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Review

Utilization of Agro-Industrial By-Products for Sustainable Poultry Production

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Abstract: Agro-industrial by-products (AIBPs) that are not intended for human consumption can be used as alternatives to conventional feedstuffs in animal nutrition to produce animal products without competing for land or triggering the food-feed competition, thus leading to environmental, social, and economic sustainability. These by-products are also known to contain several bioactive compounds and have a potential to become nutraceuticals that can promote the health and well-being of poultry. The potentials of some AIBPs (e.g., fruit juice industry leftovers, oilseed industrial by-products, distillers' grain by-products, vinification by-products, olive oil industry by-products, pomegranate by-products, tomato processing by-products) and their derivative products as functional feeds for poultry, but also potential limitations of utilizing AIBPs in poultry nutrition are elaborated in the present review. The possible mechanisms through which AIBPs may improve the health status and productivity of poultry are also discussed. We suggest that nutrient variability across countries should be stabilized and potential hazards such as mycotoxins and pesticides should be eliminated, and the potential hazards present in AIBPs (e.g., mycotoxins) should be better controlled through appropriate legislation and proper application of control measures. Modern processing methods, new types/classifications, and proper developmental strategies foster the utilization of AIBPs in animal nutrition. This review focuses on the AIBPs as feeds, not only for their nutritional value but also for their contribution to sustainable practices.

Keywords: distillers' grain; fruit juice industry leftovers; olive oil industry by-products; oilseed industrial by-products; pomegranate by-products; tomato processing by-products; vinification by-products

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1. Agro-Industrial By-Products and Sustainability

By 2050, the world population is projected to increase from 8 billion in 2022 to 9.7 billion [1]. This is translated to an additional 2 billion people with increased wealth to elevate the demand for food, including meat produced with substantial amounts of resources [2]. Furthermore, greenhouse gas emissions are forecast to rise at an average rate of 2–6% annually until 2030 [2]. At the same time, global hunger is exacerbated by the COVID-19 pandemic [3] and by conflicts in Eastern Europe in 2022 [4], which increased inflation and made healthy diets less affordable [3].

There is a challenge to address the need to be more resource-efficient due to the limitation of finite land and natural resources and the pressure to increase meat production posed by the rising population and the increase in incomes in developing countries. Although a large effort has been undertaken to address sustainability, triggering a change in food systems requires more than technical innovation [2]. All parts of a food ecosystem are crucial for this purpose, including consumers. Individual attitudes about food are formed by culture and temperament/identity [2], which often lack proper education and awareness of sustainable attitudes. For instance, a dietary change could be directed towards a low-meat diet containing meat from livestock fed on low-opportunity-cost feeds [5]. Such feeds include agro-industrial by-products (AIBPs), which result mainly from the processing of crop plants [6], food waste, and grass resources that are not intended for human consumption and can be used in animal nutrition to produce animal products without competing for land or triggering the food-feed competition [5]. Thus, a human diet containing products from low-cost livestock demands less arable land and resources than a vegan diet [5]. Van Hal et al. [7] estimated that 31 g of animal protein per EU capita per day can be produced if we incorporate low-opportunity-cost feed in animal diets. In this scenario, laying hens production should be reduced by 98%, and broiler raising should be ceased [7]. However, the contribution of poultry production to household food security and its importance to small-scale farmers, especially in the developing world [8], should not be overlooked. Although the scenario of van Hal et al. may seem utopic since it requires complete reformation of the food system and adaptation of the human diet [7], the agro-food system could be reformed towards the direction of environmental, social, and economic sustainability.

In the last years, much interest has been devoted by the agro-food sector to contemporary issues such as respect for the environment and human resources, production traceability, product quality, and food safety [9]. In academia, there is a large discussion about reducing dependence on conventional feedstuffs, i.e., corn and soybean, and using alternative feedstuffs in order to reduce the food-feed competition and the environmental impact of the animal production systems and to foster the production of healthy products. In the EU, it is estimated that approximately 1.6 million tons of AIBPs are produced annually, with Germany, the United Kingdom (UK), Italy, France, and Spain being the top producers [10]. Many agro-industrial by-products are commonly included in animal diets by-products from food processing or breweries, such as spent brewer's grains, maize gluten meal, cakes or meals, sugar beet pulp (SBP), tomato pulp, distillery products, and sunflower meal (SFM) [10,11]. On the other hand, fruit and vegetable wastes are underutilized resources [10], but they are commonly utilized in animal nutrition in developing countries in an informal way [12]. However, AIBPs are usually disposed of in landfills or are incinerated, posing a significant burden to the environment [13]. Instead, the AIBPs or the isolated bioactive compounds can be incorporated into animal diets and thus provide a market opportunity. In the developing world, food losses are much more than in the developed world due to a lack of infrastructure, and more opportunities to transform AIBPs into animal feed are provided [14]. Locally produced AIBPs is an environmentally-friendly alternative to soybean meal, the cultivation of which is one of the causes of deforestation in South America, given that bird performance is not compromised [15]. Furthermore, several studies, as reviewed in our work, examine the replacement of maize and other conventional feedstuffs with AIBPs, a practice that could abate feed-food competition. Some of the favorable properties of AIBPs that can be utilized in animal nutrition include high protein content, suitable amino acid profile, high digestibility, palatability, reduced levels of indigestible fibrous substances, starch, anti-nutrients [16], no difficulties in the handling of the materials and safety. Many AIBPs contain a plethora of bioactive compounds that are shown to have anti-inflammatory and anti-bacterial activity and to favor the antioxidant status of animals and thus improving growth performance, production quality, and endogenous antioxidant systems [17,18]. The mode of actions of bioactive compounds in poultry are reviewed by other researchers [19]. The nutritional characteristics of AIBPs have been compiled in tables by other reviewers [20] or can be found in repositories such as "Feedipedia" (http://www.feedipedia.org/ accessed on 1 December 2022) and "Feed Tables" (https://www.feedtables.com/ accessed on 1 December 2022) [21]. Information on feed terms can be retrieved from the Association of American Feed Control Officials [22]. In the current study, the inclusion of by-products in animal diets, the benefits in poultry performance and health, and the quality of the derived products are reviewed.

2. Agro-Industrial By-Products in Poultry Nutrition

2.1. Fruit Juice Industry Leftovers

The global production of apples was estimated to be about 9.3 million tons in 2021 [23]. Apple pomace (AP) is a by-product of apple processing and cider production, and it is estimated that 4 million metric tons (MMT) are produced globally every year [24]. AP is a significant by-product in many European countries, such as the UK, France, Spain, Ireland, and Germany. The most popular way of utilizing this by-product is by incorporation in animal feed [25]. AP consists of peel, core, seed, calyx, stem, and soft issue [26], and accounts for 25–35% of the weight of the processed raw material [27].

In broilers, dietary inclusion of 3–6% dried AP did not affect growth performance, gut morphometry, and histopathology but increased the weight of ileum and ceca and the ileum digesta viscosity and influenced the activity of some bacterial enzymes in the ileum [28]. However, the incorporation of higher levels of apple by-products in broiler diets provided unfavorable results. Air-dried apple peel waste at 50 g/kg of diet did not affect growth performance, while a level of 100 g/kg decreased the weight gain of broilers. Both dietary interventions had positive effects on the weight of some organs of the gastrointestinal system, blood cholesterol levels, digestibility, and the heat stress response of broilers [29]. Similarly, inclusion levels of 12–20% of dried AP adversely affected growth performance, immune response, gut development, antioxidant capacity, and blood biochemical parameters of broilers. AP was included in the feed in a dried and ground form [26].

In laying hens, dietary incorporation of dried AP up to 10% with the concomitant addition of a multi-enzyme additive at 0.05% improved laying hens' performance, egg traits, and blood parameters without influencing other traits. The AP was dried and fine-milled before incorporation in the diet [30]. Inclusion of 10–25% dried AP enhanced reproductive performance, semen quality, and fatty acid profile of spermatozoa in aging broiler breeder roosters. The AP was dried, ground, and screened prior to inclusion in the diet [31]. In a study focused on geese, 7% dried AP application resulted in enhancement of egg laying performance and vitality of goslings [32].

The global production of oranges was estimated to be around 75.57 million tons in 2021, and the global production of lemon and limes was 20.828 million tons [23]. Orange by-products (e.g., peels, seeds, and membranes) are an essential waste stream in South European countries such as Spain, Italy, Greece, and Portugal [25]. The utilization of orange processing by-products in animal nutrition is the most widely used practice [25]. The primary by-products from citrus processing are fresh citrus pulp (CP) or dried CP (DCP). Fresh CP is the residue that results from the extraction of juice, while DCP is generated by shedding, liming, pressing, and drying the peel, pulp, and seed residues [33]. Although the protein content in CP is low, enhancement was observed with ensiling to a level comparable to cereal grains. In regard to antinutritional factors, protease inhibitors, phytate, and tannins are present in citrus peel [34].

Dried sweet orange (*Citrus sinensis*) peel (DCSP) in broiler diets at levels of 0.5–2% DCSP reduced liver and abdominal fat and serum triglycerides without negative effects on feed conversion ratio (FCR) [35]. In another study, the application of 0.8% DCSP powder in the diet reduced some blood biochemical parameters (e.g., cholesterol) of broilers without adverse effects on growth performance and carcass traits [36]. Inclusion rates of 1.5–3% DCSP in broiler diets did not affect final weight and carcass characteristics [37]. Concurrently, supplementation with 3% DCSP decreased plasma cholesterol, low-density lipoprotein, and triglycerides levels [38] but reduced feed intake, body weight gain, and increased feed conversion rate during the starter and grower period [37]. Moreover, the blood biochemical parameters, such as plasma cholesterol, triglyceride, and aspartate aminotransferase of broilers, decreased linearly with increasing dried citrus waste from 2.5 to 7.5% in the diet. The citrus waste used was sun-dried and ground prior to incorporation into the diet [39]. However, the substitution of maize with DCSP at levels up to 20% in broiler diets did not influence growth performance, health, and weights of the most significant carcass cuts and internal organs, while substitution levels higher than 20% decreased body weight and some carcass cuts. In this study, the peels were sun-dried and milled before inclusion in the diet [40]. The modified blood biochemical profiles reported in the above-mentioned studies may be explained by the presence of vitamin C and other components of DCSP [35].

DCP inclusion rates of up to 10% in broiler diets did not affect intestinal morphometry [41], body weight, carcass traits, and meat quality, but it favorably decreased oxidation rate in chicken meat [41,42] and increased PUFAs, n-3-, and n-6 fatty acid contents in the breast intramuscular fat [42]. On the contrary, CP inclusion in broiler's diets at levels of 5–10% exhibited an increase in feed intake and feed conversion rates, and significantly decreased daily weight gain, while elevated small intestine relative length and decreased carcass yield were observed, with the 10% CP group recording significantly higher PUFA content [43]. The incorporation of sun-dried lemon pulp at levels of 2.5–12% in broiler diets worsened growth performance, intestinal morphology, and humoral immunity [44].

Other poultry species have also been examined in relation to CP utilization. In ostrich diets, supplementation of 20% DCP (ground prior to inclusion in the diet) elevated PUFA content and n-6/n-3 ratio of meat and decreased meat cooking loss [45]. In goose diets, the application of DCP up to 12% did not influence growth performance and carcass yield. Lime was added to the CP prior to drying [46]. In hen diets, DCP inclusion of up to 9% supported egg yolk oxidative stability but deteriorated growth performance and egg quality [47]. Conversely, the incorporation of dried DCP at 12% in hen diets did not influence performance and egg quality in the early phase of production [48]. In quail diets, dietary addition of 3–6% DCP did not affect performance but influenced egg traits [49]. Key ingredients in various agro-industrial by-products are summarized in Table 1.

Table 1. Key ingredients in agro-industrial by-products.

By-Product Origin	Agro-Industrial By-Product	Key Ingredients	References
Apple	Apple pomace	Pectin, catechins, hydroxycinnamates, phloretin glycosides, quercetin glycosides, procyanidins	[50,51]
Citrus fruits	Citrus pomace	Essential oil (mainly monoterpenes and triterpenoids), phenols (coumaric, caffeic, and ferulic acids), and flavonoids, mainly flavanones glycosides (hesperidin, naringin, and narirestin), flavones (hesperetin, naringenin), flavones aglycon (luteolin), and polymethoxylated flavones (tangeretin)	[16,52]
	Citrus seeds	Flavonoids	[53]
	Orange peels	Vitamin C (ascorbic acid), phenolic compounds, pectin, coumarin, volatile oils, flavonoids, and flavones (hesperidin, naringenin), nobiletin D-limonene and pigments (carotenoids)	[37]
	Lemon peels	Hesperidin and eriocitrin	[54]
Sunflower	Defatted cake	Peptides	[51]
Dried distillers' grain with solubles	Corn dried distillers' grain with solubles	Betaine and phenolic compounds	[55]
Grape and winery by-products	Grape pomace	Polyphenols (catechin, epicatechin, procyanidin B1, quercetin and kaempferol)	[56]
	Red grape pomace	Anthocyanins, flavonols	[57]

Table 1. *Cont.*

By-Product Origin	Agro-Industrial By-Product	Key Ingredients	References
Olive	Olive pomace	Hydroxytyrosol, tyrosol, caffeic protocatechuic, vanillic, p-coumaric and syringic acids, vanillin, oleuropein, apigenin	[51,58]
	Olive mill wastewater	Hydroxytyrosol, gallic acid, oleuropein, ligstroside isomers and derivatives, squalene, tocopherols, triterpenes, soluble sugars, polyphenols	[51]
	Olive flesh, stone, and seeds	Polyphenols, tocopherol	[51]
	Olive leaves	Polyphenols	[51]
Pomegranate	Pomegranate husks	Poly- and monomeric phenols	[51]
Tomato	Tomato skin and seeds	Lycopene, β-carotene, sterols, tocopherols, terpenes, glycoalkaloids	[51,59]
Brewing industry	Brewer's spent grains	Xylitol, cellulose, hemicelluloses, lignin, xylose, glucose, arabinose, protein, ferulic and p-coumaric acids	[51]

Based on references [51,60].

2.2. Nonconventional Oilseed Industrial By-Products

Sunflower seed global production was approximately 58.185 million tons in 2021 [23]. SFM is a by-product of oil extraction from sunflower seeds and can be used as a protein source for broilers [61]. There is variability between SFMs depending on the processing methods used to extract the oil (solvent/crush) [62]. The main antinutritional factor found in SFM is chlorogenic acid [63]. The main constraint in using high inclusion levels of SFM in broiler diets is the high fiber content, which is higher than 11–12%, including dehulled SFM [64].

In broilers, dietary levels of SFM up to 12% did not affect body weight, feed intake, feed conversion ratio, mortality, the European Production Efficiency Factor index, carcass percentage, and cut yield [65]. SFM at levels up to 140 g/kg in the diet enhanced the performance of broilers without worsening digestive enzyme activity, organ weight, and histological alterations of intestinal villi [66]. SFM inclusion at 15% in diets formulated on digestible amino acid basis improved broilers' performance and did not affect carcass and cut yields but resulted in an increase in digesta viscosity [67]. However, increment levels of SFM in the diet was found to deteriorate performance (reduced weight gain and increased feed conversion ratio) and carcass traits (linear reduction of a carcass, breast, breast fillet, and abdominal fat weights) of broilers, but the inclusion of 8% SFM and an enzyme mixture had the highest economic efficiency index among the groups [68]. SFM supplementation at 20% in the diet improved the feed/gain ratio and reduced feed intake in the starter and total period, but weight gain and carcass or cut yields were not affected [69]. High-protein SFM (45.4% crude protein) was recommended to be included in the broiler diets at different levels during the starter (up to 10%), grower (up to 20%), and finishing period (up to 23%), which did not affect growth performance. Furthermore, the substitution of 10% soybean meal with SFM can decrease diet costs by 3.74% to 4.61%, depending on the rearing period [70]. Moreover, high-protein SFM was suggested to be added in broiler diets at different levels during starter (5–15%), growing (8–20%), and finisher (12–22%) periods without affecting body weight and feed conversion ratio [71]. However, high-protein SFM incorporation at levels of between 10 and 15% in the diet deteriorated growth performance, but it was attributed to the lower than the optimum size of the particles of the feed [72]. Low-fiber SFM addition of up to 25% in diets led to growth performance and carcass traits of broilers comparable with broilers fed soybean meal-based diet [73].

