Bioactive components, in vitro digestibility, microstructure and application of soybean residue (okara): a review

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Abstract
Okara is a by-product of soymilk production with a rich nutritional profile, particularly in proteins, fibers, lipids, and bioactive components. Okara has the potential for value-added production and utilization—choices that, at the same time, deliver on the promise of increased economic advantages along with a reduction in environmental pollution. Research on bioactive constituents, in vitro digestibility and structural aspects (microstructure and infrared spectroscopy) suggests its potential as an ingredient with high bioactive components and digestibility score, along with varied structural strength, which may be of great importance to the food industry while developing new products with okara integration. Further, various food formulations made from the addition of okara flour also suggested the potential of this low-cost waste ingredient to enhance the nutritional value and address the various health-related issues such as obesity, diabetes and hyperlipidemia diseases. Therefore, this mini review summarizes the existing literature with a view to establish an extensive knowledge base for the composition and utilization of okara. In addition, structural and digestibility aspects of okara are also highlighted as they may determine the quality and acceptability of the product.

KEYWORDS
Digestibility, Glycemic index, Isoflavones, Structural properties

1 | INTRODUCTION

Okara is a gluten-free residue of soybean generated during soybean and tofu processing after aqueous fractions have been extracted (Kamble et al., 2019). Okara is also referred as soybean, bean curd/dreg, douzha or tofuzha (Chinese), bejee (Korean) or tofukasu (Japanese). Around 1.2 kg of wet (fresh) okara waste was produced when 1 kg of soybean was processed for tofu (Bo, 2008). Okara’s world production is around 1.4 billion tons, most of which is produced by Asian countries including Japan, Korea, China and Singapore. The tofu industry produces around 800,000 tons of okara in Japan, about 310,000 tons in Korea, and around 2,800,000 tons of okara in China annually. Soybean consumption is presently on the rise in European countries. Spain, for instance, imported 2.5 million tons of soybeans in 2004, which led to a rise in okara production (Li, Qiao, & Lu, 2012). The generation of a large quantity of okara is a major problem in the manufacturing of soybean-based foods like soy milk (Santos et al., 2019). For the purpose of reducing the environmental impacts resulting from residue generation, food technologists are looking for alternatives to the use of agro-industrial by-products as a source of nutrients (Guimarães et al., 2018).
Although okara flour is considered as a depreciated product from wet okara, it has low storage volume and greater storage stability as the product’s moisture content is low after drying. It may therefore be an alternative to the use of this by-product as a whole (Santos et al., 2019). Advanced and hygienic large-scale production techniques must be applied efficiently to ensure high-quality and sustainable products (i.e., quick removal of moisture to produce a dry solid product of >94% with a low water activity \([a_w]\) confirming its storage stability; Schved & Hassidov, 2010). Dried okara may be an excellent alternative as a new food ingredient, not only for food enrichment but also for increasing its use and quality (Porcel, Victorri, Campderrós, & Rinaldoni, 2017). It is a good source of dietary fiber, protein, and lipid along with phyto-terols, isoflavones, lignans, coumestans, phytic acid, and saponins (Lu, Liu, & Li, 2013). Okara flour is stated to have a high percentage of proteins (24.5–37.5/100 g), dietary fiber (14.5–55.4/100 g), and lipids (9.3–22.3/100 g; Schved & Hassidov, 2010). Bioactive ingredients of okara have been reported to safeguard against hypolipidemic, hypcholesterolemic, and type 2 diabetes syndrome by reducing glycemic index (GI) ingestion (Kamble, Singh, Rani, & Pratap, 2019). According to a study by Wang and Cavins (1989), okara accounts for 11% of soybean oil, 20% of soybean protein, and 30% of soybean solids. In general, the nutritional profile of okara will rely on the quantity of water removed from ground soybeans and whether additional water is applied to extract residual extractable constituents. Today, okara is commonly used for the livestock feed in adjacent proximity to soy drink manufacturing facilities, sold as a wet food item that contains about 75–88% water (Schved & Hassidov, 2010). It could be utilized as a basis for low-cost synthetic silkworm food for the first to the third larval stage of growth. Studies continue to develop uses for okara, comprising the manufacturing of food for human consumption (O’Toole, 2004). Potentials for improving the nutritive and functional properties of foodstuffs, such as bread, cookies, cakes, noodles, and yogurt, with okara integration, have already been explored in recent years (Kang, Bae, & Lee, 2018; Lu et al., 2013; Mbaeyi-Nwaoha & Uchendu, 2016; Park, Choi, & Kim, 2015). Soybean okara is important not only from a bioactive point of view but also because of its digestibility and structural properties, and a good understanding of these aspects of okara is important before it is used in the formulation of food products for human consumption. Previous work on the structural characteristics and digestibility aspects of okara shows that the incorporation of okara into various food products contributes to a good in vitro digestibility of protein and starch along with an altered structural strength (Kamble et al., 2019; Kang et al., 2018; Li et al., 2013; Voss, Rodríguez-Alcalá, Valente, & Pintado, 2018). The purpose of this study is therefore to examine, review, and summarize the scientific literature in order to develop a detailed knowledge base for the composition and implementation of okara.

