Review Article

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Black pepper (Piper nigrum Lam) as a natural feed additive and source of beneficial nutrients and phytochemicals in chicken nutrition

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Abstract: Tropical countries are rich in medicinal herbs that have the potentials to improve poultry productivity and health by increasing digestive enzyme activity, immune responses, and modulation of gut microbiota composition through the action of their bioactive constituents. Presently, black pepper (BP), one of such tropical herbs is gaining popularity as a substitute for antibiotics in poultry production, which have been found to promote the development of anti-resistant strains of bacteria and incorporation of drug residues in animal products. BP belongs to the genus - Piper, species – nigrum, and family - Piperaceae. The leaves, fruits, and seeds of BP are moderate in essential nutrients such as minerals and vitamins, but low in anti-nutritional factors. It is also high in important bioactive compounds such as polyphenols and flavonoids. These bioactive compounds play important roles in regulating the normal physiological functions of animals such as growth, egg production, and immune responses. Therefore, the aim of this review is to pool evidence on the chemical composition of BP that acts as feed additives and their mode of action in enhancing performance and product quality, as well as the reasons for the inconsistent results among authors on the feed additive value of BP in chicken nutrition.

Keywords: black pepper, performance parameters, microbiota composition, product quality, chickens

1 Introduction

The world poultry population has increased by 86% in the last two decades (2001–2021) [1]. Given the steady increase in the world population [2], the demand for poultry products is likely to persist in the future. This has led to the use of eco-friendly nutraceuticals like black pepper (BP; Piper nigrum L.) and their derivatives to improve performance and product quality in poultry.

BP (Family – Piperaceae) is a perennial climbing vine that is used in folklore medicine to manage several diseases like fever, cold, muscular pains, dysentery, cough, worm, etc. BP belongs to the genus Piper and species nigrum. It originated in India but is now cultivated in several tropical and sub-tropical countries, including Sri Lanka, Nigeria, Thailand, Malaysia, Ghana, China, Madagascar, Brazil, and Indonesia, among others due to its ability to withstand harsh tropical conditions. Generally, BP is a multi-purpose herb (Figure 1) that is currently being investigated as growth promoting agent in animal feed due to its reported nutritional and medicinal values [3–6]. The plant also has a wide variety of medicinal benefits comprising antidepressant, antimicrobial, antioxidant, antifungal, anticancer, anti-inflammatory, and anticoccidioiostat [7–9]. A comprehensive review of medicinal benefits of BP has been published [10]. The pharmacological values of BP are credited to the existence of beneficial metabolites such as terpenoids, xanthophyll, phenols, and flavonoids, among others [9,10]. There are convincing body of knowledge that BP leaves and seeds are moderate in proteins, ether extract, minerals (phosphorus, calcium, potassium, magnesium, zinc, iron, etc.), and vitamins such as thiamine, ascorbic acid, riboflavin, and niacin [3,10].

Some studies indicated that BP had no influence on aspects of zootechnical parameters of broiler chickens [11–13]. However, several others reported that BP improves feed intake, boosts nutrient digestibility via digestive enzyme stimulation, and inhibits pathogen proliferation in the gastrointestinal tract (GIT) via their antimicrobial
actions [14], or perhaps, enhances the absorptive ability of villi to assist nutrient uptake and assimilation [15,16]. It has also been found that dietary BP supplementation improved ileal muscle contraction [17,18], increased mucosa and sub-mucosa thickness of the duodenum, jejunum, and ileum in broiler chickens [19]. Akinwumi et al. [20] found improved egg quality in layers fed with BP at 0.1–0.5 g/kg feed when compared with the layers fed with a diet without BP supplementation. Similarly, Ghaedi et al. [13] reported significantly reduced abdominal fat pad content in broilers fed with BP at 0.2 g/kg feed and 2 mg/ml, respectively. Improved feed conversion ratio (FCR) and body weight gain (BWG) were also obtained in broiler chickens fed with BP at 2.5, 5.0, 7.5, and 10 g/kg feed when compared to the group fed with 0 g BP/kg feed [21]. This improvement could be ascribed to the activity of bioactive constituents in BP in protecting the villi from oxidative damage [9,10], leading to higher BWG.