On the other hand, sunflower cake inclusion reduced the performance of broilers (1–21 d), but the loss of weight was regained during 22–42 d with a corn-and-soybean-based diet; however, compromised carcass yield and intestinal morphometric development were observed [74]. Similarly, the inclusion of up to 16% SFM negatively affected performance and intestinal morphometry without influencing carcass yields, but the addition of an enzyme complex prevented the above-mentioned negative effects [75]. Likewise, weight gain was compromised by the incorporation of 10 or 16% SFM in the finisher diet of broilers, and gut viscosity was increased in the 16% SFM group, while enzyme supplementation counteracted these effects, especially during the growing period [76]. The above studies showed inconsistent results on utilizing SFM in broiler diets in terms of growth performance. In laying hens, dietary levels up to 25% SFM did not affect performance or egg fatty acid content and reduced yolk cholesterol level and production costs [77]. Similarly, the inclusion of up to 20% SFM in the diet of dwarf dam line hens did not affect egg quality characteristics apart from the Haugh unit that was increased [78].

2.3. Dried Distillers' Grain with Solubles

Dried distillers' grain with solubles (DDGS) is a co-product generated from the production of bioethanol by the extraction of starch from cereals during fermentation [79]. Approximately 40 million tons of DDGS are produced worldwide, with the USA accounting for 58% of global production [80]. DDGS is produced mainly by wheat in Europe, while in North America, it is generated mainly by maize. Maize DDGS contains high levels of crude protein (30%), but the content of lysine is low, and it is not consistent [81]. DDGS are one of the most studied co-products in poultry nutrition compared to other by-products. DDGS exhibits high nutrient variability depending on its source [82]. The main limitations of the wide use of DDGS in animal nutrition include the high variability of nutrient composition and the mycotoxin occurrence [83], which is discussed in Section 3.

In broilers' diets, the incorporation of 8, 16, and 24% DDGS increased body weight gain without other adverse effects [84]. Inclusion levels up to 160 g/kg in broiler diets from 22 to 42 d did not affect performance, carcass and cut yields, meat quality, and litter characteristics [85]. In the starter period of broilers, an 8% DDGS level did not have any effect on their growth performance. On the other hand, in the grower period, body weight gain and liver-relative weight (g of organ/kg of body weight) reduced linearly with increasing levels of DDGS, but feed conversion, mortality, ileal viscosity, and cecal *Clostridium perfringens* and *Escherichia coli* concentrations were not influenced by DDGS dietary levels (7.5, 15, 22.5, and 30%) [86]. In another study, a dietary level of 8% in the starter period of broilers increased the feed conversion ratio, while during the grower period, levels up to 14% did not affect growth, feed intake, carcass yield, and breast meat yield [87]. Corn-based DDGS supplementation at values up to 15% in broiler diets was found to affect specific meat quality traits and liver malondialdehyde production but increased PUFA/SFA ratio [88]. The meat quality of breast and thigh meat of broilers was not affected by dietary inclusion with 6 or 12% DDGS but levels greater than 12% increased total PUFAs, linoleic acid, and susceptibility of thigh meat to oxidation [89]. High-protein DDGS in the diet of broilers did not affect performance and can cover the requirements for supplemental lysine and arginine since DDGS can be a good source of digestible lysine [90]. Low-oil DDGS could be included at 10% in broiler diets providing improved performance or 20% with no adverse effects on performance traits [91]. From an environmental standpoint, although DDGS can be beneficial in poultry nutrition, considering DDGS as broiler feed was found to have the highest effect on elevating greenhouse gas emissions and fossil fuel consumption in comparison with diets containing soybean meal, corn, or synthetic amino acids [92].

In laying hens, no significant negative effects were observed on the production or egg traits of hens. More specifically, dietary levels of DDGS up to 32% resulted in darker (L* value) and redder (a* value) yolk, with the 16% DGGS group achieving the highest egg production compared to the 0, 8, and 24% DGGS groups [93]. In another study, inclusion levels up to 15% (from 24 to 46 wk.) and up to 25% (from 47 to 76 wk.) in hen diets did not have negative effects on performance characteristics, egg production, and quality traits, while nitrogen and phosphorus excretions were lower at the DDGS level of 25% [94]. Another study suggested that incorporating up to 12% dietary levels of DDGS in hens' diets may lead to better performance in terms of feed intake, feed conversion ratio, and egg production [95]. Likewise, supplementation of hens' diets with up to 10% DDGS did not have detrimental effects on laying performance, while enzyme supplementation may improve the use of DDGS at levels up to 20% [96]. Higher levels of DDGS in the diet, up to 50%, were found to elevate lutein and PUFA contents in egg yolk without affecting cholesterol and choline contents [97].

In a study assessing the sustainability of utilizing DDGS in laying hens' diets, it was indicated that substituting 25 or 50% of soybean meal in the diet reduced nitrogen and phosphorus excretion in hens and thus decreased pollution of these elements in the environment was achieved without affecting nutrient digestibility [98]. The reduction of nitrogen excretion may be due to the increased digestibility of the diet, while the reduction of phosphorus excretion is due to the increased bioavailability, which results in the heat-mediated destruction of phytate during drying. Moreover, the addition of 20% DDGS in hen diets aged 21–26 wk. was found to reduce daily NH_3 and H_2S air emissions by 24% and 58%, respectively, while egg weight, egg production, and feed intake were not affected [99]. In ducks, a study suggested that dietary inclusion of 10% corn DDGS did not have adverse effects on growth performance, carcass characteristics, serum biochemical indexes, meat physical and chemical quality, nutrient utilization, and the standardized ileal digestibility of amino acids of the diets [100].

2.4. Vinification By-Products

Global production of grapes accounts for 73.5 million tons annually [23]. Grape pomace (GP), which is the solid residue of grapes, constitutes around 20% of the total grape weight and results from the extraction of the juice for winemaking. It is estimated that more than 9 million tons of GP are generated every year [101]. GP comprises the skins, seeds, and stems of grapes [102]. The use of GP in monogastric nutrition is limited due to the high content of the lignified cell wall fraction and the high level of some antinutritional factors, such as condensed tannins and phytic acid, which are present in lower levels [102–104]. Treatment of GP with polyethylene glycol can inactivate, to some extent, condensed tannins [105,106].

In broiler diets, diet enrichment of 5–60 g/kg of GP enhanced intestinal morphology, the antioxidant capacity, and PUFA content of breast muscle and reduced serum cholesterol values without affecting feed intake, feed efficiency, growth performance traits and weights of pancreas, liver, spleen, and abdominal fat [107–110]. Similar levels of GP (20–60 g/kg) in heat-stressed broiler diets improved plasma biochemical indices and antioxidant enzyme activities without influencing growth performance, relative length of different small intestine segments, jejunal morphology, and antibody titer against sheep red blood cells [111]. The incorporation of 2.5–7.5% red GP in broiler diets did not affect weight gain, carcass traits, meat quality characteristics, blood biochemical parameters, and serum biochemistry, while an increase in meat redness was observed [112]. The final body, giblets, and breast weight of broilers were elevated after dietary enrichment with 3% of GP into the diet [113] without affecting malondialdehyde values in breast and thigh meat [114]. GP addition at levels of 2.5–7% in the diet increased PUFA levels and reduced the lipid oxidation rate of meat without affecting meat quality characteristics [115]. A higher dietary level of GP (20%) also led to raised antioxidant capacity of chicken meat without affecting the productive traits of broilers [116]. On the contrary, meat lightness and yellowness, lipid oxidation levels, and bacterial spoilage were not affected by the inclusion of lower dietary levels (2.5–10 g/kg) of GP [117]. Dietary levels of GP concentrate at 15–60 g/kg increased the antioxidant capacity of breast muscle, ileal content and excreta without affecting growth performance, crude protein ileal digestibility and the weight of pancreas, liver, spleen, and abdominal fat of broilers [118]. In another study, supplementation of 1.5% red GP improved apparent nutrient digestion, diet metabolizable energy, number of different

Lactobacillus spp. in the ileum, and plasma antioxidant activity without affecting growth characteristics [119]. The addition of GP up to 10% in the diet enhanced the antioxidant and immune responses of broilers without impairing growth performance [120].

In laying hen diets, the incorporation of 4 or 6% did not influence growth traits, egg production, egg quality indices, live weight, and liver weight, while egg weight was enhanced at a 4% dietary level [121]. The inclusion of 1–3% GP in heat-stressed laying hen diets at the end of the productive cycle improved growth performance, egg quality, serum total antioxidant capacity, and the activities of glutathione peroxidase and superoxide dismutase activities [122]. In quail diets, 2–6% GP dietary addition did not affect egg production, feed intake, and feed conversion rate, but a linear reduction of albumen weight, egg-specific gravity, and egg weight with increased levels of GP were observed [123].

2.5. Olive Oil Industry By-Products

Large quantities of olive by-products are generated during olive oil extraction, such as leaves, stones, olive mill wastewater, and the solid wastes' pomace residues and olive cake (OC). In 2020, approximately 3.373 million tons of olive oil were produced worldwide [23]. For every 1 kg of olives, around 800 g of OC is generated [124]. The improper disposal of these by-products is notorious for the impact they pose on the environment due to the phytotoxicity and high organic content of the by-products [125]. Olive pomace, due to its oil content, undergoes rancidity when exposed to oxygen and moisture. Drying may delay this chemical reaction [126].

In broiler diets, supplementation of up to 10% olive leaves or OC did not alter bone mineralization nor affected the growth performance of broilers [127]. For broilers at 1–28 d of age, the optimal production index and productive performance were the achieved with application of 5% OC combined with 0.4 g/kg of *Saccharomyces cerevisiae* yeast [128] or with 10% OC supplemented and 500 FTU/kg bacterial *E. coli* phytase [129,130]. During the final growth stage (28–49 d) of broilers, OC could be added at 10% of the diet or up to 20% supplemented with 1 g/kg citric acid without deteriorating feed conversion and health status [131]. The addition of *Bacillus licheniformis* enhanced the fat and nutrient utilization, growth performance, and antioxidant response in broilers [132]. Furthermore, the addition of fermented defatted OC may favor intestinal mucosa and cecal microbiota of broilers and thus control the dissemination of pathogenic bacteria and improve digestibility and absorption capacity [133]. Likewise, OC at levels up to 10% in diets of slow-growing broilers was found to improve productive traits, meat oxidation, and intestinal morphometric features [134]. In another study, it was concluded that OC at levels above 50 g/kg diet may affect some quality characteristics and the oxidative stability of meat, while at lower levels, the oxidative stability, oleic acid, and monounsaturated fatty acids (MUFA) of meat were increased [135]. Similarly, the addition of 50 g/kg of OC and an enzyme blend significantly increased carcass and offal weights [136] but decreased jejunum weight and length, serum triglycerides, and cholesterol levels of broilers [137]. Higher levels of OC (82.5–165 g/kg diet) seemed to enhance daily weight gain, meat antioxidant status, and oxidative stability [138]. The inclusion of 5% olive pomace in broiler diets also improved breast and thigh sensory attributes and antithrombotic properties [139].

Olive pulp (OP) inclusion of up to 5% in broiler diets did not affect final body weight, carcass yield, total antioxidant activity, and expression of selected antioxidant enzymes [140]. Furthermore, OP incorporation up to 100 g/kg did not affect growth and nutritional characteristics and the nutritional cost of the diet, and no influence of the studied parameters was observed with the addition of an enzyme blend in the diet containing OP [141]. In another study, growth performance, carcass traits, blood biochemistry parameters, humoral immunity response, and cecum microbiota were not affected by the addition of 4% olive meal in broiler diets [142]. Another by-product of olive oil extraction, olive mill wastewater, when added to broiler diets, improved total antioxidant capacity and redox status and reduced protein and lipid peroxidation rates in plasma and tissues [143]. In a recent study, the incorporation of silage from olive mill wastewater solids, grape pomace solids, and feta cheese whey solids at levels up to 10% showed promising results for growth performance and meat quality [144], and increased n-3 fatty acids and antioxidant capacity in meat [145]. The application of an olive pomace extract at 750 ppm in broiler diets positively affected animal growth and anti-inflammatory properties [146]. Likewise, 1500 ppm of an olive pomace extract mitigated some of the adverse effects of the fasting challenge [147].

In laying hens, OC dietary levels up to 16% elevated MUFA and PUFA and reduced saturated fatty acids (SFA) and cholesterol contents in egg yolk without any effects on productive performance [148]. In other studies, 9% OC addition in hens' diets increased egg and eggshell weights and decreased blood triglycerides level [149,150]. Higher levels of OC up to 20% combined with 0.1% citric acid could also be used in hens' diets without adverse effects on blood metabolites, laying performance, and egg quality [151]. In quails, the inclusion of OC at levels of 5–7.5% reduced SFA and PUFA and increased MUFA levels in breast muscle, and decreased total serum cholesterol and low-density lipoprotein cholesterol [152]. In another study, it was observed that up to 10% OC in quail diets improved the antioxidant status, immune response, and growth performance [153]. Similar inclusion levels (5–10%) of OC in laying quails diets led to an improvement in serum lipid profile and antioxidant status, egg cholesterol content, and performance during early laying periods [154].

2.6. Pomegranate By-Products

Pomegranate (*Punica granatum* L.) pulp (PP) is generated during pomegranate juice extraction and comprises outer peel, seeds, and residual pulp [155]. Global production of pomegranate is estimated at about 3 million tons, and the global generation of the by-products (peels and seeds), which account for approximately 54% of the fruit, is calculated to be around 1.62 million tons annually [156]. Fat, crude protein, and fiber contents in PP and their antioxidant properties can be useful in poultry nutrition [17]. Different processing methods have been reported for pomegranate by-products in the literature. In one study, a pomegranate by-product consisting of 80% peel and rind and 20% of seed was dried in a forced air oven (80 °C for 3 d), ground into powder employing a milling machine, and a 0.15-mm sieve, packed in polyethylene bags and stored at room temperature [157]. In another study, fermentation of pomegranate by-products, including peels, rinds, and seeds, was applied by drying in a forced air oven (80 °C, 2 d), grinding and sieving, pasteurization (85 °C, 30 min) and solid substrate fermentation [158].

