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REVIEW ARTICLE

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A review of okara (soybean curd residue) utilization as animal feed: Nutritive value and animal performance aspects

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Abstract

Year by year, huge quantities of by-products are generated during the manufacturing process of soybean-based products. Okara is one of the by-products, and it is an insoluble portion of the soybean. It consists of high moisture (8.4–22.9%); on dry matter basis, it contains high metabolizable energy (9.0–14.2 MJ/kg) and other components that include crude protein (20.9–39.1%), crude fiber (12.2–61.3%), crude fat (4.9–21.5%), and ash (3.4–5.3%). Fermentation of okara improves its nutritional quality and reduces its anti-nutrient contents. Due to animals' palatability, okara can be used to replace the soybean meal/concentrate feed partially or completely in ruminant's diet and partially in nonruminant's diet. Okara feeding does not depress the intake, digestibility, growth, milk production, blood metabolic profiles, and meat quality of animals. However, this by-product decays quickly due to its high moisture content, and its heavy weight and sticky nature make it difficult to process and expensive to dry using conventional methods. This paper thoroughly summarizes the utilization of okara as animal feed in the cause of developing a general guideline with favorable levels of inclusion in the diets of animals for its exploitation and valorization. This review will encourage further research to develop eco-friendly and value added feed for animals.

KEYWORDS
animal performance, anti-nutrients, chemical composition, fermentation, okara

1 | INTRODUCTION

Feed shortage in developing countries is a main concern for the development of the animal industry, and this shortage is expected to increase year by year. To overcome the feed problems, farmers frequently use locally available alternative feed sources, such as agro-industrial by-products. Due to the increasing trend in human population, the amount of by-products will continue to increase in the future. These by-products may have little value as human food, but they can be extensively fed to animals. Okara is a household and agro-industrial by-product, the left over that remains after the making of soya products such as soymilk and tofu. It is a white or yellowish pulp consisting insoluble portion (shell, hull, or husk) of soybean. Furthermore, it has many synonyms, depending on the usage or context, such as soya waste, draff, tofukasu, soy pulp, soybean curd residue, ampas tahu (Malaysian/Indonesian), douzha (Chinese), bejee (Korean), soybean-curd lees, sapal (Filipino), tempe gembus, or tofu cake (Amaha et al., 1996; Faisal et al., 2016; O'Toole, 1999).

About 0.8, 2.8, 0.01, and 14 million metric tons of okara are disposed annually for making soymilk and tofu in Japan, China, Singapore and worldwide, respectively (Boh, 2017; Choi et al., 2015; Li et al., 2013). Grizotto et al. (2010) estimated that about 7 metric tons of soymilk and 2 metric tons of okara are generated from 1 metric ton of soybeans. A significant amount of water is needed for tofu processing which results in a greater amount of okara and liquid waste (Amaha et al., 1996). As a result, okara contains a significant amount of water (77.7%), as well as water-insoluble components (protein, fiber, fat and mineral), which makes it susceptible to spoilage (Harthan & Cherney, 2017; Rahman et al., 2015; Vong & Liu, 2016). In addition, okara is difficult to handle and transport due to its high moisture and sticky nature.

Those not knowing how to utilize okara accordingly burn the resource as fuel, dump it inside landfills or throw it in rivers which contribute to environmental pollution due to its rapid putrefaction. A lot of money is put aside for disposing okara; in Japan, the cost of okara disposal is about 16 billion yen per annum (Muroyama et al., 2006). The proper method of using this by-product is by using it in huge quantities (45%) as livestock feed, especially for pigs and dairy cows (Fibria, 2007; Gupta et al., 2018; Sinha et al., 2013; Wlek & Zollitsch, 2004), and fertilizer, while relatively small amount (5%) as human food. Due to its quick putrefaction and high cost of drying, a significant portion (50%) of okara is directly destroyed by incineration or dumped in landfills (Corp, 2020; Pan et al., 2018; Sugiura et al., 2009; Vong & Liu, 2016).

The aim of this review paper is to focus on the chemical composition of okara and its proper utilization as animal feed to evaluate the feeding effect on the animal performance especially in terms of feed intake, digestibility, growth, milk production, reproduction, and meat quality.

2 | PROCESS OF OBTAINING OKARA FROM SOYBEANS

Soybeans can be processed by these steps: (1) washing; (2) dipping; (3) milling; (4) boiling; (5) filtration; and (6) residue from filtration treated with hot water gives soybean milk and okara. Coagulant is then added to the soybean milk to give tofu and waste water (liquid waste) (Amaha et al., 1996); thus, okara is generated along the process.

3 | POTENTIAL INTERESTS

Soybean-based products are being increasingly consumed worldwide due to its health benefits for humans. Proper utilization of okara will lead to mutual benefits between farmers and manufacturers, since it provides good nutrients for animal consumption and usage of okara in this way eliminates disposal problem, reducing environmental pollution. For the purpose of reducing the environmental impacts resulting from residue generation, animal scientists and food technologists are looking for alternatives to the use of agro-industrial by-products as a source of nutrients (Guimaraes et al., 2018; Rahman et al., 2020). Okara has an immense potential to be used as animal feed, fertilizer, and human foods due to its high nutritional and biological value. While using okara as an animal feed, there are several benefits: (i) reduce environmental pollution, (ii) promote a more sustainable production system, (iii) provide with increased availability of nutritious feedstuffs for livestock, (iv) reduce human competition for feed by reducing the amount of feedgrains fed to livestock, and (v) help to keep the cost of livestock products low.

