Recent advances in the incorporation of leaf meals in broiler diets

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Recent advances in the incorporation of leaf meals in broiler diets

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Abstract

The increase in feed price has been a serious problem in broiler industry as it may increase broiler production cost. Attempt has been carried out to reduce the feed cost by for example partly replacing the conventional-expensive protein-rich feed ingredients with the alternative protein-rich feedstuffs. Among the alternatives, leaf meals containing high content of protein have been incorporated in broiler diets. Besides being rich in protein, leaf meals also contain a wide variety of biological active components that may serve as growth promoting and health-improving agents for broiler chickens. Yet, the high contents of fibre and anti-nutritional factors may limit the inclusion levels of leaf meals in broiler diets. To obtain the benefits of bioactive compounds in leaf meals with no detrimental effects on the production traits of broilers, dietary supplementation of enzymes and fermentation have been conducted. This review provided a comprehensive view regarding the recent advances in the application of leaf meals in broiler diets.

Keywords: *duckweed, green leaf, growth, health*

Introduction

Feed has been a major cost in modern broiler production, accounting about 70% of the total production cost (Sugiharto 2019). The increase in feed price may therefore imply in the increase in total production cost and thus decrease the profit margin of broiler industry. Attempt has recently been taken to reduce the cost of feed, including the incorporation of agro-industrial by-products in broiler diets as an energy source (Sugiharto et al 2018a; Sugiharto 2019; Sugiharto and Rajitkar 2019). However, some limitations may exist when using the agro-industrial by-products as the ingredients in broiler rations. The high and low contents of fibre and protein in the by-products may limit the digestibility and thus inclusion level of such by-products (Sugiharto et al 2018a). In addition to the agro-industrial by-products, the application of leaf meal as the ingredient in broiler feeds has also been conducted (Abdulsalam et al 2015; Aroche et al 2018; Mustafa 2019). Compared to agro-industrial by-products, the content of crude protein in leaf meal is much higher (Tesfaye et al 2013; Sugiharto et al 2018a). This may be beneficial in reducing the proportion of the conventional-expensive protein-rich feed ingredients in broiler rations.

It has been known that some particular foliages contain a number of bioactive compounds that are beneficial for the health of chickens (Rama Rao et al 2019). These compounds include vitamins, phenolic acids, flavonoids, isothiocyanates, tannins as well as saponins (Vergara-Jimenez et al 2017). In this regard, the use of leaf meal in rations may not only reduce the cost of feeds, but also elicit the health-promoting effect on broiler chickens. Apart from their benefits, the use of leaf meals in broiler diets may be limited by their high content of crude fibre (Santoso and Sartini 2001; Ubua et al 2019). In general, broiler chickens showed low tolerance to dietary fibre, and therefore feeding diets containing high levels of leaf meal may impose in compromised nutrient digestibility and thus alleviated growth performance of broilers (Buragohain 2016). To deal with the latter problem, dietary supplementation of enzymes (fibre-degrading enzymes) (Fasuyi and Akindahunsi 2007; Oloruntola et al 2016) and fermentation has been conducted to particularly degrade the fibre and hence increase the incorporation levels of leaf meal (Mandey et al 2015; Santoso et al 2015). The present review provided a comprehensive view concerning the recent advances in the application of leaf meal in broiler rations.

Nutritional properties and potential of leaf meals as feed ingredients for broiler chickens

In generally speaking, leaf meals may be defined as the dried and ground products of plant leaf. The products may be used for human consumption as well as livestock feeds. In broilers, the potential of leaf meal as feed ingredients has long been studied (Wyllie and Chamanga 1979). Today, due to the increase in feed price particularly for the protein-rich feed ingredients, the incorporation of leaf meal in broiler diets is encouraged (Oloruntola et al 2019; Sebola et al 2019; Ubua et al 2019). This could be understood as the majority of leaf meals contain considerable levels of crude protein (Table 1). Previously, Onyimonyi and Ernest (2009) used papaya leaf meal to partially reduce the proportion of groundnut cake, which is rich in protein, in broiler rations. Likewise, Tesfaye et al (2013) used *Moringa olifera* leaf meal as an alternative protein source to reduce the use of soybean meal in broiler rations. In addition to protein, most of leaf meals contain high amounts of ash (Table 1), and therefore could be a good source of minerals for poultry. It should, however, be noted that the minerals contents of leaf meal may vary across the plant leaf. Tsega and Tamir (2009) provided an example that sweet potato leaf meal contains high concentration of Ca, but has low concentration of P. In the latter case, dietary supplementation of P should be conducted to achieve the ideal ratio of Ca to P in broiler rations. Apart from the potential of leaf meal as an alternative protein source, study showed that application of leaf meal in broiler diets is often limited by the high content of crude fibre in the foliage (Table 1). Tesfaye et al (2013) suggested that the increased fibre content in rations with the increased levels of leaf meal may consequently depress feed intake and thus growth performance of broilers. The fibre may increase the bulkiness in the gastrointestinal tract and thereby reduce feed consumption (Buragohain 2016).

