Chapter

Nontraditional Feedstuffs as an Alternative in Poultry Feed

Mohamed I. Alshelmani, Emhimad A. Abdalla, Ubedullah Kaka and Muhammad Abdul Basit

Abstract

Soybean meal and yellow corn are conventional feedstuffs used as the main ingredients in poultry feeds due to their high nutrients availability. On the other hand, these two feedstuffs are high in demand by other animals (soybean meal) and humans (yellow corn). By the year 2050, the world's population is expected to increase up to 9.1 billion. Global consumption of poultry products, such as meat or eggs is increasing predominantly in developing countries. Consequently, the global demand for poultry feedstuffs would increase. The availability of feedstuffs for poultry nutrition nowadays is becoming more competitive. Thus, food security, especially in the developing countries, would be threatened. Currently, efforts are being made to use alternative feedstuffs to substitute portion of soybean meal and yellow corn in poultry diets. This chapter discusses the alternative feedstuffs that can be incorporated in poultry feeds. In addition, the nutritive content and availability are examined as well as how to improve the nutritive quality of such nontraditional feedstuffs.

Keywords: alternative feedstuffs, insects, algae, poultry feed

1. Introduction

Due to their high nutrients contents, soybean meal and yellow corn are conventional feedstuffs in poultry feeds. Moreover, these two feed ingredients are also high in demand by other animals (soybean meal) and humans (yellow corn). The global consumption of poultry products, such as meat or eggs, appears to be increasing in the developing countries. Therefore, the global demands of the main poultry feedstuffs would increase leading to higher cost of poultry production. Studies have shown that the world's population is expected to increase to 9.1 billion by the year 2050, [1]. This tremendous increase in population would produce competition in the available poultry feed ingredients for poultry nutrition. Furthermore, this increase in population will increase demand for poultry products. As a result, the availability of feed ingredients for poultry nutrition would become more competitive. In addition, there is an increasing trend to produce biofuel from feedstuffs, especially corn, to meet the demand all over the world. This further poses a serious food security risk, especially in the developing countries.

Currently, efforts are being made worldwide to use alternative sources of protein and energy to be substituted for soybean meal and yellow corn in monogastric animals such as poultry and swine. It is known that some developing countries produce a huge amount of alternative feedstuffs, considered as agro waste by–products such as wheat bran, rice bran, cotton seed meal, copra meal and palm kernel cake. However, many of these agro waste by–products are featuring on presence of non-starch polysaccharides (NSPs) such as xylan and mannan as well as anti-nutritional factors [2].

The NSPs are found to be the main reason for increasing the viscosity in the small intestine of the birds, and hence lead to increased moisture content of the excreta. Hence, the productivity and health status of the chickens could be affected [2]. Therefore, the inclusion of these agro waste by–products in poultry feed are limited. The nontraditional feedstuffs can be defined as those feed ingredients that have not been conventionally or commercially used in poultry rations. This chapter discusses the nontraditional feedstuffs with potential to be replaced partially or totally with soybean meal and yellow corn in poultry feeds.

2. Alternative feed ingredients for yellow corn

It is well known that yellow corn is used as a main source of energy ingredient in poultry diets [2]. There are some nonconventional feed ingredients that can substitute certain amount of yellow corn in poultry rations. However, there are some limitations such as presence of anti-nutritional factors that lead to decrease feed intake and growth performance (**Table 1**). The other important point to consider is that the lack of knowledge about the composition of nutrients and their availability, due to the lack of research centers in the developing countries limit use of these feed ingredients.

2.1 Sorghum

Sorghum is the main food grain in Africa and parts of India and China [3]. The nutritive value of sorghum is almost 90–95% similar to that of yellow corn. Moreover, its global price is less than yellow corn [4]. The problem of sorghum is the high tannins content, which is water soluble polyphenolic metabolites and leads to reduce growth performance of poultry. Tannins in higher concentration are anti-nutritional because made chelates and reduce protein digestibility [5]. Sorghum is usually classified as bird resistant (less than 0.5% tannin) or non-bird resistant (1.5% tannin or higher) varieties. The negative effects of tannins are decreasing growth, feed intake, protein digestibility, egg production and leg abnormalities with broilers [4]. There are some procedures that can be applied to the sorghum to minimize tannins and improve the nutritive value of such feed ingredients. These methods include soaking in alkali solution and water. It is reported that tannic acid can be hydrolyzed in the chicks to gallic acid which excreted in urine as

Ingredient	Limitation
Sorghum	High tannins content.
Wheat bran	High fiber content, low metabolizable energy.
Distillers dried grains with solubles (DDGS)	Variability and availability of nutrients.
Date wastes	High fiber content in the date pits, low lysine, methionine, leucine and isoleucine.
Millets	High fiber and tannins.