### 2 NUTRITIONAL VALUE OF OKARA

The chemical composition of okara will depend on the amount of water obtained from ground soybeans and whether additional water has been used to remove residual extractable constituents. It also relies on soybean cultivars and procedures of extraction. In the Chinese process, soybeans are soaked, rinsed, and ground, and the okara has been filtered off; in the Japanese system, rehydrated soybeans are cooked prior to grinding and filtering (O’Toole, 1999; Figure 1). Fresh okara comprises about 81.7–84.5% of moisture (Bo, 2008). Variations in the nutritional profile of fresh and dry okara have also been reported in previous studies (Table 1), which can be attributed to differences in soybean cultivars, production processes, and analysis methods (Li et al., 2012). Dietary fibers, which are the main constituents of okara, can be categorized into four different forms: crude fiber, total dietary fiber, soluble dietary fiber, and insoluble dietary fiber and reported to play an important role in a wide range of biological processes and in the fight against syndromes of different origins. Okara can be regarded as a good source of dietary fiber as it is a major component, and the price is low. According to another study by Mateos-Aparicio, Mateos-Peinado, and Rupérez (2010), dried okara was reported having a higher level of total dietary fiber (55%), mainly insoluble dietary fiber (50%), low-soluble dietary fiber (5%), and protein (30%).

Li et al. (2013) claimed that okara had 58.60% total dietary fiber, 55.63% insoluble dietary fiber, and 1.91% soluble dietary fiber. Okara’s dietary fiber primarily consists of arabinose, xylose, galactose, and galacturonic acid with a molecular weight between 724 and 2081 kDa. Guermani et al. (1992) also reported the fiber content, which consists of cellulose, hemicelluloses, and lignin at about 19%, 41%, and 38%, respectively. The key constituent of the dietary fiber

![FIGURE 1](image_url) Flow chart of the okara manufacturing process (Adapted from Vong & Liu, 2016; Guimaraes et al., 2018)
in okara is ruptured cells of cotyledon, and the seed coat does not act in the same way as the cotyledon cells when macerated by different methods. The insoluble fiber content is 5.5% cellulose, 12% hemicellulose, 11.5% lignin, and 0.2% phytic acid (O’Toole, 2004). The okara, free monosaccharides, and oligosaccharides comprise glucose (0.2%), fructose (0.1%), galactose (0.2%), arabinose (1%), sucrose (0.6%), and stachyose + raffinose (1.4%) with 0.5% starch (Mateos-Aparicio et al., 2010). Other constituents of soy products likely to occur in okara comprise isoflavones, phytoestrogens, lignans, phytyates, coumestans, and saponins (Li et al., 2012). Because of its high dietary fiber content, the addition of okara shows a loss of body weight, positive effects on lipid metabolism, and possible prebiotic effects, as previously described in rats and syriacs. However, the key benefit assigned to dietary fibers relates to soluble dietary fibers such as prebiotic effects, regulation of cancer, and obesity-related metabolic syndrome (Pérez-López et al., 2018). Phytic acid (inositol hexa-phosphate), when consumed in large amounts in the diet, has resulted in reduced calcium balance and poor bioavailability of zinc and metal ion (O’Toole, 2004). Okara also contains a significant quantity of fat (8.3–10.9%) and protein (15.2–33.4%). Linoleic acid (54.1%) is the utmost fatty acid, accompanied by oleic acid (20.4%), palmitic acid (12.3%), linolenic acid (8.8%), and stearic acid (4.7%; Li et al., 2012). Dry okara has a high nutritional value, with an average 25% protein and 10% lipid (Voss et al., 2018). Park et al. (2015) recorded 6.6% ash, 11.0% crude fat, 13.0% crude protein, and a total dietary fiber of 63.7% in dried okara. Voss et al. (2018) reported that okara is produced from soybean seeds with a high proportion of fat (18–22%) and may still be referred as a high fat by-product. All okara samples were made of polysaturated fatty acid, primarily linoleic acid followed in all samples by linolenic acid. The okara also showed reference levels of monounsaturated fatty acids, approximately 21/100 g of fat, whereas oleic acid (C18:1 n-9) was more than 19/100 g of fat. The primary saturated fatty acids are palmitic acid (C16:0) and stearic acid (C18:0) with a fat content of approximately 6–14/100 g.