Table 1. Proximate composition of some species of leaf meals

Types of leaf meal	Proximate composition (%, DM basis)					References
	DM	CP	CF	EE	Ash	
Sauropus androgynus	89.2	16.8	35.0	22.3	14.3	Santoso and Sartini (2001)
Microdesmis puberula	84.9	17.3	24.8	6.52	12.2	Esonu et al (2002)
Gliricidia sepium	92.8	18.2	12.9	2.70	18.2	Kagya-Agyemang et al (2007)
Mucuna	93.9	18.8	22.3	NM	0.91	Perez et al (2008)
Rosemary	91.5	5.12	19.4	15.4	7.06	Ghazalah and Ali (2008)
Amaranthus cruentus	88.0	23.0	8.80	5.40	19.3	Fasuyi and Akindahunsi (2009)
Papaya	89.8	30.1	5.60	1.20	8.45	Onyimonyi and Ernest (2009)
Dried sweet potato	91.0	25.0	8.41	3.37	13.2	Tsega and Tamir (2009)
Cassava	91.3	22.2	12.0	3.61	14.6	Adeyemi et al (2012)
Mulberry	89.9	26.6	14.3	2.79	14.0	Olmo et al (2012)
Moringa oleifera	90.9	28.2	6.50	6.60	11.9	Tesfaye et al (2013)
Guava	94.3	13.2	NM	4.00	24.0	Mahmoud et al (2013)
Pumpkin	91.5	3.44	1.60	3.67	8.04	Imasuen et al (2014)
Acacia angustissima	90.0	23.4	13.0	NM	4.77	Ncube et al (2017)
Polyalthia longifolia	99.3	10.0	19.7	0.18	6.02	Alagbe (2017)
Mistletoe (*Viscum album*)	92.3	3.50	8.90	7.11	11.2	Ologhobo et al (2017)
Neem	94.0	22.4	20.5	3.00	12.2	Ubua et al (2019)

DM: dry matter, CP: crude protein, CF: crude fibre, EE: ether extract, NM: not measured

In addition to the species of plants, the nutritional qualities of leaf meal may also be determined by the maturity stage of leaf. Sebola et al (2019) noticed that compared to mature leaf, young leaf of *Moringa oleifera* had considerable higher organic matter and crude protein, and lower crude fibre, crude fat and ash contents. Hence, the stage of maturity of the foliage should be considered when formulating broiler rations using leaf meal as it may influence the nutritional contents of diets. Indeed, the different nutritional contents may also exist within the species of plant. For example, Kagya-Agyemang et al (2007) showed that *Gliricidia sepium* leaf meal contained 18.2% crude protein and 12.9% crude fibre, while Oloruntola (2018) found that such leaf meal contained 24.4% crude protein and 12.5% crude fibre. The variation of crude protein content in *Gliricidia sepium* leaf meal may be due to the differences in the nature of plants, age, water, temperature/climate and soil conditions where the plants are grown.

Functional properties of leaf meal

The role of functional feeds or feed ingredients is becoming noticeable during the post-antibiotic era. With their active components, the functional feeds may exert beneficial impacts on the health and production traits of broiler chickens (Sugiharto et al 2018a). Among the sources of functional properties, green leaf have been known to naturally contain numerous active compounds that are beneficial for the health and wellbeing of both humans and animals. These bioactive components include phenols, flavonoids, alkaloids, saponins, tannins, terpenoids, steroids, etc. Mashayekhi et al (2018) revealed that phenolic compounds in the *eucalyptus* leaf can act as antioxidants, antimicrobial agent, appetite enhancer, growth promoter and immunostimulator. Also, polyphenols in summer-autumn tea leaf improved the oxidative status and immune competences of broiler chickens in the study of Wang et al (2018). Study by Ouyang et al (2016) showed the efficacy of alfalfa flavonoids in improving the antioxidative status and fatness in broiler chickens. Likewise, Kamboh et al (2016) demonstrated that plant flavonoids (genistein and hesperidin) improved the immune competences and antioxidant status of broiler chicks. With regard to saponin, Manjaniq et al (2017) exhibited that saponin in *Moringa* leaf meal was responsible for protecting the erythrocytes from destruction (caused by the free radicals or reactive oxygen species) as well as stimulating the erythrocytes production in broiler chickens. In line with this, Zhang et al (2017) showed that saponins derived from mango leaf improved growth performance, meat characteristics and plasma lipid profile of broilers. In term of alkaloids, study by Santoso (2018) showed that feeding *Sauropus androgynus* leaf meal rich in alkaloid was beneficial in improving the growth performance of broilers. In agreement, Alagbe (2017) reported that *Polyalthia longifolia* leaf meal containing 0.51% alkaloids may be employed as an antibiotic substitute for improving the growth performance of broilers. Another active compound that is largely found in green leaf is condensed tannins, which is valuable in protecting the chicks from infectious diseases and improving their growth performance (Alagbe 2017; Hidanah et al 2018; Sebola et al 2019). In general, there are a great variation in the types and levels of active components within and among the species of plant leaf (Alagbe 2017; Sebola et al 2019). Both genetic and environmental factors may determine the types and levels of the bioactive compounds in the plant leaf (Makita et al 2016). Also, the age or degree of maturation affects the concentration of bioactive compounds in the leaf (Sebola et al 2019). To optimize the role of leaf meals in improving the health and production traits of broilers, it is therefore crucial to select the leaf according to its species, origin and degree of maturation before being included in broiler rations.

