolus vulgaris* L. using chemical and enzymatic gravimetric methods. *Food Chemistry 59*(1), 171-174. https://doi.org/10.1016/S0308-8146(95)00231-6

García-Segovia, P., Igual, M., Noguerol, A. T., and Martínez-Monzó, J. (2020). Use of insects and pea powder as alternative protein and mineral sources in extruded snacks. *European Food Research and Technology 246*(4), 703-712. https://doi.org/10.1007/s00217-020-03441-y

Gharibzahedi, S. M. T., Mousavi, S. M., Jafari, S. M. and Faraji, K. (2012). Proximate composition, mineral content, and fatty acids profile of two varieties of lentil seeds cultivated in Iran. *Chemistry of Natural Compounds 47*, 976-978. https://doi.org/10.1007/s10600-012-0119-2

Ghumman, A., Kaur, A. and Singh, N. (2016). Impact of germination on flour, protein and starch characteristics of lentil (*Lens culinari*) and horsegram (*Macrotyloma uniflorum L.*) lines. *LWT - Food Science and Technology 65*, 137-144. https://doi.org/10.1016/j.lwt.2015.07.075

Giannini, A. N., Krokida, M. K. and Bisharat, G. I. (2013). Structural properties of corn-based extrudates enriched with plant fibers. *International Journal of Food Properties 16*(3), 667-683. https://doi.org/10.1080/10942912.2011.565536

Gilani, G. S., Xiao, C. W. and Cockell, K. A. (2012). Impact of antinutritional factors in food proteins on the digestibility of protein and the bioavailability of amino acids and on protein quality. *British Journal of Nutrition 108*(S2), S315-S332. https://doi.org/10.1017/S0007114512002371

Gomes, K. S., Berwian, G. F., Tiepo, C. B. V. and Colla, L. M. (2023). Development and evaluation of extruded protein snacks added. *Food Science and Technology 43*. https://doi.org/10.5327/fst.1123

Gomez, M. H. and Aguilera, J. M. (1984). A physicochemical model for extrusion of corn starch. *Journal of Food Science 49*(1), 40-43. https://doi.org/10.1111/j.1365-2621.1984.tb13664.x

Gómez-Favela, M. A., Reyes-Moreno, C., Milán-Carrillo, J., Partida-Preciado, R. A., Espinoza-Moreno, R. J., Preciado-Ortiz, R. and Gutiérrez-Dorado, R. (2021). Gluten-free healthy snack with high nutritional and nutraceutical value elaborated from a mixture of extruded underutilized grains (quality protein maize/tepary bean). *Acta universitaria 31*. https://doi.org/10.15174/au.2021.3024

Gopala Krishna, A. G., Prabhakar, J. V. and Aitzetmüller, K. (1997). Tocopherol and fatty acid composition of some Indian pulses. *Journal of the American Oil Chemists' Society 74*(12), 1603-1606. https://doi.org/10.1007/s11746-997-0084-2

Gopirajah, R. and Muthukumarappan, K. (2018). Effect of extrusion process conditions on the physical properties of tef-oat healthy snack extrudates. *Journal of Food Processing and Preservation 42*(3), e13559. https://doi.org/10.1111/jfpp.13559

Graybosch, R. A. (2004). Grain crops, overview. *Encyclopedia of Grain Science 2*, 46-55.

Gujska, E. and Khan, K. (1991). Functional properties of extrudates from high starch fractions of navy and pinto beans and corn meal blended with legume high protein fractions. *Journal of Food Science 56*(2), 431-435. https://doi.org/10.1111/j.1365-2621.1991.tb05297.x

Gulewicz, P., Martínez-Villaluenga, C., Frias, J., Ciesiołka, D., Gulewicz, K. and Vidal-Valverde, C. (2008). Effect of germination on the protein fraction composition of different lupin seeds. *Food Chemistry 107*(2), 830-844 https://doi.org/10.1016/j.foodchem.2007.08.087

Gupta, P., Singh, R., Malhotra, S., Boora, K. S. and Singal, H. R. (2010). Characterization of seed storage proteins in high protein genotypes of cowpea [*Vigna unguiculata* (L.) Walp.]. *Physiology and Molecular Biology of Plants 16*, 53-58. https://doi.org/10.1007/s12298-010-0007-9

Hall, C., Hillen, C. and Garden Robinson, J. (2017). Composition, nutritional value, and health benefits of pulses. *Cereal Chemistry 94*(1), 11-31. https://doi.org/10.1094/CCHEM-03-16-0069-FI

Hardacre, A. K., Clark, S. M., Riviere, S., Monro, J. A. and Hawkins, A. J. (2006). Some textural, sensory and nutritional properties of expanded snack food wafers made from corn, lentil and other ingredients. *Journal of Texture studies 37*(1), 94-111. https://doi.org/10.1111/j.1745-4603.2006.00041.x

Hegazy, H. S., El-Bedawey, A. E. A., Rahma, E. H. and Gaafar, A. M. (2017). Effect of extrusion processs on nutritional, functional properties and antioxidant activity of germinated chickpea incorporated corn extrudates. *American Journal of Food Science and Nutrition Research 4*(1), 59-66.

Hess, J. M., Jonnalagadda, S. S. and Slavin, J. L. (2016). What is a snack, why do we snack, and how can we choose better snacks? A review of the definitions of snacking, motivations to snack, contributions to dietary intake, and recommendations for improvement. *Advances in Nutrition 7*(3), 466-475. https://doi.org/10.3945/an.115.009571

Hodge, A. M., English, D. R., O'Dea, K. and Giles, G. G. (2004). Glycemic index and dietary fiber and the risk of type 2 diabetes. *Diabetes Care 27*(11), 2701-2706. https://doi.org/10.2337/diacare.27.11.2701

Hoover, R. and Ratnayake, W. S. (2002). Starch characteristics of black bean, chick pea, lentil, navy bean and pinto bean cultivars grown in Canada. *Food Chemistry 78*(4), 489-498. https://doi.org/10.1016/S0308-8146(02)00163-2

Hoover, R. and Sosulski, F. J. S. S. (1985). Studies on the functional characteristics and digestibility of starches from *Phaseolus vulgaris* biotypes. *Starch-Stärke 37*(6), 181-191. https://doi.org/10.1002/star.19850370602

Hoover, R., Hughes, T., Chung, H. J. and Liu, Q. (2010). Composition, molecular structure, properties, and modification of pulse starches: A review. *Food Research International 43*(2), 399-413. https://doi.org/10.1016/j.foodres.2009.09.001

Huber, G. R. (2001). Snack Foods from Cooking Extruders. In: *Snack Foods Processing*. E.W. (Lucas and L.W. Rooney, eds), pp. 107-138, CRC Press, United States of America

Hurtado, M. L., Escobar, B. and Estévez, A. M. (2001). Mezclas legumbre/cereal por fritura profunda de maiz amarillo y de tres cultivares de frejol para consumo" snack". *Archivos Latinoamericanos de Nutrición 51*(3), 303-308.

