Review Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.5327/fst.80621

A review on the improvement of extruded food processing equipment: extrusion cooking in food processing

Yermek ABILMAZHINOV[1]*, Galiya ABDILOVA[1], Anton NESTERENKO[2], Zhanna DIBROVA[3], Vladimir ERMOLAEV[4], Irina MIRONOVA[5,6], Viacheslav ZHENZHEBIR[4], Evgeny PONOMAREV[3], Valentina VLASOVA[3]

Abstract

The extrusion technique, which combines mixing, shaping, texturing, and heating to create a unique food product, is gaining popularity in the worldwide agro-food processing sector. Extrusion cooking is a high-temperature, short-time (HTST) method that kills bacteria and inactivates enzymes. Compared to conventional cooking, extrusion cooking is favored because of its high productivity and substantial nutrient retention. Extrusion technology has become an essential tool in the food processing industry with its various benefits over other processing methods. It is a low-cost approach that provides a platform for processing a variety of items from several food categories by altering major or minor components and processing conditions. Extrusion technique is used in the food sector to create a wide range of supplemental foods, pet foods, morning cereals, pasta, snacks, and other textured foods. It's a low-cost method of reintroducing food processing waste and by-products into the food supply. Extrusion technology's flexibility allows for the production of value-added products and nutritionally dense fortified goods using various low-cost raw ingredients. Extruded goods are microbiologically safe, have a longer shelf life, and have less moisture content. This technology's advantages include product diversity and excellent quality and new food productivity and low processing time.

Keywords: versatility; textured foods; supplementary foods; extruded product; extrusion.

Practical Application: Extrusion technique in food processing.

1 Introduction

Extrusion processing is the technique of plasticizing proteinaceous, starchy, and wet food ingredients using a mixture of mechanical shear, heat, pressure, and moisture in a die (Shelar & Gaikwad, 2019). The late 1950s saw the introduction of extrusion cooking in food and feed production. The technologies employed have gained the reputation, efficiency, and adaptability since then (Cheftel, 1986; Y. Liu et al., 2019; Moscicki, 2011; Moscicki & van Zuilichem, 2011; Tiwari & Jha, 2017; Zhang et al., 2021). The extrusion cooking technique is generally employed in the food business for cereal and protein processing and in the pet food and feed industries (Ganjyal, 2020; Moreno et al., 2018; Mosibo et al., 2020). Extruder technology has advanced in the previous decade, allowing for more complex goods, novel flavor creation, encapsulation, and sterilizing (Ajita, 2018; Offiah et al., 2019; Zhang et al., 2017).

In the food sector, thermoplastic extrusion is referred to as High-Temperature, Short-Time (HTST) process because it allows for the manufacture of a wide range of food and feed products with little or no change of basic equipment and proper process management (Adeleye et al., 2020; Shelar & Gaikwad, 2019). Rice, wheat, corn, and more recently, soy have all been subjected to this method. Extruders can work at low, medium, or high shear based on the raw materials being used and required qualities for the finished product; typically, thermoplastic extruders are utilized at high shear (Xu et al., 2015). Low shear (cold extrusion) is used in the production of pasta and processed meat products, medium shear is used in the production of meat analogs and some pet foods, and high shear (thermoplastic extrusion) is used in the production of expanded snack foods, morning cereals, and textured vegetable proteins (Guy, 1994).

Raw material qualities and extruder operational circumstances, according to Fellows (2009), are the two most important elements that determine extruded product attributes. The following might be highlighted as key features of the raw material: pH, chemical composition, physical condition, moisture content, and kind of material. Die diameter, pressure, temperature, and shear force, the latter of which is controlled by the extruder's internal design and length, as well as screw geometry and rotation speed, are the operating factors that might be highlighted as essential. The thermoplastic extrusion method has the following benefits, according to Harper (2019) and Steel et al. (2012): high production yields, low prices, flexibility, excellent product quality,

Received 29 Aug., 2021
Accepted 23 Sept., 2021
[1] *Shakarim University of Semey, Semey city, Kazakhstan*
[2] *Kuban State Agrarian University, Krasnodar, Russian Federation*
[3] *K.G. Razumovsky Moscow State University of technologies and management (the First Cossack University), Moscow, Russian Federation*
[4] *Plekhanov Russian University of Economics, Moscow, Russian Federation*
[5] *Bashkir State Agrarian University, Ufa, Russian Federation*
[6] *Research Institute of the Federal Penitentiary Service of Russia, Moscow, Russian Federation*
*Corresponding author: eras71@mail.ru

and no effluents. Food extrusion is a type of extrusion used in food processing in which a mixture of raw materials is pushed through an aperture or die with a food-specific pattern and then trimmed to size by blades. The extruder is the machine that pushes the mixture through the die, and the mixture is known as the extrudate (Reque et al., 2014; Riaz, 2000).