Extraction and isolation of specific component have widely been practiced from the green leaf. This is necessary as green leaf contain wide spectrum or mixed of active compounds (Alagbe 2017; Sebola et al 2019). The extraction and isolation are generally expected to obtain particular compound with certain functional effect on chickens. Oke et al (2017) extracted phenolic compound (oleuropein) from olive leaf and supplemented in the drinking water of broilers. They found that such treatment improved broiler growth performance under thermal stress. In line with this, Zhang et al (2017) found that saponins extracted from the mango leaf was attributed to the improved growth performance, meat characteristics and plasma lipid profiles of broiler chickens. In practice, supplementation of the active compounds should be conducted regularly in broiler chickens. This because the active components are rapidly metabolized and not accumulated in the body of broilers. Moreover, the chicks cannot synthesise these active components, and therefore dietary supplementation of these components is necessary.

Anti-nutritional factors in leaf meals

The presence of anti-nutritional factors such as tannin, alkaloids, saponins, flavonoids, cyanide, oxalate, phytate, etc. has been a great concern when incorporating leaf meals into broiler diets as they may negatively affect the nutrient digestibility and utilization of broiler chicks (Kagya-Agyemang et al 2007; Buragohain 2016). Buragohain (2016) revealed that the presence of tannin in *Tithonia diversifolia* leaf meal was attributed to the decreased feed intake and nutrient digestibility in broilers. Tannin may bind protein and digestive enzymes to be a complex form that are not readily digestible (Buragohain 2016). This consequently reduces the protein digestibility and utilization. The presence of tannin in leaf meals may also damage the mucosa of enterocytes and interrupt the metabolic processes leading to compromised growth performance of broilers. However, the effect of tannin seems to be ambiguous as many studies exhibited the improving effect of tannin on the health and growth performance of broilers (Alagbe 2017; Hidanah et al 2018; Sebola et al 2019). The similar condition is observed for saponins in leaf meals, in which feeding leaf meal rich

in saponins could improve the health and growth of broilers (Zhang et al 2017). Conversely, the presence of saponins in leaf meals may act as anti-nutritional factors for broiler chickens (Peiretti 2018). According to Chamorro et al (2019), administration of moderate amounts of phenolic compounds and other secondary plant metabolites (such as tannin and saponins) may positively affect the health and production performance of broilers, whereas the high levels of such compounds negatively affect the nutrient utilization of broilers. In this regard, study to optimize the level of leaf meals in broiler rations is necessary to obtain the functional properties of leaf meals without compromising the growth of broilers.

Some methods may be conducted to reduce the anti-nutritional factors in leaf meal. Among the methods, sundrying has been reported to reduce the anti-nutritional factors content in leaf meal (Fasuyi et al 2008). Other methods such as cooking, autoclaving, dehulling, soaking, toasting and using the anti-nutritional binding agents may also be carried out to reduce the contents of anti-nutritional factors in leaf meals (Medugu et al 2012). Moreover, fermentation may also be conducted to reduce the anti-nutritional factors in leaf meals (Santoso et al 2015; Sugiharto and Ranjitkar 2019).

Leaf meals as feedstuffs for broiler chickens

A number of works has incorporated leaf s in broiler diets (Table 2). The incorporation of leaf meal is primarily subjected to reduce the use of protein-rich feed ingredients in broiler rations and, hence, reduce the cost of feeds. The other is to take the advantages from the bioactive components in leaf meal to improve the growth performance of broiler chicks. Rahman and Yang (2018) noted that supplementation of pineapple (*Ananas comosus*) leaf powder up to 3% in diets was able to improve the growth performance of broiler chicks. It seemed that leaf meals increased the production and activities of digestive enzymes as well as improved the intestinal morphology (villi development) of broilers resulting in improved nutrient digestibility and utilization (Mariana et al 2018; Mustafa 2019). The improvement of intestinal microbial ecosystem, immune responses and physiological conditions of chicks may also be attributed to the increased growth rate in broilers fed with leaf meals (Fasuyi et al 2008; Liaqat et al 2016; Rahman and Yang 2018; Mustafa 2019).