Hussein, E. H. (2000). Chemical and nutritional evaluation of high protein extrudates. Doctoral dissertation, Doctor of Philosophy Thesis, Faculty Home Economic, Minufiya University, Egypt.

Ilo, S. and Berghofer, E. (1999). Kinetics of colour changes during extrusion cooking of maize grits. *Journal of Food Engineering 39*(1), 73-80. https://doi.org/10.1016/S0260-8774(98)00148-4

Ilo, S. and Berghofer, E. (2003). Kinetics of lysine and other amino acids loss during extrusion cooking of maize grits. *Journal of Food Science 68*(2), 496-502. https://doi.org/10.1111/j.1365-2621.2003.tb05701.x

Iqbal, A., Khalil, I. A., Ateeq, N. and Khan, M. S. (2006). Nutritional quality of important food legumes. *Food Chemistry 97*(2), 331-335. https://doi.org/10.1016/j.foodchem.2005.05.011

Izzo, M. T. and Ho, C. T. (1989). Protein-lipid interaction during single-screw extrusion of zein and corn oil. *Cereal Chemistry 66*(1), 47-51.

Jensen, M. L. and Schwartz, M. B. (2021). Junk food consumption trends point to the need for retail policies. *The American Journal of Clinical Nutrition 114*(3), 837-838. https://doi.org/10.1093/ajcn/nqab189

Johnston, A. J., Mollard, R. C., Dandeneau, D., MacKay, D. S., Ames, N., Curran, J., Bouchard, D.R. and Jones, P. J. (2021). Acute effects of extruded pulse snacks on glycemic response, insulin, appetite, and food intake in healthy young adults in a double blind, randomized, crossover trial. *Applied Physiology, Nutrition, and Metabolism 46*(7), 704-710. https://doi.org/10.1139/apnm-2020-0572

Kahlon, T. S., & Woodruff, C. L. (2002). *In vitro* binding of bile acids by soy protein, pinto beans, black beans and wheat gluten. *Food Chemistry 79*(4), 425-429. https://doi.org/10.1016/S0308-8146(02)00192-9

Kaneko, H., Itoh, H., Kiriyama, H., Kamon, T., Fujiu, K., Morita, K., Yasunaga, H. and Komuro, I. (2021). Possible association between eating behaviors and cardiovascular disease in the general population: Analysis of a nationwide epidemiological database. *Atherosclerosis 320*, 79-85. https://doi.org/10.1016/j.atherosclerosis.2021.01.022

Karaca, A. C., Low, N. and Nickerson, M. (2011). Emulsifyin g properties of chickpea, faba bean, lentil and pea proteins produced by isoelectric precipitation and salt extraction. *Food Research International 44*(9), 2742-2750. https://doi.org/10.1016/j.foodres.2011.06.012

Kaur, M., Singh, N. and Sodhi, N. S. (2005). Physicochemical, cooking, textural and roasting characteristics of chickpea (*Cicer arietinum* L.) cultivars. *Journal of Food Engineering 69*(4), 511-517. https://doi.org/10.1016/j.jfoodeng.2004.09.002

Kocherla, P., Aparna, K. and Lakshmi, D. N. (2012). Development and evaluation of RTE (Ready to Eat) extruded snack using egg albumin powder and cheese powder. *Agricultural Engineering International: CIGR Journal 14*(4), 179-187.

Koehler, H. H., Chang, C. I. H., Scheier, G. and Burke, D. W. (1987). Nutrient composition, protein quality, and sensory properties of thirty-six cultivars of dry beans (*Phaseolus vulgaris* L.). *Journal of Food Science 52*(5), 1335-1340. https://doi.org/10.1111/j.1365-2621.1987.tb14076.x

Koinov, K., and Radkov, P. (1981). Chemical composition and technological quality of regional and prospective kidney bean cultivars. *Rastenievudni Nauki 18*, 17-23

Korkerd, S., Wanlapa, S., Puttanlek, C., Uttapap, D. and Rungsardthong, V. (2016). Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing by-products. *Journal of Food Science and Technology 53*, 561-570. https://doi.org/10.1007/s13197-015-2039-1

Kothakota, A., Jindal, N. and Thimmaiah, B. (2013). A study on evaluation and characterization of extruded product by using various by-products. *African Journal of Food Science 7*(12), 485-497. https://doi.org/10.5897/AJFS2013.1065

Krupa-Kozak, U. and Soral-Śmietana, M. (2010). Bean seed proteins digestibility affected by pressure and microwave cooking. *Acta alimentaria 39*(2), 234-238. https://doi.org/10.1556/aalim.39.2010.2.14

Kutoš, T., Golob, T., Kač, M. and Plestenjak, A. (2003). Dietary fibre content of dry and processed beans. *Food Chemistry 80*(2), 231-235. https://doi.org/10.1016/S0308-8146(02)00258-3

Lai, L. S. and Kokini, J. L. (1991). Physicochemical changes and rheological properties of starch during extrusion (a review). *Biotechnology Progress 7*(3), 251-266. https://doi.org/10.1021/bp00009a009

Lam, C. D. and Flores, R. A. (2003). Effect of particle size and moisture content on viscosity of fish feed. *Cereal Chemistry 80*(1), 20-24 https://doi.org/10.1094/CCHEM.2003.80.1.20

Lazou, A. and Krokida, M. (2010). Functional properties of corn and corn–lentil extrudates. *Food research international 43*(2), 609-616 https://doi.org/10.1016/j.foodres.2009.09.017

Lazou, A. E., Michailidis, P. A., Thymi, S., Krokida, M. K. and Bisharat, G. I. (2007). Structural properties of corn-legume based extrudates as a function of processing conditions and raw material characteristics. *International Journal of Food Properties 10*(4), 721-738. https://doi.org/10.1080/10942910601154305

Limón-Valenzuela, V., Aguilar-Palazuelos, E., Zazueta-Morales, J. D. J. and Martinez-Bustos, F. (2017). Paste and microstructural properties of extruded starch pellets enriched with qpm and milk protein concentrate. *Revista Mexicana de Ingeniería Química 16*(1), 193-205.