Table 1.
Alternative energy sources that can replace yellow corn in poultry diets.

4 – O – methyl gallate [4]. Therefore, the action of methyl donors such as calcium hydroxide or slurry of sodium carbonate could be included in poultry rations to improve the feed intake of high tannin sorghum. As a result, low tannin sorghum can completely replace yellow corn in poultry diets.

2.2 Wheat bran

Wheat bran is the outer seed coat from flour mills. High in fiber, low in metabolizable energy (ME) and its usage in poultry nutrition is limited [4]. The ME can be increased up to 10% by simple steam pelleting, and the availability of phosphorus up to 20% under the same condition [6]. This by product could be beneficial for gut health which is reported to modify the gut microflora [4]. It is reported that wheat bran can be added in poultry diets up to 5–8% without negative effect [4]. Wheat bran contains xylan which may lead to increase viscosity in the small intestines. Therefore, xylanase supplementation is recommended for broilers fed more than 15% wheat bran in their diets [4].

2.3 Distillers dried grains with solubles (DDGS)

Alternative and clean sources of energy are more attractive nowadays against fossil energy. The production of biofuel has globally increasing [7]. Therefore, the by-product obtained from this process is known as distillers dried grain with solubles (DDGS). It can be defined as a product obtained after ethanol extraction by distillation from the yeast fermentation, and drying at 75% of the resultant [8]. Including DDGS in poultry diets to replace part of yellow corn and soybean meal have shown positive results in terms of growth performance [9]. The main limitation of using DDGS in monogastrics is the variability of its nutrients content and availability [9]. This is due to the variation of growing conditions, ethanol production method and oil extraction. Therefore, it was reported that there are two types of DDGS; high protein and conventional DDGS (**Table 2**).

Nutrient	High protein DDGS	Conventional DDGS
Dry matter	83.10	89.80
Crude protein	34.10	27.10
Crude fiber	8.35	7.85
Ether extract	7.91	9.63
Arginine	1.49	1.10
Cystine	0.58	0.45
Glycine	1.25	0.60
Histidine	0.88	0.62
Isoleucine	1.26	1.15
Leucine	4.32	2.40
Lysine	1.16	0.70
Methionine	0.74	0.50
Phenyl alanine	1.57	1.35
Serine	1.60	1.30
Threonine	1.31	0.93
Tryptophan	0.30	0.20

Nutrient	High protein DDGS	Conventional DDGS
Tyrosine	1.34	0.80
Valine	1.60	1.40
Metabolizable energy (Kcal/Kg)	2628	2628

Table 2.
Nutrient composition of DDGS (% as –fed basis) [9].

Not only can DDGS provide energy in poultry diets, but also can provide protein and available phosphorus. It was shown that DDGS can be included in broiler diets at 8% or 15% in starter and grower phase, respectively without negative effects in their performance [8]. The supplementation of fiber-degrading enzyme could be an efficient way to enable the use of increased levels of DDGS in poultry and pig diets [10].

2.4 Date wastes

Dates are rich in vitamins and minerals. Usually, dates wastes consisting on the pulp and pits (stones). Date wastes are high in fiber, low in lysine, methionine, leucine and isoleusine [11]. The limitation of using date wastes is the high crude fiber in the date pits. Date wastes can be included in poultry diets up to 30% without negative effects on their performance [12]. In addition, the use of 30% of date pits (stones) with a supplementation of multi enzymes in broiler diets had no adverse effects on the final body weight [13]. Regarding date pits meal, it could be fed to laying hens up to 5% without adverse effects on their performance and egg quality. In addition, broilers fed diet incorporated with 4% date pits meal showed an ability to resist the deleterious effects of aflatoxine B1 [14].

2.5 Millets

Millets is adrought-resistant plant that produces a nutritious grain. It can be grown successfully under environmental conditions where corn and wheat fail to survive [15]. The nutrient content is variable, so that it contains 8–10% CP, 3395–3738 kcal/kg metabolizable energy, 3.60–5.27% fat and 1.59–2.36% fiber [15]. The limitation of using high levels of millets in poultry diets is the tannin content and fiber [16].

3. Alternative feedstuffs for soybean meal

Routinely, soybean meal is used as a main source of protein ingredient in poultry diets [4]. There are some nontraditional feed ingredients that can replace certain amount of soybean meal in poultry diets. Nevertheless, there are some limitations such as presence of anti-nutritional factors that lead to reduce feed intake and growth performance (**Table 3**).