Table 2. Examples of leaf meals as alternative feed ingredients for broilers

Types of leaf meal	Levels in rations	Effect on birds	References
Cassava	Added to the basic ration at levels of 10, 20, and 30%	Addition (all levels) compromised body weight gain and feed efficiency of broilers	Montilla et al (1977)
Sauropus androgynu	Included at 0, 10, 20 and 30 g/kg diets	Inclusion at 30 g/kg diet reduced feed intake and improved feed conversion ratio	Santoso and Sartini (2001)
Sauropus androgynus	Incorporated at 5% in broiler diets contaminated with aflatoxin	Inclusion at 5% improved growth performance of broilers contaminated with aflatoxin	Prakoso et al (2018)
Microdesmis puberula	Included in broiler diets at 0, 10 and 15%	Inclusion at 10% resulted in no deleterious effects on broiler performances	Esonu et al (2002)
Gliricidia sepium	Included at levels of 0, 50, 100 and 150 g/kg in broiler diets	Treatment depressed feed intake, feed conversion efficiency and body weight gains	Kagya-Agyemang et al (2007)
Gliricidia	Incorporated in broiler diets at 0, 5 and 10%	Incorporation of 5% resulted in no detrimental effect on the growth performance and carcass traits of broilers	Oloruntola et al (2018)
Amaranthus cruentus	Included in broiler rations at levels of 5, 10, 15, 20 and 25%	Inclusion at 5% favoured of growth performance, nitrogen utilization, muscle development and blood indices	Fasuyi et al (2008)
Mucuna	Included at broiler ration at levels of 50, 100 and 150 g/kg	Inclusion up to 100 g/kg did not affect apparent ileal digestibility of protein and amino acids	Perez et al (2008)
Rosemary	Included in broiler rations at levels of 0.5, 1.0 and 2.0%	Inclusion of 0.5% resulted in higher body weights, greater weight gain, and better feed conversion	Ghazalah and Ali (2008)
Papaya	Incorporated at broiler diets at levels of 0, 0.5, 1.5 and 2.0%	Inclusion of 2% papaya leaf meal in finisher diets improved growth performance of broilers	Onyimonyi and Ernest (2009)
Dried sweet potato (*Ipomoea batatas*)	Included at broiler rations at levels of 0, 5, 10, 15 and 20%	Inclusion at 10% resulted in similar dry matter intake and body weight gain compared to control. Inclusion more than 10% resulted in detrimental effect on intake and gain of broiler	Tsega and Tamir (2009)
Dried sweet potato	Included at levels of 0, 50, 100, 150, and 200 g/kg DM	The leaf meal can be optimally included in diet at the level of 100 g/kg DM	Tamir and Tsega (2010)
Oregano	Included in broiler rations at levels of 0, 2.5, 5, 10 and 20 g/kg diets	Different levels of oregano leaf meal did not have effect on growth, feed efficiency and mortality of broiler chicks	Karimi et al (2010)
Lemmon grass	Added 1% to basal diet	Improved growth performance of broilers	Mmereole (2010)
Azadirachta indica dried	Supplemented in broiler rations at levels 1.25, 2.5 and 5.0 g /kg of feed	Supplementation of 2.5 g/kg resulted in no negative effects on broiler performance, serum biochemical constituents and haematological indices	Ansari et al (2012)
Neem	Included at broiler rations at levels of 0, 0.1, 0.3, 0.5 and 0.7%	Neem leaf meals may be optimally included in broiler rations at the level of 0.3%	Wiryawan et al (2017)
Neem	Incorporated at levels of 0, 1 and 2 g/kg broiler diets	Treatment improved body weight gain and feed conversion ratio of broilers	Kharde et al (2014)
Neem	Included in broiler rations at levels of 0, 2.5, 5 and 7.5%	The leaf may be included in broiler rations at maximum of 5% without impairing the growth and carcass traits	Ubua et al (2019)
Pumpkin	Included at levels 0, 5, 10, 15% in broiler rations	The use of pumpkin leaf meal more than 5% in rations may depress the growth performance of broilers	Imasuen et al (2014)
Moringa oleifera	Included at broiler rations at levels of 0, 5, 10, 15 and 20%	Inclusion of 5% *Moringa oleifera* leaf meal in rations did not have negative effect on growth performance, whereas at 10-20% inclusion levels reduced growth performance of broilers	Tesfaye et al (2013)
Moringa oleifera	Incorporated at 0, 7.5, 15 and 30% in broiler rations	The foliage can only be included in the feed to levels of up to 7.5% as higher levels affected weight gain, feed intake and dry matter digestibility	Gakuya et al (2014)
Moringa oleifera	Included at levels of 0, 0.5, 0.75 and 1.0%	The leaf meal adversely affected the performance during starter period, but enhanced the performance during finisher and whole period	Abdulsalam et al (2015)
Moringa oleifera	Incorporated at 0, 5, 10, 15 and 20% in broiler rations	Incorporation of *Moringa oleifera* at 15% and 20% improved growth performance of broilers	Alnidawi et al (2016)
Moringa oleifera	Included at 3.0% in commercial diet	Treatment had no effect on blood profile of broilers	Manjaniq et al (2017)
Moringa oleifera	Included at broiler rations at 0, 25, 50 and 100 g/kg DM	Dietary treatment did not negatively affect the nutrient digestibility of broilers	Sebola et al (2019)
Moringa oleifera	Supplemented to broiler rations at 0, 500 and 1000 mg/kg	Supplementation had no effect on bodyweight gain, feed conversion efficiency and carcass characteristics of broilers	Rama Rao et al (2019)
Alchornea cordifolia	Included in broiler diets at levels of 0, 5 and 10% (with or without exogenous enzymes supplementation)	Inclusion up to 10% in broiler diets may be implemented without detrimental effects on growth rate, carcass traits and health status of broilers	Oloruntola et al (2016)
Tithonia diversifolia	Incorporated at levels of 0, 2, 4, 6, 8 and 10%	Incorporation at 4% may be safe for the growth rate, nutrient utilization and feed efficiency of broiler chickens	Buragohain (2016)
Mistletoe (*Viscum album*)	Included at levels of 0, 2.5, 5.0 and 7.5%	At all levels, treatment did not affect weight gain, feed intake and carcass characteristics of broilers	Ologhobo et al (2017)
Holy basil leaf powder	Supplemented in broiler rations at levels of 0, 0.5 and 1%	Supplementation (all levels) improve body weight gain and feed efficiency of broilers	Sheoran et al (2017)
Polyalthia longifolia	Included in broiler rations at levels of	Inclusion up to 3.5% had no detrimental effect of	Alagbe (2017)