The extruder is made out of a big, spinning screw that is snugly fitted into a stationary barrel and has a die at the end that forms the desired enlarged result. Food preparation at high temperatures poses a difficulty in the food processing industry, as high temperatures cause food to lose its nutritional content. As opposed to traditional cooking, Extrusion cooking is recommended to prevent this since it has a short processing time, considerable nutrient retention, and great productivity. Extrusion cooking is an HTST technique for reducing microbial contamination and inactivating enzymes in food (Mościcki et al., 2012). Extrusion causes the starch to gelatinize, proteins to denaturize, lipid oxidation to be reduced, and antinutritive factors to be reduced.

Furthermore, it is regarded as a flexible, low-cost, and highly efficient food processing technology capable of delivering a wide variety of nutritionally rich value-added products (Bordoloi & Ganguly, 2014). It is a modern food processing technology used to create a wide range of supplemental, textured, and snack foods. Extruded foods contain less moisture, are nutritionally dense, are microbiologically safe, and have a longer shelf life (Pathak & Kochhar, 2018).

2 Extrusion process principles

Raw ingredients are put into the extruder barrel, and the food is conveyed along with it by the screws. Smaller flights further down the barrel limit the amount of the meal and make it more resistant to movement. As a consequence, it compresses the barrel as well as the gaps between the screw flights. The screw kneads the material into a semi-solid, plasticized mass as it advances deeper down the barrel. Extrusion cooking (or hot extrusion) occurs when food is cooked to a temperature above 100 °C (Senanayake & Clarke, 1999). The temperature rises quickly as a result of frictional heat and any extra heating. The food is subsequently transferred to a portion of the barrel where pressure and shearing are enhanced even more because of the smaller flight. Eventually, when the food emerges under pressure from the die, it expands to its finished state and cools quickly as moisture is blasted out as steam via one or more limited dies at the discharge end of the barrel (Mulye et al., 2014) (Figures 1 and 2).

Shells, squirls, doughnuts, strips, spheres, rods, and Tubes are just a few examples of the forms that may be made. Enlarged, low-density snack foods and ready-to-eat (RTE) puffed cereals are typical items (Cho et al., 1995). Foods like pasta and meat products are mixed and shaped using cold extrusion, where the item's temperature remains constant (Menis-Henrique et al., 2020). Pet meals, liquorice, surimi, and fish pastes are all made with low-pressure extrusion at temperatures below 100 °C (Navale et al., 2015).

3 The categorization of an extruder

Extruders are machines that are used to process extrusions. Homogenization or mixing, size reduction, shaping, dehydration, pasteurization, heat cooking, enzyme inactivation, texturization, protein denaturation, starch gelatinization, and shearing are some of the unit activities that food extruders may execute simultaneously (Singh et al., 2020). Extruders are made up of five basic components (Mount 3rd, 2017) (Figure 1).

- The system of pre-conditioning:

Steam or water is used for pre-conditioning, and the mixture is done by hand. This is utilized when the moisture level of the substance is approximately 20-30%, and the material has a long