Despite the aforementioned characteristics of BP in poultry production, not much has been done to aggregate this large amount of data into a single document for evidence-based decision-making by policymakers and relevant stakeholders in the poultry industry. To fill this gap, this study was designed to aggregate published data on the chemical composition of BP used in animal feed to enhance chicken health, promote productivity, and modulate immune responses. The mode of action of bioactive constituents in BP was also reviewed. The present review discusses the reasons for the inconsistent results among studies that evaluated the effect of dietary BP supplementation in chicken performance in order to maximise their potential as an eco-friendly feed additive in the poultry industry.

2 Methodology

Papers utilised for this review were retrieved from a search done in Google scholar, Web of Science, Scopus, and PubMed with the help of the following keywords: “black pepper,” “Piper nigrum,” “chemical composition,” “proximate composition,” “nutrient content,” “phytochemical,” “essential oils,” “mechanisms of action,” “chicken nutrition,” “broiler chickens,” “black pepper AND intestinal microbiota of chickens,” “black pepper AND intestinal histomorphology of chickens,” “black pepper AND blood characteristics of chickens,” “laying hens,” “black pepper AND laying performance of chickens,” “black pepper AND broiler chicken performance,” “black pepper AND carcass yield of broiler chicken,” “black pepper AND cut-part yield of broiler chickens,” “black pepper AND meat quality of broiler chicken,” and “product quality.” Reference sections of identified articles were also assessed, and full-text articles were collected if considered relevant for the review. The
systematic search was restricted to works published in English. Included publications satisfied the following conditions; the topic focused on the impact of BP and its derived products on all or any of the parameters of interest in broiler chickens and laying hens. Published results on the chemical composition and mechanisms of action of BP were also included in the review. Studies that were not in any of the parameters of interest were excluded from the review. Three hundred and sixty-five full-text studies were assessed for eligibility of which 94 were used for the study.

3 Botanical description

Taxonomically, BP belongs to the Piperaceae family of the genus *Piper*. Another genus related to BP is shown in Table 1. BP is a shade-loving perennial climbing vine. It reaches the height of 10 m or above, and has 10–20 roots that emanate from the base of the mature stem [22]. Its broad odiferous green leaves are alternately arranged and vary in size and shape. The BP fruits are called peppercorns or drupes, and the diameter is about 5 mm. The fruit containing one single seed is yellowish red when ripe. The seeds are small with copious endosperm and minute embryo and have a pungent taste.

4 Phytochemistry of BP

BP contains beneficial chemicals as shown in Table 2. BP plant contains tannins, alkaloids, saponins, terpenes, steroids, flavones, flavonoids (catechin, myricetin, and quercetin), and piperine, among several others [9]. A study conducted by Zheng et al. [23] revealed that BP fruits are endowed with essential oils (1.0–2.5%) and alkaloids (5–9%). Also, piperine, piperetine, chavicine, and piperidine are the predominant alkaloids in the BP fruits. Khan et al. [24] found BP fruits contained 1.7–7.4% piperine. BP also contained glutathione peroxidase and glucose-6-phosphate dehydrogenase that has antioxidant and immunomodulatory effects in animals [7,25]. The presence of glutathione peroxidase, flavonoids, and phenolic compounds in BP may explain its antioxidant and antimicrobial properties [9,26–28]. Piperine and volatile oils, which have antimicrobial, antioxidant, anti-tumor, anti-inflammatory, and other physiological and pharmacological activities, are primarily responsible for the aroma and pungency of BP [29]. The pharmacological role of BP is also linked to the activities of its phytochemicals like terpenoids, phenols, flavonoids, alkaloids, and carotenoids [8–10]. Piperine, the main bioactive compound in BP has been found to aid nutrient digestion and utilisation by stimulating the release of digestive enzymes [30]. BP oil is rich in nerolidol and several other bioactive compounds (Table 3). The essential oil yield of BP seeds (1.24–5.06%) and leaves (0.15–0.35%) has been reported [10]. Notwithstanding, the amount of oil to be extracted from BP plant depends on the variety of BP used, plant age, plant part, and extraction techniques [10,31,32]. Extensive information on essential oil yield and composition of different parts of BP plant has been highlighted [10,33,34].