	1.5, 2.5 and 3.5 %	growth, carcass characteristics and blood indices of broilers	
Eucalyptus (*Eucalyptus globulus* L.) leaf powder	Added to basal diets at levels of 0, 1 and 3 g/kg	Addition of 1 and 3 g/kg decreased body weight gain, while feeding 3 g/kg reduced feed intake during days 7-28	Farhadi et al (2017)
Eucalyptus leaf powder	Added to basal diets at levels 0, 0.25 and 0.5%	Addition 0.5% reduced feed conversion ratio, but all levels had no effect on growth performance and feed intake of broiler chicks	Mashayekhi et al (2018)
Eucalyptus camaldulensis	Added with basal diet at levels of 0.5, 1.0 and 2.0%	Dietary addition with 1% *Eucalyptus camaldulensis* increased body weight, body weight gain and economic profit	Mustafa (2019)
Acacia angustissima	Included in broiler rations at levels of 0, 5 and 10%	Inclusion up to 5% had no deleterious effect on growth, carcass yield and meat quality of broiler chicks	Ncube et al (2018)
Summer-autumn tea leaf powder	Supplemented in broiler rations at levels of 0.5, 1.0, and 2.0%	Inclusion of 2% resulted in lower body weight gain of broilers	Wang et al (2018)
Mixed powder of leaf of *Anacardium occidentale* (60%), *Psidium guajava* (20%), and *Morinda citrifolia* (20%)	Included at 0.5 % in broiler rations	Treatment decreased the feed intake and efficiency, but had no effect on nutrient digestibility of broiler chickens	Aroche et al (2018)
Trichantera, Moringa or *Arachis*	Included at 10% in broiler rations into commercial rations	Feeding plant leaf meal at 10% level reduced feed cost without any detrimental effects	Jonna et al (2018)
Pineapple (*Ananas comosus*) leaf powder	Supplemented to broiler rations at levels of 0, 1, 2 and 3%	All levels of supplementation improved growth performance and balanced intestinal microbial population of broilers	Rahman and Yang (2018)
Bamboo	Included at 5 g/kg in broiler rations	Improved the body weight gain of broilers	Oloruntola et al (2019)
Duckweed (*Lemna minor*)	Incorporated in broiler diets to replace fish meal for 0, 25, 50, 75 and 100%	Duckweed may safely be used to replace fish meal in broiler diets at maximum of 25% at starter and 50% at finisher phase	Aderemi et al (2018)

In general, the response of broilers in term of production performance to dietary leaf meal seems variable, depending on the types of leaf meal and levels of incorporations. *Moringa oleifera* may be included at the levels up to 20% to improve the growth rate of broilers (Alnidawi et al 2016), while *Alchornea cordifolia* leaf meal can only be included at 10% in rations without any deleterious effect on broiler performance (Oloruntola et al 2015). Different form the above mentioned leaf, *Tithonia diversifolia* leaf meal (Buragohain 2016) and Summer-autumn tea leaf powder (Wang et al 2018) may only be included in broiler rations at maximum of 4% and 2%, respectively, as higher levels of inclusion resulted in depressed nutrient utilization and thus compromised growth performance of broilers. In addition to the fibre content, the presence of anti-nutritional factors, nutritional composition of the whole diets, age of chicks, environmental factors, etc. may limit the use of leaf meal in broiler rations. To increase the dietary inclusion levels of leaf meal, the use of exogenous enzyme in concomitant with leaf meal may be conducted. Oloruntola et al (2016) reported that the use of exogenous enzymes improved the nutrient utilization of *Alchornea cordifolia* leaf meal by broiler chickens. The latter authors further suggested that the exogenous enzymes may work synergistically with the digestive enzymes of chicks to degrade the polysaccharides, protein and anti-nutritional factors resulting in increased nutritional values of leaf meal. The presence of the exogenous enzymes may also compensate the activity of endogenous enzymes that are inhibited by the presence of anti-nutritional factors such as tannin in leaf meal. In accordance with this, Fasuyi and Akindahunsi (2009) demonstrated that the use of enzyme such as Roxazyme G2 (containing cellulase, glucanase and xylanase) may increase the nutritional benefits of *Amaranthus cruentus* leaf meal as well as increase the incorporation levels of the leaf meal up to 25% in broiler rations. The use of enzymes may thereby increase the economical values of leaf meal in broiler production. From the economical point of view, the application of exogenous enzymes in conjunction with dietary leaf meal should, however, be practiced with caution as enzyme supplementation may increase the cost of broiler production. Indeed, Martens et al (2012) suggested that enzymes are not suitable for the smallholder broiler producers because of the cost and limited availability of enzymes in the market especially in the rural area.

It is generally believed that feeding of leaf meal may reduce the cost of feed in broiler production. Yet, the economic benefits seems to depend on the local circumstances. This is because some plants may grow well in certain place but not in other particular place. The season/climate and soil condition may determine the production and nutritional qualities of leaf meal, while the competition with the human needs may affect the supply of leaf meal for broiler production.

Due to the latter competition, the use of, for example, water spinach (*Ipomoea aquatica*) and taro (*Colocasia esculenta*) leaves in broiler rations is limited. Note that in some countries such as Indonesia, water spinach and taro leaves have traditionally been used as foodstuffs (vegetables). Other factor that may limit the use of particular leaf meals as broiler feed ingredients is the high cost of production of leaf meal. In this regard, Sońta et al (2019) noticed that high cost is needed for harvesting and processing of fresh duckweed into duckweed meal.