4 | PRESENTATION FORM AND POTENTIAL WAYS OF PROCESSING

It is difficult to preserve the fresh wet okara due to its high moisture content (70%–85%) (Li et al., 2013; Thakur et al., 2016). Due to high moisture content, its shelf-life under aerobic condition is very short. Hence, wet okara should be fed to the animals as soon as possible and should not be kept more than 3 days. Otherwise, undesirable microorganisms such as mold and fungus can grow in it, which may cause an unpleasant odor. To overcome this problem, any of the following methods may be chosen to store the okara longer:

a. Dry the okara using sunlight. The disadvantage of this is that the okara may take longer periods to dry if the hours of sunlight in a day are short, and that there is a risk of okara rotting if there is no sufficient amount of sunlight hours. Moreover, if rains are frequent and insects are abundant, it is not feasible to propose sun-drying. A countermeasure against this is by speeding up the drying process by mixing wet okara with dry feed ingredients like rice bran.
b. Preserve it by making of silage. The best method of doing this is to sundry it or mix it with other dry feed ingredients before making it into silage, as this can reduce the moisture content of the okara up to 75%, and then storing it in an air-tight silo for at least 21 days. The benefit of using this method is that okara will not have to be delivered frequently to farms in fear of the okara rotting and, therefore, being rendered useless. Ensiling may be a practical alternative and it can improve the nutritive value of okara.
c. Preserve it in a freezer (0% to −20°C) to inhibit the growth of pathogenic microorganisms.
d. Dry (>85% dry matter) it in an oven at a low temperature or in a vacuum freeze. The available drying methods include the jet-spouted bed of sorbent particles method (Wachiraphansakul & Devahastin, 2007), air jet impingement drying (Wang et al., 2016), convective drying (Perussello et al., 2009), and flash drying (Grizotto & de Aguirre, 2011). Drying temperature should be about 55°C to stimulate enzymatic hydrolysis with the pH of okara maintained at 9.0 (Hui & Biani, 2018). Thus, dry okara with minimum moisture content (14–22%) can be achieved using appropriate drying methods. However, drying in an oven is hard to access, if use of okara is focused on soybean processing countries, in low developed systems.

The above mentioned drying methods require special equipment and high energy, which may be considered uneconomic and unfeasible (Redondo-Cuenca et al., 2008). Moreover, its flavor, color and aroma may also be altered. Thus, more studies are needed to find out the most appropriate drying methods that will both reduce okara's moisture and avoid any alteration in its flavor, color and aroma.

5 | POSSIBLE FORMS OF UTILIZATION

Okara can be fed to animals as fresh, dried, and ensiled forms. It can be used as a sole source of concentrate or incorporated with other feed ingredients such as corn, rice bran and forage crops when being fed to animals (Rahman et al., 2015; Rahman et al., 2020). Due to the sticky nature of okara, there is a possibility of it sticking in the holes of the feeder, which will enable the growth of pathogenic microorganisms, and which will ultimately cause detrimental effects on animal health. Therefore, special attention should be taken when cleaning the feeder where wet or ensiled okara was placed.

6 | NUTRITIVE VALUES

Okara serves as a source of both energy and protein for livestock, which is either fed alone or mixed with other feed ingredients to make a complete supplement. The composition of okara may vary widely based on different processing methods (Li et al., 2013). Due to the several steps of processing as mentioned above, a significant amount of okara and liquid waste can be generated from the soybean processing factories. Although the liquid waste contains very high organic substances, there still remains a high level of nutrients in okara after the filtration. Okara is high in fiber because it is composed mainly of ruptured cotyledon cells and outer layer of the seed. Liquid waste is generally discharged into the river without any treatment, while okara is used for various purposes due to the following nutritional properties:

6.1 | Dry matter

As shown in Table 1, okara contains low levels of dry matter (DM) ranging from 8.4% to 22.9%, since making of soya products from soybean is involved in filtration process with water, and the ratio of water and soybean is usually between 8:1 and 10:1 (Liu, 1997). Apparently, a major problem of utilization of this by-product is its high water content, which limits handling, preservation, feeder's maintenance and even intake.

6.2 | Crude protein

As shown in Table 1, okara contains significant amount of crude protein (CP) with ranges of 15.2% to 39.1% on a DM basis. Li et al. (2013) also mentioned that the CP content in okara ranged from

TABLE 1 Chemical composition (%) of okara

Dry matter	Crude protein[a]	Crude fiber[a]	Ash[a]	Ether extract[a]	NDF[a]	References
22.9	23.3	-	3.7	-	37.4	Rahman et al. (2020)
-	34.5	15.0	3.9	11.3	-	Alabi et al. (2018)
-	23.1	26.3	4.4	-	72.6	Thakur et al. (2018)
22.3	39.1	-	-	-	31.9	Harthan and Cherney (2017)
-	35.6	-	-	21.5	12.7	Diaz-Vargas et al. (2016)
-	15.2–33.4	42.4–58.1	3.0–4.5	8.3–10.9	-	Vong and Liu (2016)
19.9	33.0	20.4	4.0	9.6	-	Nagamine et al. (2015)
22.3	22.0	-	3.4	-	27.8	Rahman et al. (2015)
22.0	22.0	-	-	-	30.5	Rahman, Abdullah, et al. (2014)
22.3	28.0	-	5.3	-	24.1	Rahman, Nakawaga, et al. (2014)
-	36.8	12.1	5.2	10.8	-	Motawe et al. (2012)
15.5	27.1	22.7	3.5	9.7	-	Fafaungwithayakul et al. (2011)
-	25.5	12.2	4.0	12.0	-	Rashad et al. (2011)
-	33.4	54.3	3.7	8.5	-	Mateos-Aparicio et al. (2010)
-	28.5	55.5	3.6	9.8	-	Redondo-Cuenca et al. (2008)
15.0	24.0	61.3	-	9.3	-	Zhu et al. (2008)
-	25.0	33.0	-	20.0	-	Suruga et al. (2011)
16.1	28.0	-	4.3	16.1	-	Turhan et al. (2007)
8.4	23.8	-	4.3	4.9	32.2	Dong et al. (2005)
17.8	30.5	-	-	10.9	-	Kwak and Yoon (2003)
20.0	25.0–29.0	-	-	-	30.0	O'Toole (1999)
-	34.0	22.5	3.8	12.7	-	Farahat et al. (1998)

Abbreviation: NDF, neutral detergent fiber.
[a]On a dry matter basis.

16.0%–33.4%. This variation might have occurred due to the use of different amounts of water for extraction process, which affects the amount of soluble protein portions being washed away with the liquid waste. Soybean meal has been applied as a protein source for livestock and poultry worldwide because it contains significant amount (45%) of CP.

Due to farmers feeding soybean meal to both ruminants and nonruminants, the feed price of soybean meal is increasing because of its high demand. Soybean meal can be replaced with okara for ruminants, which will decrease the demand for soybean meal and find usefulness for okara. According to NRC (1996), ruminants require more than 7.0% CP in their diet for normal ruminal microbial activity. Inadequate CP levels may cause reduced growth of ruminal microorganism and subsequently low productivity of the animal.