In broiler diets, the incorporation of 1–2% PP resulted in favorable effects on meat fatty acid levels, increased protein content in the breast, and reduced meat cholesterol and lipid oxidation values [157]. Supplementation with higher levels of PP at 2–4 g/kg supported growth rate, blood serum metabolites, immunological parameters, and meat quality characteristics [159]. Likewise, the inclusion of 2–4 g/kg PP in broiler diets resulted in desirable effects with respect to performance, digestibility, carcass, and organ indices compared to broilers fed a diet supplemented with α-tocopherol [160]. The incorporation of 0.5% PP in broiler rations decreased ascites mortality and favored meat shelf-life without adverse effects on growth performance [161]. Fermented PP inclusion at levels of 1–2% in broiler diet increased daily weight gain and feed efficiency and decreased fecal ammonia emission [158]. Supplementation with similar levels of fermented PP (0.5–2%) also enhanced weight gain, reduced SFA, cholesterol, thiobarbituric acid reactive substances values in meat, and increased levels of n-3 meat fatty acids [162]. On the other hand, raw or fermented PP at levels of 5–10 g/kg affected adversely ileum morphology, but malondialdehyde values in breast meat and *C. perfringens* count were lowered without affecting animal performance and serum antioxidant enzyme values [163]. The inclusion of 7–10% in the diet of heat-stressed broilers enhanced growth performance, blood cholesterol, and antioxidant status [164]. Furthermore, urea-treated PP at values of 30–50 g/kg in the diet of heat-stressed broilers supported growth performance, plasma blood biochemical indices, liver function, immune response, intestinal morphology, and meat quality [165].

Pomegranate seed oil incorporation at a level of 1.5% led to a reduction of total cholesterol levels in blood without affecting liver enzyme activities and lipid contents [166], while abdominal fat level, PUFA content, and conjugated linoleic acids (CLA) deposition in breast increased as indicated in another study [167]. Moreover, the partial substitution of soybean oil with pomegranate seed oil led to elevated levels of punicic and rumenic fatty acids without affecting carcass traits, dressing percentage, and breast and thigh muscle physicochemical composition [168].

In laying hen diets, supplementation with 2–4% pomegranate peel powder improved blood antioxidant activity and reduced plasma cholesterol and triglyceride content [169]. Pomegranate seed oil in hen diets enhanced laying rate, color, and concentrations of punicic acid and CLA in egg yolk [170]. In quail diets, the incorporation of 2.7–7.5% pomegranate peel powder enhanced feed conversion rate, egg performance, and villus height-to-crypt depth ratio, while serum triglyceride, cholesterol, and glucose levels were reduced [171].

2.7. Tomato Processing By-Products

Tomato pomace (TP) is a residue by-product of the paste production industry, which comprises the seeds, skin (or peel), and a small amount of pulp. Global production of TP is estimated to be about 5.4–9.0 million tons [172]. TP accounts for 3–5% of the raw material and can be used as a protein and energy source in poultry nutrition [173,174]. More specifically, TP consists of fibers (59%), sugars (26%), proteins (19%), pectins (8%), fat (6%), minerals (4%), and antioxidants (e.g., lycopene) on a dry basis [175]. Regarding the processing of tomato pulp, in one study, drying (up to 65 °C) until a dry 900 g/kg was reached and grinding using a hammer mill was applied [176].

In broilers, TP at inclusion levels up to 15–20% in the diet improved the economic efficiency without negative effects on performance and carcass characteristics [177–179]. In another study, the incorporation level of 5% TP mitigated the adverse effects induced by heat stress in broilers [180]. Furthermore, the use of tomato waste juice up to 120 mL/day in broiler rations was found to contribute to the development of the internal organs of broilers [181].

In laying hens, dried TP up to 10% in the diet was demonstrated to improve egg quality traits without posing adverse effects on growth performance or other egg characteristics [176,182,183]. Dried TP at increasing concentrations from 5 to 10 g/kg induced a linear increase in feed intake and favored egg performance and egg quality characteristics [184]. The addition of 5% dried tomato waste in hen diets also reduced lipid peroxidation of eggs and enriched them with n-3 polyunsaturated fatty acids (PUFA), but absorption and deposition of n-3 PUFA in egg yolk decreased with increasing dietary levels from 2.5% to 7.5% of tomato waste [185]. In another study, the yolk color score increased with increasing dried TP from 0 to 19% in the hen diet, while animal performance and egg characteristics were not significantly affected [186].

In quails, dried TP can be incorporated at levels up to 4–6% in the diet without adverse effects on growth performance [187]. In the study of Botsoglou et al. [188], PUFA and PUFA/SFA ratio significantly increased in the meat of quails, which were provided with a diet containing 10% dried TP. However, Nikolakakis et al. [189] did not detect any change in the fatty acid profile and composition of quail meat at the inclusion dietary levels of 5–10% dried TP, while growth performance and carcass characteristics were not significantly influenced. Moreover, dried TP at incorporation levels of 2.5–5% alleviated some effects of heat stress in quails and favored feed intake and live weight gain [190].

2.8. Other Agro-Industrial By-Products

Sugar beet pulp (SBP), a by-product of the sugar cane industry, can be a valuable source of highly digestible fibers, pectins, and sugars [191]. Global production of sugar beet was estimated at approximately 270 million tons in 2021 [23]. Antinutritional factors contained in SBP include saponins [192]. In broilers, the incorporation of 2.5% sugar beet meal enhanced growth performance and giblet relative weight [193]. Furthermore, 30 g/kg SBP in diets of broilers from 1 to 10 days of age improved growth performance, the relative weight of gastrointestinal tract and gizzard, gizzard digesta content, and total tract digestibility [194]. Higher levels of SBP up to 50 g/kg benefited the development of the gastrointestinal tract [195], decreased feed conversion ratio, and enhanced nutrient digestibility [196]. However, 75 g/kg SBP may affect growth performance and intestinal mucosa structure [195]. This observation was supported by a study in which 75 g/kg of SBP reduced villus height and villus height-to-crypt depth ratio [197], body weight, weight gain, low-density lipoprotein, and total cholesterol serum levels [198]. However, the ileal digestibility of organic matter, crude fat, and crude protein, and total serum cholesterol concentration were reduced with increasing levels of 23–92 g/kg SBP in broiler diets [199]. Furthermore, aqueous methanolic extract of SBP at concentrations of 100–300 mg/kg showed adequate anticoccidial activity based on the criteria of feed conversion ratio, lesion score, oocyst score, and oocysts per gram of feces [200]. In laying hens, the inclusion of 3–7% SBP enhanced egg performance, egg quality traits, and egg yolk cholesterol, triglyceride, and malondialdehyde levels, and reduced serum biochemical indices, such as cholesterol [201]. Conversely, in quail diets, productive performance, egg quality criteria, and nitrogen balance were not influenced by 20–40 g/kg SBP inclusion; however, reproductive parameters and nutrients' digestibility were negatively affected [191].

Brewery by-products are unpopular in poultry diets due to the high level of the fiber fraction [202]. The main by-products generated during the brewing process include brewers' grain (85% of the generated by-products), malt sprouts, and brewers' dried yeast. Global production of brewer's spent grains is estimated to be about 39 million tons, of which 3.4 million tons are generated in the European Union (EU) [203]. Among the brewery by-products, brewers' dried yeast is commonly used in poultry diets due to its content of riboflavin, niacin, pantothenic acid, choline, and phosphorus [16,60]. Brewers condensed solubles can be used in poultry or turkey diets due to their high energy content ([204], cited by [202]). Substitution of maize with brewers dried grains up to 75% significantly increased final live weight, weight gain, and feed conversion ratio, while feed intake decreased with increased levels of replacement [205]. The addition of sand in pullets diets containing brewers dried grains enhanced digestibility, gain, and feed conversion ratio, while the inclusion of higher levels than 15–20% decreased feed conversion efficiency [206]. Fermented brewer's spent grains incorporation in laying quail diets increased gross egg production, the intensity of egg production, and reduced feed conversion ratio [207]. Furthermore, feeding coarse brewer's spent grain instead of ground to broilers feed increased feed utilization and gizzard weight with apparent metabolizable energy and ileal digestibility not being affected [208]. Significant findings on the inclusion levels of various agro-industrial by-products in poultry diets are summarized in Table 2.

Table 2. Key findings on inclusion levels of agro-industrial by-products in poultry diets.