### Table 1: Taxonomic hierarchy of BP

<table>
<thead>
<tr>
<th>Domain</th>
<th>Eukarya</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kingdom</td>
<td>Plantae</td>
</tr>
<tr>
<td>Subkingdom</td>
<td>Viridiplantae</td>
</tr>
<tr>
<td>Infrafamily</td>
<td>Streptophyta</td>
</tr>
<tr>
<td>Superdivision</td>
<td>Embryophyta</td>
</tr>
<tr>
<td>Division</td>
<td>Tracheophyta</td>
</tr>
<tr>
<td>Subdivision</td>
<td>Spermaphyta</td>
</tr>
<tr>
<td>Class</td>
<td>Magnoliopsida</td>
</tr>
<tr>
<td>Superorder</td>
<td>Magnoliaceae</td>
</tr>
<tr>
<td>Order</td>
<td>Piperales</td>
</tr>
<tr>
<td>Family</td>
<td>Piperaceae</td>
</tr>
<tr>
<td>Genus</td>
<td><em>Piper</em> L.</td>
</tr>
<tr>
<td>Species</td>
<td><em>nigrum, caninum, bavinum, celtidiforme, methylsticum</em></td>
</tr>
</tbody>
</table>

### Table 2: Phytochemical composition of BP leaves and seeds

<table>
<thead>
<tr>
<th>Biochemical contents</th>
<th>Content range (lower value – higher value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leaves</td>
</tr>
<tr>
<td>Tannins</td>
<td>1.54&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Saponins</td>
<td>nr</td>
</tr>
<tr>
<td>Flavonoids</td>
<td>0.65&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Alkaloids</td>
<td>0.82&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cyanides</td>
<td>1.16&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Oxalate</td>
<td>0.47&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Source: <sup>a</sup>Nwoafia et al. [3]; <sup>b</sup>Ameh et al. [5]; nr – not reported.

5 Nutritional composition of BP

The inclusion of BP leaves, seeds, and their derived products in animal feed lies solely on their high medicinal and nutritional values, as well as their low levels of anti-nutrients. Analytical studies demonstrated that BP leaf and seed meals are low to moderate in protein, fibre, carbohydrates, minerals, and fat (Table 4). However, there is paucity of data on the nutrient and phytochemical contents.
of the roots. The presence of essential nutrients in this herb indicates its ability to provide nutrients to poultry when added to the diets. The pericarp contains 5.3% fat, 23.6% fibre, 25.5% protein, 37.4% carbohydrates, as well as minerals such as 0.16% magnesium, 0.20% calcium, 0.66% potassium, and 0.16% phosphorus [35,36]. Ameh et al. [5] observed that BP seed is rich in essential nutrients, including fat (16.30%), fibre (48.95%), protein (3.54%), carbohydrates (12.69%), ash (1.69%), magnesium (54.68 mg/100 g), calcium (0.64 mg/100 g), sodium (0.94 mg/100 g), potassium (5.86 mg/100 g), phosphorus (0.15 mg/100 g), zinc (17.35 mg/100 g), and iron (0.19 mg/100 g). The low protein levels in BP seeds and leaves support its use as a feed supplement rather than a feed ingredient in chicken diet. The leaves and seeds are high in calcium, magnesium, and ascorbic acid (Table 4).

6 Mechanisms of action of bioactive agents present in BP

There are several mechanisms by which BP and its derived products improve health, feed intake, FCR, BWG, and product quality in farm animals. BP essential oils contain terpenoids (δ3-carene, β-pinene, p-cymene, limonene, α-pinene, α-terpine-4-ol) and alkaloids (piperine) which function as antimicrobial agents [9,26,27]. BP may promote BWG in chickens by inhibiting biofilm, bacterial efflux pumps, bacterial swarming, and swimming motilities [37]. BP also contains glutathione peroxidase and phenolic compounds, which exerts an antioxidant effect in animals [9,38]. Piperine, one of the bioactive constituents of BP enhances digestion by stimulating the release of pancreatic enzymes, salivary amylase, and bile acids, all of which reduce feed transit time in the gut [29,39–41]. Other modes of action of BP in farm animals include direct nutritional effect, stabilisation of intestinal microbiota composition, enhancement of gut’s absorptive capacity, anti-inflammatory, and hepatoprotective activities [42]. The roles of BP as hypocholesterolemic, hypolipidemic, and immunostimulant agents in animals have also been highlighted [9].