3.1 Canola meal

Canola crop is growing widely in the west of Canada as well as in other parts of the world [4]. The production of canola was influenced by the increasing demand for canola oil. Canola meal is the by-product of oil extraction, and lysine content is less than that of soybean meal. However, sulfur-containing amino acids are higher than that of soybean meal.

Ingredient	Limitation
Canola meal	Presence of glucosinolates, senapine, phytate, fibers, tannins, and low metabolizable energy.
Peanut (groundnut) meal	Trypsin inhibitors, potential aflatoxin contamination.
Peas	Lack of sulfur containing amino acids, and moderate energy levels
Lupins	High fiber, low metabolizable energy.
Sesame meal	High levels of phytate.
Blood meal	Palatability and low growth rate.
Palm kernel meal	High fiber, coarse texture and high NSPs.
Cottonseed meal	High fiber, gossypol, dry and dusty nature, phytate, sterculic acid.
Feather meal	Low in amino acids availability.
Insects and worms	Microbial deterioration and lipid oxidation during storage.
Earthworms	High fat (PUFA), and lipid oxidation during storage.
Algae	High fat (PUFA), and lipid oxidation during storage.
Azolla	High fiber content.
Single – cell protein	High fat (PUFA), and lipid oxidation during storage.

Table 3.
Alternative protein sources that can replace soybean meal in poultry diets.

The problem of using canola meal in poultry feeds is the presence of glucosinolates, senapine, phytate, fibers, tannins as well as it has low metabolizable energy [17]. It was found that feeding canola meal to layers led to the occurring of fishy taint in egg and the reduction egg size [4].

There are attempts to improve the nutritional quality of canola meal by extrusion or solid-state fermentation using lactic acid bacteria [6, 18]. Therefore, it was reported that canola meal can be incorporated in poultry diets up to 5–8% [4], or up to 10% in broilers fed fermented canola meal based diet [17].

3.2 Peanut (groundnut) meal

Peanut meal is a by-product from oil extraction. It contains 0.5–1% oil and 47% CP. The problem of using peanut meal in poultry diets is the trypsin inhibitors. Fortunately, it can be detoxifying by heat treatment during oil extraction. The issue to consider is that its potential aflatoxin contamination. To overcome this problem, the feedstuff could be supplemented with sodium-calcium aluminosilicates because these minerals bind with aflatoxin preventing its absorption [4].

3.3 Peas

Peas can be used in poultry diets depending on local economic conditions. It contains moderate amount of energy and protein. The limitation to use peas in poultry rations is the lack of sulfur containing amino acids, and moderate energy levels [4].

3.4 Lupins

The use of low alkaloid lupins in poultry diets is going to be increased in certain regions of the world [4]. The high level of fiber in the seed leads in low metabolizable energy compared to soybean meal. Although lupins are much lower in methionine and lysine, many reports suggested that sweet lupins are comparable to soybean meal in terms of protein quality [4].

3.5 Sesame meal

Sesame meal is very deficient in available lysine. It contains high level of phytate which may cause problems with calcium absorption. Therefore, skeletal disorders or poor egg shell quality in laying hens may be occurred. It contains 35.1–47% CP [16]. It is recommended that diet incorporated with more than 10% sesame meal should be increased by 0.2% extra calcium [4].

3.6 Blood meal

Blood meal is high in protein (65–85%), rich in lysine, arginine, methionine, cysteine and leucine. However, it is very poor in isoleucine [19]. The use of blood meal is very limited in poultry diets because of its palatability and poor growth rate [4]. It was reported that blood meal can be incorporated up to 3% in broiler diets without negative effects in their performance [19].

3.7 Palm kernel cake

Tropical regions have an abundant amount of palm kernel cake (PKC), which is considered an agro-industrial waste derived from the extraction process of oil from palm fruits. It has been used in poultry diets as an alternative to soybean meal. Nevertheless, the use of PKC is limited in monogastrics because of its high content of fibers, coarse texture, and non-starch polysaccharides (NSPs) [2, 20–24]. The main NSPs in the PKC are mannan, xylan, arabinoxylan, and glucoronoxylan [20]. This is considered a significant issue faced by nutritionists, and it has limited the use of PKC for manipulation of feed formulation. It has been reported that 10% is the maximum level of PKC that can be given to broiler chickens. However, solid-state fermentation by cellulolytic bacteria may improve the nutritive value of PKC to be incorporated up to 15% in the diet [2, 24].

The treated PKC by enzyme [25], cellulolytic bacteria via solid state fermentation [2, 23, 24] or extrusion [26] may contribute to improve the nutritive value and poultry performance (**Table 4**). It was reported that extrusion led to 6% increase in apparent metabolizable energy and 32% in crude protein digestibility in broiler chickens [27].