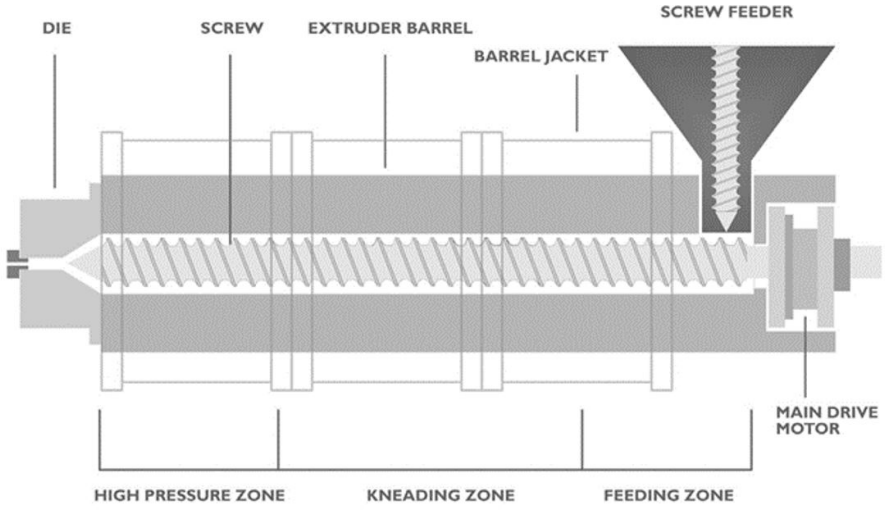

Figure 1. An extruder's major sections and zones.

residence period. Preconditioning promotes consistent particle hydration, lowers retention periods inside the extruder, and boosts throughput, all while extending the equipment's life and lowering energy costs.

- The system of feeding:

For an effective and consistent extrusion process, raw material feeding into the extruder should be continuous and uninterrupted.

- The worm or screw:

Material is conveyed into the extruder barrel by a screw, which shears the material and ensures the quality of the finished product. The screw of the extruder influences the protein denaturation, dextrinization and gelatinization of starch, and cooking degree, but it also ensures the quality of the end product. Mono-piece or multi-piece screws are available. The quantity and form of screw components might differ, and each segment serves a unique role. Certain components simply transport raw or pre-conditioned content into the extruder barrel, whereas others compact and degas the feedstock. Shear, backflow, and kneading must all be promoted. To promote mechanical energy dissipation, backflow, and dispersive mixing into the extruder, certain kneading screws feature interrupted flights. The following are the main aspects of screw design (Kowalski et al., 2018; Liu et al., 2010) (Figure 3).

- o axial flight land width;
- o clearance between screw and barrel;
- o the direction of drag flow;
- o the direction of leakage flow;
- o the direction of pressure-flow;
- o leading flank angle;
- o screw channel depth;
- o screw channel width;
- o screw diameter;
- o screw helix angle;
- o screw length;
- o screw pitch;
- o trailing flank angle;

- The barrel:

It is separated into three sections (Figure 1): sleeves, kneading, and feeding, which are frequently jacketed to allow for the circulation of superheated oil or steam for heating and air or water for chilling, allowing for exact control of temperature in the different parts of the extruder.

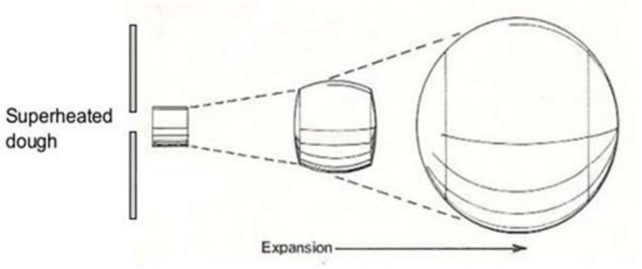

Figure 2. Dough expansion as it exits the die.

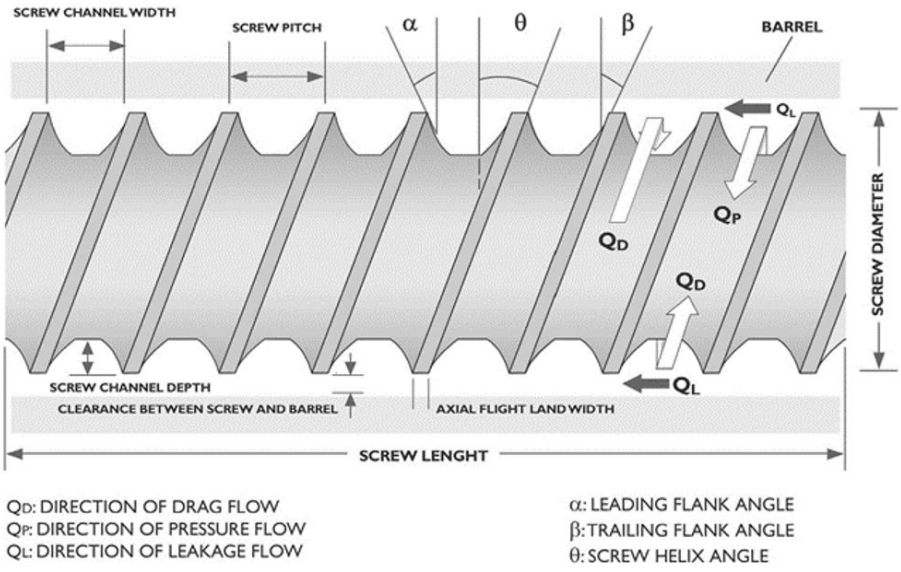

Figure 3. The most important aspects of screw design.

