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A Review of Converting Industrial Food Waste into High-Value Extruded Snack Products

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Abstract: *Producing fruit and vegetable by-products produces a lot of waste, which poses a disposal challenge for the food industry and may have adverse environmental implications if left unused. This waste contains bioactive materials such as flavonoids and lycopene, as well as nutrients including vitamins, minerals, and dietary fiber. In order to increase the nutritional value of snack foods, this study looks into the functional and nutritional qualities of by-products from the processing of fruits and vegetables. It also explores how these by-products may be used as noble components in food extrusion technology. This research also offers a method for producing a value-added component at a lesser cost, which would save the manufacturer money and lessen the quantity of waste that is now disposed of in an environmentally hazardous fashion. This study looks at the potential for adding fruit and vegetable by-products to extruded snack foods in order to increase the snack's fiber content and other beneficial components. The sectors that produce ingredients are always searching for cheaper, higher-value raw materials. Therefore, this study will also extend the viewpoints of the food industries and promote microfood entrepreneurs, Self Help Groups, and some other domestic food firms in terms of the value and development plans for food waste.*

Keywords: Extrusion technology, Fortified snack.

I. INTRODUCTION

Extrusion cooking is a method used in the food business to make infant meals, ready-to-eat snacks, and cereal sources for morning cereals (Sebio and Chang 2000). It provides several processing benefits over conventional processing methods. Excellent product quality, automated control, high output, less effluent, less processing area needed, faster reaction times, energy efficiency, and—possibly most importantly—more flexibility are some advantages of this technology. Extrusion cooking processing offers a wide range of processing techniques for ready-to-eat nutritious snack foods with the ideal texture, flavor, and taste due to its numerous processing possibilities.

The main objective of fruit and vegetable processing is to provide food that is safe, wholesome, tasty, and nutritious for consumers all year round (Raleng et al. 2022). Vegetable and fruit by-products are abundant, widely dispersed, and have greater dietary fiber content, high water binding capacity, and lower enzyme concentration of easily digested organic matter (Serena and Kundsen, 2007). Studies have looked into using pineapple by-products to provide wholesome fiber to processed and enhanced foods (Raleng et al. 2016). Dietary fiber has been shown to protect against diverticular diseases, heart disease, and colon cancer (Maetinez-Flores et al., 2008). Dietary fibre is therefore the third most sought-after commodity in markets all across the world, including those in Western Europe, India, North America, and Australia (Mehta 2005). The co-products can also be used to change the physicochemical composition of meals because of their high dietary fiber content.

The bulk of extruded snacks that are sold in India are high in fat, protein, and carbohydrates and are manufactured using grain flours. In the present world, there is an increasing consumer need for therapeutic and nutritional meals. Snacks made from fruit and vegetable byproducts can meet this need. Using a special, flexible extrusion process to create fiber-rich extruded treats out of this waste might also have major economical and health benefits. Extrusion processing has several advantages over other methods for handling fruit and vegetable by-products, including cheap cost, high output, flexibility, energy efficiency, and no effluents. Furthermore, because it will be formed from food industry by-products, it may be produced at a competitive cost that is far lower than what is now available on the market.

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Fruits and vegetables by-products

The processing of berries, vegetables, and fruits results in a large number of residual by-products for the fruits and vegetable business. They consist of pomace, skins, roots, berries, and fruit cores; they are also high in fiber and other phytochemicals. These by-products are rich in fiber and other phytochemicals; it would be creative and wise to utilize them to enhance other foods. Extrusion technology, for instance, may be utilized to create food snacks high in fiber. The outcome is food that is nutrient-dense, safe, and fairly priced (Tables 1 and 2).

Apple: Since apple pomace is a rich source of sugars and an excellent source of pectin, it can be used, on a limited scale, with low-pectin fruits to make jams, jellies, and other foods that need more pectin. Due to its high fiber content and higher amounts of antioxidants and phenolic compounds, apple pomace has been thoroughly researched as a possible food product in recent years (Cetkovic et al. 2008). More phenolic powder, sometimes known as apple skin powder or ASP, is used to make muffins. It has been demonstrated to improve taste and raise antioxidant and phenolic value levels (Rupasinghe et al. 2008). Rupasinghe et al. suggest that ASP from its variety Idared might be used for wheat flour in muffin recipes (2009). Even after substituting wheat for 16% (weight basis [w/w]) of the ASP, the sensory assessments remained positive. The cakes were similarly infused with apple pomace (AP), however the scientists observed that when the pomace level rose, the cake's volume reduced. Because AP binds water, it took more water to completely moisten the dough. The researchers also discovered that the cake's color deteriorated as its AP concentration dropped.