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Apple pomace (AP)	Broiler	0, 4, 8, 12, 16, or 20% and multi-enzyme	Aghili et al. indicated compromised growth performance and reduced antibody titer production, intestinal morphology, total antioxidant capacity, and blood parameters with increasing dietary levels of apple pomace.	[26]
		0, 3, 6%	Colombino et al. observed an effect on growth performance, gut morphometry, and histopathology, elevated ileum and ceca weight and ileum digesta viscosity and activities of α-glucosidase, α-galactosidase, β-galactosidase, β-glucuronidase, and xylase were influenced.	[28]
	Aging breeder roosters	0, 10, 20, 25%	Akhlaghi et al. demonstrated an improvement in sperm fertility and motility, hatchability rate, seminal total antioxidant capacity and sperm characteristics, and increased values of polyunsaturated fatty acids (PUFA) and monounsaturated fatty acids (MUFA) and integrity of the sperm plasma membrane.	[31]
	Goose	0, 7%, 10%, and 0.05% multi-enzyme supplement	Fiialovych and Kyryliv observed an enhancement in egg laying, hatchability, and vitality of goslings with 7% AP in the diet. Blood biochemical parameters, egg laying rate, and traits were improved with AP up to 10% supplemented with 0.05% multi-enzyme supplement in the diet, without any further adverse effect in laying hens.	[32]
	Laying hen	0, 5, 10, 15% AP and 0 or 0.05% multi-enzyme	Ghaemi et al. indicated that AP levels up to 10% combined with 0.05% multi-enzyme supplement led to enhanced blood biochemical parameters, egg laying rate, and traits without affecting other parameters.	[30]
Apple peel waste	Broiler	0, 50, or 100 g/kg and 0 or 500 mg/kg multi-enzyme	Heidarisafar et al. found increased gizzard and small intestine weights and high-density lipoprotein (HDL) cholesterol levels, decreased low-density lipoprotein (LDL) cholesterol and malondialdehyde content and apparent ileal protein digestibility, while 100 g/kg apple peel waste decreased weight gain of heat-stressed broilers.	[29]
Dried *Citrus sinensis* peel (DCSP)	Broiler	0, 1.5, 3.0%	Ebrahimi et al. demonstrated that final weight, hot carcass weight, and carcass yield were not affected by the incorporation of DCSP at levels 1.5–3%. DCSP addition at 3% during the starter period (1–21 d) achieved the highest values for breast and pancreas weight and ileum length, but during the whole period (1–42 d), the lowest values for breast and thigh weight were indicated at 1.5 and 3% DCSP, respectively. However, reduced feed intake, body weight (BW) gain, and increased feed conversion rate during both the starter and growing periods were indicated.	[37]
		0, 1.5, 3.0%	Ebrahimi et al. DCSP inclusion at the dose of 3% led to a reduction of plasma cholesterol, LDL, triglycerides values, and glucose.	[38]
		0, 0.5%, 1.0%, 1.5%, 2.0%	Abbasi et al. observed an elevation in feed intake and BW gain and a decrease in liver and abdominal fat content and serum triglyceride levels, with feed conversion rate not being affected.	[35]
		0, 0.8%	Alzawqari et al. observed reduced serum glucose, cholesterol, LDL and HDL, triglyceride concentration and enhanced total antioxidant status without affecting feed intake, BW gain, feed conversion rate, and carcass traits with 0.8% DCSP level.	[36]
Citrus sinensis peel	Broiler	0, 10, 20, 30, 40, 50% substitution of maize	Agu et al. indicated a reduction in BW with the substitution of maize with higher than 20% sweet orange peel with feed intake, BW gain, feed conversion rate, weights of the most important carcass cuts (thigh, breast, back, neck, and shoulder) and internal organs (kidney, liver, heart, spleen, and lung) not being influenced. Dressing percent, drumstick, and wing were significantly affected at substitution levels of maize with sweet orange peel above 30%.	[40]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Citrus pulp (CP)	Broiler	0, 5, 10%	Mourão et al. observed elevated small intestine relative length and decreased carcass yield. Furthermore, PUFA meat content, feed intake and feed conversion rate increased, but daily weight gain decreased with a 10% CP dietary level.	[43]
	Ostrich	0, 20%	Lanza et al. indicated that the *iliofibularis* muscle exhibited reduced ultimate pH and lighter color compared to the *gastrocnemius* muscle. M. *gastrocnemius* recorded higher moisture and reduced crude protein contents compared to M. *iliofibularis*. Reduced content of C14:0, C16:0, and C16:1 and increased content of C18:0, C20:2n-6, C20:4n-6, and C20:5n-3 in M. *gastrocnemius* compared to M. *iliofibularis*. The CP group exhibited elevated meat ultimate pH and decreased cooking losses, crude fat, and ash percentages compared to the control. The proportions of intramuscular saturated fatty acids (SFA) and MUFA were decreased in the CP group. The percentage of PUFA (C18:2n-6 and C20:4n-6) and n-6/n-3 ratio in the meat of the CP group was increased.	[45]
Dehydrated citrus pulp	Broiler	0, 2, 4, 6, 8, 10%	Diaz-Vargas et al. did not observe any negative effect on BW, carcass traits, meat quality, and intestinal morphometry among the dietary treatments; however, decreased oxidation rate in chicken meat was observed.	[41]
Orange pulp (OPU)	Broiler	Control (without additives), 50 g/kg OPU, 0.15 ppm Se, or 50 g/kg OPU and 0.15 ppm Se	Zoidis et al. (2022) reported that the OPU and Se-supplemented group and the Se group exhibited enhanced meat oxidative stability (assessed based on malondialdehyde (MDA) content) during frozen storage (90–210 d), with a synergistic action between OPU and Se. BW, cumulative feed intake, feed conversion ratio (FCR), carcass weight, weights of liver, heart, gizzard, fat pad, percentage of chickens standing at the feeder, and percentage of chickens standing at the drinker were not significantly different among dietary treatments. Meat lightness (L*), redness (a*), yellowness (b*), hue angle (H*), chroma (C*) were not significantly different. Meat pH and dressing percentage declined in the OPU groups. The PUFA and α-linolenic acid (ALA) contents in breast meat were elevated in the OPU groups. Feeding and drinking behaviors were not affected by the addition of OPU and/or Se.	[42]
	Laying hen	0, 9%	Goliomytis et al. observed enhanced egg yolk oxidative stability but also a deterioration of performance and egg quality with 9% OPU.	[47]
Dried citrus pulp (DCP)	Laying hen	0, 4, 8, 12, 16%	Nazok et al. stated that dried DCP up to 12% did not affect performance and egg quality in early-phase hens reducing at the same time egg cholesterol levels.	[48]
	Goose	0, 4, 8, 12, 16%	Wang et al. found that dried DCP up to 12% in the diet did not influence weight gain, feed intake, feed/gain ratio, the carcass yields (%) of breast and leg meat, subcutaneous fat and skin, and abdominal fat.	[46]
	Laying quail	0, 3, 6%	Florou-Paneri et al. reported that BW increased in the DCP groups, while BW gain was not influenced among the dietary groups. Egg production declined in the 3% DCP group compared to the control, but no effect was observed in the 6% DCP group. Hatchability increased in the 6% DCP group compared to the control. Average egg weight was higher in the DCP groups. Average specific gravity was decreased in the 6% DCP group compared to the other groups. Mortality was not affected among the groups.	[49]
Citrus waste (CW)	Broiler	0, 2.5, 5.0, 7.5% CW and multi-enzyme	Behera et al. indicated a linear reduction of plasma cholesterol, triglyceride, and aspartate aminotransferase values with increment levels of CW, while total protein, albumin, globulin, and blood urea nitrogen content were not influenced.	[39]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Dried lemon (*Citrus aurantifulia*) pulp (DLP)	Broiler	0, 2.5, 5.0, 7.5, 10, 12%	Basir et al. reported that 2.5–12% DLP dietary levels reduced final BW, daily weight gain, and deteriorated feed conversion rate. The 7.5–12% DLP levels reduced jejunal crypt depth and antibody titers against influenza disease virus and sheep red blood cells.	[44]
Sunflower meal (SFM)	Broiler	0, 4, 8, or 12%	Sangsoponjit et al. reported that BW, feed intake, FCR, mortality, and the European Production Efficiency Factor index of broilers were not significantly affected by the dietary treatments. Carcass percentage and cut yield of breast, fillet, three joint wings, thigh, and drumstick (including abdominal fat) were not different among the dietary treatments. Feed intake was higher in the 12% SFM broiler (22–42 d) group compared to the 8% SFM group.	[65]
		0, 70, 140, or 210 g/kg	Moghaddam et al. observed an enhancement with respect to BW gain, feed intake, and FCR with inclusion levels of SFM up to 140 g/kg, while 210 g SFM/kg had adverse effects on performance. Relative weights of the gastrointestinal tract and gizzard were elevated in the experimental groups. The activities of digestive enzymes (protease and α-amylase) were not affected by the inclusion of SFM in the diet. HDL cholesterol was elevated, while LDL was reduced in the experimental groups. With increasing levels of SFM in the diet, villus height decreased, and crypt depth increased in the duodenum and jejunum.	[66]
		0 or 15%	Araújo et al. reported that 15% SFM incorporation in a diet formulated on a total amino acid basis deteriorated FCR and BW gain and did not affect feed intake, while when the diet was formulated on a digestible amino acid basis, FCR was not affected among treatments. Carcass and cut yields were not affected in the SFM groups, while digesta viscosity was elevated in the 15% SFM group.	[67]
		0, 8, 16, and 24%, and three levels of enzyme blend	Araújo et al. indicated that the weight gain and FCR of broilers (21–42 d) deteriorated with increasing levels of SFM. The most favorable economic efficiency index was recorded in the 8% SFM group. Carcass, breast, breast fillet, and abdominal fat weights were reduced with increasing levels of SFM in the diet.	[68]
		0 or 20%, with or without enzyme complex	Tavernari et al. did not observe any interactions between SFM and the enzyme blend with respect to performance. In the starter phase and total period, feed intake was decreased, but weight gain did not differ. The feed/gain ratio was enhanced in the SFM groups in all phases. Weight gain was higher in the groups fed the enzyme complex in the starter phase. Dietary apparent metabolizable energy corrected for N values was not affected by the supplementation of the enzyme complex, while apparent metabolizability coefficients of P and Ca were enhanced. Carcass and cut yields were not influenced by the SFM or enzyme complex dietary addition.	[69]
		0, 4, 8, 12, or 16% SFM, with or without enzyme complex	De Oliveira et al. reported that growth performance deteriorated with the dietary addition of SFM, but weight gain and feed intake increased with the enzyme supplementation. Intestinal morphometry was impaired by the SFM inclusion in the diet, but the parameter was improved with the enzyme supplementation in the diet. With an increasing level of SFM, the villus height in the jejunum and the crypt depth in the duodenum and ileum were reduced linearly. Higher villus height in the duodenum and decreased crypt depth in the jejunum were observed in the enzyme-supplemented groups. Significant differences were observed with respect to villus height in the duodenum and ileum among the groups. Wing yields linearly increased with increment dietary levels of SFM. Thigh and leg yields were higher in the groups fed SFM than in the enzyme-supplemented groups.	[75]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
		Group I (0% SFM or enzyme blend), group II (6% SFM in grower and 10% in finisher diet, with or without 0.01% enzyme blend), group III (8% in grower and 16% in finisher diet, with or without 0.01% enzyme blend)	Horvatovic et al. indicated an enhancement in weight gain and FCR by the enzyme supplementation during the grower phase, while weight gain decreased by the SFM addition in the diet during the finisher phase. Feed intake was unaffected by the inclusion of SFM or enzyme blend. The 16% SFM group had elevated ileal viscosity, and the interaction between diet and enzyme on the parameter was significant. Dressing percentage and breast, thigh and drumstick, and abdominal fat yields were not affected in the experimental groups. Decreased maltase activity was observed in the SFM groups.	[76]
	Laying hen	8.26, 16.52, or 24.84%	Shi et al. did not observe any significant differences with respect to growth performance (BW gain, egg production, daily egg mass, daily feed intake, and feed conversion) and egg quality (average egg weight, egg specific gravity, shell strength, shell color, shell thickness, shell percentage, albumen percentage, yolk percentage, yolk color, and Haugh units). C17:0 fatty acid concentration in yolk was reduced in the SFM groups, while no differences were observed for yolk SFA, MUFA, and PUFA. Egg yolk cholesterol (at 6 wk) decreased in the SFM groups.	[77]
		0, 10, 15, or 20%	Das et al. reported that there were no significant differences in egg quality traits, except for the Haugh unit, which was higher in the white dwarf line compared to the colored dwarf, and an increasing effect on the parameter was observed due to the inclusion of SFM in the diet. Significant differences in egg quality traits depending on the line (white-plumaged dwarf broiler breeder dam line or colored dwarf dam line hens) were observed.	[78]
High-protein sunflower meal (HPSFM)	Broiler	Starter diet (from 5 to 15% HPSFM and from 20 to 29.9% soybean meal (SBM)), grower diet (from 10 to 25% HPSFM and from 5.5 to 20% SBM), finisher diet (from 15 to 26.5% HPSFM and from 0 to 11.3% SBM)	Gerzilov and Petrov did not observe any differences with respect to BW among treatments. The lowest costs for 1 kg weight gain were recorded in the group fed 10% HPSFM and 24.9% SBM during the starter phase (1–10 d), 20% HPSFM and 10.5% SBM during the grower phase (11–24 d), and 23% HPSFM and 3.5% SBM during the finisher phase.	[70]
		Group I (5, 8, and 12% in starter, grower, and finisher diets, respectively), group II (15, 20, and 22%, respectively), group III (32.95, 28.55, and 26.50%, respectively)	Kyrkelanov et al. reported a significant increase in BW at d 10 in groups I and II (5 and 15% HPSFM in the starter phase, respectively). In the grower and finisher periods, live BW was not significant among treatments. FCR was improved from d 0 to 10 in group I, while group III recorded the highest value among the treatments. During the grower and finisher phases, no significant differences were observed for FCR among treatments. The daily gain was not different among treatments at d 42.	[71]
		0, 10, 15%	Chobanova indicated that live weight was decreased, and the feed/gain ratio increased in the HPSFM groups.	[72]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Low-fiber sunflower meal (LFSFM)	Broiler	0, 25, 50, or 75% substitution of SBM with LFSFM, and 0 or 0.2 g/kg phytase	Ciurescu et al. reported that substitution of SBM with LFSFM beyond 25% reduced FCR and BW gain. No interactions were observed with regard to the inclusion of LFSFM and phytase on growth performance. Carcass traits were not affected in the experimental groups. Abdominal fat was reduced in the 50 and 75% LFSFM groups, while the weight of the small intestine was elevated. Plasma HDL cholesterol and total cholesterol increased by the inclusion of LFSFM in the diet.	[73]
Sunflower cake (SC)	Broiler	0, 5, 10, 15, or 20% SC, with or without enzyme complex	Berwanger et al. indicated that, with increasing levels of SC in the diet, the weight gain, final weight, and feed intake linearly decreased during d 1–21. During the 1–21 d period, carcass yield was reduced, and abdominal fat increased in the SC groups. Thigh, breast, and carcass yield increased with the supplementation of the enzyme complex in the diet. At d 21, villus height decreased, and crypt depth increased with increasing levels of SC.	[74]
Dried distillers' grains with solubles (DDGS)	Broiler	0, 10, 40, 70, 100, 130, or 160 g/kg	Damasceno et al. reported that BW gain, feed intake, and FCR of broilers (22–42 d) were not significantly different among treatments. Serum total protein concentration, uric acid (UA), and gamma-glutamyl transferase were not affected, but there was a quadratic effect on cholesterol with the highest concentration at the 160 g/kg DDGS group. Blood glucose was elevated in the experimental groups, while serum albumin concentration and aspartate aminotransferase concentrations were higher in the 160 g/kg DDGS compared to the control. Carcass, breast, legs, and wings yield, abdominal fat percentage (42 d), meat pH, water retention capacity, cooking loss, shear force, luminosity (L*), redness (a*), and yellowness (b*) were not affected by dietary treatment. Volatilized ammonia levels, litter pH, and dry matter were not influenced by the inclusion of DDGS. Relative weights of the proventriculus, gizzard, pancreas, small and large intestine, and intestine length were not different among treatments, but relative liver weight decreased in the 10 g/kg DDGS group.	[85]
		5% conventional DDGS (control group), or 10, 15, or 20% high-protein DDGS (34% crude protein on a wet basis)	Fries-Craft and Bobeck indicated that BW was lower, feed intake was not influenced, and thus FCR was higher in the 15 and 20% high-protein DDGS groups compared to the control. The standardized ileal amino acid digestibility of lysine and methionine was found to be 80.9% and 88.6%, respectively. The N-corrected metabolizable energy of high-protein DDGS was determined to be 11.4 MJ/kg.	[90]
		0, 8, 16, 24%	Shim et al. reported that the BW gain of broilers was not significantly different at 42 d, but the parameter was elevated during 0–18 d in the DDGS groups. The percentage of the fat pad of female broilers was reduced with increasing levels of DDGS. The Pellet durability index was reduced due to the incorporation of DDGS. In the second experiment, higher BW gain in the DDGS groups compared to the control was observed.	[84]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
		Starter diet (0 or 8% DDGS), grower diet (0, 7.5, 15, 22.5, or 30% DDGS)	Loar II et al. reported a linear decrease in pellet quality with increasing levels of DDGS. BW gain and relative liver weight decreased linearly with increasing levels of DDGS during the starter phase. Broilers that were not fed DDGS during the started phase had reduced feed consumption with increasing levels of DDGS during the grower phase; however, the 8% DDGS group (starter phase) was not affected by DDGS inclusion during the grower phase. Feed conversion, mortality, ileal viscosity, and cecal *Clostridium perfringens* and *Escherichia coli* concentrations were not affected in the grower DDGS groups.	[86]
		0, 5, 10, 15, 20, and 25%	Min et al. reported that increased b* (yellowness) values and shear force, decreased cooking loss, and differences in the fatty acid profiles of the breast and thigh were observed. SFA, MUFA, and PUFA were not affected, but PUFA/SFA ratio was elevated total superoxide dismutase (SOD) activity in breast meat and liver tissue decreased. Total SOD activity in breast and liver tissue decreased in the DDGS groups. Glutathione peroxidase (GPx) activity in the liver was similar between 0 and 15% DDGS groups. MDA production of breast muscle was not affected, but liver MDA increased.	[88]
		Starter and grower diet (0 or 8%), finisher diet (0, 7, 14, 21, or 28%)	Loar II et al. indicated an increase in FCR and a decrease in BW gain during 0–28 d. During the finisher phase, increasing levels of DDGS in the 14, 21, and 28% DDGS groups, BW gain, and feed intake decreased linearly in comparison with the control. Dressing percentage and breast meat yield decreased linearly with increasing dietary levels of DDGS. Large intestine and relative gizzard weights increased linearly with increasing levels of DDGS during the finisher phase. *E. coli* concentrations in the ileum exhibited a linear reduction with high levels of DDGS. Interactions between *E. coli* and *Listeria monocytogenes* in the ileum and for *L. monocytogenes* in the ceca were observed during the pre-finisher and finisher phases.	[87]
		0, 6, 12, 18, or 24%	Schilling et al. did not observe any differences in terms of cooking loss, instrumental color, and consumer acceptability of breast meat among the groups, but the shear force of breast meat from the control group was slightly reduced compared to the 18 and 24% DDGS groups. The proximate composition of breast and thigh meat was no different among treatments. Linoleic acid and PUFA increased linearly with increasing levels of DDGS, and thiobarbituric acid (TBA) values were higher in the 18 and 24% DDGS groups at d 5 in comparison with the control and 6% DDGS groups.	[89]
	Laying hen	0, 8, 16, 24, or 32%	Loar II et al. reported that egg production was higher in the 16% DDGS group compared to the 0, 8, and 24% DDGS groups, while the 32% exhibited intermediate values with no significant differences with the other treatments. Incorporation of DDGS in the diet led to darker (L*) and redder (a*) yolk compared with the control group. The flavor and overall consumer acceptability of eggs were slightly better in the case of DDGS-fed hens compared to the non-DDGS-fed hens.	[93]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
		0, 5, 10, 15, 20, or 25%	Masa'deh et al. reported that daily feed intake, egg production, and overall weight gain were unaffected by the inclusion of DDGS in the diet. Egg weight decreased at dietary levels of DDGS past 15% during 24–46 wk, while the parameter was not different during 47–76 wk. Yolk color increased with increasing dietary levels of DDGS. N and P retention was higher in the 25% DDGS group, and N and P excretion decreased linearly with increasing levels of DDGS in the diet.	[94]
		0, 17, 35, or 50%	Sun et al. indicated that total PUFA increased in the DDGS groups, while choline and cholesterol contents were higher in the 50% DDGS during the beginning of the 24-wk study period but did not differ at the end of the period in comparison with the other treatments. Lutein content increased linearly with increasing dietary DDGS levels.	[97]
		0, 6, 12, or 18%, and 0 or 250 mg enzyme mixture/kg	Abd El-Hack et al. reported that the lowest egg production and daily feed intake and the worst FCR were observed in the 18% DDGS group. Shell thickness and shell percentage were increased in the 6% DDGS group. The 6% and 12% DDGS groups exhibited higher egg weights compared to the control and 18% DDGS groups. The interaction effect of DDGS and the enzyme mixture was significant in most of the egg traits. Yolk color density increased with increasing dietary levels of DDGS. Yolk cholesterol, total fat, and total USFA increased in the DDGS groups.	[95]