3.8 Cottonseed meal

Cottonseed meal is a byproduct after oil extraction. Usually, this byproduct used for poultry in cottonseed producing regions [4]. It is high in crude protein (41%). However, the big problem for using cottonseed meal in poultry rations are the high fiber levels (14.5%) and gossypol [4]. Gossypol is a yellow polyphenolic pigment, and usually found at 0.1% free gossypol. The big issue with gossypol is binding with lysine during processing, and then the lysine will be unavailable to the chickens. The byproduct is not acceptable by poultry because of its dry and dusty nature [3]. Gossypol may lead to decrease feed intake and growth rate in broiler chickens [3]. The byproduct is low in calcium, and the phosphorus is chelated with phytate. Therefore, phytase supplementation could be beneficial to release unavailable phosphorus. In case cottonseed meal is used for poultry, it is recommended to supply fish meal to balance the essential amino acids and calcium [3].

Nutrient (%)	PKC [23]	FPKCa[1] [23]	FPKCb[2] [23]	PKC [26]	Extruded PKC [26]
Crude protein	16.43	16.80	16.68	16.90	16.90
Dry matter	91.42	92.62	92.44	89.81	91.79
Ash	474	4.67	4.80	4.50	5.70
Crude fiber	16.96	14.09	14.29	17.30	14.60
NDF	82.29	71.70	73.54	75.00	75.40
ADF	51.48	47.27	47.45	37.30	39.30
Indispensable amino acids					
Lysine	0.37	0.41	0.38	0.5	0.46
Leucine	0.89	0.94	0.95	1.08	1.05
Isoleucine	0.50	0.59	0.53	0.60	0.55
Valine	0.69	0.78	0.72	0.90	0.87
Phenyl alanine	0.57	0.66	0.63	0.66	0.57
Threonine	0.41	0.51	0.46	0.54	0.50
Histidine	0.23	0.29	0.24	0.31	0.31
Methionine	0.22	0.27	0.26	0.30	0.28
Arginine	1.60	1.76	1.69	1.94	1.95
Glycine	0.60	0.78	0.71	0.80	0.81
Dispensable amino acids					
Aspartic acid	1.12	1.27	1.23	1.14	1.15
Glutamic acid	2.48	2.80	2.76	3.06	3.17
Proline	0.44	0.59	0.52	0.57	0.53
Serine	0.56	0.69	0.66	0.75	0.74
Tyrosine	0.25	0.24	0.24	0.30	0.31
Cysteine	0.20	0.22	0.21	0.36	0.17
Alanine	0.62	0.70	0.71	0.87	1.10

[1]*FPKCa; fermented palm kernel cake by P. polymyxa ATCC 842.*
[2]*FPKCb; fermented palm kernel cake by P. curdlanolyticus DSMZ 10248.*

Table 4.
Nutrient content of palm kernel cake and treated palm kernel cake (dry matter basis).

The other important point to consider with gossypol is that it leads to discoloration of the yolk in laying hens. It causes a olive-green color in the yolk, especially during egg storage at low temperature [3, 4]. The other problem with cottonseed meal is the presence of sterculic acid witch found to cause a pink color in the albumen. However, this can be avoided by using a byproduct with less residual oil because of the content of cyclopropenoid fatty acids [5].

It has been found that iron can bind with gossypol by 1:1 ratio, and may detoxify the gossypol. Therefore, the addition of 0.5 kg ferrous sulfate/tonne allowed the broilers and layers to tolerate up to 200 ppm and 30 ppm free gossypol, respectively without any negative effect in their performance [4].

In case iron was supplemented to cottonseed meal based diet, the balance between iron and copper should be considered to be 10: 1 iron to copper, respectively.

Studies have also shown that enzyme supplementation (β-glucanase and xylanase) may lead to increase the metabolizable energy and protein utilization in broiler chickens [28].

3.9 Feather meal

Feathers are considering as an industrial waste resulted during birds processing in slaughter houses. Several million tons of feathers are generated from the poultry processing industry are disposed as a waste [29, 30]. Feather meal contains about 85% crude protein, 5% cysteine and 3000 kcal/kg metabolizable energy. The cysteine availability is about 60% depending on the processing conditions [4].

Usually, feathers are partially dried, and hence steam-treated to introduce hydrolysis. However, the extreme temperature will lead to destruct the amino acids, especially lysine. Therefore, leads to reduce the amino acids digestibility. To overcome this problem, the use of keratinase enzyme may play an important role in improving the protein digestibility [29] and poultry performance [4]. In addition, fermentation with bacteria-degrading keratin such as *Bacillus licheniformis* for five days at 50°C can produces a fermented product comparable in nutritional value to soybean meal [4].