Limón-Valenzuela, V., Martínez-Bustos, F., Aguilar-Palazuelos, E., Caro-Corrales, J. J. and Zazueta-Morales, J. J. (2010). Physicochemical evaluation and optimization of enriched expanded pellets with milk protein concentrate. *Cereal Chemistry 87*(6), 612-618. https://doi.org/10.1094/CCHEM-02-10-0030

Limsangouan, N., Takenaka, M., Sotome, I., Nanayama, K., Charunuch, C. and Isobe, S. (2010). Functional properties of cereal and legume based extruded snack foods fortified with by-products from herbs and vegetables. *Agriculture and Natural Resources 44*(2), 271-279

Lue, S., Hsieh, F. and Huff, H. E. (1991). Extrusion cooking of corn meal and sugar beet fiber: effects on expansion properties, starch gelatinization, and dietary fiber content. *Cereal Chemistry 68*(3), 227-234.

Lusas, E. W. and Rooney, L. W. (2001). *Snack foods processing*. Editorial CRC Press, United State of America

Mallillin, A. C., Trinidad, T. P., Raterta, R., Dagbay, K. and Loyola, A. S. (2008). Dietary fibre and fermentability characteristics of root crops and legumes. *British Journal of Nutrition 100*(3), 485-488. https://doi.org/10.1017/S000711450891151X

Manosalvas, A., Taimal, R. and Villacrés, E. (2019). Efecto de la humedad de alimentación y temperatura de extursión sobre el contenido nutricional de un snack a base de maíz, chocho y papa. *Revista Bases de la Ciencia 4*(3), 67-80. https://doi.org/10.33936/rev_bas_de_la_ciencia.v4i3.1911

Marquez, U. L. and Lajolo, F. M. (1981). Composition and digestibility of albumin, globulins, and glutelins from *Phaseolus vulgaris*. *Journal of Agricultural and Food Chemistry 29*(5), 1068-1074. https://doi.org/10.1021/jf00107a043

Martin, A., Schmidt, V., Osen, R., Bez, J., Ortner, E. and Mittermaier, S. (2022). Texture, sensory properties and functionality of extruded snacks from pulses and pseudocereal proteins. *Journal of the Science of Food and Agriculture 102*(12), 5011-5021. https://doi.org/10.1002/jsfa.11041

Martín-Cabrejas, M. A., Ariza, N., Esteban, R., Mollá, E., Waldron, K. and López-Andréu, F. J. (2003). Effect of germination on the carbohydrate composition of the dietary fiber of peas (*Pisum sativum* L.). *Journal of Agricultural and Food Chemistry 51*(5), 1254-1259. https://doi.org/10.1021/jf0207631

Martín-Cabrejas, M. A., Díaz, M. F., Aguilera, Y., Benítez, V., Mollá, E. and Esteban, R. M. (2008). Influence of germination on the soluble carbohydrates and dietary fibre fractions in non-conventional legumes. *Food Chemistry 107*(3), 1045-1052. https://doi.org/10.1016/j.foodchem.2007.09.020

Martínez-Villaluenga, C., Frías, J. and Vidal-Valverde, C. (2006). Functional lupin seeds (*Lupinus albus* L. and *Lupinus luteus* L.) after extraction of α-galactosides. *Food Chemistry 98*(2), 291-299. https://doi.org/10.1016/j.foodchem.2005.05.074

Masood, T., Shah, H. U. and Zeb, A. (2014). Effect of sprouting time on proximate composition and ascorbic acid level of mung bean (*Vigna radiate* L.) and chickpea (*Cicer arietinum* L.) seeds. *The Journal of Animal & Plant Sciences 24*(3).

McCarthy, J. A. (2001). The snack industry: history, domestic and global status. In: *Snack Foods Processing*, (Lucas and L.W. Rooney, eds). Pp. 29-35 CRC Press, Boca Raton.

Meiners, C. R., Derise, N. L., Lau, H. C., Ritchey, S. J. and Murphy, E. W. (1976). Proximate composition and yield of raw and cooked mature dry legumes. *Journal of Agricultural and Food Chemistry 24*(6), 1122-1126. https://doi.org/10.1021/jf60208a035

Meng, X., Threinen, D., Hansen, M. and Driedger, D. (2010). Effects of extrusion conditions on system parameters and physical properties of a chickpea flour-based snack. *Food Research International 43*(2), 650-658. https://doi.org/10.1016/j.foodres.2009.07.016

Mercier, S., Moresoli, C., Mondor, M., Villeneuve, S. and Marcos, B. (2016). A meta-analysis of enriched pasta: What are the effects of enrichment and process specifications on the quality attributes of pasta? *Comprehensive Reviews in Food Science and Food Safety 15*(4), 685-704. https://doi.org/10.1111/1541-4337.12207

Mitchell, J. R. and Areas, J. A. G. (1991). Structural changes in biopolymers during extrusior. In: *Food extrusion: Science and Technology*. (J. L. Kokini; C.T. Ho and M. V. Karwe, eds.) Pp. 345-360. Mercel Dekker, Boca Raton.