Many farmers in developing countries offer low quality forage like Napier grass (*Pennisetum purpureum*) (<7.0% CP) to ruminants which does not fulfill the protein requirement of ruminants. If protein is not supplemented properly, animals will not be able to perform optimal productivity levels. Fortunately, low quality forage with supplementation of okara has the ability to solve this problem (Rahman et al., 2015; Rahman et al., 2020).

Amino acid composition (mg/g of protein) of okara is shown in Table 2 as reported by Colletti et al. (2020). One disadvantage of okara is that methionine and cysteine are found scarcely in it as reported by Ma et al. (1996). This by-product also contains lower lysine content than soybean meal (Kim et al., 2012). The biggest difference between okara and soybean meal is tryptophan. Tryptophan is about 55.5% less found in okara compared to soybean meal (Diaz-Vargas et al., 2016). For nonruminants, careful attention should be taken for their ration formulation (if okara is used) since they cannot synthesize amino acids by their body mechanism.

Waliszewski et al. (2002) reported that the ratio of essential amino acids to total amino acids is similar among soybean milk, okara and bean curd. As shown in Table 3, fermentation using probiotics can enhance okara's nutrient values, especially in the increase of amino acids (Rashad et al., 2011; Tian et al., 2020).

6.3 | Fiber

As shown in Table 1, okara has high and extremely variable proportions of crude fiber (CF) with a range of 12.1 to 61.3% and neutral detergent fiber (NDF) with a range of 12.7%–72.6% on a DM basis. The variability is so high that makes doubts about the possibility of being the same product; however, this may have occurred due to the use of various processing methods by soybean manufacturers.

Soluble fibers of okara can be increased using different processes such as fermentation, chemical/enzymatic treatment, high pressure, extrusion, etc. Various processing techniques can increase the nutrients of the insoluble portion of the okara and enhance its palatability prior to being fed to animals. Because of its high fiber content, the inclusion of okara in poultry diet should be limited so as to prevent the animals (under the poultry section) from getting an inadequate diet. This high fiber content can be partially degraded in ruminants due to the presence of rumen microorganism. Dong et al. (2005) reported that okara contains much more fiber than soybean meal. Feeding of okara to ruminants will contribute to decreasing of the competition of soybean meal purchasing between ruminant farmers

TABLE 2 Amino acid composition (mg/g of protein) of okara (Colletti et al., 2020)

Amino acids	Content
Aspartic acid	117
Threonine	41
Serine	50
Glutamic acid	195
Glycine	46
Alanine	46
Cysteine + methionine	26
Valine	51
Isoleucine	51
Leucine	81
Tyrosine + phenylalanine	95
Lysine	65
Histidine	28
Arginine	75
Proline	36
Tryptophan	Not determined

TABLE 3 Effect of fermentation with probiotics on free amino acid composition (mg/100 g) in okara (Tian et al., 2020)

Composition	Unfermented okara	Fermented okara
Aspartic acid	0.49	0.68
Threonine	0.22	0.33
Serine	0.28	0.40
Glutamic acid	0.68	1.17
Glycine	0.14	0.20
Alanine	0.28	0.55
Valine	0.25	0.34
Cysteine	2.31	3.32
Isoleucine	0.11	0.22
Leucine	0.35	0.68
Tyrosine	0.16	0.30
Phenylalanine	0.25	0.39
Lysine	0.29	0.30
Histidine	0.38	0.41
Arginine	0.44	0.51
Proline	0.32	0.52
Total free amino acids	6.26	10.42

and poultry farmers, and which may lead to the reduction of the price soybean meal.

6.4 | Ether extract

As shown in Table 1, okara contains a significant amount of crude fat, that being a range from 4.9% to 21.5% of DM. Mateos-Aparicio et al. (2010) reported that the fatty acids in okara mostly consists of linoleic acid, oleic acid, palmitic acid, α-linolenic acid and stearic acid, which represents 54.1%, 20.4%, 12.3%, 8.8%, and 4.7% of total fatty acids, respectively. The content of fat in okara is quite high and variable, which may limit inclusion of okara in ruminant diet, since more than 70 g fat/kg DM intake may depress fiber digestion and affect ruminant animal metabolism (Palmquist, 1994).

6.5 | Minerals

As shown in Table 1, okara contains crude ash with a range between 3.4% and 5.3%. Vong and Liu (2016) reported that okara contained various types of minerals (Table 4). The concentrations of calcium (Ca) were 0.26%–0.43% (Vong & Liu, 2016), and the concentrations of Ca and phosphorus (P) were 0.7% and 0.6%, respectively, on a DM basis (Marlina & Askar, 2004). In contrast, Harthan and Cherney (2017) reported that okara contains 2.3% Ca and 4.6% P. Dong et al. (2005) reported that okara contains higher Ca content (1.2%) than that in soybean meal (0.4%), while soybean meal contains higher ash (7.4%) and P (0.9%) than that in okara (4.3% and 0.9%, respectively).

6.6 | Metabolizable energy

For ruminants, the energy value of total mixed ration is to be ranged from 8.2 to 11.9 MJ/kg of DM for metabolizable energy (ME) (Van Es, 1978). Okara contains reasonably high ME contents with values of 14.2 (Hermann & Honeyman, 2004), 11.2 (Dong et al., 2005), 12.3 (Diaz-Vargas et al., 2016), and 14.2 (Sinha et al., 2013) MJ/kg of DM, which can fulfill the energy requirement for most ruminants. Motawe et al. (2012) reported that okara contains slightly lower ME than that in soybean meal (9.0 vs. 9.3 MJ/kg of DM, respectively).

TABLE 4 Mineral composition (mg/100 g on a dry matter basis) of okara (Vong & Liu, 2016)

Minerals	Content
Potassium	936–1,350
Sodium	16–96
Calcium	260–428
Magnesium	130–165
Iron	0.6–11
Copper	0.1–1.2
Manganese	0.2–3.1
Zinc	0.3–3.5

6.7 | Anti-nutrients

Raw soybean contains anti-nutrients including trypsin inhibitors, phytic acid, saponin, hemagglutinin and isoflavones (Li et al., 2013), but these contents can be reduced by processing methods such as soaking and grinding, which will make the soybean safe to be fed to animals (Rahman et al., 2020; Stanojevic et al., 2013). These anti-nutrients can be partially inactivated by heat, or eliminated through the various steps of the manufacturing process (i.e., soaking, grinding, and filtration) (Friedman & Brandon, 2001). Anti-nutrients in okara can also be inactivated significantly by fermentation (Mukherjee et al., 2016; O'Toole, 1999).