		0, 5, 10, 15, or 20%, with or without two different enzymes	Shalash et al. indicated that no significant differences were observed with respect to digestibility coefficient values of crude protein, ether extract, crude fiber, nitrogen-free extract, BW gain, feed intake, and egg quality by the addition of DDGS in the diet. No significant differences were observed for semen quality, fertility, hatchability, and BW of chicks in the hatch in the experimental groups. Egg production, egg number, and egg mass were elevated in the 5% DDGS group. In the 15 and 20% DDGS groups, yolk color and shell thickness increased, while egg production, egg number, egg weight, and egg mass decreased, with the FCR being the worst compared to the 0, 5, and 10% DDGS groups. Enzyme supplementation exhibited favorable results with respect to the digestibility coefficient value of ether extract and egg traits.	[96]
	Laying hen	0, 10, 20%	Wu-Haan et al. reported that egg production, egg weight, and feed intake were not influenced by dietary treatments. NH_3 emissions of hens (21–26 wk) were reduced by 24% and H_2S emissions by 58% in the 20% DDGS group compared to the control.	[99]
		0, 25, 50, 75, or 100% substitution of SBM with DDGS (corresponds to 0, 5.5, 11, 16.5, and 22% DDGS in the diet, respectively), and additives (without, 250 mg enzyme/kg, or 200 mg vitamin E/kg)	Abd El-Hack et al. reported that digestion coefficient values of nutrients were improved in the 25% DDGS substitution group of hens (22–42 wk), whereas the 100% DDGS group exhibited a reduction of the parameter. The amount of daily excreted N was reduced in the 25 and 50% DDGS groups, while N excretion was increased in the 75 or 100% DDGS groups. P excretion was reduced with increasing substitution levels of DDGS. The supplementation with the enzyme nor vitamin E did not affect the studied parameters.	[98]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
	Duck	0, 5, 10, 15, 20%	Ding et al. reported a linear and quadratic decrease in BW (42 d), average daily gain, and average daily feed intake from d 11 to 42, breast meat yield, the moisture and protein content in the breast meat, and dietary dry matter and ether extract utilization with increasing levels of DDGS in the diet. b* value of the breast meat and serum total cholesterol and triglyceride concentrations exhibited a linear and quadratic increase. No negative effects were observed with respect to growth performance, carcass characteristics, serum biochemical indexes, meat physical and chemical quality, nutrient utilization, and the standardized ileal digestibility of amino acids of the diets in the 10% DDGS group compared to the control.	[100]
Low-oil distillers dried grains with solubles (LO-DDGS)	Broiler	0, 10, or 20%	Guney et al. indicated that feed efficiency (0–18 d) was enhanced in the 10% LO-DDGS group compared to the 20% LO-DDGS group. Abdominal fat pad weights were elevated in the 10 and 20% LO-DDGS groups. BW and fat pad weights varied depending on the source (sample) and levels of DDGS.	[91]
Grape pomace (GP) and fermented grape pomace (FGP)	Broiler	Basal diet (no additives), 0.25 g/kg synthetic antioxidants (AO), 15 g/kg GP, or 15 g/kg FGP	Gungor et al. reported that mortality rate, dressing percentage, and relative weights of heart, liver, gizzard, gastrointestinal tract, abdominal fat, spleen, and edible internal organs were not different among the treatments. pH and L*, a*, and b* values, MDA level, pH, and color of breast meat were not different among the treatments. Elevated serum GPx and SOD concentrations, and ileum lamina muscularis thickness were observed in the GP groups, while caecal bacterial species were not affected. Dietary inclusion of FGP increased BW, the serum catalase (CAT) level, and decreased the caecal *C. perfringens* count, while ileal morphology was not affected. The AO groups exhibited similar growth performance to the FGP group but recorded better BW and FCR than the GP group. The villus height and villus height-to-crypt depth ratio were higher in the AO group compared to the control. Lamina muscularis mucosa thickness was higher in the GP group compared to the FGP group.	[109]
Grape pomace	Broiler	5, 15, 30 g/kg	Goñí et al. observed increasing content of α-tocopherol concentration in liver with increasing GP dietary levels, but it was lower than in the case of vitamin E dietary supplementation. Furthermore, lipid oxidation of meat during refrigeration storage was reduced.	[108]
		0, 5.0, 7.5, 10 g/kg	Aditya et al. found that BW, feed intake, FCR, serum levels of glucose, triglyceride, and HDL cholesterol were not influenced. Thiobarbituric acid reactive substances (TBARS) linearly increased with increment levels of GP. Meat color values such as redness decreased.	[107]
		0, 3, 6%	Turcu et al. found a higher meat color difference for breast and thigh meat, increased meat hardness, improved meat color and texture, and decreased TBARS in thigh meat. Breast meat yellowness value increased at 6% white GP dietary inclusion, while the intensity of breast meat red color (C*) was reduced at 6% red GP dietary inclusion.	[110]
		0, 2.5, 4.5, 5.5, 7.5%	Kumanda et al. reported no effect of red GP dietary incorporation on weight gain, blood biochemical parameters, serum biochemistry, carcass traits, and meat quality characteristics except for increased meat redness, while feed conversion efficiency was higher at 5.5 and 7.5% GP dietary levels.	[112]
		0, 1, 2, 3%	Haščík et al. indicated an increase in the final body, giblets, and breast weight at a 3% GP dietary level.	[113]
		0, 1, 2, 3%	Jurčaga et al. did not observe any effect on lipid oxidation in meat.	[114]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
		0, 2.5, 5, 7.5%	Bennato et al. showed an elevation in PUFA values and a reduction in the lipid oxidation rate of meat without affecting meat pH, cooking loss, and lightness.	[115]
		0, 1.5%	Lichovnikova et al. reported no negative effects on feed intake, feed/gain ratio, and an improvement in apparent nutrient digestion, diet metabolizable energy, number of the considered beneficial bacteria *Lactobacillus* spp. in the ileum, and plasma antioxidant activity.	[119]
		0% GP, 200 mg/kg vitamin E, 5% GP, 7.5%, 10%	Ebrahimzadeh et al. did not observe any negative effects on growth performance, while improved antioxidant and immune responses at dietary GP levels up to 10% were reported.	[120]
		0, 2.5, 5, 10 g/kg	Kasapidou et al. indicated no effect on meat lightness and yellowness, lipid oxidation levels, and bacterial spoilage.	[117]
	Heat-stressed broiler	0 g/kg (rearing at comfort temperatures), or 0, 20, 40, and 60 g/kg (rearing at comfort temperatures initially and heat stress application from d 25 to 42)	Hosseini-Vashan et al. reported that feed intake linearly increased with increasing levels of GP (starter and grower periods), while it linearly reduced blood concentration of triglycerides, plasma cholesterol, LDL, and enzyme activity of aspartate aminotransferase. MDA concentration decreased in the GP groups, and GPx and SOD activities increased. Blood concentration of HDL cholesterol and total protein (24 d) increased in the experimental groups. Antibody titer against sheep red blood cells, growth performance, relative length of different small intestine segments, and jejunal morphology indices were not influenced by GP inclusion in a heat-stressed broiler. Thigh, drumstick, bursa, and thymus percentages were elevated abdominal fat percentage decreased in the GP groups.	[111]
	Laying hen	0, 4, 6%	Kara et al. reported that feed intake, feed efficiency, live weight and egg production, eggshell thickness, eggshell ratio, albumen index, egg-specific gravity, egg yolk index, Haugh unit, yolk color, total protein, total cholesterol, and triglyceride levels were not affected. Egg yolk and plasma malondialdehyde and serum glucose levels decreased. Enhancement of egg weight at 4% GP inclusion and of liver weight at 4 and 6% GP was observed.	[121]
	Heat-stressed laying hen	0, 1, 2, 3%	Reis et al. found that heat-stressed hens at the end of the productive cycle showed elevated serum total antioxidant capacity and GPx and SOD activities, and improved performance, and antioxidant capacity, while it reduced lipid peroxidation rate in the yolk.	[122]
	Quail	0, 2, 4, 6%	Fróes et al. reported no effect on egg production, feed intake, FCR, Haugh unit, and eggshell thickness. Albumen weight, egg-specific gravity, and egg weight were linearly reduced with increment dietary levels of GP.	[123]
Wine-grape pomace flour (WGPF)	Broiler	0% WGPF, 20% red WGPF, or 20% white WGPF	Reyes et al. reported that BW, daily weight gain, feed intake, and FCR were not affected in the white WGPF group. FCR was higher in the red WGPF group. Ether extract of breast meat was higher in the red WGPF group due to the higher inclusion of soy oil in the diet compared to the other groups. The antioxidant capacity of breast and leg meat exhibited an increase in the white WGPF group compared to the other groups.	[116]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Grape pomace concentrate (GPC)	Broiler	Control group (without GP or additives), 15, 30, or 60 g/kg GP, or 200 mg/kg α-tocopheryl acetate (vitamin E)	Brenes et al. reported that growth performance, apparent ileal digestibility of crude protein, the relative weight of abdominal fat, liver, pancreas, and spleen, and the relative intestinal length were not affected by the incorporation of GPC in the diet. Fat digestibility was higher in the vitamin E-supplemented group. The ileal and fecal digestibility of hydrolyzable polyphenols was lower in the GPC groups. Antioxidant activity in the GPC diet, ileal content, and excreta recorded higher scavenging free radical capacity compared to the other groups. The lipid oxidation in breast meat was reduced (1, 4, and 7 d of refrigeration) in the vitamin E-supplemented group. Oxidative stability in breast meat was similar (1, 4, and 7 d) between the GPC and the vitamin E-supplemented groups. The bioavailability of hydrolyzable polyphenols was higher than that of condensed tannins.	[118]
Olive cake (OC)	Broiler	0, 5, or 10% OC and 0.2, or 0.4 g/kg yeast	Al-Harthi reported that the best BW gain, FCR, and European production efficiency index were recorded in the 5% OC plus 0.4 g/kg yeast-supplemented group. The highest survivability rate (100%) was recorded in the 5 and 10% OC plus 0.2 g/kg yeast and the 10% OC plus 0.4 g/kg yeast-supplemented groups. Carcass traits and inner organs were not affected by the addition of OC to the diet.	[128]
		0, 5, 10% OC and 0 or 500 FTU/kg of phytase	Al-Harthi et al. indicated that the growth rate, European production index, and economic efficiency of broilers (7–28 d) were not affected by OC dietary inclusion, while these parameters increased with phytase supplementation. Plasma cholesterol and triglycerides were reduced, and plasma inorganic phosphorus increased with OC and phytase addition. The economic efficiency of broilers fed 10% OC was the highest among treatments.	[130]
		0, 5, 10% OC with or without galzym or phytase	Al-Harthi et al. reported that incorporation of OC up to 10% did not affect BW gain, final BW, survival rate, FCR, dressing percentage, inner and immune organs ratios to live BW 5% OC and galzyme enzyme significantly increased feed intake. 10% OC and galzyme enzyme achieved the best FCR.	[129]
		0, 10, 20% with or without 1 or 2 g/kg citric acid	Al-Harthi and Attia indicated that 10% OC inclusion did not affect the following parameters of broilers (28–49 d): BW gain, feed intake, FCR, survival rate, European production efficiency index, meat pH, meat color, water holding capacity, meat tenderness, dressing percentage, abdominal fat, the proportions of heart, pancreas, intestine, and cecum, red blood cell characteristics, hepatocellular leakage markers; however, the liver proportion was lower compared to the control group. 20% OC and 1 g/kg citric acid did not affect FCR and the health status of broilers.	[131]
		0, 2, 4% OC with or without *Bacillus licheniformis* (BL)	Saleh et al. reported that the inclusion of OC and BL did not influence feed intake, improved weight gain, and reduced FCR, abdominal fat, or blood total cholesterol. Blood total protein, albumin, Newcastle disease titer, and HDL cholesterol were elevated in the experimental diets. Muscle oleic and linoleic acids, and vitamin E were elevated in the 4% OC and BL group, while linolenic acid was elevated in all groups but not in the BL and control groups. Liver MDA was reduced in the BL group and in the 2% or 4% OC and BL groups.	[132]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
	Laying hen	0, 10, or 20% and 0, 0.1, or 0.2% citric acid	Al-Harthi and Attia reported that in the OC groups without citric acid addition, there was no effect on laying performance, egg quality, or liver function indices in laying hens (40–56 wk), but feed intake was increased, and FCR deteriorated compared to the OC-free groups. The relative weight of the liver was reduced when 0.1% citric acid was added compared with the other citric acid-supplemented groups, while the relative weight of the ovary increased compared to the control group. The 0.1% citric acid-supplemented group exhibited similar FCR to the unsupplemented control.	[151]
	Quail	0, 2.5, 5, 7.5%	Ozcan et al. found that the 5 and 7.5% OC meal groups recorded reduced serum total cholesterol and LDL cholesterol levels, and elevated cholesterol levels in the breast muscle. The OC groups had decreased SFA and PUFA, and increased MUFA and total USFA levels in the breast muscle. 5% OC meal was recommended in quail diets.	[152]
Olive cake and olive leaves (OL)	Broiler	0, 5, or 10% OC, or 0, 5, or 10% OL	Pečjak et al. did not observe significant differences in growth performance (final live weight, feed intake) and in the mineral content in the femur, tibia, and humerus among dietary treatments. Higher feed intake in the 10% OL group compared to the 5% OL group during the first wk. In the 5 and 10% OL groups, Cu content in the humerus was higher without affecting bone mineralization.	[127]
Defatted olive cake	Broiler	0 or 2%	Rebollada-Merino et al. indicated that broilers (14–35 d) had increased villus height in the duodenum and villus and crypt depth in the duodenum and the cecum, which may improve mucosal renewal.	[133]
Semi-solid olive cake	Broiler	0, 82.5, 165.0 g/kg	Branciari et al. reported that growth rate increased with increasing levels of OC, and meat antioxidant status and oxidative stability were enhanced, especially at 165 g/kg OC was applied. Meat quality parameters, such as meat color traits, pH_{24}, drip loss, cooking loss, and shear force, were not affected.	[138]
Olive pulp (OP)	Broiler	0, 5, 10%	Tufarelli et al. reported that there was no effect on growth performance, dressing percentage, breast yield, or breast meat fatty acid composition. The meat was less susceptible to lipid and protein oxidation in the experimental diets. Breast muscle pH_{24}, duodenal villus height, crypt depth, and villus height-to-crypt depth ratio, villus surface area were higher in the 10% OP diet.	[134]
		T1: 0% OP, T2: 25 or 50 g OP/kg, T3: 50 g OP/kg, T4: 50 or 80 g OP/kg	Papadomichelakis et al. reported that FCR was higher in T2 and T3 in comparison with the control group during the grower phase, while it was higher in T3 compared to T1, T2, and control groups during the finisher phase. C18:1ω9 and total MUFA contents in breast muscle were elevated in the OP diets. Decreased oxidative stability, lower pH_{24}, and an increased lightness of breast meat were observed in T3 compared to the control, T1, and T2 groups. Papadomichelakis et al. suggested that 25 g OP/kg in grower diets and 50 g OP/kg in finisher diets could be used.	[135]
		0, 2.5, 5, 8%	Pappas et al. reported that no differences were observed in terms of final BW, carcass yield, total antioxidant activity, and the values of serum glutamic oxaloacetic transaminase/aspartate aminotransaminase (SGOT/AST), serum glutamic pyruvic transaminase/alanine aminotransferase (SGPT/ALT), blood urea nitrogen (BUN), γ-glutamyl transferase (γ-GT), alkaline phosphatase, cholesterol, total protein, albumins, globulins, and hematocrit among treatments. FCR was not affected by the inclusion of up to 5% OP, while in the 8% OP group, the parameter was statistically lower.	[140]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
		0, 50, and 100 g/kg processed or unprocessed OP with or without enzyme (ENZ) blend	Sayehban et al. reported that there were no significant differences in feed intake, weight gain, feed efficiency, energy intake, energy efficiency, protein intake, protein efficiency, feed cost per kg live weight, and production index between dietary treatments. The inclusion of processed OP improved feed and energy efficiencies, while the enzyme blend did not affect the studied parameters.	[141]
		50 or 100 g/kg	Sayehban et al. indicated that serum triglycerides and cholesterol levels, jejunum weight, and length were decreased by OP inclusion. Processed OP decreased jejunum weight and length, jejunum relative weight, left cecum length, serum triglycerides, and very LDL cholesterol levels. Enzyme supplementation had no effect on any parameter. 100 g/kg OP levels increased jejunum relative weight and jejunum length.	[137]
	Laying hen	2 control diets, 160 g/kg OP with or without probiotics	Afsari et al. reported that OP dietary addition did not affect egg production and egg mass, BW, and excreta pH, while feed intake, FCR ratio increased, and serum levels of cholesterol and HDL decreased. At sampling week 3, the Haugh unit, yolk color, and shell weight were reduced, while at sampling week 7, probiotic treatment of feed decreased the Haugh unit. At wk 7, yolk color decreased in the OP group. Probiotic treatment decreased egg production and egg mass.	[148]
		0, 4.5, or 9.0% OP with or without 0 or 0.05% enzyme	Zangeneh and Torki reported that experimental diets did not show any significant difference in overall egg production, egg mass, FCR, and feed intake, while eggshell weight was higher in the OP groups than in the control diet. The 9% OP group showed the highest egg weight and decreased Haugh unit compared with the other experimental diets. Enzyme supplementation did not affect egg quality characteristics.	[149]
		0 or 9% OP with or without commercial cocktail enzyme	Zarei et al. indicated a reduction in egg production and blood triglycerides levels, and an increase of the yolk index in the 9% OP group, while there was no effect on feed intake and egg mass between OP and control groups, and between enzyme-fed and control groups. Enzyme supplementation enhanced FCR during wk 6.	[150]
	Quail	0, 50, or 100 g/kg OP (irradiated or not)	Abd El-Moneim et al. suggested that 5% OP or irradiated OP has the highest live BW and daily BW gain and the lowest values of daily feed intake and FCR, followed by the 10% OP group. Digestibility coefficients such as dry matter, organic matter, and crude protein were not affected in the experimental groups except for crude fiber. No effects were recorded in serum levels of total protein, albumin, liver enzymes, UA, creatinine, and lipid constituents of quails in the OP groups, but LDL and serum MDA was reduced. Serum glutathione was reduced, and glutathione reductase was not affected in the OP groups. Antibody titer against sheep erythrocytes was increased in the OP groups.	[153]
	Laying quail	0.1% *Aspergillus awamori*, 5% OP, 5% OP and *A. awamori*, 10% OP or 10% and 0.1% *A. awamori*	Abd El-Moneim et al. reported that the experimental diets had increased egg weight, and final BW, feed consumption, FCR, and egg mass were not affected by dietary treatment. Yolk (%) and yolk:albumin ratio were improved in 5% OP and 0.1% *A. awamori*, 10% OP, and 10% OP and 0.1% *A. awamori.* All experimental groups had enhanced egg shape index except for the 10% OP group during 16–20 wk. Yolk contents of cholesterol and total lipids and serum levels of triglycerides, cholesterol, and LDL cholesterol decreased in almost all groups fed *A. awamori*-treated diets. Glutathione content and glutathione reductase activity increased, and lipid peroxidation was reduced.	[154]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Olive pulp and commercial enzyme blend	Broiler	Unprocessed OP (50 g/kg, 100 g/kg, 50 g/kg with ENZ, 100 g/kg with ENZ), processed OP (50 g/kg, 100 g/kg, 50 g/kg with ENZ, 100 g/kg with ENZ), and control groups (without OP, and without OP with ENZ)	Sayehban et al. reported that carcass traits such as live BW, de-feathered BW, full abdomen carcass weight, empty abdomen carcass weight, eviscerated carcass weight, breast weight, thigh, and drumstick weight (legs), wing weight, and relative breast and wing weights were not different among dietary treatments. The 50 g OP/kg inclusion increased the eviscerated carcass, leg, and neck percentage values. Processing of OP increased breast percentages in broilers.	[136]
Olive meal (OM)	Broiler	0, 2, 4, 6, and 8% and enzymes	Sateri et al. indicated that BW and BW gain, feed intake, feed conversion efficiency, carcass traits, meat cuts (breast, drumsticks, and wings), the cecum microbiota, blood LDL and HDL cholesterol, triglycerides, total protein, albumin, glucose, and UA were not significantly different among the dietary groups. However, total cholesterol was higher in the 2% OM group (no enzyme supplementation) at 42 d compared to the 4% OM group (with enzyme addition). Birds fed 4% OM exhibited higher antibody titers after vaccinations against infectious bronchitis virus and Gumboro disease.	[142]
Olive pomace (OPO)	Broiler	0, 2.5, 5, 7.5%	Nasopoulou et al. reported higher growth rates at the 5 and 7.5% OPO groups, while the 5% OPO group had more potent in vitro antithrombotic properties compared to the control group. Grilled broiler meat of the 5% OPO group had acceptable sensory properties.	[139]
Olive pomace extract (OPE)	Broiler	Control (no additives), 100 ppm monensin, 500 or 1500 ppm OPE	Herrero-Encinas et al. found that OPE addition up to 1500 ppm did not affect daily gain, feed intake, and FCR. 500 ppm OPE supplementation decreased duodenal crypt depth, mannitol concentration, and ileal IL-8 expression in comparison with the control group.	[147]
		Control (no additives), 100 pm monensin, or 750 ppm OPE	Herrero-Encinas et al. reported that average daily gain was increased and FCR decreased in the experimental diets with no effect on feed intake. Bacterial composition at a family level in the caeca of broilers, plasma, and intestinal bile acid composition was not affected in the experimental groups. The OPE group showed a reduction of IL-8 expression in the ileum, while upregulation of the expression of TGF-β4 and Bu-1 in both experimental groups was observed.	[146]