7 Role of BP-based diets on modulating gut microbiota composition of chickens

Research has linked increased chicken productivity to balanced intestinal microbiota composition [43]. Chicken
performance and health are negatively impacted by an imbalance in gut microbiota brought on by dietary or environmental changes. On the other hand, balanced gut microbiota allows for optimal performance [44]. In vitro investigations show that BP has antimicrobial activities [9,27,45]; however, it is difficult to compare these results because the methodologies used by the different authors differ. Chaudhry and Tariq [46] discovered that aqueous BP extract suppressed bacterial growth in vitro. The antimicrobial effect of BP could be attributed to the ability of the bioactive constituents in BP to destroy bacterial cell membrane [46,47]. The use of BP as an alternative to antibiotic growth promoters in chicken nutrition appears logical because of the reported in vitro antimicrobial activity of BP. Antimicrobial effects of dietary BP in broiler chicken gut have been reported by others [13,44]. These antimicrobial activities are credited to the negative effect of phenolic compounds contained by BP in microbial cells [9,23]. However, antimicrobial activity of medicinal herbs is not always noticed in feeding studies, which could be linked to improved management and housing conditions [48]. Furthermore, the inclusion levels of BP in livestock feed is typically lower than the quantity used in in vitro studies [49]. This suggests that BP’s action on gut microflora is more than just a direct bactericidal activity.

Evidently, it has been discovered that BP promotes the growth of healthy gut microbes like Lactobacillus [13,44,47]. Naidu et al. [50] found that BP inhibited the proliferation of pathogenic microbes in chicken gut. BP-based diets may have accomplished this by increasing the production and release of mucus in the digestive tract of chicken, which in turn inhibits the adhesion of pathogens and aids in stabilisation of intestinal microbial eubiosis in chickens [51]. Administration of high doses of BP extract to animals other than chickens linearly increased the number of Lactobacillus and reduced the number of E. coli in the GIT [52]. These results supported the findings of Yan et al. [53], who reported that administration of BP extract to chicken suppressed the proliferation of E. coli in the intestine.

The suppression of Clostridium by medicinal herbs is a welcome development and opens the door to the elimination of antibiotics in animal feed [50,54]. Clostridia, especially C. perfringens, causes necrotic enteritis in poultry even though it is found in a small number in the digestive tract of healthy birds [55]. In vitro studies revealed that bioactive compounds suppress the proliferation of clostridia [50,54]. BP may have accomplished this by reducing clostridia colonisation in the gut. Researchers [56,57] found that broiler chickens orally challenged with C. perfringens and fed with herbal-based diets had less severe necrotic lesions, reduced number of C. perfringens in chicken’s gut, and reduced mortality when compared to challenged broiler chickens fed with diets not supplemented with herbal products.

The anticoccidial potential of BP and other herbal products and preparations in chickens has been investigated, with promising results [58–60]. Rahman et al. [60] observed that administration of alcoholic extracts of BP at 9 ml/kg body weight reduced oocyst counts in coccidiosis-challenged chickens. This corroborated the finding of Reisinger et al. [61] who observed that herb-based feed additives improved intestinal functions in broilers administered with mild doses of coccidial vaccine. The anti-inflammatory, antioxidant, and antimicrobial properties of BP could play a vital role as anti-coccidioestat, as highlighted by Rahman et al. [60] who reported that oral administration of alcoholic extracts of BP reduced oocyst counts in coccidiosis-challenged chickens.

8 Influence of BP-based diets on intestinal morphology of chickens

Research has shown that BP improves ileal muscle contraction [17,18]. Dietary BP supplementation increased mucosa and sub-mucosa thickness of the duodenum, jejunum, and ileum in broiler chickens [19]. In addition, BP increases the total diameter and the absorption surface area of the different sections of the small intestines. These morphological alterations in the gut prompted by BP may provide additional clue on the importance of herbal products to the GIT. Pearlín et al. [62] discovered that the pH of the GIT is influenced by a number of factors, one of which is dietary composition. Sugiharto et al. [63] found that administration of fermented BP at 10 g/kg feed to chicken diet had no effect on gut pH. In contrast, Loh et al. [64] noticed that inclusion of fermented products into laying hen diets resulted in lowering the pH values of the excreta. The exact reason for the inability of 10 g fermented BP (i.e., BP fermented with lactic acid bacteria at room temperature for 4 days)/kg feed to influence the intestinal pH of broiler chickens was unknown. However, the buffering activity of the intestine in response to dietary fermented BP may have stabilised the digesta pH of broiler chickens [62]. Sugiharto et al. [63] observed that broilers fed with 10 g fermented BP/kg feed had enhanced villi height (VH), crypt depth (CD), and VH/CD ratio in the duodenum, jejunum, and the ileum of
broiler chickens, implying that BP improves efficiency of digestion and nutrient uptake in chickens as reported by Baurhoo et al. [65]. These observations supported others [61,66,67] who observed that herbal products and preparations improved intestinal histomorphometric traits of chickens. In converse, Cardoso et al. [68] found that high dose levels of piperine (0.12 and 0.18 g/kg) lower the absorptive capacity of the jejunum. The observed variation could be attributed to dosage and age of the birds.