Some reports mentioned that *B. subtilis* and *Aspergillus fumigatus* had an ability to degrade keratin in feathers [30]. Feather meal can be included in poultry diets at 2–3%. Nevertheless, the fermented feather meal may give promised results in poultry nutrition, and therefore it would be an additional commercial benefit for the poultry industry by replacing part of soybean meal in poultry feeds.

3.10 Insects and worms

Insects can be used to produce cheap source of protein. It is known that insects are considered as a natural food for birds. Insects are rich in protein (40–76%) and essential amino acids [31], particularly sulfur containing amino acids [32]. Insects meal are usually featuring on high fat content [31]. Therefore, microbial deterioration and lipid oxidation should be considered during storage [33]. Ssepuuya et al. [34] indicated that insects meal may replace the conventional protein sources by 10–100% without any negative growth performance whether in fish or poultry. It was also mentioned by Kareem et al. [31] that the incorporation of black soldier fly larvae to broiler diets up to 10% had no negative effect in their growth performance under humid tropical environment. In addition, no adverse effects on growth performance, carcass characteristics, hematological and serum biochemical indices in growing Japanese quail when meat and bone meal replaced with *Spodoptera littorails* in their diets [35]. It was claimed by Neumann et al. [36] that partly adding defatted insects meal of *Hermetia illucens* larvae in broiler diets – 26% and 22% in starter and grower phase, respectively – were acceptable. In terms of meat quality, it was reported that complete substitution of soybean meal by *Hermetia illucens* led to inducing lipid oxidation in broiler meat [37]. This was attributed to the high content of poly unsaturated fatty acids (PUFA) in *Hermetia illucens*.

3.11 Earthworms

Earthworms are a natural source of protein for poultry raised in free-range system. Earthworm can produced even in small-scale system. Earthworms species require a temperature ranging from 15 to 25°C, and 60–85% soil moisture content [38]. It can be considered as an alternative source of protein (64–76%) [39]. At the same time, it can be degrade animal manure to clean the environment. It was reported that the total essential amino acids in earthworms are comparable with egg protein. Moreover, the omega – 3 PUFA are quite high and similar to that of some fish oil [40]. It was mentioned by Parolini et al. [38] that earthworms contain

6–11% fat, 5–21% carbohydrate, 2–3% minerals and range of vitamins, especially niacin and cyanocobalamin. In comparison with insects meal, it has been found that earthworm meal has no deficiencies in the essential amino acids and better fatty acids profile with no chitin content, so that it was more acceptable and palatable for chickens [38]. Earthworm meal could be integrated in broiler diets up to 10% without negative effects in growth performance and meat quality [38].

3.12 Algae

Algae represent an important source of unconventional protein (50–60%), oils, vitamins, minerals, antioxidant and colorants [41], carotenoids, omega-3 and omega-6 PUFA [42, 43]. Some types of algae contain up to 76% crude protein [44]. In terms of nutrition, algae were used in broiler diets up to 16% without adverse effects. On the other hand, it was a replacement for approximately 60% of soybean meal and 40% of animal vegetable blended fat into practical broiler diets [44].

The most common species of algae used in poultry nutrition are *chlorella* and *Spirulina*. It was reported by Moury et al. [45] that supplementation of *Spirulina platensis* in broiler diets may completely replace the incorporation of vitamin-mineral premix. Moreover, it can be substitute the antibiotic usage in animals [46].

It is reported that algae can be a good option for 100% organic poultry feed [47]. Neumann et al. [36] reported that incorporation of *Spirulina platensis* at 21% and 17% in starter and grower phase, respectively was acceptable. However, nutritionists have to pay attention to the presence of PUFA in algae which may affect the meat quality of broilers and lead to lipid oxidation. Gkarane et al. [37] mentioned that complete substitution of soybean meal in broiler diets by *Arthrospira platensis* influenced the meat quality and led to lipid oxidation.

3.13 Azolla

Azolla is an aquatic and floating fern of the family Azollaceae. It contains 25–35% crude protein, 10–15% minerals and 7–10% amino acids, especially lysine [48]. Azolla forms a symbiotic with blue green algae which lives within its leaves. This relationship makes azolla as a beneficial source of protein, and can be fed safely to the farm animals [49]. It is recommended that azolla (*Azolla pinnata*) can be incorporated in poultry diet up to 5% with positive effect on their growth performance [49]. The limitation of using high levels of Azolla is its high level content [48].

3.14 Single-cell protein

The production of single-cell protein (SCP) can be done by microbial fermentation with selected strains of microorganisms. SCP also known as microbial protein or bio-protein [50]. Bacteria such as *Pseudomonas* spp. can be grown in methanol, ethanol and organic acids [3]. The protein and sulfur containing amino acids in bacteria are higher than that of yeast. The oil content in bacteria and yeast is high and rich in unsaturated fatty acids. Chen et al. [51] concluded that SCP produced by *Chlostridium autoethanogenum* had 88.93% crude protein and most of essential amino acids were higher than that of fish meal.