Leaf meal as functional feedstuffs for broiler chickens

In the post-antibiotic era, effort has been intensified to search the alternative stuffs for in-feed antibiotics. The use of leaf meal has been reported to improve the health status and physiological conditions of broilers in farms (Table 3). Hence, there is potential to use leaf meal as the alternative to in-feed antibiotics for broiler chickens. Several active ingredients in leaf meal are most likely to involve, either alone or in conjunction, in improving the immune competences of broilers. Among the active compounds, phenols have been reported to promote the immune organ development as well as stimulate the immune system of chicks (Kamboh et al 2015). Phenols may also serve as antimicrobial agents and antioxidants that eventually protect the immune system of broilers from the dangerous effect of reactive oxygen species (free radicals) (Mahmoud et al 2013; Kamboh et al 2015). With regard to tannins, although at high level it may act as anti-nutritional factors, in moderate level this compound has been reported to improve the immune competence, intestinal microbial ecology and gut health for broiler chicks (Huang et al 2018). Other active compound in plant leaf, such as flavonoids, may also contribute in improving the health of broilers. Kamboh et al (2016) showed that dietary supplementation of plant flavonoids increased the immune organ indices as well as improved the humoral immunity by elevating the

numbers of intestinal intraepithelial lymphocyte and antibody titre against New castle diseases and avian influenza virus. The treatment with flavonoids also reduced lipid peroxidation in the liver and improved the antioxidative status of broilers (Kamboh et al 2016; Rama Rao et al 2019). Note that the increased antioxidant capacity is essential for broilers, as the low antioxidant capacity may be associated with cellular damage, immune system deterioration and metabolic disturbances. Eventually, it is difficult to infer that the health-improving effects of leaf meal depend only on one active compound, but rather on combined effect of several compounds as contain mixed of active compounds.

Table 3. Examples of leaf meals as functional feedstuffs for broilers

Types of leaf meal	Application	Functional effects	References
Rosemary	Included in broiler rations at levels 0.5, 1.0 and 2.0%	Treatment (all levels) increased antibody production against sheep red blood cells and the percentage of the lymphoid organs and increased thyroid function, while 0.5% rosemary increased plasma total protein, albumin and globulin, decreased glucose, total lipids and cholesterol content	Ghazalah and Ali (2008)
Lemmon grass	Added at 1% to basal diet	Reduced mortality rate in broiler chickens	Mmereole (2010)
Guava	Supplemented at 1% to basal diet	Improved antioxidant activity, total leukocyte counts and lipid profile of serum and meat of broilers	Mahmoud et al (2013)
Papaya	Included at 0, 5 and 10% in broiler diets	Inclusion of 5% papaya leaf meal reduced oxidative stress in broiler chickens	Ebrahimi et al (2015)
Moringa oleifera	Incorporated at 0, 5, 10, 15 and 20% in broiler rations	Incorporation at 15 and 20% improved blood biochemical (triglycerides, total cholesterol, low-density lipoprotein and high-density lipoprotein) of broilers	Alnidawi et al (2016)
Moringa oleifera	Incorporated at 0, 2, 4, 6 and 8% in broiler rations	Inclusion of *Moringa* leaf meal up to 6% improved antibody titre against Newcastle disease and infectious bursal disease	Liaqat et al (2016)
Moringa oleifera	Incorporated in broiler diets at levels 0, 3, 5 and 8%	Dietary inclusion of *Moringa* leaf meal up to 8% resulted in improved immune response against Newcastle disease and welfare	Ramadan (2017)
Moringa oleifera	Included at levels 0, 10 and 20%	Improved intestinal villi development and increase immunoglobulin (Ig) Y concentration in broiler chickens	Mariana et al (2018)
Moringa oleifera	Supplemented to broiler rations at 0, 500 and 1000 mg/kg	Improved antibody titre against Newcastle disease vaccine and reduced lipid peroxidation in liver of broilers	Rama Rao et al (2019)
Holy basil leaf powder	Supplemented in broiler rations at levels 0, 0.5 and 1%	Supplementation (all levels) augmented T-cell mediated immune response in broiler	Sheoran et al (2017)
Eucalyptus leaf powder	Added to basal diets at levels 0, 1 and 3 g/kg	Increased primary antibody response to sheep red blood cells (SRBC) compared to the control	Farhadi et al (2017)
Eucalyptus leaf powder	Added to basal diets at levels 0, 0.25 and 0.5%	Treatment (all levels) increased relative weight of Bursa of fabricius and leukocytes and decreased cholesterol levels, while addition of 0.5% increased secondary titres	Mashayekhi et al (2018)
Sauropus androgynous	Incorporated at 5% in broiler diets contaminated with aflatoxin	Improved cellular and humoral immune responses, reduced the residue of aflatoxin in the organ, protected the liver, kidney, spleen, and bursa of fabricius histopathology and increased in the immune-expression of CD4+/CD8+ lymphocytes ratio	Prakoso et al (2018)
Summer-autumn tea leaf powder	Supplemented in broiler rations at levels 0.5, 1.0, and 2.0%	Inclusion of 1% improved immune indices, serum antioxidant enzyme activity levels, Ig levels, and SRBC antibody titres	Wang et al (2018)
Gliricidia	Incorporated in broiler diets at 0, 5 and 10%	Incorporation of 10% *Gliricidia* leaf meal increased count of leukocytes of broilers	Oloruntola et al (2018)
Binahong	Incorporated in broiler diets at levels 0, 1, 2, 4 and 8%	Inclusion of 2% binahong leaf meal reduced the count of *E. coli*, increased the count of lactic acid bacteria, villi height, villi width and crypt depth	Widodo et al (2018)
[illegible] leaf [illegible] %)	Included at 0.5 % in broiler rations	Increased the IgG concentration compared with the control treatment, but did not affect IgA concentration	Aroche et al (2018)
Bamboo	Included at 5 g/kg in broiler rations	Treatment lowered glucose, triglycerides, cholesterol, alanine aminotransferase and creatinine levels, and increased superoxide dismutase, glutathione peroxidase and catalase concentrations	Oloruntola et al (2019)
Eucalyptus camaldulensis	Added with basal diet at levels of 0.5, 1.0 and 2.0%	Feeding 1% leaf meal increased small intestine relative length, number of goblet cells, villus height, crypt depth of duodenum, improved the secretion of amylase, lipase, trypsin and chymotrypsin, increased total count of *Lactobacillus*, blood vitamin E, decreased broiler mortality, pH value,*E. coli*, *Clostridium perfringens* and *Salmonella typhimurium* in duodenum. Treatment also decreased blood TBARS concentration, Heat shock protein (Hsp: 40, 70 and 90)	Mustafa (2019)