9 Effect of dietary BP supplementation on growth performance parameters of chickens

BP is endowed with essential nutrients and phytochemicals which lay credence to the use of this spice as a feed supplement. Several parts of BP plant have been employed to boost animal performance. Significant improvement in zootecchnical parameters of chickens by feeding BP has been highlighted [11,69,70]. Improved FCR and BWG (2–9%) were obtained in broiler chickens fed with BP at 2.5, 5.0, 7.5, and 10.0 g/kg feed [21], which is attributed to the antioxidative activity of BP in protecting the villi from oxidative damage [9,10], leading to higher BWG. These findings were corroborated by Ufele et al. [70] who reported that inclusion of BP at 5 g/kg feed had a beneficial influence on feed intake and BWG in broiler chickens. This improvement in zootecchnical traits may be ascribed to the ability of bioactive constituents in BP-based diets to upregulate the expression of digestive-enzyme-related genes and reduce the proliferation of pathogenic microbes in the GIT. This could also be attributed to the BP’s ability to stimulate the release of digestive enzymes, increase digestion and utilisation in the GIT, and reduce feed transit time, all of which lead to higher BWG [11].

Ghaedi et al. [13] indicated that Ross 308 broiler chickens fed with 2 mg/ml BP and 200 g/ton virginiamycin had numerically higher BWG and lower FCR (FCR) than those offered diet without BP supplementation. Rahimian et al. [71] recorded a 6% increase in BWG in Cobb 500 broiler chickens fed with 20 g BP/kg feed, which they ascribed to the ability of bioactive compounds present in BP to encourage the proliferation of beneficial gut microbes. In a similar study, Ndelekwute et al. [69] observed comparable BWG in starter (1–21 days) and finisher (22–49 days) broiler chickens fed 0, 2.5, and 5.0 g BP seeds/kg feed. Finisher broiler chickens fed 0, 2.5 and 5.0 g BP seeds/kg feed had better FCR than those fed 7.5 and 10.0 g BP seeds/kg feed. Conversely, Puvaca et al. [72] revealed that BWG and FCR were not influenced in birds fed with BP-based diets at 5 and 10 g/kg feed for 42 days. Ndelekwute et al. [69] found that finisher broiler chicken fed with 7.5 and 10 g BP seeds/kg feed had poor BWG and FCR when compared to the birds fed with a diet without BP supplementation, implying that higher inclusion of BP seeds in the chicken diet is detrimental to growth. This finding supported Akbarian et al. [73], who discovered that male broilers fed 5 g BP/kg feed had no effect on BWG when compared to the control. These variations in performance traits of chickens fed PP-based diets may be connected to chicken’s age or the supplementation level of BP.

10 Influence of BP-based diets on relative organ weights, carcass characteristics, and meat quality

Several researchers [11–13,21–71] have investigated the effect of BP-based diets on carcass yield, and organ

Table 5: Performance indices of broiler chickens on varying levels of BP

<table>
<thead>
<tr>
<th>References</th>
<th>Dosage (%)</th>
<th>DOS (week)</th>
<th>Feed intake (g/day/birds)</th>
<th>FCR</th>
<th>BWG (g/day/birds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CTL</td>
<td>BPG</td>
<td>Diff %</td>
</tr>
<tr>
<td>Galib et al. [11]</td>
<td>0, 0.25, 0.5, 0.75, 1.0</td>
<td>0–6</td>
<td>101.35</td>
<td>115.10</td>
<td>14.0</td>
</tr>
<tr>
<td>Ghaedi et al. [13]</td>
<td>0, 0.2 mg/ml</td>
<td>0–6</td>
<td>87.17</td>
<td>88.16</td>
<td>1.0</td>
</tr>
<tr>
<td>Shahverdi et al. [19]</td>
<td>0, 0.02</td>
<td>0–6</td>
<td>68.33</td>
<td>70.33</td>
<td>3.0</td>
</tr>
<tr>
<td>Sugiharto et al. [28]</td>
<td>0, 1.0</td>
<td>0–5</td>
<td>87.86</td>
<td>86.74</td>
<td>-0.2</td>
</tr>
<tr>
<td>Abou-Elkhair et al. [12]</td>
<td>0, 0.5</td>
<td>0–5</td>
<td>74.16</td>
<td>73.97</td>
<td>-0.2</td>
</tr>
<tr>
<td>Ndelekwute et al. [69]</td>
<td>0, 0.25, 0.5, 0.75, 1.0</td>
<td>0–7</td>
<td>69.00</td>
<td>67.98</td>
<td>-1.5</td>
</tr>
<tr>
<td>Rahimian et al. [71]</td>
<td>0, 0.2</td>
<td>0–6</td>
<td>87.20</td>
<td>88.16</td>
<td>1.0</td>
</tr>
</tbody>
</table>