- The cutting mechanism and the die:

The die has two purposes; it shapes the finished product and promotes material flow resistance within the extruder, increasing inside pressure. The die can come in a variety of shapes and sizes, as well as a variety of orifice counts. The cutting mechanism should be able to produce uniformly sized end items. The rotation speed of the cutting blades determines the size of the product. This system can be vertical or horizontal (Tiwari & Jha, 2017).

Screw, barrel, and die configurations can all affect them. The raw material utilized and the intended final result will determine which of these things is chosen. Extruders are classified according to (Muthukumarappan & Swamy, 2020):

- Operational strategy

o Hot extruders:

HTST settings under pressure are often used to thermo-mechanically change raw materials. It's mostly utilized to make textured food and feed items like ready-to-eat breakfast cereals and snacks, among other things.

o Cold extruders

It's used to gently combine and mold dough within the extruder without using direct heat or cooking. It's mostly used to make pasta in the food industry.

- Construction method

o Single-screw extruder

A single revolving screw is contained in a metal barrel in a single screw extruder. Single scews with a consistent pitch and a variety of patterns are the most often used single scews. The raw materials are supplied into the feed section by a hopper, and the material is conveyed to the transition section via a revolving screw. The screw channel gets shallower at the transition region, and the material is compressed, resulting in a rise in the material's temperature. The substance gets more cohesive when the starch becomes gelatinized. The metering portion transports it farther and pushes it through the die hole (Rokey, 2000).

o Twin-screw extruder

It's made up of two equal-length parallel screws that spin inside the housing for greater control. Twin-screw extruders are used for huge numbers of twin-screw extruders in the same barrel, generally the interior face of the barrel of moisture extrusion. It's much more intricate than constituents like fibers, lipids, etc., and other complex ingredients, as well as more advanced goods. The location of the screws and their non-intermeshing screws will vary depending on the situation (Huber, 2000) (Figure 4).

- counter-rotating non-intermeshing screws;
- counter-rotating intermeshing screws;
- co-rotating non-intermeshing screws;
- co-rotating intermeshing screws;

4 Extrusion's raw materials and ingredients

Extrusion cooking techniques may be used with various foods, such as proteins, meat, cereals, legumes, oilseeds, tubers, starches, and grains. The kind of material, its physical condition, chemical composition, pH, and moisture content are the most important aspects of raw materials for extrusion cooking (Twombly, 2020). Solid raw materials make up most of the raw materials used in food extrusion (Zhu & Yu, 2020). Starch is used to make numerous goods, such as biscuits, morning cereals, and snacks, whereas protein is utilized to make meat-like products used as partial or full meat substitutes in several pet food products, dry foods, and ready meals (Offiah et al., 2019).

5 Extrusion technology's advantages

- By varying the ingredients, extruder working conditions, and dies, you may create a wide range of products.