Rumen microbiota is able to degrade phytic acid, but it is unsuitable for monogastric (pigs and poultry) animals. Thus, emphasis on phytic acid is important in feed for nonruminants. The undigested phytate that ends up in the excrements of the animals will lead to the run-off of P into aquatic ecosystems, which consequently contributes to severe pollution risks (Brinch-Pedersen et al., 2014).

There were no detrimental effects on blood metabolite parameters and animal health from okara-feeding after summarizing the results in Tables 5 and 6. However, Nagamine et al. (2015) gives a contrasting report that there are problems in goat kids (problem: goiter) and female goats (problems: parturient paresis, premature birth and still birth) after being fed a mixture of okara and hay; nevertheless, this report does not have much strong evidence as they did not actually conduct an experiment regarding this matter.

7 | PRESERVATION FORM AND PROCESSING WAY AFFECTING THE NUTRITIVE VALUES, INTAKE, AND DIGESTIBILITY

7.1 | Ensiling form

Enisling process alters the chemical composition of okara, which can enhance its palatability, flavor, and nutritive values, especially in the case of polysaccharides, lactic acid and amino acid (Giang et al., 2012; Li et al., 2016; Mok et al., 2019; Quintana et al., 2017). Due to the subtle flavor and savory taste of okara, it can increase the palatability of the feed. Preservation form and processing way of okara affecting its nutritive values and animal performances are shown in Figure 1. Ensiling process can acidify the okara materials by the action of anaerobic microorganisms, and thus extend its shelf life. During the fermentation process, microorganisms degrade the fiber partially to form volatile fatty acids, such as lactic, acetic and butyric acids (Cao et al., 2009). Moreover, microbial fermentation can reduce toxicity of some anti-nutritional factors including trypsin inhibitors (Mukherjee et al., 2016); this can produce beneficial metabolites including

TABLE 5 Performance of ruminants fed okara as affected by different species and dietary treatments

Species	Treatment	Preservation form and processing way	Results	References
Cow/steer	Diet including okara	Corn grain ensiled with 30% okara, which was added into diet at 20.88%.	Resulted in benefits in digestibility and ruminal fermentation characteristics.	Tres, Jobim, Diaz, et al. (2020)
		Corn grain ensiled with 30% okara, which was added into diet at 32%.	Reduced intake and increased digestibility, but no adverse effects on milk production and composition.	Tres, Jobim, Rossi, et al. (2020)
	Replace soybean meal with okara	Total mixed ration included 15% dried okara meal.	Maintained performance and appeared to improve N use efficiency.	Santana et al. (2016)
	Replace soya by-products with okara	Soybean cake and full fat soya in concentrate mixture replaced with dried okara at 0%, 10%, 20%, and 30%.	(i) no adverse effects on palatability, blood metabolites, milk fat, SNF and TS contents. (ii) improved milk production.	Thakur et al. (2015); Thakur et al. (2018)
	Diet including okara	Total mixed ration included fresh okara at 10%, 20%, 25%, 30%, and 35%.	Enhanced intake, weight gain, feed efficiency, carcass weight and meat quality.	Kim et al. (2012)
	Replace soybean meal with okara	Diet contained 12% dried okara.	No adverse effects on milk yield, milk fat% and concentrate consumption.	Wang et al. (2003)
Goat	Replace soybean meal with okara	Concentrate mixtures contained fresh okara at 0%, 28%, and 56%.	(i) no adverse effects on intake, digestibility, FCR and growth. (ii) increased intake and digestibility of NDF.	Rahman et al. (2020)
	Diet including commercial pellet or okara	Goats were fed fresh okara at 2.0% of BW/day.	(i) no effects on performance or carcass traits. (ii) kids fed okara showed higher grass and NDF intakes, digestibility (except CP), lean, lean to fat ratio and kidneys weight than those fed pellet.	Rahman et al. (2016)
	Diet including okara	Goats were fed fresh okara at 0.5%, 1.0%, and 2.0% of BW/day.	No adverse effects on intake, weight gain and reproduction.	Rahman et al. (2015)
	Diet with commercial pellet or okara	Goats were fed fresh okara at 0.8% of BW/day.	Resulted lower intakes of DM and OM, and lower FCR than those fed pellet, but had similar growth.	Rahman, Abdullah, et al. (2014)
	Replace commercial protein with okara	Animals were grazed and fed concentrate mixture (80% commercial feed + 20% oven-dried okara) at 1.5% of their BW.	No adverse effects on intake, weight gain, hip height gain and girth circumference gain.	Ramsey et al. (2011)
	Replace groundnut, corn bran and wheat offal with okara	Groundnut cake, corn bran and wheat offal in goat's diets were replaced with air dried okara (up to 35%).	No adverse effects on blood profiles and carcass traits.	Olubunmi et al. (2005)
			Resulted higher intake and digestibility than control diet, but no effect on weight gain.	Odeyinka et al. (2003)

(Continues)

TABLE 5 (Continued)

Species	Treatment	Preservation form and processing way	Results	References
Sheep	Diets including with or without okara	Wet okara was stored in cooler at −1 to 4.4°C; then mixed with diets at 54.5% and 86.0%.	No adverse effects on weight gain and milk composition.	Harthan and Cherney (2017)
	Diet containing ensiled okara	Diets included 20% okara (either fresh okara or ensiled okara).	Increased glucogenic propionate contents in rumen without any adverse effects on ruminal fermentation.	Xu et al. (2001)
	Replace concentrate with okara silage	Diet contained 80% hay and 20% okara silage (okara silage containing 15% beet pulp).	(i) Resulted a positive N balance and found similar plasma amino acid and glucose kinetics. (ii) No effect on VFA contents in rumen, while propionate content was higher in sheep fed okara.	Harjanti et al. (2012)

Abbreviations: N, nitrogen; BW, body weight; CP, crude protein; OM, organic matter; FCR, feed conversion ratio; SNF, solids-not-fat; TS, total solids; VFA, volatile fatty acids.

prebiotics and digestive enzymes (Mok et al., 2019), resulting in enhanced immunity and digestion-physiological function in animals. Additionally, Zhou et al. (2019) also found a positive result which showed that fermented okara had a prebiotic function and could increase short chain fatty acids.