Moraghan, J. T. and Grafton, K. (2002). Distribution of selected elements between the seed coat and embryo of two black bean cultivars. *Journal of Plant Nutrition 25*(1), 169-176. https://doi.org/10.1081/PLN-100108788

Moreira-Araújo, R. S., Araújo, M. A. and Arêas, J. A. (2008). Fortified food made by the extrusion of a mixture of chickpea, corn and bovine lung controls iron-deficiency anaemia in preschool children. *Food Chemistry*, *107*(1), 158-164. https://doi.org/10.1016/j.foodchem.2007.07.074

Morris, M. A., Hutchinson, J., Gianfrancesco, C., Alwan, N. A., Carter, M. C., Scott, E. M. and Cade, J. E. (2019). Relationship of the frequency, distribution, and content of meals/snacks to glycaemic control in gestational diabetes: the myfood24 GDM pilot study. *Nutrients*, *12*(1), 3. https://doi.org/10.3390/nu12010003

Mosibo, O. K., Ferrentino, G., Alam, M. R., Morozova, K. and Scampicchio, M. (2022). Extrusion cooking of protein-based products: potentials and challenges. *Critical Reviews in Food Science and Nutrition 62*(9), 2526-2547. https://doi.org/10.1080/10408398.2020.1854674

Mwangwela, A. M., Waniska, R. D., McDonough, C. and Minnaar, A. (2007). Cowpea cooking characteristics as affected by micronisation temperature: a study of the physicochemical and functional properties of starch. *Journal of the Science of Food and Agriculture 87*(3), 399-410. https://doi.org/10.1002/jsfa.2711

Naivikul, O. and D'Appolonia, B. L. (1979). Carbohydrates of legume flours compares with wheat flour III: nonstarchy polysaccharides. *Cereal Chemistry 56*(1), 24-28

Natabirwa, H., Nakimbugwe, D., Lung'aho, M., Tumwesigye, K. S. and Muyonga, J. H. (2020). Bean-based nutrient-enriched puffed snacks: Formulation design, functional evaluation, and optimization. *Food Science & Nutrition 8*(9), 4763-4772. https://doi.org/10.1002/fsn3.1727

Neder-Suárez, D., Lardizabal-Gutiérrez, D., Zazueta-Morales, J. D. J., Meléndez-Pizarro, C. O., Delgado-Nieblas, C. I., Ramírez Wong, B., Gutiérrez-Méndez, N., Hernández-Ochoa, L.R. and Quintero-Ramos, A. (2021a). Anthocyanins and functional compounds change in a third-generation snacks prepared using extruded blue maize, black bean, and chard: An optimization. *Antioxidants 10*(9), 1368. https://doi.org/10.3390/antiox10091368

Neder-Suárez, D., Quintero-Ramos, A., Meléndez-Pizarro, C. O., de Jesús Zazueta-Morales, J., Paraguay-Delgado, F. and Ruiz-Gutiérrez, M. G. (2021b). Evaluation of the physicochemical properties of third-generation snacks made from blue corn, black beans, and sweet chard produced by extrusion. *LWT – Food Science and Techonology 146*, 111414. https://doi.org/10.1016/j.lwt.2021.111414

Neder-Suárez, D., Vázquez-Rodríguez, J. A., González-Martínez, B. E., Meléndez-Pizarro, C. O., Hernández-Ochoa, L. R., Murowaniecki-Otero, D., Ródriguez-Roque, M.J. and Quintero-Ramos, A. (2024). Effect of using alternative flours on the development and characteristics of a third-generation snacks. *Food Chemistry Advances 4*, 100571. https://doi.org/10.1016/j.focha.2023.100571

Nongmaithem, R., Meda, V., Niranjan, T., Shukla, R. M., Hashmi, S. and Dwivedi, M. (2024). Effect of extrusion process on germinated lentil (*Lens culinaris*) based snack foods: Impact on starch digestibility, physio-functional, and antioxidant properties. *Measurement: Food 13*, 100132. https://doi.org/10.1016/j.meafoo.2023.100132

Nugdallah, G. A. and El Tinay, A. H. (1997). Effect of cooking on cowpea protein fractions. *Plant* *foods for human nutrition 51*, 277-282. https://doi.org/10.1023/A:1007920221382

Obatolu, V. A. and Cole, A. H. (2000). Functional property of complementary blends of soybean and cowpea with malted or unmalted maize. *Food Chemistry 70*(2), 147-153. https://doi.org/10.1016/S0308-8146(99)00248-4

Obradović, V., Babić, J., Šubarić D., Ačkar, D. and Jozinović, A. (2014). Improvement of nutritional and functional properties of extruded food products. *Journal of Food & Nutrition Research 53*(3), 189-206.

Onwulata, C. I., Konstance, R. P., Smith, P. W. and Holsinger, V. H. (2001). Co-extrusion of dietary fiber and milk proteins in expanded corn products. *LWT-Food Science and Technology 34*(7), 424-429. https://doi.org/10.1006/fstl.2000.0742

Oomah, B. D., Blanchard, C. and Balasubramanian, P. (2008). Phytic acid, phytase, minerals, and antioxidant activity in Canadian dry bean (*Phaseolus vulgaris* L.) cultivars. *Journal of Agricultural and Food Chemistry 56*(23), 11312-11319. https://doi.org/10.1021/jf801661j

Ozer, E. A., Herken, E. N., Güzel, S., Ainsworth, P. and Ibanoğlu, Ş. (2006). Effect of extrusion process on the antioxidant activity and total phenolics in a nutritious snack food. *International Journal of Food Science & Technology 41*(3), 289-293. https://doi.org/10.1111/j.1365-2621.2005.01062.x

Paes, M. C. D. and Maga, J. (2004). Effect of extrusion on essential amino acids profile and color of whole-grain flours of quality protein maize (qpm) and normal maize cultivars. *Revista Brasileira de Milho e Sorgo 3*(01). https://doi.org/10.18512/1980-6477/rbms.v3n01p%25p

Pansawat, N., Jangchud, K., Jangchud, A., Wuttijumnong, P., Saalia, F. K., Eitenmiller, R. R. and Phillips, R. D. (2008). Effects of extrusion conditions on secondary extrusion variables and physical properties of fish, rice-based snacks. *LWT-Food Science and Technology 41*(4), 632-641. https://doi.org/10.1016/j.lwt.2007.05.010

Parada, J., Aguilera, J. M. and Brennan, C. (2011). Effect of guar gum content on some physical and nutritional properties of extruded products. *Journal of Food Engineering*, *103*(3), 324-332. https://doi.org/10.1016/j.jfoodeng.2010.11.001

Pastor-Cavada, E., Drago, S. R., González, R. J., Juan, R., Pastor, J. E., Alaiz, M., and Vioque, J. (2011). Effects of the addition of wild legumes (*Lathyrus annuus* and *Lathyrus clymenum*) on the physical and nutritional properties of extruded products based on whole corn and brown rice. *Food Chemistry 128*(4), 961-967. https://doi.org/10.1016/j.foodchem.2011.03.126

Pastor-Cavada, E., Drago, S. R., González, R. J., Juan, R., Pastor, J. E., Alaiz, M. and Vioque, J. (2013). Physical and nutritional properties of extruded products based on whole grain with the addition of wild legumes (*Vicia lutea* subsp. lutea var. *hirta* and *Vicia sativa* subsp. *sativa*). *International Journal of Food Science & Technology 48*(9), 1949-1955. https://doi.org/10.1111/ijfs.12175

Pathania, S., Singh, B., Sharma, S., Sharma, V. and Singla, S. (2013). Optimization of extrusion processing conditions for preparation of an instant grain base for use in weaning foods. *International Journal of Engineering Research and Applications 3*(3), 1040-1049.