Olive oil mill wastewater (OMWW) permeate or retentate	Broiler	-	Gerasopoulos et al. reported that broilers of the experimental groups had lower protein oxidation and lipid peroxidation levels and higher total antioxidant capacity in plasma and tissues. CAT activity in erythrocytes and tissues was significantly increased in the experimental groups. Erythrocytes in broilers with low glutathione (GSH) showed an increase in GSH levels with the inclusion of OMWW retentate, but in broilers with high GSH, it was reduced.	[143]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Pomegranate peel powder (PPP)	Broiler	Control group, or 0.5% colostin antibiotic, or 2, 3, 4 g PPP/kg, or 2, 3, 4 g PPP and 1 cm^3 probiotic	Abdel Baset et al. reported that live BW (5 wk) and BW gain (1–5 wk) were highest in the 2 and 4 g PPP, and positive control (PC, with antibiotic supplementation) groups compared to the negative control (NC, without additives) and other PPP groups. Feed intake was unaffected among dietary treatments but was affected during 1–3 wk of age. FCR was unaffected by the inclusion of PPP or additives in the diet. Daily feed conception and FCR were not affected by PPP dietary addition. The highest amounts of dressing and thigh output were recorded in the 3.0 g PPP plus 1 cm^3 probiotic and in the 4.0 g PPP plus 1 cm^3 probiotic/kg diet. The liver percentage was lower in the PPP-supplemented groups compared to the PC and NC groups (5 wk), while heart and gizzard were lower in the PC and NC groups compared to the PPP or additive-supplemented groups. AST was reduced in the 3 g PPP plus 1 cm^3 probiotics/kg diet and 4 g PPP/kg groups compared to the NC and PC groups. Alanine aminotransferase decreased in the 3 g and 4 g PPP plus 1 cm^3 probiotics/kg groups compared to the PC and NC groups. Urea and creatinine concentrations were lower in all treatments compared to the ones with no inclusion levels. Creatinine, total protein, and albumin concentrations were elevated in all treatments except for the NC group, and the PC group exhibited the lowest values. IgM and lysozyme were increased due to the incorporation of PPP in the diets. Reduced oxidative rancidity of meat was observed in the PPP groups.	[159]
	Laying hen	2 or 4%	Eid et al. reported that the negative effects of oxidative stress induced by dexamethasone on BW and egg production were alleviated in the PPP groups. Plasma cholesterol, triglyceride contents, and lipid peroxidation indicators (MDA) were reduced in the PPP groups, while the antioxidative enzymes (SOD, CAT, and GPx) and total antioxidant blood capacity were enhanced.	[169]
	Quail	2.5, 5.0, or 7.5%	Abbas et al. found that final BW was similar between treatments, while the 7.5% PPP group had the highest feed intake, and the feed intake in 2.5 and 5% PPP groups were not affected. FCR, egg production, egg numbers, egg weight, and egg mass were enhanced in the PPP groups. Serum cholesterol, triglyceride, glucose concentration, and GPT, 5% PPP) were reduced, and total protein increased, while the GOT to GPT ratio was not affected. PPP groups exhibited the highest relative weight in liver and heart, villus height, and crypt depth. 5 and 7.5% PPP groups recorded the highest ratio of villi length/villi depth. Liver weight, villus length, and crypt depth were higher in females than in males.	[171]
Pomegranate peel (PP)	Broiler	Control (no additives), vitamin E (100 mg/kg), or pomegranate peel (15,000 mg/kg), and others	Rajani et al. reported that the experimentally induced ascites mortality and MDA occurrence in meat (PP inclusion had the best effect) were decreased, and the right ventricular weight ratio was improved in the experimental groups. Growth performance was not affected, and meat shelf-life was extended in the experimental groups.	[161]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
		2, 4, 6, or 8 g/kg PP or 0, 200 g/ton α-tocopherol acetate (vitamin E)	Akuru et al. indicated that the feed intake and FCR were increased in the vitamin E group at wk 3, but FCR was comparable to the control, 4, and 6 g/kg PP groups. The average final BW and average daily weight gain exhibited the highest values in the 2 and 4 g/kg PP groups, and the 2 g/kg PP groups had enhanced FCR and protein efficiency ratios in comparison to the vitamin E group. Thigh weight was the highest in the 4 g/kg PP group, while breast weight was the highest in the 8 g/kg PP group in comparison with the vitamin E group. The highest spleen and gizzard weights values were in the 4 g/kg PP group compared to the control (no additives) group, and nutrient digestibility was improved in comparison with the vitamin E group. The concentration of serum aspartate aminotransferase was reduced in the 4 g/kg PP group, while CAT enzyme activity in meat was the highest in the 8 g/kg PP group. The 4 g/kg PP group had better performance, digestibility, carcass, and organ indices compared to the vitamin E group.	[160]
Urea treated pomegranate peel (UTPP)	Broiler	0, 15, 30, or 50 g/kg	Hosseini-Vashan and Raei-Moghadam reported that BW gain increased during the start and overall experimental periods but decreased feed intake during starter and growing periods. FCR was enhanced in the experimental groups. Increasing levels of UTPP quadratically increased the breast yield, and the liver and abdominal fat decreased. The concentration of blood glucose, HDL, and globulin linearly increased with increasing UTPP dietary levels, while the plasma albumin, alkaline phosphatase, alanine aminotransferase, lactate dehydrogenase, cholesterol, LDL, and malondialdehyde concentrations were reduced at day 42 The bursa percentage increased with increasing levels of UTPP. The primary total, IgM, and IgG responses and the secondary total and IgG responses against sheep red blood cells were enhanced in the UTPP groups. The villus height, crypt depth, and villus height/crypt depth ratio, while decreasing the villus width, were increased, and the oxidative stability and water-holding capacity of breast meat was enhanced in the UTPP groups.	[165]
Pomegranate by-products (PB)	Broiler	0, 0.5, 1.0, or 2.0%	Ahmed et al. reported that crude protein and moisture contents were elevated, while ether extract in breast and thigh meat and cholesterol in breast meat were reduced. SFAs were reduced, and the sum of mono-unsaturated and n-3 fatty acids was increased in breast and thigh meat. n-6/n-3 ratio of breast and thigh meat was lower in 1 and 2% PB groups. The TBARS values and pH of breast and thigh meat were decreased in the BP groups.	[157]
Fermented pomegranate byproducts (FPB)	Broiler	0, 0.5, 1.0, or 2.0%	Bostami et al. reported that average daily weight gain during the finisher and overall period was increased in 1 and 2% FPB groups, while daily feed intake and FCR were not affected. Fecal pH tended to decrease in 0.5 and 2% FPB groups. Fecal ammonia emission was reduced in all the FPB groups, and hydrogen sulfide emission was decreased in 0.5 and 1% FPB groups. Feed cost per unit of weight gain was lower in the 1 and 2% FPB groups.	[158]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
		0, 0.5, 1.0, and 2.0%	Ahmed et al. reported that increasing levels of FPB linearly increased weight gain and feed intake, and linearly reduced FCR. In the breast meat, crude protein, iron, magnesium, and sodium content were linearly higher, while cholesterol was linearly reduced. In thigh meat, ether extract and cholesterol were linearly lower with high moisture. The SFA % was linearly and quadratically reduced in breast and thigh meat, while MUFA of the breast (linear and quadratic) and n-3 fatty acids of breast and thigh (linear) increased in the FPB groups. The n-6/n-3 ratio of breast meat decreased in the FPB groups. The hypocholesterolaemic to the hypercholesterolaemic ratio of thigh meat increased with FPB inclusion. Breast and thigh meat had reduced TBARS and pH values in the FPB groups.	[162]
Raw (PPO) and fermented (FPPO) pomegranate pomace	Broiler	Control (no PP), 5 or 10 g/kg PPO, and 5 or 10 g/kg FPPO	Gungor et al. indicated that BW and FCR, serum GPx, SOD, and CAT levels were not affected in the experimental groups; however, malondialdehyde in breast meat was reduced. Caecal *C. perfringens* count and the villus height were reduced in the 10% PPO, 5% FPPO, and 10% FFPO groups compared to the control group. Ileum morphology was negatively affected by PPO and FPPO dietary inclusion. Crypt depth increased in the 5% PPO and 10% FPPO groups compared to the control and 10% PPO groups. The villus height-to-crypt depth ratio was reduced in the 5% PPO, 5% FPPO, and 10% FPPO groups.	[163]
Pomegranate pulp (PPU)	Broiler	0, 40, 70, or 100 g/kg	Hosseini-Vashan and Raei-Moghadam investigated the effect of PPU in thermoneutral and heat-stressed broilers in comparison with no added PPU diets. The concentration of uric acid, malondialdehyde, the enzyme activity of GPx, total antioxidant capacity, abdominal fat, and liver percentage were significantly affected by the inclusion of PPU in the heat-stressed broilers. Plasma protein and the enzyme activities of SOD were reduced in the PPU groups compared to the thermoneutral group. Plasma The plasma cholesterol and LDL concentrations were decreased compared to the control.	[164]
Pomegranate seed oil (PSO)	Broiler	0.0, 0.5, 1.0, 1.5% with or without 2% linseed oil (LO)	Manterys et al. reported that white blood cell levels were increased in 0.5 and 1% PSO supplemented with LO groups. Total cholesterol was increased with 1.5% PSO or with LO supplementation. PSO dietary treatment resulted in c9,t11 conjugated linoleic acid (CLA) concentration-dependent deposition in adipose tissue. ALA content was increased, and the n-6/n-3 ratio was reduced with LO addition. PSO and ALA influenced oleic acid proportion in adipose tissue. Liver parameters were not affected by PSO or LO incorporation. Health status was not affected by PSO dietary inclusion.	[166]
		0.0, 0.5, 1.0, 1.5% PSO with 0.0 or 2.0% LO	Szymczyk and Szczurek reported that the feed-to-gain ratio was enhanced with PSO inclusion in the diet of broilers (22–42 d). The abdominal fat percentage was higher in the 1.5% PSO group. Deposition of CLA in breast lipids increased with increasing levels of PSO. PUFA increased, MUFA increased, and SFA in breast lipids was not affected in the PSO groups. 2% LO incorporation increased total PUFA, decreased total MUFA proportions, and enhanced the n-6/n-3 ratio in breast meat compared to non-LO groups.	[167]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
	Laying hen	2.5% sunflower oil (control), 0.5, 1.0, or 1.5% punicic acid (CLnA)	Kostogrys et al. reported that the color of the eggs' yolk was improved, while the hardness of hard-boiled egg yolks was not influenced. Dietary punicic acid incorporation resulted in an increase of CLnA and CLA levels in egg yolk. The Haugh units and pH values were similar between treatments. The egg albumen index was significantly higher in the 1% CLnA group. Feed consumption was the lowest in the 1.5% CLnA group. Egg yield increased in the CLnA groups. Eggs Shape Index of the CLnA was lower in the 0.5% CLnA group. SFA proportion increased, MUFA decreased in the experimental groups, while content and proportion of PUFA increased in the 0.5% CLnA and the lowest was observed in the 1.5% CLnA group.	[170]
Pomegranate and grape seed oil (GPO)	Broiler	2% replacement of soybean oil (5% in the diet)	Banaszkiewicz et al. indicated that the source of oil did not influence the slaughter yield, basic nutrients, and physical characteristics of the breast and thigh muscles. PSO inclusion enhanced the palatability of thigh muscles. GPO reduces the saturated fatty acids (palmitic) in muscles. The GPO group exhibited the deposition of a small amount of punicic acid and increased rumenic acid. The sum of the n-6 fatty acids and the n-6/n-3 ratio increased in the GPO group compared to the control group.	[168]
Tomato pomace (TP)	Broiler	0, 5, 10, or 15% substitution of SBM	Ghazi and Drakhshan reported that feed intake, weight gain, and FCR were similar between the treatments. No significant differences were recorded for breast, abdominal fat, liver, and gizzard weight.	[177]
		0% TP (rearing under thermoneutral zone), 0, 3 or 5% TP (heat-stressed broilers)	Hosseini-Vashan et al. indicated that BW and production index were elevated, and FCR was reduced in the 5% TP group (1–28 d), while reduced serum triglycerides and higher HDL cholesterol concentration were recorded in 28 d. The activities of GPx and SOD were elevated, and the concentration of MDA decreased in the 5% TP group (28 d). The adverse effects of heat stress on immune response were alleviated in the 5% TP group. The ash and Ca contents of the tibia were not significantly different between thermoneutral and heat-stressed broilers fed on 5% TP.	[180]
	Grower chicks	0, 5, 10, 15, or 20%	Yitbarek reported that TP groups recorded higher dry matter intake than the control group, and daily BW gain was highest in the 5% TP group. A significant difference in FCR was observed between the 5 and 20% TP groups. Economic efficiency was the highest in the 20% TP.	[179]
	Laying hen	0, 150, 170, or 190 g/kg	Salajegheh et al. found that BW, feed intake, egg production, FCR, egg weight, egg mass, eggshell weight, eggshell thickness, and Haugh unit were not affected by the dietary inclusion of TP. The yolk color score increased in the TP groups. Total serum protein, cholesterol, LDL, HDL, albumin, glucose, and triglyceride levels were not significantly different among treatments.	[186]
Tomato meal (TM)	Laying hen	0, 80, or 150 g/kg	Yannakopoulos et al. indicated that body weight gain, egg number, feed consumption, mortality, eggshell quality, and egg shape index were not influenced in the experimental groups. The yolk color score was improved, and the number of blood and meat spots decreased in the TM groups.	[183]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Tomato pulp (TPU)	Laying hen	Control (no additives), 28 g/ton carophyll, 40, 60, 80, or 120 g/kg TPU	Dotas et al. reported that egg production was not affected in the experimental groups, and food consumption, food efficiency, and egg weight were not different between the control and TPU groups. The number of broken eggs and the number of eggs without shells were not affected by dietary treatment. The yolk color was enhanced in the TPU groups, with the carophyll groups recording the same.	[182]
		0, 50, 100, or 150 kg/t	Jafari et al. reported that egg production and egg mass of hens (27–38 wk) were higher by the inclusion of up to 100 kg/t than the control, while final BW, egg weight, daily feed consumption, eggshell weight, eggshell thickness, Haugh units, and yolk color were similar to the control group. Conversely, lower egg production and egg mass, and increased feed efficiency were recorded in the 150 kg/t TPU group.	[176]
	Quail	0, 5, 10%	Nikolakakis et al. reported that final BW, daily feed consumption, FCR, and carcass weight, yield, and composition were similar among treatments, while ether extract content was lower in both TPU groups. Thigh and breast skin coloring was darker in the TPU groups, with the 10% TPU group exhibiting the darkest color. Carcass coloring, the fatty acid profile of carcasses, total SFA, MUFA, and PUFA were not different among treatments.	[189]
		0, 5, 10%	Botsoglou et al. indicated that MDA values in raw meat were higher after 6–9 d in the 10% TPU group and lower in the 5% TPU group. The oxidation profile of cooked meat was similar after 3, 6, and 9 d of storage among dietary treatments. MDA values of raw meat in the 5% TPU group were lower only at 100 and 150 min of iron-induced lipid oxidation. PUFA and USFA/SFA ratio (unsaturated fatty acids/SFA) was higher in the 10% TPU group.	[188]
Tomato powder (TPO)	Laying hen	0, 5, or 10 g/kg	Akdemir et al. indicated that feed intake, egg production, egg weight, and yolk color increased linearly, and feed conversion decreased linearly with increment dietary levels of TPO. Shell weight, shell thickness, and Haugh unit were not affected in the TPO groups. Concentrations of serum and egg yolk lycopene, β-carotene, lutein, and vitamin A were elevated in the TPO groups, while MDA decreased linearly with increasing levels of TPO in the diet.	[184]
	Quail	0, 2.5, 5%	Sahin et al. reported that increasing dietary levels of TPO linearly increased feed intake, live weight gain, and feed conversion under heat stress conditions but not under thermoneutral conditions. Serum lycopene and vitamin C, E, and A concentrations linearly increased with increasing levels of TPO. MDA in serum, liver, and muscles linearly decreased with increasing levels of TPO in both heat-stressed and thermoneutral groups.	[190]
Tomato pulp powder (TPP)	Quail	0, 2, 4, 6, 8%	Jouzi et al. reported that feed intake was similar between treatments, while BW and pre-slaughter weight was elevated in the 4% TPP group compared to the other groups. The feed coefficient was higher in the 6 and 8% TPP groups compared to the control. Wing weight was lower in the 2 and 4% TPP groups compared to the control. Breast, drumstick, and carcass yield, triglyceride, cholesterol, Zn, Cu, and Fe levels were reduced in the 2, 4, and 6% TPP groups.	[187]
Tomato waste juice (TWJ)	Broiler	0, 40, 80, 120 mL/d	Wahyuni et al. reported that the relative weight of the thymus, duodenum, jejunum, caecum, and liver was elevated in broilers (15–35 d) fed on TWJ. Cumulative feed intake, final BW, daily weight gain, and FCR were not affected by TWJ incorporation.	[181]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Tomato waste (TW)	Broiler	0, 5, 10, 15, or 20%	Lira et al. reported that feed intake was elevated during 1–7, 8–14, and 29–36 d, while gain weight and FCR deteriorated up to 29 d but not during 29–42 d. Carcass weight and weight of the noble parts, breast, drumstick, and thighs were reduced linearly with increasing TW levels (up to 28 d), while yield (%) was not affected except for heart and liver yields.	[178]
	Laying hen	5% flaxseed and 2.5, 5.0, or 7.5% TW	Panaite et al. reported that average daily feed intake and laying percentage were reduced in the 5 and 7.5% TW groups in comparison with the control. Yolk Roche color score was improved in the TW groups due to the enrichment of yolk with carotenoids, but transfer efficiency from feed to egg was reduced. In 5 and 7.5% TW groups (4 wk), lutein and zeaxanthin levels of egg yolk were elevated, and the color score was 3.5-fold compared to the control. The n-3 fatty acid content of egg yolk increased from 3.1 to 3.7-fold due to flaxseed addition compared to the control group, while the n-6/n-3 ratio decreased from 18.3 in the control to 4.1–5.4 in the flaxseed-supplemented groups.	[185]
Sugar beet pulp	Broiler	0, 30 g/kg oat hulls (OH) or SBP	Gonzalez-Alvarado et al. indicated that BW gain and feed-to-gain ratio were improved in the SBP diets compared to the control. Feed intake was reduced at 25–42 d, and the relative weight of the gastrointestinal tract and gizzard, the digesta content of the gizzard, and the total tract apparent digestibility of nutrients were improved in the SBP group.	[194]
		0, 25, 50, and 75 g/kg SBP or OH	Jimenez-Moreno et al. reported that feed intake or BW gain was not affected, while FCR was enhanced quadratically in the SBP and OH groups (1–18 d). Energy efficiency improved linearly in the SBP and OH groups (1–18 d). The coefficient of total tract apparent retention was improved by the incorporation of up to 50 g/kg SBP or OH.	[196]
		0, 25, 50, and 75 g of either OH or SBP	Jimenez-Moreno et al. reported that the relative weight of the gastrointestinal tract with digesta contents increased linearly with increasing levels of dietary fiber. The weight of the pancreas increased with increment levels of SBP, while the relative weight of the gizzard and its dry matter (DM) content was elevated, and gizzard pH was decreased in the experimental diets at all ages of broilers. Gizzards were heavier with higher DM content and gizzard pH in the OH group compared to the SBP one, while villus height (12 d) decreased in the SBP group. The pH of the digesta of the duodenum was elevated in the SBP and OH groups at 6 d and at 12 d in the SBP group.	[195]
		0%, 7.5% SBP, or 15% potato peel, with or without enzyme	Abdel-Hafeez et al. reported that the SBP or potato peel inclusion decreased BW, while feed intake, weight gain, and feed conversion were lower in the SBP group but were not different in the potato peel group compared to the control. Enzyme addition increased BW, feed intake, and feed conversion. The total cholesterol, LDL cholesterol serum levels, and carcass fat content were lower in the experimental groups, while carcass yield was not different. At the same time, SBP addition at greater levels (7.5%) decreased BW, weight gain, LDL, and total cholesterol serum levels.	[198]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
		0%, 7.5% SBP, or 15% potato peel, with or without enzyme	Abdel-Daim et al. indicated that the digestibility of ether extract, crude fiber, or crude protein, physicochemical and sensory characteristics of the breast or thigh muscles, and intestinal morphology during starter and growing periods were not affected in the experimental groups. Villus height and villus height/crypt depth ratio decreased during the starting period but not in the grower period. Enzyme addition increased the digestibility of nutrients, enhanced the development of the small intestine, increased the crude protein content and the water-holding capacity, and reduced the ether extract of the meat and the cooking loss rate.	[197]
		23, 46, and 92 g/kg	Petterson and Razdan reported that the ileal digestibilities of organic matter, crude fat, and crude protein were reduced with increasing dietary levels of SBP. Total serum cholesterol levels decreased in the SBP groups. High triacylglycerol and total serum cholesterol concentrations of the restricted level-fed chickens exhibited a meal frequency factor. Growth performance was improved in the SBP groups, but with no statistical differences.	[199]
	Laying hen	0, 3, 5, 7%	Selim and Hussein reported that feed intake, egg production, egg weight and mass, and improved FCR, yolk color core, and Haugh unit linearly increased with SBP addition. Higher protein and lower ether extract in eggs of the SBP groups were observed, while serum total lipids, cholesterol, alanine aminotransferase, aspartate aminotransferase, and creatinine decreased. Egg yolk MDA, cholesterol, and triglyceride linearly decreased, and GPx increased with SBP dietary inclusion.	[201]
	Quail	0, 20, 40 g/kg and multi-enzyme 0, 1, or 2 g/kg	Alagawany and Attia reported that feed consumption, FCR, egg number, egg weight, egg mass, external and internal egg quality, N consumption, N in egg, N excretion, N fecal, N intake, and N retention were not affected by SBP inclusion. Increasing levels of SBP reduced final BW and fertility percentage. Hatchability percentages from fertile eggs increased with decreasing levels of SBP. Digestion coefficients of the nutrients excluding the N digestibility were significantly affected by SBP addition.	[191]
Sugar beet meal	Broiler	Control, 2.5% sugar beet meal, 2.5% neem leaf meal, 2.5% linseed meal, or 2.5% coriander seed meal	Kumari et al. reported enhanced BW, weight gain, feed conversion rate, performance index, and giblet relative weight in the sugar beet meal-fed group.	[193]
Aqueous methanolic extract of sugar beet	Broiler	100, 200, and 300 mg/kg BW, vitamin E 87 mg/kg, Baycox® 1 mL/L of water, PBS group (infected non medicated control group). Group served as non-infected, non-medicated group	Abbas et al. indicated that sugar beet exhibited good anticoccidial activity, which was evaluated based on the improvement of FCR, lesion score, oocyst score, and oocysts per g of feces. The serum profile of infected broilers was not significantly different by the inclusion of the sugar beet extract.	[200]