DOS – duration of study; CTL – control; Diff – difference; BPG – black pepper group; FCR – feed conversion ratio; BWG – body weight gain.
weight of broilers (Table 5). However, findings from these investigations have not been consistent. Abou-Elkhair et al. [12] demonstrated that carcass yield, liver, gizzard, heart, proventriculus, spleen, thymus, and bursa of Fabricius weights were not affected in broilers fed with 5 g BP/kg feed. Similarly, Galib et al. [9] noticed that dietary BP supplementation up to 10 g/kg feed in the broiler ration had no significant influence on relative organ weights. Other researchers [25,21] found similar trend in gizzard weights of broilers fed with BP powder (up to 10 g/kg feed). These findings supported the results of Puvaca et al. [74], who found comparable relative weights of liver, heart, drumstick, and breast in broiler chickens fed with 5 and 10 g BP/kg feed. In contrast, Rahimian et al. [71] found that 2 g BP powder/kg feed increased the relative weights of liver, drumstick, breast meat, and carcass yield in broiler chickens. Additionally, Sugiharto et al. [28] found significantly higher gizzard weight in broiler chickens fed with 10 g acidified BP/kg feed compared to birds fed with 0 g acidified BP/kg feed. The reported higher gizzard weight could be an attempt by the birds to increase the nutrient digestion through prolonged feed retention time, as well as grinding and mixing of diet with digestive enzymes as over-acidification has been found to lower feed digestibility in avian species [75].

The potential efficacy of herbs to improve carcass yield, cut-part, dressing percentage, and meat quality parameters of broiler chickens has been documented [28,76,77]. Prabhakaran et al. [78] observed that dietary BP supplementation did not affect organoleptic parameters of breast meat of animals other than chickens. According to Garcia et al. [79], the light colour indicates the freshness of meat, and directly influences the consumer’s final purchase decision. The inclusion of 10 g acidified BP/kg feed reduced the lightness ($L^*$) values and increased the yellowness ($b^*$) values of breast and thigh meat in broiler chickens [28]. This implies that dietary acidified BP supplementation at 10 g/kg feed enhanced the quality of broiler chicken meat. Lighter breast meat and thigh colour in birds fed with BP when compared to birds fed with diets without acidified BP could be attributed to high concentrations of carotenoids in BP [9]. The beneficial influence of BP on meat parameters is majorly connected to the antioxidative activities of its bioactive agents.

Abdominal fat pad which is the most common way for assessing dietary energy use efficiency was significantly lower in birds fed diet having up to 10 g BP powder/kg feed [71,74]. There is a positive correlation between abdominal fat deposition and total fat in animals. A decline in abdominal fat pad at a dose of 2 g BP/kg feed in a broiler diet have been reported [74]. This corroborated the findings of researchers [13,19] who reported significantly lower abdominal fat pad content in broilers fed with BP at 0.2 g/kg feed and 2 mg/ml BP, respectively. This observation connotes the efficient use of energy by birds fed with BP-based rations. The significantly lower abdominal fat pad weight may be linked to a reduction in blood lipid level as phytogenic feed additives have been found to have hypolipidemic and hypocholesterolemic properties in farm animals [11,19,80]. The potential of bioactive agents in BP to inhibit the action of fatty acid synthase in bird liver could account for the significant decline in the abdominal fat weight.