Paula, A. M. and Conti-Silva, A. C. (2014). Texture profile and correlation between sensory and instrumental analyses on extruded snacks. *Journal of Food Engineering 121*, 9-14. https://doi.org/10.1016/j.jfoodeng.2013.08.007

Pérez-Hidalgo, M. A., Guerra-Hernández, E. and García-Villanova, B. (1997). Dietary fiber in three raw legumes and processing effect on chickpeas by an enzymatic-gravimetric method. *Journal of Food Composition and Analysis 10*(1), 66-72. https://doi.org/10.1006/jfca.1997.0522

Pérez-Navarrete, C., Gonzalez, R., Chel-Guerrero, L. and Betancur-Ancona, D. (2006). Effect of extrusion on nutritional quality of maize and Lima bean flour blends. *Journal of the Science of Food and Agriculture 86*(14), 2477-2484. https://doi.org/10.1002/jsfa.2661

Pusztai, A., Clarke, E. M., King, T. P. and Stewart, J. C. (1979). Nutritional evaluation of kidney beans (*Phaseolus vulgaris*): Chemical composition, lectin content and nutritional value of selected cultivars. *Journal of the Science of Food and Agriculture 30*(9), 843-848. https://doi.org/10.1002/jsfa.2740300902

Rahman, L., Rowe, P., Cheyne, A. and Wilson, D. I. (2002). Ram extrusion of potato starch dough through multi-holed dies. *Food and Bioproducts Processing 80*(1), 12-19. https://doi.org/10.1205/096030802753479061

Reyes-Moreno, C., Argüelles-López, O. D., Rochín-Medina, J. J., Milán-Carrillo, J., Rivera-López, J., Valdez-Ortiz, A., López-Valenzuela, J.A. and Gutiérrez-Dorado, R. (2012). High antioxidant activity mixture of extruded whole quality protein maize and common bean flours for production of a nutraceutical beverage elaborated with a traditional Mexican formulation. *Plant Foods for Human Nutrition 67*, 450-456 https://doi.org/10.1007/s11130-012-0324-y

Rico, D., Cano, A. B. and Martín-Diana, A. B. (2021). Pulse-cereal blend extrusion for improving the antioxidant properties of a gluten-free flour. *Molecules 26*(18), 5578. https://doi.org/10.3390/molecules26185578

Rodríguez-Miranda, J., Ramírez-Wong, B., Vivar-Vera, M. A., Solís-Soto, A., Gómez-Aldapa, C. A., Castro-Rosas, J., Medrano-Roldan, H. and Delgado-Licon, E. (2014). Efect of bean flour concentration (*Phaseolus vulgaris* L.), moisture content and extrusion temperature on the fuctional properties of aquafeeds. *Revista mexicana de ingeniería química 13*(3), 649-663.

Ruiz-Armenta, X. A., Zazueta-Morales, J. D. J., Aguilar-Palazuelos, E., Delgado-Nieblas, C. I., López-Diaz, A., Camacho-Hernández, I. L., Gutiérrez-Dorado, R. and Martínez-Bustos, F. (2018). Effect of extrusion on the carotenoid content, physical and sensory properties of snacks added with bagasse of naranjita fruit: optimization process. *CyTA-Journal of Food 16*(1), 172-180. https://doi.org/10.1080/19476337.2017.1368717

Ruiz-Ruiz, J., Martínez-Ayala, A., Drago, S., González, R., Betancur-Ancona, D. and Chel-Guerrero, L. (2008). Extrusion of a hard-to-cook bean (*Phaseolus vulgaris* L.) and quality protein maize (*Zea mays* L.) flour blend. *LWT-Food Science and Technology 41*(10), 1799-1807. https://doi.org/10.1016/j.lwt.2008.01.005

Rumiyati, R., James, A. P. and Jayasena, V. (2012). Effect of germination on the nutritional and protein profile of Australian sweet lupin (*Lupinus angustifolius* L.). *Food and Nutrition Sciences 3*, 621-626. https://doi.org/doi:10.4236/fns.2012.35085

Ryan, E., Galvin, K., O'Connor, T. P., Maguire, A. R. and O'Brien, N. M. (2007). Phytosterol, squalene, tocopherol content and fatty acid profile of selected seeds, grains, and legumes. *Plant Foods for Human Nutrition 62*, 85-91. https://doi.org/10.1007/s11130-007-0046-8

Rzedzicki, Z. and Moscicki, L. (1994). The investigations of the texture of extruded plant materials. *International agrophysics 8*(4), 671-680.

Saha, S., Singh, G., Mahajan, V. and Gupta, H. S. (2009). Variability of nutritional and cooking quality in bean (*Phaseolus vulgaris* L) as a function of genotype. *Plant Foods for Human Nutrition 64*(2), 174-180. https://doi.org/10.1007/s11130-009-0121-4

Sahoo, M. R., Kuna, A., Devi, M. P., Sowmya, M. and Dasgupta, M. (202). Fortification of ready–to–eat extruded snacks with tree bean powder: nutritional, antioxidant, essential amino acids, and sensory properties. *Journal of Food Science and Technology* 59 2351-2360. https://doi.org/10.1007/s13197-021-05251-w

Sathe, S. K. and Salunkhe, D. K. (1981). Isolation, partial characterization and modification of the great northern bean (*Phaseolus vulgaris* L.) starch. *Journal of Food Science 46*(2), 617-621. https://doi.org/10.1111/j.1365-2621.1981.tb04924.x

Sathe, S. K., Deshpande, S. S., Salunkhe, D. K. and Rackis, J. J. (1984). Dry beans of phaseolus. A review. Part 1. Chemical composition: Proteins. *Critical Reviews in Food Science & Nutrition 20*(1), 1-46. https://doi.org/10.1080/10408398409527382

Sawant, A. A., Thakor, N. J., Swami, S. B., Divate, A. D. and Vidyapeet, B. S. (2013). Physical and sensory characteristics of ready-to-eat food prepared from finger millet based composite mixer by extrusion. *Agricultural Engineering International: CIGR Journal 15*(1), 100-105.