Liu (1997) stated that the okara protein is of superior quality compared with other soy products; for example, okara protein efficiency ratio was 2.71, whereas soy milk was only 2.11. Wang and Cavins (1989) have stated that in okara, the proportion of essential to total amino acids is comparable with that of tofu and soy. The protein obtained from heat-treated and nonheated okara is different; the latter comprises the identical basic 7S globulin found in soybeans, unlike the former (O’Toole, 2004). Ma, Liu, Kwok, and Kwok (1996) focused on the essential amino acid content and digestibility of okara proteins. The essential amino acid levels of the two okara-protein isolates examined were generally analogous to that of traditional soy protein isolates. The content of cysteine and methionine in okara protein was significantly reduced but improved with the processing temperature. Both the overall essential amino acid content and the essential amino acid profiles of soy protein foods are equivalent to the Food and Agriculture Organization/World Health Organization norm, with the exemption of the sulfur group comprising amino acids (methionine, cysteine) and tyrosine, which were in limited amount inside the soy proteins. Other nutrient components of okara include riboflavin, thiamine, and nicotinic acid, along with calcium, phosphate, iron, zinc, magnesium, and copper (O’Toole, 2004). Santos et al. (2019) reported that okara flour had high levels of phosphorus (313 mg/100 g), calcium (126 mg/100 g), and potassium (286 mg/100 g), with moderate level of zinc (3.14 mg/100 g), copper (0.77 mg/100 g), and iron (4.45 mg/100 g). Lu et al. (2013) also reported mineral content of okara as 9.36 mg/g potassium, 4.19 mg/g calcium, 2.57 mg/g magnesium, 0.026 mg/g zinc, and 0.11 mg/g iron.

| Parameters          | Dry okara<sup>a,b</sup> | Dry okara<sup>b,c,d</sup> | Fresh okara<sup>e,f</sup> | Fresh okara<sup>b,g,h</sup> |
|---------------------|--------------------------|---------------------------|---------------------------|---------------------------|
| Moisture (%)        | 6.71 ± 0.01              | 4.71 ± 0.06               | 80.25 ± 0.04              | 74.0 ± 0.20               |
| Ash (%)             | 3.85 ± 0.02              | 6.36 ± 0.17               | 0.86 ± 0.00               | 1.26 ± 10.24              |
| Fat (%)             | 5.90 ± 0.12              | 16.29 ± 0.04              | 6.22 ± 0.45               | 1.98 ± 0.12               |
| Protein (%)         | 15.31 ± 0.33             | 33.53 ± 0.11              | 7.91 ± 0.25               | 32.8 ± 0.63               |
| Crude fibre (%)     | 17.9 ± 0.20              | 36.32 ± 0.01              | 4.1 ± 0.00                | 23.4 ± 0.09               |
| Total dietary fibre (%) | 58.60 ± 0.20         | 56.6 ± 0.00               | 13.83 ± 0.49              | 34.67 ± 2.91              |
| Insoluble dietary fibre (%) | 55.63 ± 0.07         | 42.0 ± 0.00               | 10.58 ± 0.40              | 17.79 ± 0.61              |
| Soluble dietary fibre (%) | 1.91 ± 0.06             | 14.6 ± 0.00               | 3.25 ± 0.09               | 16.88 ± 0.00              |
| Calcium (mg/100 g)  | 4.19 ± 0.46              | 0.32 ± 0.00               | 80 ± 0.0                  | 50 ± 0.0                  |
| Iron (mg/100 g)     | 0.11 ± 0.06              | 0.62 ± 0.1                | 1.30 ± 0.0                | 0.08 ± 0.01               |
| Copper (mg/100 g)   | 0.01 ± 0.01              | 0.10 ± 0.00               | 1.46/100 g                | <0.01                    |