### 11 Impact of BP-based diets on haematology and blood chemistry of chickens

Blood indices are useful for assessing health status of animals because they reflect various metabolic changes in organs and tissues [81]. Research indicates that poor nutrient intake and utilisation affect blood variables in farm animals [70,81]. Low haemoglobin (Hb) levels indicate normocytic iron deficiency anaemia since there is a clear link between dietary iron intake, Hb, and serum iron [82]. Packed cell volume (PCV) is the most precise method for assessing red blood cell (RBC) concentration in the blood and may be used to deduce the amount of Hb in the blood [83]. Report on blood characteristics of broiler chickens fed with 5 g BP/kg feed had comparable blood values when compared to the control [12]. Galib et al. [11] found similar white blood cells (WBC) in broiler chickens fed with 0 and 5 g BP/kg feed. On the contrary, Shahverdi et al. [19] showed that chickens fed with BP-based diets had significantly lower Hb, PCV, RBC, heterophil (H)/lymphocyte (L) ratios, and cholesterol relative to the control group. The mechanism by which high doses of BP reduced PCV and RBC in broiler chickens is not well known; however, it could be ascribed to the action of bioactive constituents on oestrogen, which reduces the levels of RBC and PCV in the blood [84]. Incorporation of BP to animal feed reduced RBC counts in broiler chickens [21,63], implying that BP had an adverse influence on erythropoiesis. This also suggests that the inclusion of high levels of BP in chicken diets may not be well-utilised by broilers for best blood values.

Blood biochemical traits can be changed by feeding birds with herbal products and their related products.
The higher the protein levels in the plasma, the better the quality of protein in the diet \[81\]. Akinfola et al. \[85\] found positive relationships between protein intake and total plasma proteins in birds. The inclusion of 0.5 g BP oil/kg feed in the diet of broiler chickens increased plasma proteins \[44\], suggesting that the quality of protein in the diet was not compromised by BP supplementation. The improvements in BWG of chickens fed with BP-based diets as reported by other investigators \[11,69,70\] could be linked to increased total plasma proteins and globulin, as there is a positive correlation between total plasma proteins and BWG in farm animals \[81\]. The higher globulin levels in birds fed with BP-based diets indicate improved immunity because globulin is a precursor for immunoglobulin formation \[85\]. On the other hand, other researchers \[12,63\] found that BP did not affect plasma total protein and albumin levels in broiler chickens. The observed disparity could be attributed to the part of BP used and the amount included in the diet.

Plasma levels of aspartate aminotransferase (AST) and alanine aminotransferase (ALT) indirectly reflect the health status of the liver, and an increase in their levels above a certain threshold is viewed as signs of liver damage. BP has been shown to have hypoglycemic effects in broiler chickens \[19,86\]. This may be connected to the strong agonistic effect of bioactive agents in BP, specifically piperine on β adrenergic receptors \[87\]. Several investigators \[12,44,63\] found no significant effect of BP on plasma ALT and AST levels in broiler chickens, indicating the hepatoprotective effect of BP in broiler chickens. The non-significant increase in ALT and AST levels of broilers fed with BP essential oils could in part be attributed to the hepatoprotective activity of BP, as Damanhouri and Ahmad \[42\] noticed that feeding BP improved the liver function.

Herbal products improve immune responses, because they induce the production and release of immunoglobulin, lymphocytes, and interferon-γ \[88,89\]. The addition of 0.25 and 0.5 g BP oil/kg feed to broiler diet increased plasma immune traits, as evidenced by increased lysozyme activity, immunoglobulin levels, and phagocytic indices when compared to birds fed with a diet without BP oil supplementation \[44\]. This finding supported Awaad et al. \[90\], who discovered that mint oils have potent immunomodulatory effects in avian species. BP upregulates the expression levels of the IL-10 and IgA genes in broiler chickens \[44\].

High-density lipoprotein (HDL) is essential for lipid transport and delivery to the cells and tissues. Low doses of BP (≤5 g/kg feed) have been reported to cause mild changes in cholesterol metabolism by increasing the activity of cholesterol 7a-hydroxylase \[91\]. Increased activity of this rate-limiting enzyme implies greater use of cholesterol for bile acid synthesis. This observation is consistent with the findings of other authors who reported that BP had hypolipidemic and hypocholesterolemic effects in chickens \[13,19,44,73\]. This could be ascribed to the inhibition of acetyl-CoA synthesis by BP, which is necessary for lipid metabolism. Research has shown that bioactive compounds in BP, particularly piperine have antiperoxidative properties in animals \[92\]. As a result, the lower blood cholesterol and LDL-cholesterol concentrations observed in broiler chickens fed with BP-supplemented diets \[11,13,19,72\] could be attributed to antioxidative property of BP \[9,33\]. Incorporation of BP to the diet has also been found to significantly increase blood HDL cholesterol concentrations. This could be partly connected to the stimulatory effects of active agents in BP-based diets on the activities of lipoprotein lipase (LPL) and cholesterol acyl transferase (LCAT) as earlier research has shown that increased activity of blood LPL and LCAT results in an increase in HDL biosynthesis and a decrease in LDL levels \[91\].