Sebastian, R. S., Cleveland, L. E. and Goldman, J. D. (2008). Effect of snacking frequency on adolescents' dietary intakes and meeting national recommendations. *Journal of Adolescent Health 42*(5), 503-511. https://doi.org/10.1016/j.jadohealth.2007.10.002

Sebio, L. and Chang, Y. K. (2000). Effects of selected process parameters in extrusion of yam flour (*Dioscorea rotundata*) on physicochemical properties of the extrudates. *Food/Nahrung 44*(2), 96-101. https://doi.org/10.1002/(SICI)1521-3803(20000301)44:2%3C96::AID-FOOD96%3E3.0.CO;2-9

Selvaprakash, N., Geetha, P., Manoharan, A. P. and Sudha, K. (2021). Conjoint analysis for optimizing the level of ingredients in millet and pulse based Ready-To-Eat (RTE) Extruded Product. *Madras Agricultural Journal 108*. https://doi.org/10.29321/MAJ.10.000560

Seth, D. and Rajamanickam, G. (2012). Development of extruded snacks using soy, sorghum, millet and rice blend–A response surface methodology approach. *International Journal of Food Science & Technology 47*(7), 1526-1531. https://doi.org/10.1111/j.1365-2621.2012.03001.x

Sgarbieri, V. C., Antunes, P. L. and Almeida, L. D. (1979). Nutritional evaluation of four varieties of dry beans (*Phaseolus vulgaris*, L.). *Journal of Food Science 44*(5), 1306-1308. https://doi.org/10.1111/j.1365-2621.1979.tb06425.x

Shad, M. A., Pervez, H., Zafar, Z. I., Zia-Ul-Haq, M. and Nawaz, H. (2009). Evaluation of biochemical composition and physicochemical parameters of oil from seeds of desi chickpea varieties cultivated in arid zone of Pakistan. *Pakistan Journal of Botany 41*(2), 655-662.

Shah, F. U. H., Sharif, M. K., Butt, M. S. and Shahid, M. (2017). Development of protein, dietary fiber, and micronutrient enriched extruded corn snacks. *Journal of Texture Studies 48*(3), 221-230. https://doi.org/10.1111/jtxs.12231

Sharma, P., Gujral, H. S. and Singh, B. (2012). Antioxidant activity of barley as affected by extrusion cooking. *Food Chemistry 131*(4), 1406-1413. https://doi.org/10.1016/j.foodchem.2011.10.009

Shevkani, K., Kaur, A., Singh, G., Singh, B. and Singh, N. (2014). Composition, rheological and extrusion behaviour of fractions produced by three successive reduction dry milling of corn. *Food and Bioprocess Technology 7*, 1414-1423. https://doi.org/10.1007/s11947-013-1194-5

Shevkani, K., Singh, N., Rattan, B., Singh, J. P., Kaur, A. and Singh, B. (2019). Effect of chickpea and spinach on extrusion behavior of corn grit. *Journal of Food Science and Technology 56*, 2257-2266. https://doi.org/10.1007/s13197-019-03712-x

Shi, L., Mu, K., Arntfield, S. D., & Nickerson, M. T. (2017). Changes in levels of enzyme inhibitors during soaking and cooking for pulses available in Canada. *Journal of Food Science and Technology 54*, 1014-1022. https://doi.org/10.1007/s13197-017-2519-6

Shimelis, E. A. and Rakshit, S. K. (2007). Effect of processing on antinutrients and *in vitro* protein digestibility of kidney bean (*Phaseolus vulgaris* L.) varieties grown in East Africa. *Food Chemistry 103*(1), 161-172. https://doi.org/10.1016/j.foodchem.2006.08.005

Shriver, L. H., Marriage, B. J., Bloch, T. D., Spees, C. K., Ramsay, S. A., Watowicz, R. P. and Taylor, C. A. (2018). Contribution of snacks to dietary intakes of young children in the United States. *Maternal & Child Nutrition 14*(1), e12454. https://doi.org/10.1111/mcn.12454

Siddiq, M., Kelkar, S., Harte, J. B., Dolan, K. D. and Nyombaire, G. (2013). Functional properties of flour from low-temperature extruded navy and pinto beans (*Phaseolus vulgaris* L.). *LWT-Food Science and Technology 50*(1), 215-219. https://doi.org/10.1016/j.lwt.2012.05.024

Silva-Cristobal, L., Osorio-Díaz, P., Tovar, J. and Bello-Pérez, L. A. (2010). Chemical composition, carbohydrate digestibility, and antioxidant capacity of cooked black bean, chickpea, and lentil Mexican varieties Composición química, digestibilidad de carbohidratos, y capacidad antioxidante de variedades mexicanas cocidas de frijol negro, garbanzo, y lenteja. *Cyta–Journal of Food 8*(1), 7-14. https://doi.org/10.1080/19476330903119218

Simons, C. W., Hall III, C., Tulbek, M., Mendis, M., Heck, T. and Ogunyemi, S. (2015). Acceptability and characterization of extruded pinto, navy and black beans. *Journal of the Science of Food and Agriculture 95*(11), 2287-2291. https://doi.org/10.1002/jsfa.6948

Simons, C., Hall III, C. and Biswas, A. (2017). Characterization of pinto bean high-starch fraction after air classification and extrusion. *Journal of Food Processing and Preservation 41*(6), e13254. https://doi.org/10.1111/jfpp.13254

Singh, N., Shevkani, K., Kaur, A., Thakur, S., Parmar, N. and Singh Virdi, A. (2014).