The nutritive value of okara can be increased by fermentation using specific yeasts or microorganisms. For example, Rashad et al. (2011) observed that antioxidant activities of okara were increased by solid yeast fermentation. Fermented okara using *Bacillus subtilis* can enhance cellulase and xylanase enzymes (Mok et al., 2019), whereas, using *Lactobacillus plantarum* can enhance the unsaturated and saturated fatty acids ratio (Quintana et al., 2017). Sitanggang et al. (2020) also reported that fermentation of okara using *R. oligosporus* or *A. oryzae* could improve its antioxidant activity, protein content and protein digestibility. Total phenolic compounds and total amino acids of fermented okara can be increased 4 and 20 times higher than the unfermented okara, respectively (Shi et al., 2013), when okara was fermented by *G. lucidum*. Ensiling process improves peptide bond cleavage resulting in more free amino acids, thereby increasing the protein digestibility (O'Toole, 1999).

Wang and Nishino (2008) observed a low level of lactic acid production (0.22%) when okara was ensiled alone, which indicates that okara is better preserved when ensiled with other feed ingredients. Yang (2005) reported that okara ensiled with peanut hulls (78:22) after 8 weeks of fermentation had a beneficial effect on both in-vitro ruminal fermentation and ideal silage characteristics due to decrease of fiber content and lignification. Okara ensiled with 15% beet pulp showed good silage characteristics such as low pH and high lactic acid content (Harjanti et al., 2012).

Although the inclusion of okara (fresh or dry) in diets showed higher intake and digestibility than those without okara (Rahman et al., 2015, 2016; Rostagno et al., 2011; Thakur et al., 2015), there are still limited data on how the ensiled okara influences these parameters. We inferred that ensiled okara can improve the intake and digestibility because of the presence of readily available free amino acids, small peptide and low content of anti-nutritional factors resulted by microbial fermentation.

7.2 | Dry form

Fresh okara can be dried at ambient temperature or using an oven. The nutritional values of okara may not be increased by drying process, unlike ensiling process; however, both processes can extend its shelf life. As expected, total viable bacteria, yeasts and molds counts of wet Okara were significantly higher than dried Okara (Sengupta et al., 2012).

The digestibility of crude protein, amino acids and lipids in okara is higher than that of soybean (Rostagno et al., 2011). They reported that digestibility of CP in okara was higher (99.6%) than that of soybean meal (91.0%). Protein content, protein efficiency coefficient, and essential amino acids of okara are usually higher than those of other soybean-based products, which may be related to the heat process

TABLE 6 Performance of nonruminants fed okara as affected by different species and dietary treatments

Species	Treatment	Preservation form and processing way	Results	References
Chicken	Replace groundnut cake with okara and addition of enzyme in diet	In broiler chick diets, groundnut cake was replaced with dried okara at 25% and 50%. Nonstarch polysaccharides degrading enzyme @ 50 g per 100 kg added into the diets.	No adverse effects on weight gain under 25% replacement of ground nut cake with okara meal and addition of non-starch polysaccharides degrading enzyme.	Sinha et al. (2013)
	Replace soybean meal with okara up to 100%	Diets included dried okara at 0%, 6%, 12%, 18%, and 24%.	No adverse effects on performance, digestibility and economics, when soybean meal replaced with okara up to 75%.	Motawe et al. (2012)
	Diets including different levels of okara	Dried okara was substituted commercial layer diet at 0%, 10%, and 20% levels.	(i) Intake and growth of hen decreased with increased okara in diet, but egg production, weight and quality were not affected. (ii) recommended to include okara up to 10% in hen's diet.	Tarachai et al. (1999)
	Diets including different levels of okara in broiler chicks diet	Okara was dried at ambient temperature, milled and added in starter broiler diets at 0%, 2.5%, 5.0%, 7.5%, and 10.0%.	(i) Reduced intake and weight gain from 1 to 21 day of age. (ii) no adverse effects on FCR, carcass, breast, drumstick, and thigh yields at 42 day of age.	Diaz-Vargas et al. (2016)
Duck	Diet including okara	Diets with fresh okara at ad libitum.	(i) no adverse effects on performance, when replaced 60% soybean meal with fresh okara. (ii) resulted the lowest feed cost, when replaced 100% soybean meal with fresh okara. (iii) appeared healthy and good appetites.	Dong et al. (2005)
Quail	Replace ground nut cake with okara	Groundnut cake was replaced in quail's diet with dried okara meal at 0%, 25%, 50%, and 75%.	Replacement of 50% okara in diet was considered optimum as there was depression in performance beyond this level.	Mahto et al. (2017)
Pig	Replace partial corn-soybean meal with probiotics—Fermented okara	Okara with 60%–70% moisture fermented anaerobically using *S. cerevisiae*, *B. subtilis*, and *L. plantarum* (1:1:1 ratio) for 8 days. Diet included 36.6% fermented okara (as fed-basis).	(i) Improved growth, meat colour and antioxidant capacity. (ii) improved eating quality of pork by increasing intramuscular fat.	Tian et al. (2020)
	Diet including okara	Diets included sun-dried okara at 0%, 5%, 10%, and 15%.	No adverse effects on growth, carcass, blood biochemical and hematological parameters.	Abora (2013)
	Diet including dry okara	Diets contained dried okara at 0%, 15%, and 30%.	Reduced meat quality, especially juiciness.	Shidara et al. (2005)
	Diets including okara	Diets included dried okara (initially pelleted form and then ground) at 0%, 25%, and 50%.	No reduction in weight gain, intake and FCR, when pigs fed okara up to 25% in diet.	Hermann and Honeyman (2004)
Rabbit	Replace soybean meal with okara	Dried okara was added to rabbit's diets at 0%, 5%, and 10%.	No adverse effects on consumption, health, growth and carcass yield.	Alabi et al. (2018)
	Replace maize and groundnut cake with okara	Groundnut cake (5%) and maize (15.5%) in diets were replaced with air dried okara (20%).	No adverse effect on intake, weight gain and dressing percentage.	Odeyinka et al. (2007)

(Continues)

TABLE 6 (Continued)