Recently, treatment with leaf meal may be exploited to alleviate the harmful effect of toxin contamination on the growth performance of broilers. For examples, Prakoso et al (2018) incorporated 5% of *Sauropus androgynus* leaf meal in broiler diets and found that the treatment increased the final body weight of broilers contaminated with aflatoxin. It was most likely that phenolic compounds in could act as antitoxin or deactivate the toxin (inhibit the toxin activity) and thereby alleviating the negative effect of aflatoxin in broiler chickens (Prakoso et al 2018). In addition to the antitoxin activity, green leaf may also be used as therapeutic agents for bacterial infections in broiler chickens. For example, Suryani et al (2014) and Sharma et al (2016) used *Morinda citrifolia* leaf extract and neem leaf extract, respectively, to reduce the prevalence of colibacillosis in broiler chickens. The antibacterial properties and immunomodulatory effects of the bioactive compounds in the green leaf seems to be attributable to the therapeutic

effects of the leaf (Sharma et al 2016). Different from the above reports, Balami et al (2018) showed that feeding of *Moringa oleifera* leaf meal neither protected the liver from pathological damage nor prevented the lipid peroxidation in broilers following the challenge with variant strains of infectious bursal disease virus (vIBDV). It was not clear what the particular compound in the leaf meal that was expected to protect the liver from the infection in the latter study, but the relatively low level of the active compounds in the leaf meal as compared to that in extract may be the reason for such above divergent results. Taken together, to improve the therapeutic effects of the leaf, it is better to extract the leaf before being included in the diets or drinking water of broilers (Suryani et al 2014; Sharma et al 2016).

Recently, there has been a trend to use leaf meal in combination with other active ingredients to further improve the functional effects of green leaf on broiler chickens. In our previous study, we combined *Moringa oleifera* leaf powder and garlic powder, and found that such combination better reduced the number of *Enterobacteriaceae* in the ileum as well as decreased the fat deposition in the abdomen of broilers, when compared with the use of *Moringa* leaf powder or garlic powder alone (Sugiharto et al 2018b). Likewise, the combination of guava leaf meal and olive oil improved performance and health of broiler chickens as compared to control (Mahmoud et al 2013). The combination of neem leaf meal and ginger extract was also reported to improve the immune status and growth performance of broilers (Rahman et al 2015). Moreover, Abujradah et al (2018) demonstrated that the combination of neem leaf meal, garlic and probiotics boosted immune responses of broiler chickens. It was most likely that the combination may result in positive synergistic effect on the immune system of broilers.

In addition to the improved health and wellbeing of chicks, feeding leaf meal was also noticed to improve the product qualities of broiler. Mustafa (2019) reported that dietary incorporation of 1% *Eucalyptus camaldulensis* leaf meal improved the sensory evaluation such as flavour and juiciness of thigh and breast meats of broilers. The feeding treatment also produced less hardness and thiobarbituric acid reactive substances (TBARS) in the thigh and breast meats of broiler compared to control. In line with this, Onyimonyi and Ernest (2009) showed that dietary inclusion of 2% papaya leaf meal in finisher diets improved carcass and organoleptic traits of broiler meats. Dietary inclusion of papaya leaf meal has also been shown to reduce lipid peroxidation and increased antioxidant activity of broiler breast meats (Ebrahimi et al 2015). Moreover, feeding of *Sauropus androgynous* leaf meal reduced fat deposition in abdomen, liver and carcass (Santoso and Sartini 2001). The phenolic compounds in plant leaf seems to be responsible for the reduced oxidative susceptibility and hence improved the sensory and nutritional characteristics of broiler meats (Starčević et al 2015). In term of fat deposition, the phenolic compounds in leaf meal may serve as a lipid-lowering agent (by inhibiting the synthesis of lipid) and thereby reduce fat deposition in the body of broilers (Santoso and Sartini 2001; Starčević et al 2015). However, it should be noted that different types of leaf meal may exert different impacts on broiler meat traits due to a vast variety on types and levels of phenolic compounds across the plant leaf.