Grape: Grape pulp is the remaining press residue that is left over after pressing grapes to produce wine. Pressed skins, seeds, broken-up grape pulp cells, and stems make up the pomace. Meyer et al. (1998) state that grape pomace is one of the fruits with the most easily available phenolic compounds due to its extraordinarily high phenol content. Several studies have demonstrated the antioxidant and health-promoting qualities of the phenolic compounds found in wine and grapes, especially with regard to heart disease (Scalbert et al. 2005). Thus, grape pomace has the potential to be a useful source of phenolic antioxidants, with technical uses as a flexible food additive and advantageous outcomes. According to Valiente et al. (1995), grape pomace contains a greater content of dietary fiber and associated polyphenols, suggesting that it might be employed as a component in dietary fiber formulations (Martin-Carron et al. 2000).

Pineapple: A byproduct of the pineapple industry is pineapple pomace. About 76% of the fiber included in pineapple goods and waste (pearl and heart) is soluble (0.8%) and insoluble (99.2%) (Martinez et al. 2012). Pineapple pomace, which is high in dietary fiber, can be supplemented with meals to enhance their quality. In reality, extrusion is one method for using these by-products as raw materials in a particular agro-processing system. It can also help reduce contamination associated with the juice processing industry's elimination of byproducts.

Blackcurrant: Packed in stearidonic and g-linolenic acids, currant seeds are rich in these skin-beneficial acids that may help relieve atopic dermatitis syndrome (Johansson et al. 1997). According to Viuda-Martos et al. (2010) and Ayala-Zavala et al. (2011), flavoring compounds, antimicrobial agents to extend shelf life, and colorants and anti-browning agents are examples of potential side-stream exploiters. Food and medicine may benefit from the usage of phenolic compounds or the proportion of seed oil (Sandell et al. 2009, Wijngaard et al. 2012).

Carrot: Carrot pomace is a byproduct of making carrot juice. Carrots are a vegetable that has roots. Carrot juice yields can vary from 60 to 70%, and residual carrot pomace can lose as much as 80% of its carotene content (Bohm et al., 1999). It also contains a good amount of vitamins, dietary fiber, and minerals. Because the pomace has about 88.2% moisture content, it is extremely perishable. Durrani et al. (2011) looked at the possibility of using carrot as the main ingredient in a sweet with a honey base. The scientists reported that the product demonstrated adequate physicochemical and microbiological performance in addition to receiving good sensory scores. Given the method of manufacture, it was found that the product may be stored for six months at a safe temperature of 25 to 30 degrees Celsius.

Tomato: A byproduct of growing tomatoes is tomato pulp. Less than 4% of the fruit's total weight is made up of this byproduct (Del et al. 2006). Tomato pomace is made up of the dry, crushed skins and seeds of tomatoes (Tadeu-Pontes et al. 1996). Pomace tissues contain lycopene, an important component. Natural food pigment lycopene has several health advantages and is frequently used as a functional ingredient (Kaur et al. 2005). It has been effectively demonstrated that adding tomato peel to hamburgers may boost their nutritional value by lycopene. The only bad thing

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about the hamburgers was that the meat became brown due to a color change. This is explained by the high concentration of carotene pigment in hamburgers, according to Luisa et al. (2009).

Lemon: After processing, juicy citrus fruits like grapefruits, lemons, and oranges leave behind pulp. Lemons, like many other citrus fruits, are rich in polyphenols and antioxidants. According to Marn et al. (2002), lemon juice contains a very high concentration of vitamin C. Ascorbic acid is thought to help with iron absorption, hormone production, and cell oxido-reduction. Carotenoid was another phytochemical present, but it was not as common as the flavonoids. On the other hand, some academic articles have emphasized the benefits of the by-product. Dietary fiber content in peeled fruit is 7.34 g/100 g DM; however, according to Gorinstein et al. (2001), it is 14 g/100 g DM in lemon peels. Dietary fiber was divided into two groups: soluble (4.93 g/100 g DM) and insoluble. The researchers also discovered that one important source of iron is the peel from lemons. Orange: Oranges are a wonderful, healthy, pulpy fruit. It has a unique scent, flavor, and appearance. In terms of calories, it is one of the most complete suppliers of vitamin C among fruits and vegetables. It includes sugar, fiber, carotenoids, flavonoids, essential oils, and a few minerals in addition to vitamin C (Niu et al. 2008). Fresh orange juice, pasteurized orange juice, or concentrate juice are the most common ways that oranges are ingested. It's commonly used in a variety of cuisines as a spice or vegetable seasoning. 85% of oranges are turned into orange juice after fermentation, which results in tons of solid trash. Typically, the producer pays for the disposal of this waste, or animals are fed it (Topuz et al. 2005). Chau and Huang (2003) examined the dietary fiber content of orange peel (cv. Liucheng). Of the total dietary fiber in the peel (57% DW), 9.41% is soluble and 47.6% is insoluble. The most prevalent component, the insoluble one, provides health advantages including improved stool volume and intestinal function. The main elements of the fiber were found to be cellulose and peptic polysaccharides.