12 Effect of dietary BP supplementation on egg quality characteristics of laying hens

Melo et al. \[93\] showed that commercial layers fed with basal diet containing BP at 1, 2, 3, 4, 5, and 6 g/kg feed did not affect egg quality attributes compared with a control group. In contrast, Akinwumi et al. \[20\] reported improved egg weight, egg shape index, shell weight, albumen height, and yolk characteristics of layers fed with diets having 0.1–0.5 g BP/kg feed when compared with the control layers fed with a diet without BP supplementation. Also, the authors noticed that BP improves the crude protein and the lipid profile of eggs. This indicates that inclusion of increasing levels of BP in laying hen diets improved aspects of egg quality traits in laying hens.

13 Dosage, presentation forms, and route of administration

The effects of graded doses of BP in chicken nutrition have been reported \[11,19,69,70\]. However, there are consistent results among authors due to variations in layer age, BP composition, supplementation level, health status, feeding duration, and chicken strain \[13,19\]. The dose rate
of up to 2 g BP/kg feed was found to enhance performance parameters and health status of chickens [21,69,63]. The most common form and route for BP is powder administered via feed [11,13,19,69,70].

14 Limitations and strengths of this review

This review condensed the evidence on the effect of BP on performance, health parameters, and product quality of broiler chickens and laying hens and may not extend to other poultry species. Disparities in BP composition, plant part used, diet composition, dosage, and duration of supplementation, as well as the season of the year the experiment was carried out, may all have an impact on the accuracy of the results. Furthermore, variations in chicken’s age, sex, assay types, and analytical methods used by the different studies may pose a limitation. Despite these limitations, the results of this study have contributed significantly to our understanding of the potential of BP-based diets to improve growth performance, health status, and product quality of chickens.

15 Conclusion and future research

The use of BP in animal nutrition to improve chicken performance and health is gaining momentum due to the ban on the use of antibiotics as growth promoters. Although the results on the impact of BP on productivity and product characteristics of chickens differ, the majority of the findings indicated that BP improved chicken performance. There is convincing evidence that BP is high in nutrients, essential oils, and beneficial phytochemicals. Aside from being feed palatants and digestion stimulants, BP has been demonstrated to influence other physiological activities in chicken’s body which help to improve chicken performance and product quality. Furthermore, the addition of BP to the diet of chickens has been found to increase egg quality, reduce the concentration of triglycerides and cholesterol in the plasma, lower the concentrations of liver enzymes in the plasma, modulate immune responses, balance intestinal microbiota composition, and enhance the activities of intestinal morphological traits. These observations also support the use of BP in chicken diet to fight enteric pathogens. BP may have actualised these positive impacts in chickens via one or a combination of the following modes of action: (i) modulation of intestinal microbiota and immune systems, (ii) antimicrobial effect and direct nutritional properties, (iii) alteration of gut function to favour the synthesis and release of digestive enzymes, and (iv) improvement in feed intake, digestion, and nutrient absorption. Like other medicinal herbs, the effect of BP in chicken performance has not been totally explored, possibly due to the fact that their action is dependent on some factors like composition, variety, supplementation level, the type of soil where the plant was grown, age of chicken, dietary composition, and several others. In view of this, the use of quadratic optimisation model and meta-analysis to determine the dose levels of BP that optimised different parameters of chickens, as well as factors that lead to inconsistent results among authors is recommended.

There is lack of information in the literature on the nutrient and phytochemical compositions of BP roots, as well as the effects of the different parts of BP plant on intestinal histology, meat quality, egg production, and quality of chickens; therefore, more studies are recommended in this direction. To guarantee the safe and efficient use of BP in the poultry industry, the negative effects of overdosage must be evaluated. Future studies should centre on standardising the composition of BP used in feeding studies so that these results can be easily compared. Potential synergistic effects of phytochemical compounds in BP are likely; however, this needs to be investigated in more detail and under standardised conditions.

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