The incorporation of 15% of SCP in pigs diet exhibited a comparable results with those group of pigs fed diet containing soybean meal [3]. It is recommended that SCP can be included in 2–5% in broiler diets, and up to 10% in laying hens [3].

4. Alternative ingredients for oil and vitamins sources

It is known that – ingredients mentioned above – insects, worms, earthworms, algae, azolla and SCP contain significant amount of oil. In addition, these ingredients can provide omega-3 and omega-6 PUFA to the poultry [42, 43]. Interestingly, these ingredients are rich in vitamins and minerals as mentioned above [46].

5. Conclusion

In conclusion, the use of alternative feedstuffs nowadays in poultry sector is going to be increased because of their nutritive quality and as a cheap source of protein and energy. In addition, these nontraditional feedstuffs are not competitive with humans. At the same time, their inclusion to poultry diets can replace portions of soybean meal and yellow corn. Therefore, reduce the cost of production.

Author details

Mohamed I. Alshelmani[1], Emhimad A. Abdalla[2], Ubedullah Kaka[3*] and Muhammad Abdul Basit[4]

1 Department of Animal Production, Faculty of Agriculture, University of Benghazi, Benghazi, Libya

2 Centre for Genetic Improvement of Livestock, University of Guelph, Guelph, Ontario, Canada

3 Department of Companion Animal Medicine and Surgery, Faculty of Veterinary Medicine, Universiti Putra Malaysia, Serdang, Malaysia

4 Department of Biosciences, Faculty of Veterinary sciences, Bahauddin Zakariya University, Multan, Pakistan

*Address all correspondence to: dr_ubedkaka@upm.edu.my

References

[1] FAO. How to feed the world in 2050. Food and Agriculture Organization of the United Nations (FAO). Rome, Italy 2009.

[2] Alshelmani MI, Loh TC, Foo HL, Sazili AQ, Lau WH. Effect of feeding different levels of palm kernel cake fermented by *Paenibacillus polymyxa* ATCC 842 on nutrient digestibility, intestinal morphology, and gut microflora in broiler chickens. Animal Feed Science and Technology. 2016; 216: 216-224.

[3] McDonald P, Edwards RA, Greenhalgh JFD, Morgan CA, Sinclair LA, Wilkinson RG. Animal Nutrition. 7th ed. U. K: Pearson; 2010.

[4] Leeson S, Summers J. Commercial Poultry Nutrition. Department of Animal and Poultry Science, University of Guelph. 3rd ed: University Book; 2005.

[5] NRC. Nutrient Requirements of Poultry (9th Rev. Ed.). National Academy Press, Washington, DC. 1994.

[6] Kraler M, Schedle K, Domig KJ, Heine D, Michlmayr H, Kneifel W. Effects of fermented and extruded wheat bran on total tract apparent digestibility of nutrients, minerals and energy in growing pigs. Animal Feed Science and Technology. 2014; 197: 121-129.

[7] Ghosh SK. Waste Management as Economic Industry Towards Circular Economy: Springer; 2020.

[8] Świątkiewicz S, Koreleski J. The use of distillers dried grains with solubles (DDGS) in poultry nutrition. World's Poultry Science Journal. 2008; 64 (2): 257-266.

[9] Fries-Craft K, Bobeck EA. Evaluation of a high-protein DDGS product in broiler chickens: performance, nitrogen-corrected apparent metabolisable energy, and standardised ileal amino acid digestibility. British Poultry Science. 2019; 60 (6): 749-756.

[10] Swiatkiewicz S, Swiatkiewicz M, Arczewska-Wlosek A, Jozefiak D. Efficacy of feed enzymes in pig and poultry diets containing distillers dried grains with solubles: a review. Journal of Animal Physiology and Animal Nutrition. 2016; 100 (1): 15-26.

[11] Al-Harthi MA, El-Deek AA, Yakout HM, Al-Refaee M. The Nutritive Value of Date Waste Meal as a Feedstuff for Lohmann Brown Pullets and Layers. The Journal of Poultry Science. 2009; 46 (4): 303-312.

[12] Seidavi AR, Azizi M, Ragni M, Laudadio V, Tufarelli V. Practical applications of agricultural wastes in poultry feeding in Mediterranean and Middle East regions. Part 2: tomato, olive, date, sunflower wastes. World's Poultry Science Journal. 2018; 74 (3): 443-452.