Cauliflower: According to Wadhwa et al. (2006), cauliflower has a high cellulose (16%), protein (16.1%), and hemicellulose (8%) content, as well as a high waste index (Kulkarni et al. 2001). It is a good source of dietary fiber and possesses anti-carcinogenic and antioxidant qualities. The main antioxidants in brassica vegetables are vitamin C and phenolic compounds, which are more concentrated and have antioxidant action (Podsedek 2007).

Potato: A nutrient-dense food, potatoes are high in minerals, phenolic compounds, dietary fiber, and carbohydrates (Abu-Ghannam and Crowley 2006). When potatoes are processed and prepared, tons of pulp and peel are produced, which raises the possibility of finding new applications or ways to get rid of this byproduct. Using potatoes as a novel food product might provide products like fresh meat pastes and baked goods favorable properties like gelling and added nutrition because they are high in fiber and starch (Kaack et al. 2006). Kaack et al. looked into the effects of including potato peel into a wheat bread recipe (2006). The fiber from soluble potato peels reduced the stiffness and gumminess of the bread. The professional panellists awarded the potato peel fiber (solubilized) desirable sensory ratings at 12% addition. Additionally, the amount of dietary fiber in bread supplemented with potato peels increased from 10.8 to 17.5%.

Physico-chemical properties of the extruded snack developed from fruits and vegetables by-products

The impacts of extrusion on extrudate functional qualities and the effects of tomato pulp addition on extrudate consistency parameters were studied by Caltinoglu et al. (2013). No discernible variation was seen in the volume expansion index, bulk density, longitudinal expansion index, or

Table 1: Review of industrial fruits waste used in extruded snack products

Fruit/Vegetable	Parameter	Response	Inference	Reference
Grapes	Die temperature (140– 160°C), Screw speed (150– 200 rpm), Pomace level (2–10 db)	Expansion, Bulk density, Texture, Colour, Sensory analysis	Blends of 2% grape pomace extrude at 160°C, 200 rpm and 10% grape pomace extruded at 160°C, 150 rpm has the highest sensory preference.	Altan et al. (2008)

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Tomato	Die temperature (140– 160°C), Screw speed (150– 200 rpm), Pomace level (2–10 db)	Expansion, Bulk density, Water absorpt ion and solubility indices, texture, color	Product responses were most affected by changes in temperature and pomace level and to lesser extent by screw speed.	Altan et al. (2008)
Lemon	Extrusion temperature (59.77–110.63°C), Screw speed (3.18–36.82 rpm), Moisture content (33.18–66.82 %)	Dietary fibre	The highest content of soluble fibre was 50.00% when operating conditions were high in temperature (100°C), low in moisture content (40%) and low in screw speed (10 rpm).	Mendez-Garcia et al. (2011)
Banana	Banana flour (BF), Screw speed (SS), Extrusion temperature (ET)	Color, Expansion, Flextural strength	Addition of BF resulted in higher L* and lower a* and b* values. Expansion increased with increase in the level of BF and ET. Flextural strength increased with increased in SS followed by BT and ET.	Kaur et al. (2015)
Pineapple	Moisture content, MC (17– 21%), Screw speed, SS (260– 340 rpm), Die temperature, DT (120–140°C)	Lateral expansion (LE), Bulk density (BE), Water absorption index (WAI), Water solubility index (WSI), Hardness.	Increase in DT resulted in higher LE, hardness, WAI and lower BD, WSI. Increase in SS resulted in higher LE, overall acceptability (OA) and lower BD, hardness.	Kothakota et al. (2013)

Application of fruits and vegetable by-products in extrusion studies of extruded snack