Species	Treatment	Preservation form and processing way	Results	References
Dog	Feeding of dried okara-tempeh	Vinegar was added to fresh okara, inoculated with ragi tempeh, wrapped, incubated; and fermented okara dried in oven. Dried okara-tempeh was given to dog.	Effective for improving fecal environment.	Yogo et al. (2011)
Hamster	High-fat diets supplemented with okara	Diet was supplemented with 13% or 20% of dietary fiber from freeze-dried okara.	(i) no adverse effect on intake and weight gain. (ii) reduced total lipids and cholesterol in plasma and liver.	Villanueva et al. (2011)
Rat	Diet including okara	Diet included 5% dried and milled okara.	Decreased total cholesterol, LDL and HDL cholesterols of rats.	Eze et al. (2014)
Fish	Replace fish meal with okara	Fish meal in pelletized diets was replaced with dried okara at 0%, 25%, 50%, 75%, and 100%.	No adverse effects on growth, feed efficiency, protein utilization, survival rate and body composition of fish.	Ahmad and Diab (2008)
	Diet including fermented okara	Okara was fermented with 0.001% *Lactobacillus* sp. and 10% molasses for 3 weeks and sun-dried. Dried fermented okara was added to fish feed as pellet form (32% crude protein) at 0%, 25%, 50%, and 100%.	Diet containing 50% fermented okara showed better growth and health of African catfish.	Zulhisyam et al. (2020)

Abbreviations: FCR, feed conversion ratio; LDL, low density lipoprotein; HDL, high density lipoprotein.

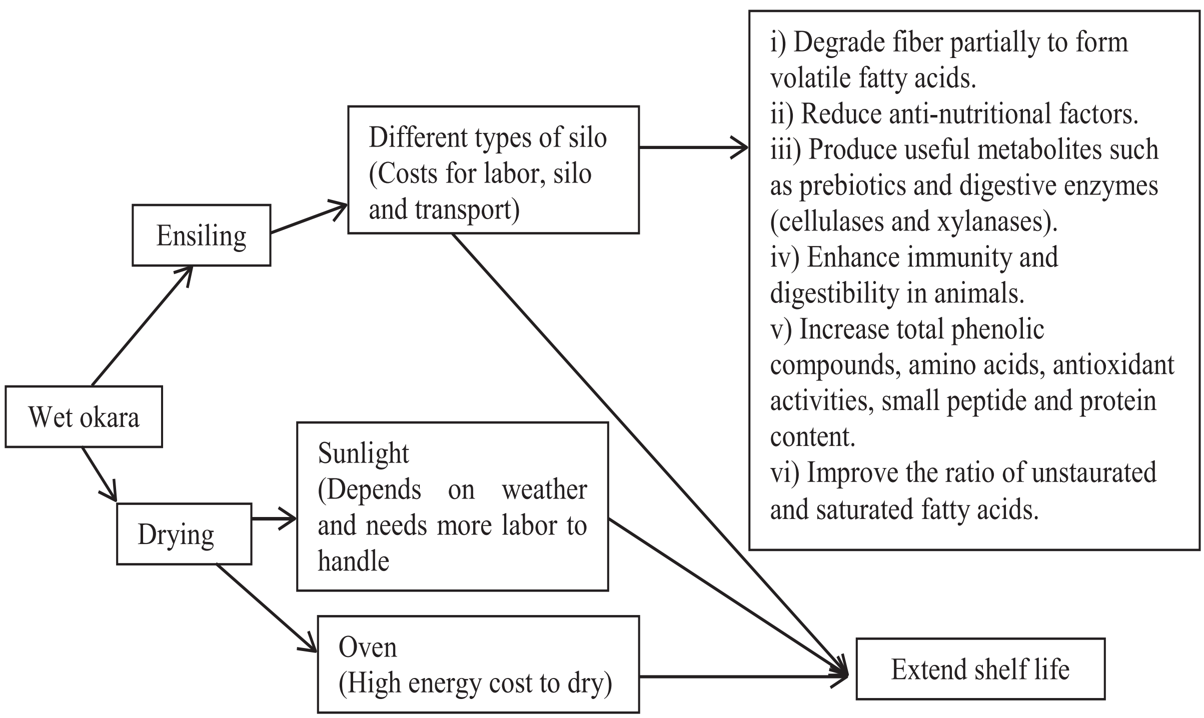

FIGURE 1 Preservation form and processing way of okara affect its nutritive values and animal performance

that soybean undergoes during processing of the soybean aqueous extract.

Due to the high fiber content, significant amount of okara can be included in ruminant's diet (Rahman et al., 2015), but limited amount in nonruminant's diet (Diaz-Vargas et al., 2016; Motawe et al., 2012). Replacement (25%–75%) of soybean meal with dry okara in the diet will not affect feed intake or mortality, and achieve comparable daily body weight gains, to 100% soya diets. Overfeeding okara could decrease feed intake and performance of nonruminants due to the high fiber content (Motawe et al., 2012). Dried okara can be included up to 10% in broiler diet without any adverse effects on performance, carcass yield, or blood parameters (Diaz-Vargas et al., 2016).

Just like ensiling form, dry form has the ability to increase okara's shelf life, and digestibility of crude protein and lipids. Unlike complete soya diets, dry okara replacement does not have adverse effects on feed intake, mortality and weight gain. Despite of these benefits, ensiling form has an upper hand as dry form does not show a prominent increase in nutritional values. Besides, fibers remain in the dry okara, decreasing feed intake and performance of nonruminants, due to lack of breakdown of the fibers by microorganisms normally seen in ensiling form. Although transporting cost of dry okara is considered cheap, its drying process comes with an additional cost.

8 | ANIMAL PERFORMANCES

Animals that were fed an okara-inclusive diet showed similar or higher feed intake than those fed diets excluding okara (Tables 5 and 6). Since okara has fine taste, high energy, protein and other nutrients, adding it in diets will make it attractive for animal feeding, with the aim of replacing part or all of their concentrates. Furthermore, inclusion of okara in the diet can also increase the palatability and feed intake of animals, which can result in increase of the body weight gain in the animals. High crude fat content in okara also contributes to the increase of the body weight gain and feed intake of the animals.

8.1 | Ruminants

Okara contains a significant amount of insoluble fiber, which can be fermented efficiently by microbes in the rumen. Previous studies have proved the ability of dietary okara in enhancing the performance in ruminants (Table 5). It shows that not only can okara be used to replace soybean meal (partially or completely) in ruminant diets, but also can replace concentrate feed completely. Due to high protein and energy, okara can be used in a total mixed ration, or alongside forage for feeding.