Characteristics of starch obtained at different stages of purification during commercial wet milling of maize. *Starch-Stärke 66*(7-8), 668-677. https://doi.org/10.1002/star.201300261

Singh, S. K. and Muthukumarappan, K. (2014). Effect of different extrusion processing parameters on physical properties of soy white flakes and high protein distillers dried grains-based extruded aquafeeds. *Journal of Food Research 3*(6) https://doi.org/10.5539/jfr.v3n6p107

Singh, S. K. and Muthukumarappan, K. (2017). A viscosity model for soy white flakes-based aquafeed dough in a single screw extruder. *Journal of Food Process Engineering 40*(2), e12357. https://doi.org/10.1111/jfpe.12357

Singh, S. K. and Muthukumarappan, K. (2017). Rheological characterization and CFD simulation of soy white flakes based dough in a single screw extruder. *Journal of Food Process Engineering 40*(2), e12368. https://doi.org/10.1111/jfpe.12368

Singh, S., Gamlath, S. and Wakeling, L. (2007). Nutritional aspects of food extrusion: a review. *International Journal of Food Science & Technology 42*(8), 916-929. https://doi.org/10.1111/j.1365-2621.2006.01309.x

Singh, U. and Jambunathan, R. (1982). Changes in starch, oligosaccharides and soluble sugars in developing pod wall and seed of chickpea. *Phytochemistry 21*(2), 297-299. https://doi.org/10.1016/S0031-9422(00)95254-3

Singha, P., Muthukumarappan, K. and Krishnan, P. (2018a). Influence of processing conditions on apparent viscosity and system parameters during extrusion of distiller's dried grains-based snacks. *Food Science & Nutrition 6*(1), 101-110. https://doi.org/10.1002/fsn3.534

Singha, P., Singh, S. K., Muthukumarappan, K. and Krishnan, P. (2018b). Physicochemical and nutritional properties of extrudates from food grade distiller's dried grains, garbanzo flour, and corn grits. *Food science & nutrition 6*(7), 1914-1926. https://doi.org/10.1002/fsn3.769

Soral-Smietana, M. and Krupa, L. (2005). Changes in the macrocomponents and microstructure of white bean seeds upon mild hydrothermal treatment. *Czech Journal of Food sciences 23*(2), 74-83. http://dx.doi.org/10.17221/3375-CJFS

Sosa-Moguel, O., Ruiz-Ruiz, J., Martínez-Ayala, A., González, R., Drago, S., Betancur-Ancona, D. and Chel-Guerrero, L. (2009). Effect of extrusion conditions and lipoxygenase inactivation treatment on the physical and nutritional properties of corn/cowpea (*Vigna unguiculata*) blends. *International Journal of Food Sciences and Nutrition 60*(sup7), 341-354. https://doi.org/10.1080/09637480903156251

Sreerama, Y. N., Sashikala, V. B., Pratape, V. M. and Singh, V. (2012). Nutrients and antinutrients in cowpea and horse gram flours in comparison to chickpea flour: Evaluation of their flour functionality. *Food Chemistry 131*(2), 462-468. https://doi.org/10.1016/j.foodchem.2011.09.008

Steel, C. J., Leoro, M. G. V., Schmiele, M., Ferreira, R. E. and Chang, Y. K. (2012). Thermoplastic extrusion in food processing. In: *Thermoplastic elastomers*, (A. El-Sonbat, eds Pp. *265*-290. InTech, London.

Su, H. S., Lu, W., & Chang, K. C. (1998). Microstructure and physicochemical characteristics of starches in six bean varieties and their bean paste products. *LWT-Food Science and Technology 31*(3), 265-273. https://doi.org/10.1006/fstl.1997.0350

Sujak, A., Kotlarz, A. and Strobel, W. (2006). Compositional and nutritional evaluation of several lupin seeds. *Food Chemistry 98*(4), 711-719. https://doi.org/10.1016/j.foodchem.2005.06.036

Sutivisedsak, N., Moser, B. R., Sharma, B. K., Evangelista, R. L., Cheng, H. N., Lesch, W. C., Tansrud, R.R. and Biswas, A. (2011). Physical properties and fatty acid profiles of oils from black, kidney, great northern, and pinto beans. *Journal of the American Oil Chemists' Society 88*(2), 193-200. https://doi.org/10.1007/s11746-010-1669-8

Thakur, S. and Saxena, D. C. (2000). Formulation of extruded snack food (gum based cereal–pulse blend): optimization of ingredients levels using response surface methodology. *LWT-Food Science and Technology 33*(5), 354-361. https://doi.org/10.1006/fstl.2000.0668

Thanuja, B. and Parimalavalli, R. (2020). Comparison of antioxidant compounds and antioxidant activity of native and dual modified rice flour. *International Journal Pharmaceutical*

Sciences Research 11, 1203-1209. https://doi.org/10.13040/IJPSR.0975-8232.11(3).1203-09

Thorsdóttir, I. and Birgisdóttir, B. (2005). Glycemic index from research to nutrition recommendations. Editorial TemaNor, Denmark.

Tobias-Espinoza, J. L., Amaya-Guerra, C. A., Quintero-Ramos, A., Pérez-Carrillo, E., Núñez-González, M. A., Martínez-Bustos, F., Meléndez-Pizarro, C.O., Báez-González, J.G. and Ortega-Gutiérrez, J. A. (2019). Effects of the addition of flaxseed and amaranth on the physicochemical and functional properties of instant-extruded products. *Foods 8*(6), 183. https://doi.org/10.3390/foods8060183

Torres, A., Frias, J. and Vidal-Valverde, C. (2005). Changes in chemical composition of lupin seeds (*Lupinus angustifolius*) after selective α-galactoside extraction. *Journal of the Science of Food and Agriculture 85*(14), 2468-2474. https://doi.org/10.1002/jsfa.2278

Tosh, S. M. and Yada, S. (2010). Dietary fibres in pulse seeds and fractions: Characterization, functional attributes, and applications. *Food research international 43*(2), 450-460. https://doi.org/10.1016/j.foodres.2009.09.005

Tovar-Jímenez, X., Aguilar-Palazuelos, E., Gómez-Aldapa, C. A. and Caro-Corrales, J. J. (2016). Microstructure of a third generation snack manufactured by extrusion from potato starch and orange vesicle flour. *Journal of Food Processing & Technology 7*, 1-6. http://dx.doi.org/10.4172/2157-7110.1000563

Trugo, L. C., Donangelo, C. M., Trugo, N. M. F. and Bach Knudsen, K. E. (2000). Effect of heat treatment on nutritional quality of germinated legume seeds. *Journal of Agricultural and Food Chemistry 48*(6), 2082-2086. https://doi.org/10.1021/jf9913920

Vadukapuram, N., Hall, C., Tulbek, M. and Niehaus, M. (2014). Physicochemical properties of flaxseed fortified extruded bean snack. *International Journal of Food Science 2014*(8). https://doi.org/10.1155/2014/478018