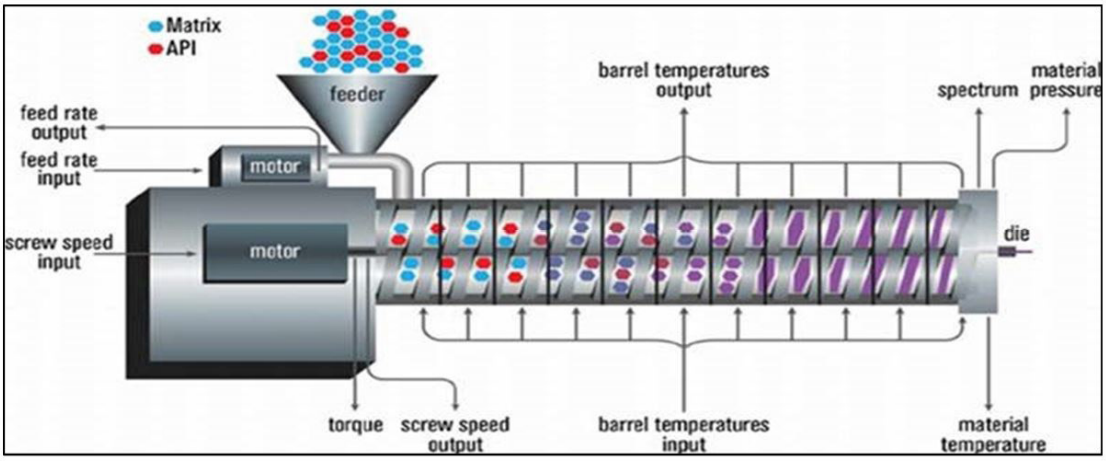

Figure 4. Twin-screw extruder.

- Extruders may alter starches, proteins, and other food components to create a wide range of novel meals (Singh et al., 2007a);
- Extrusion cooking does not create substantial process effluents because it is a low-moisture process;
- Extrusion cooking uses HTST, which keeps many heat-sensitive components of a dish intact while reducing nutritional and taste losses (Rao & Kiranmai, 2020);
- Extrusion is a continuous process that produces a large amount of material;
- Extrusion processing is energy-efficient since it cooks food items at low moisture levels. Lower moisture decreases the amount of heat needed to cook and redry the food afterward (Offiah et al., 2019);
- Compared to other heating and shaping processes, extrusion has reduced processing costs and better output (Moreno et al., 2018).

6 Extrusion technology's disadvantages

- The nutritional characteristics of proteins generally deteriorate when food item containing proteins and reducing sugars is heated (Singh et al., 2007b);
- Excessive heat causes the color of the product to fade;
- Different chemical processes, such as non-enzymatic browning and caramelization, might occur due to the high temperatures and low moisture conditions utilized (Camire, 2000).

7 Application of extrusion technology

Extrusion technology is used in the food production market to ensure extruded foods for pets and humans and add value to food residues and waste (Rizvi et al., 1995; Zhengrong, 2000). Extrusion is a cost-effective way to incorporate by-products and residues from food processing back into the food supply (Leonard et al., 2020).

8 Meat analogues

A meat analog, also known as a meat replacement, fake meat, faux meat, or imitation meat, is a substance that mimics the visual and chemical properties of many forms of meat. Meat analogs are commonly manufactured from soy protein or gluten (Chiang et al., 2019; Dekkers et al., 2018) (Tables 1 and 2).

Textured vegetable proteins (TVP) are made-up plant products that can entirely substitute meat in a meal. Defatted soya proteins make TVP heated extrusion, which results in enlarged high protein chunks, grains, strips, nuggets, and other forms with meat-like textures (Caporgno et al., 2020). TVP is a porous, insoluble, and fibrous material that can absorb many water or other liquids. When hydrated, textured soy proteins are processed to mimic poultry, fish, or meat in structure and appearance. Soy protein products have grown more popular because of their diverse functional characteristics, good nutritional quality, and low prices (Boukid, 2021).

Table 1. Meat analogs in their most common forms.

Loose-fill	Emulsified meat analogs	Coarse ground-meat analogs
Chili mixes	Frankfurters	Sausages
Taco fillings	Deli 'meats'	Pizza toppings
Sloppy Joe	Spreads	Meat' balls
		Burgers
		Batter/breaded nuggets

Table 2. Nonmeat protein sources that can be used as meat substitutes.

Sources	Type of protein
Fusarium venenatum (Filamentous fungus)	Mycoprotein
Legumes	Glycinin, Vicilin
Oilseeds	Legumin, Albumins, Globulins Glutelins
Soybean	b-conglycinin
Wheat, rye, and barley	Gluten Gliadins Glutenins

9 Conclusions

Extruder technology has progressed significantly during the previous three decades. On the other hand, technical innovations will be required in the development of new generation extruders and complementary equipment aimed at enhancing effectiveness and efficiency, improving throughput, simplifying process control, facilitating the production of a wide range of complex snacks, and boosting the quality of the end product. In addition, it's always been critical to cater to customer needs that are currently strongly linked to healthy and nutritious foods that encourage well-being and a pleasant way of life. Extruders make it possible to make a wide range of nutritious meals. In creating functional meals, extruders' capacity to mix various components in new foods may be used. Conventional snacks or morning cereals can be improved by adding additional fibers or whole-grain flour as components during extrusion, resulting in appealing cereal-based products with physiological benefits.