[13] Zaghari M, Taherkhani R, Ghasemi M, Shivazad M. Estimation of metabolisable energy content of date pit and its effect on lipid and protein oxidation in broiler chicks. Journal of the Science of Food and Agriculture. 2009; 89 (13): 2336-2341.

[14] Alyileili SR, Belal IE, Hussein AS, El-Tarabily KA. Effect of inclusion of degraded and Non-degraded date pits in Broilers' Diet on their intestinal microbiota and growth performance. Animals. 2020; 10 (11): 2041.

[15] Cisse RS, Hamburg JD, Freeman ME, Davis AJ. Using locally produced millet as a feed ingredient for poultry production in Sub-Saharan Africa. Journal of Applied Poultry Research. 2017; 26 (1): 9-22.

[16] Dinani O, Tyagi PK, Mandal A, Tiwari S, Mishra S, Sharma K. Recent unconventional feedstuffs for economic poultry production in India: A review. Journal of Entomology and Zoology Studies. 2019; 7 (5): 1003-1008.

[17] Aljubori A, Idrus Z, Soleimani AF, Abdullah N, Juan Boo L. Response of broiler chickens to dietary inclusion of fermented canola meal under heat stress condition. Italian Journal of Animal Science. 2017; 16 (4): 546-551.

[18] Aljuobori A, Idrus Z, Abdoreza Soleimani F, Norhani A, Liang J. Extrusion enhances metabolizable energy and ileal amino acids digestibility of canola meal for broiler chickens. Italian Journal of Animal Science. 2014; 13 (1): 44-47.

[19] Khawaja T, Khan SH, Ansari NN. Effect of different levels of blood meal on broiler performance during two phases of growth. International Journal of Poultry Science. 2007; 6 (12): 860-865.

[20] Alshelmani MI, Loh TC, Foo HL, Lau WH, Sazili AQ. Characterization of cellulolytic bacterial cultures grown in different substrates. The Scientific World Journal. 2013; 2013: 6.

[21] Alshelmani MI, Loh TC, Foo HL, Sazali AQ, LAU WH. Effect of feeding fermented palm kernel cake on performance of broiler chickens. Proceeding WPSA and WVPA (Malaysia Branch) Scientific Conference. 2013: 83.

[22] Alshelmani MI, Loh TC, Foo HL, Lau WH, Sazili AQ. Biodegradation of Palm Kernel Cake by Cellulolytic and Hemicellulolytic Bacterial Cultures through Solid State Fermentation. The Scientific World Journal. 2014; 2014: 8.

[23] Alshelmani MI, Loh TC, Foo HL, Sazili AQ, Lau WH. Effect of solid state fermentation on nutrient content and ileal amino acids digestibility of palm kernel cake in broiler chickens. Indian Journal of Animal Sciences. 2017; 87 (9): 1135-1140.

[24] Alshelmani MI, Loh TC, Foo HL, Sazili AQ, Lau WH. Effect of feeding different levels of palm kernel cake fermented by *Paenibacillus polymyxa* ATCC 842 on broiler growth performance, blood biochemistry, carcass characteristics, and meat quality. Animal Production Science. 2017; 57 (5): 839-848.

[25] Zamani HU, Loh TC, Foo HL, Samsudin AA, Alshelmani MI. Effects of feeding palm kernel cake with crude enzyme supplementation on growth performance and meat quality of broiler chicken. International Journal of Microbiology and Biotechnology. 2017; 2 (1): 22-28.

[26] Hakim AH, Zulkifli I, Soleimani Farjam A, Awad EA, Abdullah N, Chen WL, et al. Passage time, apparent metabolisable energy and ileal amino acids digestibility of treated palm kernel cake in broilers under the hot and humid tropical climate. Italian Journal of Animal Science. 2020; 19 (1): 194-202.

[27] Faridah HS, Goh YM, Noordin MM, Liang JB. Extrusion enhances apparent metabolizable energy, ileal protein and amino acid digestibility of palm kernel cake in broilers. Asian-Australasian Journal of Animal Science. 2020; 33 (12): 1965-1974.

[28] Abdallh M, Ahiwe E, Musigwa S, Chang'a E, Al-Qahtani M, Cadogan D, et al. Energy and protein utilisation by broiler chickens fed diets containing cottonseed meal and supplemented with a composite enzyme product. British Poultry Science. 2020: 1-9.

[29] Sivakumar N, Raveendran S. Keratin degradation by bacteria and fungi isolated from a poultry farm and plumage. British poultry science. 2015; 56 (2): 210-217.

[30] Lakshmi V, Devi DA, Rani KJ. Wealth from Poultry Waste. Waste Management as Economic Industry Towards Circular Economy: Springer; 2020. p. 67-76.