The impact of extrusion temperature (130–170°C), pea grits content (0–30%), and input moisture (18–24%) on the extrusion interaction and extrudate properties of rice grits was evaluated by Singh et al. (2007). Extruder die pressure, density, expansion ratio, water solubility index, real energy consumption, and water absorption index were among the study's subjects. Second-order polynomials were used to investigate the link between extruder parameters and product attributes, such as feed moisture content, extrusion temperature, and pea grit number. Mendez-Garcia et al. (2011) altered an extruded product made with lemon extracts to increase the soluble fiber section. A response surface approach with six central and six axial points was used to assess differences in the dietary fiber concentrations in leftover lemons. The control variables that were examined were screw speed (3.18–36.82), sample moisture levels (from 33.18–66.82%), and extrusion temperature (9.77–110.63°C). In extruded items, the estimated soluble fiber content of raw lemon extracts rose from 38.60 to 50.01%. Under working conditions with a high temperature of 100°C, low moisture content of 40%, and low screw speed of 10 rpm, the greatest quantity of soluble fiber recorded was 50%. Kumar et al. (2012) chose a polyethylene sealing device to seal extrudates (25 g) in LDPE pouches and aluminum laminated LDPE pouches within the optimal ratios (rice flour, pulse powder, and carrot pomace), moisture levels, screw speed, and die temperature. Following that, the bags were maintained in an incubator at a temperature of 382°C for a period of six months to evaluate the product's stability. We looked at the color, hardness, moisture content, and sensory characteristics of the extrudates. Aluminum laminated LDPE bags showed the least degree of increases in moisture content, hardness, or overall improvement in color E value. In their 2014 study, Makila et al. examined extrudates including potato starch (30%), cereal goods (40%) and residual blackcurrant press material (30%), together with trace levels of salt and sugar. The new non-enzymatic press residual extruded from barley or oat flour provided higher expansion, lower hardness and density, increased redness (a*), lower pH, and berry-like texture, appearance, and taste in comparison to enzymatic press residue and oat bran. It also ensured growth of fructose, glucose, and fruit acids. The project created a long-term plan for converting residual industrial press material from different berry juice pressing techniques into wholesome breakfast cereals and snacks.

Textural and microstructural studies on extruded snack products

Well before extrusion (starch digestibility), Parada et al. (2011) analyzed the microstructure, physicochemical properties (texture, expansion, density, pasting), and nutritional composition of guar gum (0–10%) added to a flour combination (maize, potato, rice, and wheat). Guar gum increased starch digestibility by 24%, 15%, 25%, and 43% in products based on maize, potato, rice, and wheat flour, respectively, at a concentration of 10%. Guar gum did not reduce starch digestibility. Greater starch digestibility is frequently linked to guar gum-containing extrudates with bigger matrix surfaces, weaker microstructures, and lower viscosities. Using a Field Emission Scanning Electron Microscope (FESEM), Noorakmar et al. (2012) examined the effects of incorporating orange sweet potato flour with tapioca starch on microstructure characteristics. Both in appearance and texture, the food was similar to a traditional morning cereal. Orange sweet potato flour and tapioca starch were used to give the fried extruded fish crackers a soft, brownish, and somewhat stiffer texture. The fried extruded fish crackers with a higher percentage of orange sweet potato flour had strong cell walls and small air cells, which deviated from the desired fried cracker consistency, according to the microstructure tests. The well-informed judges praised the fried extruded fish crackers' crunchy texture. They were made up of 30% fish, 14% orange sweet potato flour, and 56% tapioca starch. Kasprzak et al. (2013) examined the microstructure and physical properties of maize extrudates using high-fibre components (oat bran, lasting pea whole meal). The composition of the material blend and variable process parameters, such as barrel temperature distribution profile (120/145/115, 130/155/115, 140/165/115°C) and material blend moisture (11, 13.5, 16%), were analyzed in connection to the microstructure and physical properties of extrudates. The blend's material mix as well as the process variables had an impact on the products' microstructure. Depending on variations in air cell size, number of forms, and cell wall thickness, extrudates can have different physicochemical properties and sensory qualities.

Application of frying, packaging and storage studies on extruded snack products

A study on deep-fat fried extruded products made from cereals, legumes, and their mixes—which are popular due to their appealing organoleptic qualities—was carried out by Annapure et al. (1998). The diversity in oil content of extruded snacks may be explained by the physicochemical properties and chemical compositions of different types of grains. Furthermore, the frying medium has an impact on how much oil is used in deep-fat frying. A 2011 research by Saeleaw and Schleining focused on cassava crackers made using cassava starch, water, and deep-frying in oil at 140, 150, and 160°C. The moisture content, bulk density, linear expansion, sound emission, and piercing forces of the cassava crackers were optimized at 5, 10, and 15 seconds into the frying process. The results show that as frying time and temperature increase, the density, maximum, and mean force peaks drop, while the moisture content, number of force peaks, linear expansion, and sound peaks all increase. Additionally, it was discovered that when temperature rose, so did the number of small air cells.