Extrusion processing allows for creating high-nutritive, low-cost, and convenient food items with a lot of flexibility. Extruded snacks have the potential to replace low-nutrient traditional snacks. The extrusion method increased the nutritional content of the goods while lowering antinutrients such as phytic acid and tannic acid. It also enhanced antioxidant activity and protein digestibility. This technique plays a key role in manufacturing a wide variety of meals and components due to its positive benefits, such as eliminating antinutritional factors, contaminated microbes, reduced lipid oxidation, and enhanced soluble dietary fibers.

References

Adeleye, O. O., Awodiran, S. T., Ajayi, A. O., & Ogunmoyela, T. F. (2020). Effect of high-temperature, short-time cooking conditions on in vitro protein digestibility, enzyme inhibitor activity and amino

acid profile of selected legume grains. *Heliyon*, 6(11), e05419. http://dx.doi.org/10.1016/j.heliyon.2020.e05419. PMid:33225089.

Ajita, T. (2018). Extrusion cooking technology: an advance skill for manufacturing of extrudate food products. In S. Z. Qamar (Ed.), *Extrusion of metals, polymers and food products*. London: IntechOpen. http://dx.doi.org/10.5772/intechopen.73496.

Bordoloi, R., & Ganguly, S. (2014). Extrusion technique in food processing and a review on its various technological parameters. *Indian Journal of Scientific Research and Technology*, 2(1), 1-3.

Boukid, F. (2021). Plant-based meat analogues: from niche to mainstream. *European Food Research and Technology*, 247(2), 297-308. http://dx.doi.org/10.1007/s00217-020-03630-9.

Camire, M. E. (2000). Chemical and nutritional changes in food during extrusion. *Extruders in Food Applications*, 127-147.

Caporgno, M. P., Böcker, L., Müssner, C., Stirnemann, E., Haberkorn, I., Adelmann, H., Handschin, S., Windhab, E. J., & Mathys, A. (2020). Extruded meat analogues based on yellow, heterotrophically cultivated Auxenochlorella protothecoides microalgae. *Innovative Food Science & Emerging Technologies*, 59, 102275. http://dx.doi.org/10.1016/j.ifset.2019.102275.

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

Chiang, J. H., Loveday, S. M., Hardacre, A. K., & Parker, M. E. (2019). Effects of soy protein to wheat gluten ratio on the physicochemical properties of extruded meat analogues. *Food Structure*, 19, 100102. http://dx.doi.org/10.1016/j.foostr.2018.11.002.

Cho, M. H., Zheng, X., Wang, S. S., Kim, Y., & Ho, C.-T. (1995). *Production of natural flavors using a cold extrusion process*. Washington: ACS Publications.

Dekkers, B. L., Boom, R. M., & van der Goot, A. J. (2018). Structuring processes for meat analogues. *Trends in Food Science & Technology*, 81, 25-36. http://dx.doi.org/10.1016/j.tifs.2018.08.011.

Fellows, P. J. (2009). *Food processing technology: principles and practice*. USA: Elsevier. http://dx.doi.org/10.1533/9781845696344.

Ganjyal, G. M. (2020). *Extrusion cooking: cereal grains processing*. USA: Elsevier.

Guy, R. C. E. (1994). Raw materials for extrusion cooking processes. In N. D. Frame (Ed.), *The technology of extrusion cooking* (pp. 52-72). USA: Springer. http://dx.doi.org/10.1007/978-1-4615-2135-8_2.

Harper, J. M. (2019). *Extrusion of foods*. Boca Raton: CRC Press. http://dx.doi.org/10.1201/9780429290428.

Huber, G. R. (2000). Twin-screw extruders. *Extruders in Food Applications*, 81-114.

Kowalski, R. J., Li, C., & Ganjyal, G. M. (2018). Optimizing twin-screw food extrusion processing through regression modeling and genetic algorithms. *Journal of Food Engineering*, 234, 50-56. http://dx.doi.org/10.1016/j.jfoodeng.2018.04.004.