[31] Kareem KY, Abdulla NR, Foo HL, MOHD AN, ZAMRI NS, Loh TC, et al. Effect of feeding larvae meal in the diets on growth performance, nutrient digestibility and meat quality in broiler chicken. Indian Journal of Animal Sciences. 2018; 88 (10): 1180-1185.

[32] DiGiacomo K, Akit H, Leury BJ. Insects: a novel animal-feed protein source for the Australian market. Animal Production Science. 2019; 59 (11): 2037-2045.

[33] Józefiak D, Engberg RM, editors. Insects as poultry feed. 20th European Symposium on poultry nutrition; 2015.

[34] Ssepuuya G, Namulawa V, Mbabazi D, Mugerwa S, Fuuna P, Nampijja Z, et al. Use of insects for fish and poultry compound feed in sub-Saharan Africa–a systematic review. Journal of Insects as Food and Feed. 2017; 3 (4): 289-302.

[35] Hatab M, Ibrahim N, Sayed W, Sabic E. Potential Value of Using Insect Meal As an Alternative Protein Source for Japanese Quail Diet. Brazilian Journal of Poultry Science. 2020; 22 (1).

[36] Neumann C, Velten S, Liebert F. Improving the dietary protein quality by amino acid fortification with a high inclusion level of micro algae (Spirulina platensis) or insect meal (Hermetia illucens) in meat type chicken diets. Open Journal of Animal Sciences. 2017; 8 (1): 12-26.

[37] Gkarane V, Ciulu M, Altmann BA, Schmitt AO, Mörlein D. The Effect of Algae or Insect Supplementation as Alternative Protein Sources on the Volatile Profile of Chicken Meat. Foods. 2020; 9 (9): 1235.

[38] Parolini M, Ganzaroli A, Bacenetti J. Earthworm as an alternative protein source in poultry and fish farming: Current applications and future perspectives. Science of The Total Environment. 2020; 734: 139460.

[39] Prayogi HS. The effect of earthworm meal supplementation in the diet on quail's growth performance in attempt to replace the usage of fish meal. International Journal of Poultry Science. 2011; 10 (10): 804-806.

[40] Ding S, Lin X, He S. Earthworms: a source of protein. Journal of Food Science and Engineering. 2019; 9: 159-170.

[41] Kovač DJ, Simeunović JB, Babić OB, Mišan AČ, Milovanović IL. Algae in food and feed. Food and Feed Research. 2013; 40 (1): 21-32-21-32.

[42] Grigorova S, Abadjieva D, Gjorgovska N. Influence of natural sources of biologically active substances on livestock and poultry reproduction. Iranian Journal of Applied Animal Science. 2017; 7 (2): 189-195.

[43] Madeira MS, Cardoso C, Lopes PA, Coelho D, Afonso C, Bandarra NM, et al. Microalgae as feed ingredients for livestock production and meat quality: A review. Livestock Science. 2017; 205: 111-121.

[44] Evans A, Smith D, Moritz J. Effects of algae incorporation into broiler starter diet formulations on nutrient digestibility and 3 to 21 d bird performance. Journal of applied poultry research. 2015; 24 (2): 206-214.

[45] Moury SN, Sarker MT, Prabakusuma AS, Russel MIH, Islam MS. Replacement of vitamin-mineral premix by Spirulina and its effect on the performance of broiler. Journal of Scientific Agriculture. 2018: 39-51.

[46] Morais T, Inácio A, Coutinho T, Ministro M, Cotas J, Pereira L, et al. Seaweed potential in the animal feed: A review. Journal of Marine Science and Engineering. 2020; 8 (8): 559.

[47] Gerrard CL, Smith J, Nelder R, Bright A, Colley M, Clements R, et al. 100% Organic Poultry Feed: Can Algae Replace Soybean Expeller in Organic Broiler Diets? Organic farming. 2015; 1 (1): 38-45.

[48] Abd El-Ghany WA. A Review on the Use of Azolla Species in Poultry Production. Journal of World's Poultry Research. 10 (2): 378-84.

[49] Katoch S, Chauhan P, Mane BG. Effect of feeding Azolla pinnata in combination with direct-fed microbial on broiler performance. Tropical Animal Health and Production. 2020; 53 (1): 1-9.

[50] Molnár J, Mahendra Pal. Applying Single Cell Protein as Functional Foods. Journal of Microbiology. 2020; 7: 33-35.

[51] Chen Y, Sagada G, Xu B, Chao W, Zou F, Ng WK, et al. Partial replacement of fishmeal with Clostridium autoethanogenum single-cell protein in the diet for juvenile black sea bream (Acanthopagrus schlegelii). Aquaculture Research. 2020; 51 (3): 1000-1011.