Table 2. *Cont.*

Agro-Industrial By-Product	Poultry Species	Examined Inclusion Levels	Key Findings as Reported by Authors	References
Brewers dried grains (BDG)	Broiler	Substitution of maize with 0, 25, 50, 75, or 100% BDG	Ironkwe and Bamgbose reported that the 50% BDG group exhibited the highest final live weight, daily weight gains, and the lowest FCR, followed by the 25, 75, and 100% BDG groups, with the lowest. Feed intake was the highest in the control group (0% BDG) and the lowest in the 100% BDG group, while cost per kg feed was the lowest in the latter group, which decreased with increasing BDG participation in the diet. Cost per kg weight gain decreased with increasing BDG levels.	[205]
		0, 15, 20, 25, 30, 35, or 40% BDG and sand 0 or 4%	Onwudike indicated that sand incorporation in diets improved digestibility, gain, and FCR, while the inclusion of higher than 15% to 20% BDG decreased feed conversion efficiency. At levels of 0, 15, 20, 25, and 30% BDG and 4% sand inclusion in the diet, no positive effects were observed in grower diets.	[206]
Brewers spent grains (BSG)	Broiler	Group I (whole BSG without xylanase), group II (whole BSG and xylanase top-dressed), group III (whole BSG and xylanase pre-treated), group IV (ground BSG without xylanase), group V (ground BSG and xylanase top-dressed), group VI (ground BSG and xylanase pre-treated)	Denstadli et al. reported that weight gain was not different among treatments, but feed intake increased by the xylanase supplementation and by the addition of coarse BSG. Feeding coarse BSG rather than ground BSG had a better effect on feed utilization, but no effect on ileal digestibility or apparent metabolizable energy was observed. Gizzard weight was elevated in the coarse-BSG groups compared to the ground-BSG groups. Jejunal viscosity decreased due to the enzyme supplementation in the diet. Higher concentrations of arabinose and xylose in caeca in the pre-treated diets compared with the untreated or top-dressed diets were observed. Enzyme supplementation in diets affected the caecal contents of rhamnose and mannose. Elevated ileal concentrations of mannose and glucose in groups fed on pre-treated diets compared with groups fed on top-dressed diets were recorded.	[208]
Fermented brewers spent grains, mineral sorbing complex, and probiotics	Quail	0 or 1.5%	Yurina et al. reported that an additive consisting of fermented brewers spent grains, mineral sorbing complex, and probiotics increased gross egg production by 3.8%, intensity of egg production by 2.3%, the intensity of egg production by 2.3%, decreased feed consumption for the production of 1 dozen eggs by 5.5%, and increased FCR in comparison with the control group. Livability (90%) of quails was not affected among the treatments.	[207]

ALA = α-linolenic acid; AO = antioxidants; AP = apple pomace; BDG = brewers dried grains; BL = *Bacillus licheniformis*; BSG = brewers spent grains; BW = body weight; CAT = catalase; CLA = conjugated linoleic acid; CLnA = punicic acid; CP = citrus pulp; CW = citrus waste; DCP = dried citrus pulp; DCSP = dried *Citrus sinensis* peel; DDGS = dried distillers' grains with solubles; DLP = dried lemon (*Citrus aurantifulia*) pulp; DM = dry matter; ENZ = enzyme; FCR = feed conversion ratio; FGP = fermented grape pomace; FPB = fermented pomegranate byproducts; FPPO = fermented pomegranate pomace; GOT = glutamic-oxaloacetic transaminase; GP = grape pomace; GPC = grape pomace concentrate; GPO = grape seed oil; GPT = glutamic-pyruvic transaminase; GPx = glutathione peroxidase; GSH = glutathione; HDL = high-density lipoprotein; HPSFM = high-protein sunflower meal; LDL = low-density lipoprotein; LFSFM = low-fiber sun flower meal; LO = linseed oil; LO-DDGS = low-oil distillers dried grains with solubles; MDA = malondialdehyde; NC = negative control; OC = olive cake; OH = oat hulls; OL = olive leaves; OM = olive meal; OMWW = olive oil mill wastewater; OP = olive pulp; OPE = olive pomace extract; OPO = olive pomace; OPU = orange pulp; PB = pomegranate by-products; PC = positive control; PP = pomegranate peel; PPO = raw pomegranate pomace; PPP = pomegranate peel powder; PPU = pomegranate pulp; PSO = pomegranate seed oil; SBM = soybean meal; SBP = sugar beet pulp; SC = sunflower cake; SFA = saturated fatty acids; SFM = sunflower meal; SOD = superoxide dismutase; TBA = thiobarbituric acid; TBARS = thiobarbituric acid reactive substances; TM = tomato meal; TP = tomato pomace; TPO = tomato powder; TPP = tomato pulp powder; TPU = tomato pulp; TW = tomato waste; TWJ = tomato waste juice; UA = uric acid; USFA = unsaturated fatty acids; UTPP = urea-treated pomegranate peel; WGPF = wine-grape pomace flour.