8.1.1 | Dairy

Based on most published works, there was no adverse effect of dietary okara on milk production in dairy cows. Thakur et al. (2015) observed that supplementation of okara can enhance milk production, as animals have a higher DM intake and digestibility when supplemented with higher levels of okara. In addition, no differences (due to okara-feeding) were observed in fat-corrected milk, milk fat, milk solids-not-fat and milk total solids. In another study, Tres, Jobim, Rossi, et al. (2020) observed that okara-inclusive diet increased nutrient digestibility despite of decreased DM intake, maintaining the same milk production and composition, compared to the control diet, indicating its high digestibility. Wang et al. (2003) reported that Holstein Friesian cows maintained similar nutrient intake, milk yield and milk fat percent when okara replaced 50% soybean in their diet. Similar results are also observed in dairy cows (in relation to the DM intake, milk yield, milk composition and blood metabolites) when okara replaced soybean meal up to 30% and full fat soya in their concentrate mixture as reported by Thakur et al. (2015). Lactating dairy cows fed diet containing okara showed similar results (in terms of DM intake, milk yield, yield of milk fat and true protein, and plasma concentrations of methionine, lysine and histidine) with those fed diet containing soybean meal (Santana et al., 2016). They also observed that concentrations of milk true protein, milk urea nitrogen and plasma urea nitrogen were higher in cows fed okara-inclusive diet than those fed soybean-inclusive diet. Holstein steers fed okara ensiled with corn grain showed higher digestibility of nonfiber carbohydrates and ether extract, and better degradability of soluble fraction, DM, and CP compared to control-diet (Tres, Jobim, Diaz, et al., 2020). Based on above findings, we inferred that the inclusion of okara in dairy cow's diet can be considered a viable alternative to replace soybean and soybean meal.

8.1.2 | Beef

Okara has been widely fed to beef cattle. For example, Kim et al. (2012) observed that Hanwoo steers fed diets containing 25 and 35% okara showed higher DM intake (7.99 and 8.11 kg/day, respectively), carcass weight and crude fat content of meat than those fed diets without okara (7.71 kg/d); however, it did not increase the quality grade of the meat. Yasuda et al. (2016) assessed the feeding effect of dietary okara on the beef quality of Japanese black steer, and they found that those fed with diet containing okara (15.7%) and soy sauce cake (5.2%) did not show any adverse effect on the growth performance, ruminal fermentation, carcass traits and fatty acid composition in meat (except for C16:1). However, in their study, steers fed okara showed higher total cholesterol and phospholipid contents in blood than those fed nonokara based diet, whereas, in physiochemical characteristics, meat samples from steers fed okara showed lower redness color of beef (a*) and chroma values than those from nonokara based diet. The above findings suggest that okara can be considered a suitable feed for beef cattle, since it leads to benefits in feed intake, growth rate and intramuscular fatty acid composition of meat.

8.1.3 | Goats and sheep

There have recently been a number of studies evaluating okara as a feed for small ruminants. Several benefits are seen when okara is included in the small ruminant's diet, especially on performance and quality of products. Nagamine et al. (2015) reported that goats fed okara silage showed better feed conversion ratio (FCR), growth and meat production than those fed nonokara based diet. They also observed that the digestibility of DM, CP, crude fat, CF and nitrogen free extract for okara feeding in goats were 79.3%, 79.9%, 92.0%, 65.5%, and 90.3%, respectively. In another study, Rahman et al. (2015) observed that goats that were fed fresh okara and Napier grass ad libitum showed high okara intake (3.0% of their body weight, DM basis), followed by observation of diarrhea signs possibly due to its high moisture. This experiment indicates both the importance and limitation of okara in the diets of animals (Ishida, 2002). However, nutrient intake and digestibility of adult goats were enhanced when they were fed diets increasing levels (up to 2.0% DM of body weight) of okara as reported by Rahman et al. (2015). In another study, Rahman et al. (2020) reported that goats fed with diets consisting different levels of okara showed similar DM, organic matter and CP or even higher NDF digestibility than those fed diets excluding okara. In contrast, Harthan and Cherney (2017) reported that no significant effect of feeding okara on weight gain of lambs or milk composition of ewes was observed. Improvement in weight gain of the animals could be observed due to okara's taste, high nutritive values, intake and digestibility.

Feeding okara may not depress the reproductive performance of animals, since the use of this by-product did not depress the digestibility, growth and milk production as observed by numerous studies (Harthan & Cherney, 2017; Rahman et al., 2015; Rahman et al., 2020). Feeding okara up to 2.0% DM of body weight did not harm the reproductive performance of goats (Rahman et al., 2015). Since there is limited data about the feeding effects of okara in reproduction of animals, there might be no conclusive statement as research is required in this regard.

8.2 | Nonruminants

The results shown in Table 6 suggested that animals fed with an okara-inclusive diet showed similar or higher weight gain than those fed with diets exclusive of okara. Soybean meal or other protein sources can be replaced partially with okara in nonruminant diets, and the amount of replacement can vary depending on the species of animals.

8.2.1 | Pigs

Pigs fed fermented okara showed higher daily gain (0.75 vs. 0.69 kg/d) and FCR (2.89 vs. 3.06) than those fed control diet (Tian et al., 2020). They also observed an enhanced quality (meat color and antioxidant capacity) in their meat by increasing polysaccharides and intramuscular fat deposition. Increase in fat content of okara-inclusive diets may have a positive effect on high-quality meat yield, since intramuscular fat plays a vital role in meat qualities, such as flavor, texture, tenderness, water-holding capacity and juiciness. In another study, Hermann and Honeyman (2004) observed that pigs whose diet included okara up to 25% did not show any adverse effect on body weight gain, feed intake, and feed conversion.

8.2.2 | Poultry

Growth performance of broiler chicken was not affected by feeding them diets where soybean meal was replaced with okara up to 75%, and the FCR (1.83–1.88) of the okara-fed group was not significantly ($p > 0.05$) different from the control group (Motawe et al., 2012). Diaz-Vargas et al. (2016) also reported that broiler chicken fed with diets containing okara up to 10% did not show any detrimental effects on their growth performance and FCR (1.79–1.86). In another study, there were no differences in carcass yield when broiler chickens were fed diets with various levels of okara (El-Nagmy et al., 2004; Ibrahim, 2006). Okara can replace about 60% of the soybean meal in growing duck's diet without any change in performance (Dong et al., 2005). Similarly, Diaz-Vargas et al. (2016) reported that broiler chicken (from 1 to 21 days of age) fed diets containing okara up to 10% showed no adverse effects on performance, carcass yield or blood metabolic profiles.