Dar et al. (2014) fried extrudates at temperatures of 170, 180, 190, and 200°C for 5, 10, and 15 seconds using optimum flour proportions (rice flour, carrot pomace, and pulse powder), moisture contents, screw pace, and die temperature. After being wrapped in metalized polypropylene and stored for six months, the chosen product was evaluated based on sensory qualities for free fatty acid, peroxide value, crispiness, rigidity, color, and beta carotene. Raising the frying temperature and length of time resulted in a decrease in color a-values and an increase in color L-values, b-values, and oil absorption in rice extrudates made from carrot pomace. The consumer preferred and gave a higher rating to the snack that was cooked for 15 seconds at 180°C.

Raleng et al. (2019) investigated the bioactive properties of extrudates with ready-to-eat powdered pineapple pomace. Using optimal extrusion processing settings, extrudates meant for deep-frying were created and then deep-fried in rice bran oil for five to fifteen seconds at 160 to 180°C. An extruded snack that was baked for 15 seconds at 180°C had the highest color value, lowest hardness (9.59 N), and maximum acceptability (6.33). According to the results, ACL packing content performed better in terms of free fatty acid rise (0.65%), peroxidase value (4.23 meq/kg), and retention of color values "L," "a," and "b." Extrudates wrapped in ACL packaging material maintained their homogeneity better after four months.

Application of response surface methodology for process optimization of the extruded snack

Utilizing response surface techniques, Upadhyay et al. (2010) examined the effects of feed moisture (10–30% wb), die temperature (65–125°C), feed rate (2.5–8.5 g/s), and carrot pulse pomace (1.5–15.5% wb) on extrudate moisture, bulk density, expansion index, and sensory characteristics. To obtain the best desired answers, a regression equation was used to optimize the process components. With an overall acceptance score of 7.4, it was determined that 5% was the appropriate concentration of carrot pulse pomace. The study suggests that including CPP might provide an appropriate extruded product.

Alam et al. (2013) employed response surface methodology (RSM) to examine the effects on protein, fiber, color, texture, and overall acceptability of extruded goods of different screw speeds (300–500 rpm), moisture content (14–20%), and ingredient proportions (rice flour: pulse flour: carrot pomace powder–60–80%: 10–30%: 10%). Using certain consistency criteria, it was determined that the ideal operating parameters for screw speed, die temperature, moisture content, and rice percentage in component composition were 340 rpm, 120°C, 20%, and 60%, respectively. According to analysis of variance (ANOVA), sample formulation had the most important effect on all responses, followed by screw speed; die temperature and moisture content had a slightly higher effect on overall acceptability and hardness.

Chiu et al. (2013) used response surface methods to look at the best operating conditions for a single screw extruder and the effects of extrusion processing variables including yam flour content (10–30%), feed moisture (10–18%), and screw speed (250–350 rpm) on the characteristics of corn-yam extrudates (RSM). The water absorption index, bulk density, and hardness all increased as moisture content increased, but the radial expansion ratio decreased. Graphical optimization tests, on the other hand yielded yam flour levels, moisture con Analysis of variance (ANOVA) revealed that sample formulation, screw speed, and moisture content had the highest overall influence on all answers; die temperature and moisture content had somewhat bigger affects on overall acceptability and hardness.

The optimal operating conditions for a single screw extruder and the effects of extrusion processing variables on the characteristics of corn-yam extrudates (RSM), such as yam flour content (10–30%), feed moisture (10–18%), and screw speed (250–350 rpm), were examined by Chiu et al. (2013) using response surface methods. As the moisture content rose, the radial expansion ratio fell while the bulk density, hardness, and water absorption index all increased. The tent and screws have rates of 21-23%, 12-13%, and 305-320 rpm, in that order. The results suggest that snack foods might be made using maize extrudates enriched with yam.

Fruit and vegetable waste can include a variety of highly nutritious, reusable components. These cannery wastes have several possible uses and a bright future ahead of them. Fruit and vegetable by-products may be a useful source of resources for producers that are constantly looking for more profitable, higher-quality components. Dietary fiber is well recognized as an essential part of the human diet. Research has indicated that fruit and vegetable by-products are a good source of dietary fiber. Furthermore, as people's awareness of health issues grows, it would be a good idea to meet the increasing demand by including affordable sources of the necessary nutrients into food.

This study looks into environmentally friendly ways to turn fruit and vegetable processing by-products into extruded snacks. Thus, trash from factories that produce fruit and vegetable byproducts is being transformed into an affordable, nutrient-dense nutritional supplement for low-income areas using extrusion technology. Overall, the study demonstrates that the growing demand for healthier ready-to-eat meals may be met by utilizing byproducts from various fruit and vegetable manufacturing processes.

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