Leonard, W., Zhang, P., Ying, D., & Fang, Z. (2020). Application of extrusion technology in plant food processing byproducts: An overview. *Comprehensive Reviews in Food Science and Food Safety*, 19(1), 218-246. http://dx.doi.org/10.1111/1541-4337.12514. PMid:33319515.

Liu, B., Xie, Y., & Wu, M. (2010). Research on the micro-extrusion characteristic of mini-screw in the screw extruding spray head. *Polymer Bulletin*, 64(7), 727-738. http://dx.doi.org/10.1007/s00289-009-0223-z.

Liu, Y., Chen, J., Wu, J., Luo, S., Chen, R., Liu, C., & Gilbert, R. G. (2019). Modification of retrogradation property of rice starch by improved extrusion cooking technology. *Carbohydrate Polymers*, 213, 192-198. http://dx.doi.org/10.1016/j.carbpol.2019.02.089. PMid:30879660.

Menis-Henrique, M. E. C., Scarton, M., Piran, M. V. F., & Clerici, M. T. P. S. (2020). Cereal fiber: extrusion modifications for food industry. *Current Opinion in Food Science*, 33, 141-148. http://dx.doi.org/10.1016/j.cofs.2020.05.001.

Moreno, C. R., Fernández, P. C. R., Rodríguez, E. O. C., Carrillo, J. M., & Rochín, S. M. (2018). Changes in nutritional properties and bioactive compounds in cereals during extrusion cooking. In S. Z. Qamar (Ed.), *Extrusion of metals, polymers and food products* (pp. 104-124). London: IntechOpen. http://dx.doi.org/10.5772/intechopen.68753.

Moscicki, L. (2011). *Extrusion-cooking techniques: applications, theory and sustainability*. Hoboken: John Wiley & Sons. http://dx.doi.org/10.1002/9783527634088.

Moscicki, L., & van Zuilichem, D. J. (2011). Extrusion-cooking and related technique. In L. Moscicki (Ed.), *Extrusion-cooking techniques: applications, theory and sustainability* (pp. 1-24). Weinheim: Wiley.

Mościcki, L., Mitrus, M., Wójtowicz, A., Oniszczuk, T., Rejak, A., & Janssen, L. (2012). Application of extrusion-cooking for processing of thermoplastic starch (TPS). *Food Research International*, 47(2), 291-299. http://dx.doi.org/10.1016/j.foodres.2011.07.017.

Mosibo, O. K., Ferrentino, G., Alam, M. R., Morozova, K., & Scampicchio, M. (2020). Extrusion cooking of protein-based products: potentials and challenges. *Critical Reviews in Food Science and Nutrition*, 1-35. http://dx.doi.org/10.1080/10408398.2020.1854674. PMid:33297728.

Mount 3rd, E. M. (2017). Extrusion processes. In M. Kutz (Ed.), *Applied plastics engineering handbook: processing, materials, and applications* (pp. 217-264). USA: Elsevier. http://dx.doi.org/10.1016/B978-0-323-39040-8.00012-2.

Mulye, V., Zofair, M., Baraiya, S., Solanki, K., Chudasama, J., & Temkar, S. (2014). Extrusion technology: adding value to fish products. *Infofish International*, 6, 2014.

Muthukumarappan, K., & Swamy, G. J. (2020). Extrusion processing of foods. In M. S. Rahman (Ed.), *Handbook of food preservation* (pp. 647-658). Boca Raton: CRC Press. http://dx.doi.org/10.1201/9780429091483-43.

Navale, S. A., Swami, S. B., & Thakor, N. J. (2015). Extrusion cooking technology for foods: a review. *Journal of Ready to Eat Food*, 2(3), 66-80.

Offiah, V., Kontogiorgos, V., & Falade, K. O. (2019). Extrusion processing of raw food materials and by-products: a review. *Critical Reviews in Food Science and Nutrition*, 59(18), 2979-2998. http://dx.doi.org/10.1080/10408398.2018.1480007. PMid:29787291.

Pathak, N., & Kochhar, A. (2018). Extrusion technology: solution to develop quality snacks for malnourished generation. *International Journal of Current Microbiology and Applied Sciences*, 7(1), 1293-1307. http://dx.doi.org/10.20546/ijcmas.2018.701.158.