<sup>a</sup>Source: Lu et al. (2013).
<sup>b</sup>Source: Santos et al. (2018).
<sup>c</sup>Source: Mbaeyi-Nwaoha and Uchendu (2016).
<sup>d</sup>Source: O’Toole et al. (1999).
<sup>e</sup>Source: Guimaraes et al. (2018).
<sup>f</sup>Source: O’Toole (2004).
<sup>g</sup>Source: O’Toole et al. (1999).
<sup>h</sup>Source: Pérez-López et al. (2018).
3 | BIOACTIVE COMPONENTS IN OKARA, WITH SPECIAL EMPHASIS ON ISOFLAVONES

Past research has shown that soybean is abundant in phenolic and isoflavones. Soy isoflavones have important biochemical activities as part of the flavone compounds. It is an estrogen-like plant chemical that is commonly known as phytoestrogens (Baiano, Terracane, Gambacorta, & La Notte, 2009). The predominant isoflavones found in soybean consist of glycosides such as daidzein, genistein, syringic, gallic acid, chlorogenic, and ferulic acids that constitute the main phenolic components and has been accredited to perform many health-promoting functions (Li et al., 2013). The quantity of these components in soy food varies depending on the method of extraction and, in particular, on the temperature during production (Baiano et al., 2009). Okara also has good levels of isoflavones: Approximately 12–30% of soybean isoflavones are retained in okara during soy milk processing. Glucosides (28.9%) and aglycones (15.4%) are the major isoflavones in okara, with a lower amount of acetyl genistin (0.89%; Jackson et al., 2002). β-Glucosidase may enzymatically hydrolyze isoflavone glucosides to their aglycone forms, showing greater human bioavailability (Izumi et al., 2000). The selected fermentative microbes also secrete β-glucosidase (Bhatia, Mishra, & Bisaria, 2002), and therefore, the bioconversion of isoflavone glucosides in okara to aglycones by fermentation offer further potential for value addition. Vong and Liu (2014) reported on the bioactive constituents of okara as malonyl glucosides (19.7%), isoflavone glucosides (10.3%), isoflavone aglycones (5.41%), acetyl glucosides (0.32%), saponins (0.10%), and phytic acid (0.5–1.2%). Li et al. (2012) reported that the quantity of okara daidzein, glycitein, genistein, and total glucosides isoflavone was 1.79, 0.01, 1.76, and 3.56 μmol/g dry basis, respectively. Moreover, it was also reported that the total glycyne content was 0.11 μmol/g dry basis in which the value of daidzein, glycitein, and genistein was 0.05, 0.02, and 0.04 μmol/g, respectively. Li et al. (2013) reported that the total isoflavones content of okara was 355 mg/g on a dry weight basis. The concentrations of aglycones, isoflavone glucosides, malonyl glucosides, and acetyl glucosides in okara were found to be 54.1, 103.2, 196.8, and 3.2 mg/g, respectively. They suggest that soybean isoflavone enhances cancer resistance, prevents osteoporosis, decreases antibacterial inflammation, and regulates heart disease. Consumption of soy-containing foods has been reported to be linked with reduced blood cholesterol, prevention of cardiovascular syndrome, reduced possibility of cancer (colon, prostate and breast), osteoporosis, cognitive function, and menopause symptoms (Li et al., 2013).