3. Potential Limitations of Utilizing Agro-Industrial By-Products in Poultry Nutrition

Potential limitations in using AIBP in poultry rations include nutrient variability, feed safety, sensitivity to peroxidation, the presence of anti-nutritional factors, their high content of fiber, and whether it is possible to achieve profit by this practice.

The nutrient composition of AIBPs may vary depending on the area, climate, and season, which limits their use in animal diets [10]. Nutrient variability can be reduced by the processing of AIBPs to produce a uniform feed with consistent nutrient composition, while nutrient supplementation is necessary [60]. Furthermore, technological requirements are necessary to stabilize the final AIBP product and to abate seasonal variability [21]. Seasonal availability of some by-products is a limit in their wide use, such as in the case of vegetables and fruit residues, for example, in cider and wine production, which takes place from September to October [10,209]. These by-products are mainly fed raw or after drying [210]. In DDGS, variability in the nutrient composition depends on different factors, including the origin of raw material, the processing methods applied, fermentation yeast properties, and year of production, and thus, chemical analysis of DDGS from different sources should be conducted regularly [83].

Considering a processing method to be applied to AIBPs, the good nutritional value of the final product and socioeconomic and ecological feasibility should be taken into account [211]. Drying of by-products with high moisture, often exceeding 80%, such as grape and tomato pomace and skins, is necessary to prevent microbial spoilage [60,212], which should take place by the producer soon after the generation of the by-products [18]. Water content higher than 20% in the by-product prior to processing could limit storage duration. Refrigeration or treatments with exogenous enzymes or fermentation permit a longer shelf life for the by-products. In the case of fruit pomaces, steam explosion, and amination may also be used [126]. In grape by-products, the above-mentioned processing methods and polyethylene glycol treatment release non-starch polysaccharides or linked tannins from cell walls and biomass resulting in an increase in digestibility and enhanced bioactive properties [104]. Moreover, transportation costs increase when the moisture content of AIBPs is high. The energy costs of drying of high-moisture AIBPs may be higher than the value of the feedstuff itself. Thus, mixing with other dry feedstuffs to reduce water content prior to processing can be applied [60]. In order to ensure the economic feasibility of using AIBPs in animal nutrition, the relative economic value should be low [210]. Solar drying is gaining much attention as an environmentally friendly and low-cost processing method. Methods of solar drying include open-air drying (sun drying) and drying with the use of sun dryers. In the case of apple and orange waste, treatment with greenhouse solar dryers is more suitable than sun drying in terms of time efficiency, minimization of microorganisms, and nutritional value [212]. However, drying of by-products may lead to a concentration of pesticide residues, while mycotoxins can be produced by molds in low water activity levels [25].

Food safety is a prerequisite to achieving food security and protecting the income of small-scale farmers. A circular economy may introduce safety hazards in the food supply chain. Although there are numerous scientific articles on the reuse of alternative foods and feeds, the safety of these products in a circular economy is sometimes neglected in the literature. The importance of safety in a circular economy has been reviewed by researchers, for instance, for insects, former food products [213], catering waste [211], and seaweeds [214], while the significance of emerging hazards has been indicated by EFSA et al. [215].

Although a circular economy is promoted in the EU through the EC Green Deal and Farm to Fork policy, no policies to monitor the safety of by-products exist [216]. The EU Regulation (EC) 178/2002 stipulates that the food business operators are responsible for the safety of the products put on the market [216,217]. Although several feed contamination episodes have occurred over the last decades, such as the carry-over of dioxins from feed by-products [218], limited data are available in the literature on the hazards of plant by-products and their carry-over in other parts of the food supply chain [216].

Different chemical hazards have been found in plant by-products, such as heavy metals, mycotoxins, pesticides, and plant toxins. In Table 3, hazards in each AIBP reported in the literature are presented. Mycotoxin occurrence varies depending on agronomic practices, the geographic location of the crop grown, and meteorological conditions [219]. Heavy metals or other contaminants, such as antibiotic residues, may accumulate in by-products, such as sugar beet pulp, which can be taken up from the soil. The route of antibiotic residues contaminating the soil is via manure [220]. In the case of grape by-products, the level of heavy metals is variable and depends on soil composition and contamination and the grape variety [104].

DDGS and germ, rootlets, or brewer's spent grains may be contaminated by mycotoxins [216]. These by-products are of particular importance since mycotoxins are frequently found in cereals [218], and they accumulate primarily in the outer fractions of the grain, such as the fibers and husks [216]. In the case of DDGS, this co-product may contain three times the content of some mycotoxins compared to the raw material [216]. The primary mycotoxins that may be present in corn and can be found in DDGS include fumonisin, aflatoxin, deoxynivalenol (vomitoxin), zearalenone, and ochratoxin. The risk of contamination of corn DDGS is very low due to the control systems applied throughout the chain of farm-bioethanol industry-animal feed [82,221]. In sugar beet pulp silage, the mycotoxins ochratoxin A, zearalenone, mycophenolic acid, and roquefortine C were found in France [222]. Moreover, it is forecasted that a higher prevalence of aflatoxin producing species (i.e., *Aspergillus* spp.) will be evident due to climate change [223]. A reduction of mycotoxin levels in grains can be achieved by mitigation measures. These include good agricultural practices, plant breeding, use of less susceptible varieties, plant protection, crop rotation, drying, and storage. Appropriate sampling and testing are needed to identify potentially contaminated feed. Measures focusing on contaminated feed include visual/automated sorting, decontamination (e.g., ammoniation), the addition of binders, or the proper inclusion in the diet of less sensitive animal species [224]. Furthermore, risk assessment is necessary to evaluate the risk of mycotoxins to poultry and consumer health via potential carry-over. Antibiotic residues may also be found in DDGS as a result of using antibiotics in bioethanol production that function as inhibitors to microbial growth in order to enhance the fermentation process [216].

CP may be contaminated by pesticide residues and dioxins. For example, one sample of CP was found to contain the pesticide heptachlor at a level exceeding the maximum residue level (MRL) by the official control in Denmark from the results published between 1996 and 2008 [218]. In a risk assessment [218], it was concluded that if residue levels of the stobilurin pesticides azoxystrobin, pyroclostrobin, and the fungicides imazalil and thiabendazol in CP are lower than 0.5 mg/kg, inclusion levels of 20% or 23% in the poultry diet will not result in negative health effects for the consumer [218]. Distribution of pesticides in the by-products due to processing is another point to be considered. The concentration of pesticides in the by-product may occur if processing steps that include dehydration are used [25], while pesticides tend to concentrate in brewer's spent grains [220].

The transformation of pesticide residues in food processing by-products may take place depending on factors such as temperature and microbial activities resulting in contamination with other chemicals [25]. Polychlorinated dibenzo(p)dioxins and furans (PCDD/Fs) can be introduced in CP via contaminated lime (calcium hydroxide), which is used at a level of 2% to partly neutralize fruit acids and make it suitable as animal feed [225]. Another possible route of transmission of dioxin in CP was reported in Germany, The Netherlands, and Belgium, in 1998, via the use of certain types of waste as the fuel for the direct drying of CP [226]. Other persistent environmental pollutants include polycyclic aromatic hydrocarbons (PAHs), which may be present in by-products comprising fats and fatty acids, such as vegetable oils [216]. For example, PAHs have been identified in olive pomace oil [227].

The antinutritional factors that are usually present in AIBP may affect feed palatability, digestibility, and animal production performance [20]. The processing methods to deactivate the antinutritional factors include physical, chemical, and biological methods [20].

AIBPs may be a cheap source of feed, but to the best of our knowledge, economic analyses of the use of AIBPs in poultry nutrition are scarce. However, in practice, it is widely known that it may be cost-effective in comparison with using conventional feeds. In a study conducted on pomegranate by-products, feed cost per unit of weight gain was lower in experimental groups fed 1% or 2% fermented pomegranate byproducts in the diet compared to the basal diet containing solely conventional feeds [158]. In another study, the feeding cost in broilers fed a diet containing corn-silage was 1.95 –fold higher than the feeding cost in broilers fed a diet containing avocado and pomegranate by-products [228]. In a study evaluating the economic feasibility of OP in broiler diets, feed cost per kg live weight was statistically higher when 100 g/kg OP was fed compared to the inclusion level of 50 g/kg OP. In countries and regions that produce olive oil, the use of olive pomace may reduce poultry production costs, while in other regions, the cost of olive pomace can be a barrier for its use [141]. SFM inclusion level of 8% resulted in an improvement of the economic efficiency index compared to inclusion of 0, 16, and 24% SFM levels in broiler diets [68]. Increasing incorporation levels of sorghum DDGS in broiler diets decreased the cost of feed/kg, while at the level of 20% of DDGS, maximum financial returns were observed [229]. Another study found that 50% or 100% maize replacement with brewer's dried grain in the diet leads to the lowest production feed cost per kg weight gain of broilers [205]. One important factor that may reduce the cost is to maintain a small distance between livestock farms and the generation sites of by-products [230]. To calculate the true cost of AIBP feed, the Extension of the University of Georgia recommends taking into account the price of the feed delivered to the farm, the interest, the shrinkage and storage losses, and the extra handling cost [231]. It is encouraging that extensions of universities, such as in the case of the University of Georgia, provide recommendations about the incorporation of AIBP in animal diets. Economic incentives to alleviate the costs of using AIBPs in animal nutrition would foster the participation of the different stakeholders (e.g., farmers and feed manufacturers).

Table 3. Reported hazards found in agro-industrial by-products.

Agro-Industrial By-Product	Potential Hazards	References
Apple by-products	Amygdalin, pesticides (e.g., neonicotinoids and arsenic-based pesticides), patulin	[232]
Citrus pulp	PCBs and PCDD/Fs [1], ochratoxin A, pesticides (e.g., imidacloprid, abamectin, cypermethrin, and prochloraz	[218,225,233–235]
Sunflower meal	Alternariol, alternariol monomethyl ether and tenuazonic acid (*Alternaria* spp. toxins), *Fusarium* spp. toxins, aflatoxin B_1, heavy metals (e.g., Pb, Cd, Cr, As, Hg, Ni)	[236,237]
Wheat dried distillers' grain with solubles	Deoxynivalenol, enniatin B, ochratoxin, antibiotics Co-occurrence of deoxynivalenol with its acetylated and/or glycosylated derivatives, and DON with enniatins, beauvericin or zearalenone	[83,216,218,238–240]
Corn dried distillers' grain with solubles	Aflatoxins (e.g., AFB_1), deoxynivalenol, fumonisins, T-2 toxin, zearalenone, ochratoxin	[82,83,221]
Grape pomace	Heavy metals (e.g., Al, As, Pb, Cd, and Ni), toxins (e.g., ochratoxin A, biogenic amines)	[104,241]
Sugar beet pulp	Heavy metals (e.g., Al, As, Pb, Cd, and Ni)	[222]
Sugar beet pulp silage	ochratoxin A, zearalenone, mycophenolic acid and roquefortine C	
Brewery by-products	Aflatoxins (e.g., AFB_1), ochratoxin A, fumonisin B_1, acetyl-deoxynivalenols (ADONs), deoxynivalenol-3-glucoside (DON-3-Glc), HT-2, enniatins, patulin and gliotoxin, pesticides	[83,220,242]

[1] PCDD/F, polychlorinated dibenzo-p-dioxins and dibenzofurans; PCB, polychlorinated biphenyls.

4. Conclusions

AIBPs contain several bioactive compounds that may act as antimicrobial agents, antioxidants, and immune modulators. These properties may contribute to the role of AIBPs as functional feed ingredients in promoting the health, productivity, and well-being of poultry. Based on the findings reported in the present study, the following inclusion levels of agro-industrial by-products are proposed. Dried apple pomace at levels up to 6% in broiler diets and up to 25% in laying hens are recommended. Dried sweet orange peel up to 3% in broiler diets and dried citrus pulp up to 10% in broiler diets could be used, while favorable results were reported in ostrich and goose diets, while in hen diets variable results were found. Sunflower meal in broiler diets at levels up to 15%, especially when an enzyme mixture was added, provided favorable results, depending on the growing period. However, results were inconsistent among the studies. In the hen's diet, the inclusion of sunflower meal at levels up to 25% did not show negative results. In the case of dried distillers' grain with solubles, levels up to 24% in broiler diets and up to 25% in laying hen diets could be used, but variable results were reported depending on the growing period. Grape pomace can be included at levels up to 10% in broiler diets and up to 6% in hen diets. Olive cake could be incorporated at levels up to 20% in broiler and hen diets, with the addition of citric acid and olive pulp at levels up to 10%. Raw or fermented pomegranate pulp could be used at levels up to 2%. Sugar beet pulp could be incorporated at levels up to 5% in broiler diets. However, ways to reduce nutrient variability of ABIP across countries should be found.

Unfortunately, AIBPs also have shortcomings and limitations, such as the presence of anti-nutritional ingredients and chemical hazards. The importance of the control of potential hazards in AIBPs should be emphasized through proper legislation and knowledge of the different stakeholders involved. For example, the use of good agricultural practices and minimization measures of the antinutritional factors present in AIBPs. Furthermore, many of the studies reviewed herein presented notable differences in the characterization of extracts in terms of their biological properties when assessed. However, modern processing methods, new types/classifications, and appropriate developmental strategies are expanding the applications of AIBPs as animal feeds for poultry production.

Overall, given that the availability and price of the AIBPs may vary greatly across the regions, the use of such by-products as functional feed ingredients in poultry rations should therefore be adjusted according to the availability and cost of each by-product. Moreover, due to the nutrient variability of AIBPs, proximate analysis prior to feeding is necessary to manage animal diets and decrease costs. Future studies should confirm the efficacy of agro-industrial residues and their derivative products in substituting the use of conventional feedstuffs in poultry nutrition.

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