Veldhorst, M. A., Westerterp, K. R. and Westerterp-Plantenga, M. S. (2012). Gluconeogenesis and protein-induced satiety. *British Journal of Nutrition*, *107*(4), 595-600. https://doi.org/10.1017/S0007114511003254

Venn, B. J. and Green, T. J. (2007). Glycemic index and glycemic load: measurement issues and their effect on diet–disease relationships. *European Journal of Clinical Nutrition 61*(1), S122-S131. https://doi.org/10.1038/sj.ejcn.1602942

Wang, N. and Daun, J. K. (2004). Effect of variety and crude protein content on nutrients and certain antinutrients in field peas (*Pisum sativum*). *Journal of the Science of Food and Agriculture 84*(9), 1021-1029. https://doi.org/10.1002/jsfa.1742

Wang, N. and Daun, J. K. (2006). Effects of variety and crude protein content on nutrients and anti-nutrients in lentils (*Lens culinaris*). *Food Chemistry 95*(3), 493-502. https://doi.org/10.1016/j.foodchem.2005.02.001

Wang, N., Hatcher, D. W., Tyler, R. T., Toews, R. and Gawalko, E. J. (2010). Effect of cooking on the composition of beans (*Phaseolus vulgaris* L.) and chickpeas (*Cicer arietinum* L.). *Food Research International 43*(2), 589-594. https://doi.org/10.1016/j.foodres.2009.07.012

Wang, S., Ai, Y., Hood-Niefer, S. and Nickerson, M. T. (2019). Effect of barrel temperature and feed moisture on the physical properties of chickpea, sorghum, and maize extrudates and the functionality of their resultant flours—Part 1. *Cereal Chemistry 96*(4), 609-620. https://doi.org/10.1002/cche.10149

Wang, Y. Y. and Ryu, G. H. (2013). Physical properties of extruded corn grits with corn fibre by CO2 injection extrusion. *Journal of Food Engineering 116*(1), 14-20 https://doi.org/10.1016/j.jfoodeng.2012.10.041

Wani, S. A. and Kumar, P. (2016a). Influence of different mixtures of ingredients on the physicochemical, nutritional and pasting properties of extruded snacks. *Journal of Food Measurement and Characterization 10*, 690-700. https://doi.org/10.1007/s11694-016-9353-9

Wani, S. A. and Kumar, P. (2016b). Development and parameter optimization of health promising extrudate based on fenugreek oat and pea. *Food Bioscience 14*, 34-40. https://doi.org/10.1016/j.fbio.2016.02.002

Wani, S. A. and Kumar, P. (2016c). Effect of incorporation levels of oat and green pea flour on the properties of an extruded product and their optimization. *Acta Alimentaria 45*(1), 28-35. https://doi.org/10.1556/066.2016.45.1.4

Wani, S. A. and Kumar, P. (2016d). Effect of extrusion on the nutritional, antioxidant and microstructural characteristics of nutritionally enriched snacks. *Journal of Food Processing and Preservation 40*(2), 166-173. https://doi.org/10.1111/jfpp.12593

Wani, S. A. and Kumar, P. (2019). Influence on the antioxidant, structural and pasting properties of snacks with fenugreek, oats and green pea. *Journal of the Saudi Society of Agricultural Sciences 18*(4), 389-395. https://doi.org/10.1016/j.jssas.2018.01.001

Wani, S. A., Ganie, N. A. and Kumar, P. (2021). Quality characteristics, fatty acid profile and glycemic index of extrusion processed snacks enriched with the multicomponent mixture of cereals and legumes. *Legume science 3*(2), e76. https://doi.org/10.1002/leg3.76

Yoshida, H., Tomiyama, Y., Kita, S. and Mizushina, Y. (2005). Lipid classes, fatty acid composition and triacylglycerol molecular species of kidney beans (*Phaseolus vulgaris* L.). *European Journal of Lipid Science and Technology* 107(5), 307-315. https://doi.org/10.1002/ejlt.200401078

Zhang, B., Deng, Z., Tang, Y., Chen, P. X., Liu, R., Ramdath, D. D., Liu, Q., Hernandez. M. and Tsao, R. (2014). Effect of domestic cooking on carotenoids, tocopherols, fatty acids, phenolics, and antioxidant activities of lentils (*Lens culinaris*). *Journal of Agricultural and Food Chemistry 62*(52), 12585-12594. https://doi.org/10.1021/jf504181r

Zia-Ul-Haq, M., Ahmad, M., Iqbal, S., Ahmad, S. and Ali, H. (2007a). Characterization and compositional studies of oil from seeds of desi chickpea (*Cicer arietinum* L.) cultivars grown in Pakistan. *Journal of the American Oil Chemists' Society 84*, 1143-1148. https://doi.org/10.1007/s11746-007-1136-3

Zia-Ul-Haq, M., Ahmad, S., Shad, M. A., Iqbal, S., Qayum, M., Ahmad, A., Luthria, D.L. and Amarowicz, R. (2011). Compositional studies of lentil (*Lens culinaris* Medik.) cultivars commonly grown in Pakistan. *Pakistan Journal of Botany 43*(3), 1563-1567.

Zia-Ul-Haq, M., Iqbal, S., Ahmad, S., Imran, M., Niaz, A. and Bhanger, M. I. (2007b). Nutritional and compositional study of desi chickpea (*Cicer arietinum* L.) cultivars grown in Punjab, Pakistan. *Food Chemistry 105*(4), 1357-1363. https://doi.org/10.1016/j.foodchem.2007.05.004

Zielinski, H., Kozlowska, H. and Lewczuk, B. (2001). Bioactive compounds in the cereal grains before and after hydrothermal processing. *Innovative Food Science & Emerging Technologies 2*(3), 159-169. https://doi.org/10.1016/S1466-8564(01)00040-6

Zieliński, H., Michalska, A., Piskuła, M. K. and Kozłowska, H. (2006). Antioxidants in thermally treated buckwheat groats. *Molecular Nutrition & Food Research 50*(9), 824-832. https://doi.org/10.1002/mnfr.200500258

Žilić, S., Serpen, A., Akıllıogğlu, G., Gökmen, V. and Vančetović J. (2012). Phenolic compounds, carotenoids, anthocyanins, and antioxidant capacity of colored maize (*Zea mays* L.) kernels. *Journal of Agricultural and Food Chemistry 60*(5), 1224-1231. https://doi.org/10.1021/jf204367z