Anticancer and anti-inflammatory advantages, cardiovascular defenses, and enzyme inhibitory roles of isoflavone are primarily associated with their antioxidant capacity, which is equivalent to or better than that of other polyphenols (Baiano et al., 2009). Antioxidants are classified as organic compounds that can combat the adverse effects of oxygen in the tissue. Although officially the term refers to compounds that react with oxygen, it can often adhere to compounds that protect against free radicals (molecules with unpaired electrons) that inhibit these radicals from injuring healthy cells. Genistein and daidzein are the strongest isoflavones for antioxidant activity. It is interesting to note that aglycone and glycoside forms are effective antioxidants. Genistin actually protects against oxidative DNA damage resulting from hydroxyl radicals, including superoxide anion scavenging ability (Russo, Cardile, Lombardo, Vanella, & Acquaviva, 2006), and prevents low-density lipoprotein oxidation (Lee, Yang, et al., 2005). The research on the identification and quantification of isoflavones also revealed that okara is a rich source of daidzin, glycitin, genistin, daidzein, glycitein, and genistein (Figure 2). Voss et al. (2018) reported that in the high-performance liquid chromatography study, genistin was found to be the most dominant okara glucose 0.33 mg/g along with 0.25 mg/g daidzin, 0.32 mg/g genistin, 0.02 mg/g daidzein, and 0.02 mg/g genistein of dried okara.

4 | STRUCTURAL CHARACTERISTICS OF OKARA

The structural study of okara flour was previously investigated using various techniques, including scanning electron microscopy (SEM; Porcel et al., 2017; Voss et al., 2018; Santos et al., 2019) and Fourier transform infrared (FTIR) spectroscopy (Kamble et al., 2019; Li et al., 2014; Quintana, Gerbino, & Gómez-Zavaglia, 2017). SEM is a useful technique for determining the microstructure of food products by evaluating the arrangement of starch granules within the protein matrix (Kamble et al., 2019). Santos et al. (2019) conducted a study to examine the microstructure of okara flour particles by means of an SEM (Figure 3). The results showed that flour components were either loose or agglomerated; that is, a heterogeneous composition was observed in the micrograph. It was also found that the components of okara flour had irregular structures and undefined shapes that could not be distinguished. Furthermore, the particles have also been documented to be geometric structures with some gaps that are responsible for the high incidence of permeable pores. Because the pores cause high water absorption, the flour components are described as hygroscopic structures. Porcel et al. (2017) investigated the effect of the type of drying process on the microstructure of okara flour through optical microscopy. The freeze-dried sample was reported to have a porous configuration with a thin capillary form. Microwave dried and rotary dried samples had flat, rounded configurations in a dense matrix. Voss et al. (2018) studied the microstructure of fresh okara and thermally dried okara samples at two different temperatures (80°C/5 hr and 200°C/1 hr). The major difference between the samples was the moisture level, which was lower in both 80°C and 200°C dried okara samples than in fresh okara. These moisture-induced alterations in the okara structure resulted in a higher porosity, especially for those dried at 200°C/1 hr. Park et al. (2015) also researched the microstructure of okara-enriched dough by SEM. Okara micrographs showed gaps, dark-colored areas, likely to be caused by water loss during freeze-drying. Okara dough displayed the largest amount of moisture along with the presence of most irregular holes. SEM images of okara cookies revealed a poor matrix structure leading to a weakened dough. Additives reduced the amount of water,
resulting in fewer and less gaps in additive dough compared with okara dough. Particularly, the hydroxymethyl + okara dough seems to have the least empty space and also displayed a more compact arrangement of small holes between the dough samples.