Fermented leaf meal for broiler chickens

Fermentation has widely been conducted to deal with the problems related to the high fibre and anti-nutrition contents in feedstuffs (Sugiharto and Rajitkar 2019). The method has also been carried out in plant leaf not only to increase the inclusion levels of leaf in broiler diets (Syahruddin et al 2011; Has et al 2013; Mandey et al 2015), but also to increase and/or produce the biological active compounds with health-improving effects for broilers (Cao et al 2012). Table 4 shows some examples of the fermented plant leaf used in broiler diets. Indeed, feeding fermented plant leaf improved feed digestibility (Has et al 2013), intestinal ecology and function and antioxidant capacity of broilers (Zhang et al 2015). The decreased fibre and anti-nutritional factors and the increased protein contents in plant leaf due to fermentation was attributed to the improved feed utilization and thus increased the levels of plant leaf inclusion in broiler diets. In addition to the role of bioactive compounds in plant leaf, the live microbes and their metabolites produced during fermentation may also play a substantial role in improving the intestinal functions and thus nutrient utilisation by the birds (Sugiharto and Rajitkar 2019).

Table 4. Examples of fermented plant leaf and their use in broiler diets

Types of leaf meal	Application	Functional effects	References
Noni leaf (*Morinda citrifolia* L.) fermented with *Neurospora sitophila*	Included in broiler rations at levels of 0, 3, 6, 9, 12, 15, 18 and 21%	Feeding 21% of fermented noni leaf resulted in the lowest cholesterol levels, but had no effect on growth rate of broiler meats	Syahruddin et al (2011)
Mulberry leaf fermented with rumen liquor	Included in broiler rations at levels of 0, 10 and 20%	Treatment decreased final body weight and dry matter digestibility of broiler compared to control	Has et al (2013)
Banana leaf meal fermented with *Teichoderma viride*	Included in broiler rations at levels of 0, 5, 10 and 15%	Feeding up to 10% fermented banana leaf resulted in no detrimental effects on the growth and carcass traits of broilers	Mandey et al (2015)
fermented with	Included at 2.5 or 5% for each fermented leaf	All levels of fermented *Sauropus androgynus* improved carcass traits and lowered fat deposition without negatively affecting broiler performance	Santoso et al (2015)
Ginkgo biloba leaf fermented with *Aspergillus niger*	Supplemented to basal diets at 0.2, 0.35 and 0.5% in the starter and 0.4, 0.7 and 1.0% in the grower phase	Improved growth rate and lipid metabolism and increased retention of α-tocopherol and reduction in lipid peroxidation in meats	Cao et al (2012)
Ginkgo leaf fermented with *Candida utilis*, *Aspergillus niger*, or their combination	Supplemented to basal diets at 0.5%	Ginkgo leaf fermented with *Aspergillus niger* or the combination of *Aspergillus niger* and *Candida utilis* improved feed utilization, intestinal function, antioxidant capacity and intestinal microbial ecosystem of broilers	Zhang et al (2015)
Fermented Ginkgo biloba leaf	Supplemented to basal diets at 0, 1.5, 2.5, 3.5, 4.5 and 5.5 g/kg	Supplementation at 3.5 to 4.5 g/kg improved growth rate, meat quality and antioxidative status of broiler chickens	Niu et al (2017)
Fermented Ginkgo biloba leaf	Supplemented to basal diets at 0, 1.5, 2.5, 3.5, 4.5 and 5.5 g/kg	Supplementation at 3.5 to 4.5 g/kg resulted in better nutrient digestibility, intestinal digestive function and antioxidant activity of broiler chicks	Niu et al (2019)
Fermented *Leucaena glauca* leaf	Included in broiler rations at levels of 0, 5, 10 and 15%	Treatment had no effect on final body weight, consumption and feed efficiency of broilers	Widharto et al (2019)

In general, although fermentation has been associated with the increased protein and amino acid contents, such technique has often been attributed to the decreased total phenols and thus antioxidant activity of the substrates (Sugiharto et al 2018c). Fermentation has also been reported to decrease the content of flavonoids in the substrates (Cao et al 2012). Several factors may be responsible for the reduced antioxidative components in the substrates during fermentation, including the nature of substrates, species and strains of microbes used as starter inoculum and other environmental factors. Taken together, to obtain the benefits of fermentation in terms of nutritional improvement without having deleterious effect on the antioxidative properties, the selection of particular plant leaf and types of microbes as starter inoculum is crucial.

Conclusions

- Several studies have shown the benefits of dietary incorporation of leaf meal on the production performance and health status of broilers.
- Such benefits may be attributed to the high contents of protein and bioactive compounds in the leaf meal.
- The responses of broilers to dietary leaf meal in term particularly of growth performance are variable, depending on the types of plant leaf meal and levels of inclusion.
- The contents of fibre and anti-nutritional factors may suppress the nutrient utilisation of leaf meal and thus growth performance of broilers.
- Dietary supplementation of fibre-degrading enzymes and fermentation may be conducted to increase the digestibility and utilization of leaf meal by broiler chicks.

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Conflict of interests

We have no conflict of interest.

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