In contrast, Motawe et al. (2012) observed that broiler chicken fed okara based diet (replacement of soybean meal by okara at 25%, 50%, and 75%) showed lower feed intake than those fed nonokara-based diet, and full replacement (100%) of soybean meal by okara in diets had an adverse effect on carcass yield, which might have resulted due to the effect of high CF content in okara. However, no difference was observed in their digestibility of DM, organic matter or CP between okara-based diets (diets containing 25%, 50%, and 75% okara) and nonokara based diet. Tarachai et al. (1999) recommended including okara into laying hens diet strictly only up to 10% as increasing the percentage of okara in the diet may cause adverse effects such as lower egg production. Although some favorable results in pigs and poultry are given, it is difficult to accept that a feed with high levels of fiber can be included in their diets without affecting their productivity, so information about the control diet and the feed ingredients replacing the okara in the diet should be taken for consideration.

8.2.3 | Other nonruminants

Fish nutritionists have made several works on partially/completely replacing fish meal with cheap locally available protein sources to avoid the dependency on fish meal as a single protein source for aqua feeding. Okara can safely be used in aquaculture feeds in high levels since its anti-nutrients are reduced using biological treatments, such as manufacturing process and fermentation (Aya, 2017). African catfish fed with diets containing 50% fermented okara showed lower FCR (1.01) than those fed with other experimental diets (1.22–2.19) (Zulhisyam et al., 2020). In contrast, Tilapia fish (*Oreochromis* sp.) fed with okara showed no difference ($p > 0.05$) on the growth performance and feed utilization efficiency when compared over feeding of fishmeal pellet (Mohamad, 2015). Since there is still limited data on digestibility, suitability of aqua feeds and economic analysis of okara feeding in aquatic animals, more research regarding this matter is needed to evaluate the viability and profitability of this by-product in aquaculture feeds.

Overall, use of okara as feed is proposed in substitution of soybean meal by several researchers (Dong et al., 2005; Rahman et al., 2020; Thakur et al., 2015). The composition in the ingredients, for example, protein, fat and fiber, however, are extremely different.

9 | COST AND BENEFITS

The price of okara is relatively low, although handling and transport cost is high due to labor and the time taken to transport it. Farmers in Malaysia pay about US$50 per metric ton for raw okara, including the delivery cost from the factory to the farm (personal communication). Okara can be an alternative animal feed to soybean meal which would help to reduce the demand and cost of soybean meal. Besides, it can minimise the environmental problems of the improper disposal of okara. In places where there is accessibility of okara, it should be included as a concentrate supplement or as a substitution for 100% soybean meal in the diets of goats (Rahman et al., 2016; Rahman et al., 2020) so as to properly utilize this inexpensive by-product instead of dumping it. Wang et al. (2004) observed that animals fed with okara-inclusive diets showed significantly lower feeding cost compared to those fed diets consisting of soybean. In animal feeding, there is, undoubtedly, immense potential in utilizing okara as a replacement for soybean meal and other conventional protein sources, as not only does it effectively utilize okara but also reduces the feeding cost of animals.

It appears that okara, if dried or mixed wet with other ingredients (regularly), has good nutrient availability, and when fed to ruminants with diets prepared daily using wet okara as part of a supplement can markedly reduce feed cost and the cost of gain. However, preservation form and processing way of okara, ensiling and drying, generate additional costs. For sun-drying method, it requires concrete floor or plastic sheets to spread the okara and dry on it, but this method needs favorable weather and more labor to handle it. During drying okara using oven, one of the most important factors to be considered is the protein quality, which can be affected by the drying temperature. Grizotto and de Aguirre (2011) stated that the drying of okara in a drum drier is suitable in which the physicochemical composition of okara is not changed. The shelf life of the dried okara can be increased significantly by heating (45°C–50°C) in a dryer for long hour so that nutritional quality of the final product is not affected. Drying okara using dryer, however, appeared either costly or were not beneficial in terms of product quality. Hence, alternative drying method for okara that may result in making economically viable and better quality final product need to be investigated.

Besides that, in silage making process, the okara's right moisture content can be deducted up to 75% using sunlight or by adding low-moisture containing feeds, and then it is stored in a silo (plastic bag, plastic drum, well, bunker or ditch) in order to make it air-tight for at least 21 days; it is used based on requirement and remaining material is covered back. The ensiling cost for okara is expected to be the same as the cost of normal silage (can be made from forages, crop residue or industrial by-products). Since trucking cost of silage is high if transported from long distance, ensiled okara must be produced nearby the feeding place. A major benefit of making silage is that the okara can be ensiled in almost any weather condition and can also be done in a much shorter timeframe compared to drying process. Therefore, in order to avoid the high energy costs of drying, ensiling is a practical and effective way to store the okara longer.

10 | CONCLUSIONS

This review evaluated the nutritional and anti-nutritional values of okara and its effect on animal performance in terms of feed intake, digestibility, growth, milk production, reproduction and meat quality. Fermentation of okara using specific microorganisms can enhance its nutritive values. Numerous studies have been carried out on the effect of okara feeding and found it as cost-effective and an alternative source of protein and energy for specific types of animals. The optimum inclusion levels for okara in the diets for various animal species were identified in this review. Ensiling okara helps to conserve it even longer, although it is difficult to handle and transport it (when turned into silage) due to its high moisture and sticky nature.

11 | FUTURE PROSPECTIVE RESEARCHES

Although considerable progress has been made in recent years, more research is needed to be done before being fully able to exploit this by-product. Finding the answers to the following questions will help to exploit this by-product:

a. Is it possible to enhance microbial growth during fermentation of okara by addition of additives?
b. What are the bacteria that are involved in the stability of okara silage?
c. What are the suitable drying methods for high-moisture containing okara?
d. How do we develop an inexpensive and highly efficient dryer for okara?
e. What are the feeding effects of okara on animal's physiological health and reproduction?

More researches are also needed on the matter of whether including okara in the diet of aqua life is beneficial and economical.

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