FTIR spectroscopy may show structural similarities or differences between samples based on the presence or absence of specific functional groups (Rani, Singh, Kamble, Upadhyay, & Kaur, 2019). Quintana et al. (2017) studied the FTIR spectra of frozen whole and defatted okara specimens in the 4,000 – 500 cm$^{-1}$ wavelength range. FTIR spectrum of frozen okara showed the existence of bands of lipids and carbohydrates. They observed the presence of the usual narrow sCH2 bands analogous to hydrocarbon chains of lipid (2,931 and 2,860 cm$^{-1}$) and fatty acid carbonyl groups (1,750 cm$^{-1}$) in the okara flour. In addition, a prominent band was observed in regions of 1200–900 cm$^{-1}$, attributed to the glycosidic C–O–C group absorption. Their results showed a higher fiber percentage in the okara flour. Li et al. (2014) studied the FTIR spectra of okara polysaccharides at 4,000–400 cm$^{-1}$ frequency range. The reported broad bands at 3,000–3,500 cm$^{-1}$ region may be attributed to typical glycosidic linkage resulting from O–H stretching, whereas the specific peak of absorption at 1,720 cm$^{-1}$ indicates the occurrence of uronic acid. The absorption band at 1,650 and 1,400 cm$^{-1}$ regions suggested the occurrence of polysaccharides, whereas the band at 1,124 cm$^{-1}$ can be the result of stretching vibrations of C–O–C group. The absorption peak at 890 cm$^{-1}$ may be correlated with the presence of β-glycosidic bonding. It has been stated that β-glycosidic bonding is a main structural feature of immunostimulatory and antitumor effects. Kamble et al. (2019) also confirmed the existence of transmittance bands at 1,010, 1,529, 1,696, 2,362, 2,931, 3,635, 3,745, and 3,846 cm$^{-1}$ regions in pasta formed with okara flour integration. The observed transmittance peak at 1,010 cm$^{-1}$ may be correlated with the amorphous state of starch granules resulting from the C–O– stretching vibration (Bashir & Aggarwal, 2016). The high peak at 1,529 cm$^{-1}$ area could be attributed to the presence of amide II band as a result of N–H bond vibrations attached to CN stretching, whereas the peak at 1,696 cm$^{-1}$ was due to the presence of amide I band as a result of stretching vibration of C=O group. The peaks in the 2,362 and 2,931 cm$^{-1}$ regions indicated the stretching vibrations of the CN and N–H bonds. The strong transmittance peak at 3,635.25 cm$^{-1}$ suggests the presence of O–H bond stretching vibration.

5 | DIGESTIBILITY STUDY OF OKARA

Digestibility is a parameter used to assess the nutritional value of different foods because it is not enough for a nutrient to be in high amounts as it must be digestible in order to be assimilated and therefore used by the organism. From a nutritional point of view, the starches present in food are hydrolyzed and absorbed as glucose in...
the intestine, whereas the proteins are digested according to their source and food processing prior to ingestion, resulting mainly in free amino acids and some dipeptides and tripeptides. The degree of digestion and absorption of available carbohydrates is influenced by several variables: food processing, starch source, various dietary matrices with varying physical structures that indicate different digestion levels, and existence of additives in the formulation that influence the availability of physical access of enzymes to the substrate (Milde, Chigal, & Chiola Zayas, 2018). Starch digestibility, which depends on the hydrolysis of the pancreatic enzyme, determines the energy density of available grain. The chemical nature of starch, particularly the amylose and amylopectin material, is another factor affecting their digestibility (Hibberd et al., 1982). Protein digestibility is an important indicator while assessing the quality of the protein source (Kamble et al., 2019). The protein digestibility of a food is known as the proportion of nitrogen in a food that is consumed after digestion. This may be affected by various antinutritional factors: fiber, tannins, and phytates, which may interfere with proteins or certain minerals or due to the effect of thermal processing (Rayas-Duarte, Mock, & Satterlee, 1996).

Li et al. (2013) investigated the GI of three okara-containing foods (bread, noodles, and steamed bread) in vivo in order to assess the viability of using these foods as healthy products to prevent diabetes. They reported that GI of okara bread (49), okara steamed bread (54), and okara noodles (52) were significantly lower than control food (bread, 67; steamed bread, 86; and noodles, 77). Low GI could be due to the high galacturonic acid content of okara fiber. The level of starch gelatinization was also reported to have a significant impact on the GI of the products. The greater degree of gelatinization leads to a higher GI of the food. Starch in boiled foods and steamed products (e.g., noodles) have a greater degree of gelatinization than in baked foods. Thus, okara bread has a reduced GI than okara noodle and okara steamed bread, even though it contains less okara than others. Okara protein isolates displayed a high in vitro digestibility compared with 77.1% for the defatted soy flour and did not differ considerably from commercially available protein isolate (Schved & Hassidov, 2010).