Rao, B. D., & Kiranmai, E. (2020). Novel processes, value chain, and products for food, feed, and industrial uses. In V. A. Tonapi, H. S. Talwar, A. K. Are, B. V. Bhat, C. R. Reddy, & T. J. Dalton (Eds.), *Sorghum in the 21st century: food–fodder–feed–fuel for a rapidly changing world* (pp. 859-887). USA: Springer.

Reque, P. M., Steffens, R. S., Silva, A. M. D., Jablonski, A., FLôRES, S. H., Rios, A. O., & Jong, E. V. D. (2014). Characterization of blueberry fruits (Vaccinium spp.) and derived products. *Food Science and Technology (Campinas)*, 34(4), 773-779. http://dx.doi.org/10.1590/1678-457X.6470.

Riaz, M. N. (2000). *Extruders in food applications*. Boca Raton: CRC Press. http://dx.doi.org/10.1201/9781482278859.

Rizvi, S. S. H., Mulvaney, S. J., & Sokhey, A. S. (1995). The combined application of supercritical fluid and extrusion technology. *Trends in Food Science & Technology*, 6(7), 232-240. http://dx.doi.org/10.1016/S0924-2244(00)89084-6.

Rokey, G. J. (2000). *Single screw extruders*. Lancaster, PA: Technomic Publishing Co.

Senanayake, S., & Clarke, B. (1999). A simplified twin screw co-rotating food extruder: design, fabrication and testing. *Journal of Food Engineering*, 40(1-2), 129-137. http://dx.doi.org/10.1016/S0260-8774(99)00049-7.

Shelar, G. A., & Gaikwad, S. T. (2019). Extrusion in food processing: an overview. *The Pharma Innovation Journal*, 8(2), 562-568.

Singh, B., Sharma, C., & Sharma, S. (2020). Fundamentals of extrusion processing. In V. Nanda & S. Sharma (Eds.), *Novel food processing technologies* (pp. 1-46). New Delhi: New India Publishing Agency.

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

Singh, S., Wakeling, L., & Gamlath, S. (2007b). Retention of essential amino acids during extrusion of protein and reducing sugars. *Journal of Agricultural and Food Chemistry*, 55(21), 8779-8786. http://dx.doi.org/10.1021/jf071769z. PMid:17894461.

Steel, C. J., Leoro, M. G. V., Schmiele, M., Ferreira, R. E., & Chang, Y. K. (2012). Thermoplastic extrusion in food processing. In A. Z. El-Sonbati. *Thermoplastic elastomers.* London: IntechOpen.

Tiwari, A., & Jha, S. K. (2017). Extrusion cooking technology: principal mechanism and effect on direct expanded snacks–An overview. *International Journal of Food Studies*, 6(1), 113-128. http://dx.doi.org/10.7455/ijfs/6.1.2017.a10.

Twombly, W. (2020). Raw material behaviors in extrusion processing II (Proteins, lipids, and other minor ingredients). In G. M. Ganjyal (Ed.), *Extrusion cooking: cereal grains processing* (pp. 153-178). USA: Woodhead Publ. & Cereals & Grains Assoc. Bookstore. http://dx.doi.org/10.1016/B978-0-12-815360-4.00005-5.

Xu, E., Wu, Z., Wang, F., Li, H., Xu, X., Jin, Z., & Jiao, A. (2015). Impact of high-shear extrusion combined with enzymatic hydrolysis on rice properties and Chinese rice wine fermentation. *Food and Bioprocess Technology*, 8(3), 589-604. http://dx.doi.org/10.1007/s11947-014-1429-0.

Zhang, J., Liu, L., Liu, H., Shi, A., Hu, H., & Wang, Q. (2017). Research advances on food extrusion equipment, technology and its mechanism. *Nongye Gongcheng Xuebao (Beijing)*, 33(14), 275-283.

Zhang, Y., Zuo, H., Xu, F., Zhu, K., Tan, L., Dong, W., & Wu, G. (2021). The digestion mechanism of jackfruit seed starch using improved extrusion cooking technology. *Food Hydrocolloids*, 110, 106154. http://dx.doi.org/10.1016/j.foodhyd.2020.106154.

Zhengrong, S. (2000). Survey on extrusion technology and its application. *Food and Fermentation Industries*, 26(5), 74-78.

Zhu, G., & Yu, G. (2020). A pineapple flavor imitation by the note method. *Food Science and Technology (Campinas)*, 40(4), 924-928. http://dx.doi.org/10.1590/fst.26019.