Kang et al. (2018) evaluated the impact of okara addition (0–20%) on the in vitro starch digestibility (IVSD) properties of rice noodles. They reported that as the percentage of okara in rice noodles increased, the amount of glucose released decreased significantly. The sample with 10% okara flour had the lowest level of rapidly digestible starch and the highest level of resistant starch compared with the unfortified sample. They also reported increased predictive GI upon incorporating 20% okara in rice noodles and correlated this with the ability of okara to damage the structural integrity of rice noodles. Kamble et al. (2019) tested the GI of the pasta enriched with okara flour at different levels (10–50%). Durum wheat pasta reported having a GI score of 27.41, which decreased significantly among all the okara supplemented pasta samples. A maximum drop in GI was observed in pasta containing 50% okara flour (12.38).

Protein digestibility of various okara-based food formulations has been investigated earlier (Espinosa-Martos & Rupérez, 2009;...
Ambawat & Khetarpaul (2018; Kamble et al., 2019). Espinosa-Martos and Rupérez (2009) reported that okara was less digestible in vitro (84.3%) than soy seed (91.8%). According to a report by Ambawat and Khetarpaul (2018), the low nutritional quality of soybean is mainly due to the presence of antinutritional factors. The phytic acid content of okara (843.33 mg/100 g) was significantly lower than that of soybean (1,386.67 mg/100 g), whereas the in vitro protein digestibility (IVPD) of okara was found to be 68.26%, which was significantly higher than that of soybean, that is, 56.46%. Kamble et al. (2019) studied the IVPD of okara-enriched (10–50%) functional pasta in comparison with durum wheat semolina pasta (control sample). Control pasta had a 94.71% IVPD score, which is significantly decreased by mixing with okara. The highest possible decrease in IVPD was observed in pasta containing 50% okara (75.68%), whereas the lowest decrease of 91.47% was observed after fortification at 10%. They indicated that reduced IVPD of okara-enriched pasta samples could be due to the presence of high levels of dietary trypsin inhibitors and other antinutrients in okara flour that reduced IVPD by inhibiting the action of proteolytic enzymes (Gilani, Xiao, & Cockell, 2012).

### 6 APPLICATION OF OKARA IN DIFFERENT FOOD FORMULATION

Okara has been used as food or meal for a number of years in Japan and China. It is fairly easy to add to the product in order to help achieve a nutritional claim for the protein and fiber. Okara can partially replace wheat flour, soy flour, and other food-producing components in order to boost the fiber and protein content (Li et al., 2012). The use of okara in different food formulations has been investigated earlier (Genta, Genta, Alvarez, & Santana, 2002; Kamble et al., 2019; Kang et al., 2018; Katayama & Wilson, 2008; Khare, Jha, & Sinha, 1995; Pan, Liu, & Shiau, 2018; Park et al., 2015; Waliszewski, Pardio, & Carreon, 2002; Wickramarathna & Arampath, 2003).

Khare et al. (1995) studied the quality attributes of beans developed by incorporation of okara at different levels (20–100%). They noted in taste studies that biscuits with the addition of 60% of okara were the most satisfactory to consumers. The protein and dietary fiber content of the respective biscuits sample was 8.72% and 5.98%, respectively. Microbiologically, cookies have been preserved well for a period of 1 month. Genta et al. (2002) utilized okara to produce soy candy in order to increase the supply of soy protein in the human diet. They found that the lowest level of okara (18.3 g/100 g of formulation) was the most suitable and preferred by the judges. However, the unwanted flavor of okara, called the “beany” flavor in their research, was a major challenge for the production of okara-based food products. This unwanted beany taste or odor results from the oxidation of unsaturated fatty acids by lipoxygenase enzymes during the production of soy protein products. Waliszewski et al. (2002) analyzed nixtamalized corn tortillas supplemented by dried okara to determine the concentration of amino acids and sensory changes at various levels of fortification. Due to the unpleasant taste from okara, increased levels of okara fortification were considered to be inappropriate by their professional panelists. They observed the non-significant difference between traditional maize tortillas and okara-enriched tortillas with up to 10% okara fortification in maize flour. Corn tortillas fortified with 10% okara reported to have high lysine and tryptophan content and also met more than 90% of Food and Agriculture Organization requirements. Bread made by the fortification of wheat flour by 10% okara powder had nearly the same sensory and physicochemical properties as normal bread, whereas a considerable difference was found between the crust color of the white bread (control) and the okara-fortified sample. The caloric content of the bread supplemented by 10% okara (15.9 kJ/g) was greater than that of the control (14.4 kJ/g), which might be correlated with higher fat and protein percentage of okara (Wickramarathna & Arampath, 2003).

Katayama and Wilson (2008) formulated a new soybean-based snack by using a commercially dried okara powder (7.7% moisture) prepared from regular (lipoxygenase-present) soybeans and a partially dried okara (44.3% moisture) made of lipoxygenase-free soybeans. They also utilized commercially low saturated soybean oil and commercially low linolenic acid soybean oil in the same recipe to compare and discover the best recipe for deep-fried or a baked soy-based food product. The results indicated that the baked foods, prepared from commercially low-saturated soybean oil and partially dried okara-free lipoxygenase powder, had a taste, texture, and appearance similar to the reference product (commercial Japanese okara-based snack). The final product had 7.4% dietary fiber and 11.4% protein, which was 1.5 and 2.0 times higher than the standard. The amount of calcium was also 4.3 times higher than the reference score. Park et al. (2015) investigated the effect of okara and additives such as starch, soy flour, and hydroxypropyl methylcellulose (HPMC) on the quality characteristics of cookies. The results showed that okara-enriched cookies had higher levels of carbohydrate (35.3%), protein (11.6%), fat (25.7%), and ash (6.3%) compared with wheat cookies containing 59.6% carbohydrate, 15.2% protein, 20.2% fat, and 2.2% ash. Okara cookies revealed lower carbohydrate and higher ash content. The HPMC-supplemented cookies had a water holding capacity three times higher than that of control, which improved the dough performance and the quality of enriched cookies. Cookies containing additives, in particular, soy flour and HPMC, had reduced water activity, which improved the storage life and hardness along with significant improvement in the crispness of okara cookies. Kang et al. (2018) studied the quality attributes of noodles produced by fortifying rice with different levels of okara flour (0–20%). Hardness, adhesiveness, and cooking loss of the rice noodles increase with an increasing level of okara, whereas swelling index, water absorption, and cohesiveness score decrease significantly. Among all samples, noodles enriched with 10% okara flour revealed the lowest score for predicted GI. The incorporation of alginate with a CaCl2 coating improved the cooking properties without affecting the IVSD of okara-enriched rice noodles. The results suggested that noodles with good quality attributes and reduced IVSD scores could be developed by incorporating the okara flour up to 10% level.

Pan et al. (2018) investigated the influence of incorporation of okara powder on the rheological, antioxidant potential, and sensory...
quality of the noodles. The results displayed that a higher level of okara (10–15%) significantly reduced the extensibility, elasticity, tensile strength, and optimum cooking time of the noodles. Okara-enriched noodles reported improved total phenolic content, flavonoids, and antioxidant activity or free radical-scavenging activity. The results indicated that 5–10% okara powder and 6% vital wheat gluten addition produces noodles with good cooking texture, and sensory properties. Kamble et al. (2019) studied the physicochemical attributes, IVPD, and GI of microwave-processed pasta made by replacement of durum wheat with various levels of okara flour (10–50%). The results indicated that total phenolic content (158.37 to 232.90 mg GAE/100 g) and antioxidant activity (10.87 to 56.21%) improved significantly by replacement of okara up to 50% level. The GI of okara-enriched pasta (12.38) was significantly lower compared with durum wheat pasta (27.41). All these studies have shown that okara has an immense potential to be commercialized at an industrial level for nutritionally enhanced value added food products.

7 | CONCLUSION

The current review reports on chemical composition, in vitro digestibility, structural attributes, and possible application of okara, which is the by-product obtained during soymilk processing. The desirable functionality of okara protein and starch makes them commercially suitable. A literature survey shows that okara has a high nutritional value and can be used in the food sector to partially replace traditional flour in order to improve the fiber and protein content of food products. The hypoglycemic effect of okara indicates it can be used to make functional food that has the ability to provide a variety of health benefits. From the information currently available, we infer that okara has an immense potential to be integrated into a variety of food products due to its high nutritional and biological value.

CONFLICT OF INTEREST

There is no conflict of interest between the authors.

DATA AVAILABILITY STATEMENT:

None.

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How to cite this article: Kamble DB, Rani S. Bioactive components, in vitro digestibility, microstructure and application of soybean residue (okara): a review. Legume Science. 2020;2:e32. https://doi.org/10.1002/leg3.32