Poultry Science Journal
ISSN: 2345-6604 (Print), 2345-6566 (Online) http://psj.gau.ac.ir
DOI: 10.22069/psj.2022.20055.1794

GUASNR

The Potential Use of Plant-Derived Saponins as a Phytobiotic Additive in Poultry Feed for Production and Health Advancement: A Comprehensive Review

Mohamed M. Alghirani[1] , Eric Lim Teik Chung[1,2], Faez Firdaus Abdullah Jesse [2,3], Awis Qurni Sazili[1,2] & Teck Chwen Loh[1,2]

[1]Department of Animal Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[2]Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia 43400 UPM Serdang, Selangor, Malaysia
[3]Department of Veterinary Clinical Studies, Faculty of Veterinary Medicine, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Poultry Science Journal 2022, 10(2): 215-226

Keywords
Saponins
Carcass traits
Feed efficiency
Poultry industry
Immune responses

Corresponding author
Eric Lim Teik Chung
ericlim@upm.edu.my

Article history
Received: March 22, 2022
Revised: June 12, 2022
Accepted: June 14 , 2022

Abstract
The food security of a country can be harmed if the supply and demand of poultry products are affected due to any disruptions disrupted by factors such as poor growth rates and disease outbreaks. On top of that, with regard to food safety reasons, developed countries have started to prohibit the inclusion of antibiotics in livestock feed. As a result, it is essential to seek alternative preventive substitutes for growth promotion and prophylaxis in poultry rather than depending on antibiotics. Plant extracts are one of the alternatives with anti-microbial and growth-promoting effects on poultry. Saponins have many biological and pharmacological activities like anti-carcinogenic, anti-microbial, anti-parasitic, anti-fungal, anti-inflammatory, hypocholesterolemic, immunomodulatory, and anti-oxidant properties. Because of its growth-promoting effect, immunity enhancer, and microbial capabilities, saponins from diverse sources and quantities could be used as an anti-microbial alternative to synthetic antibiotics in the broiler industry. Additionally, steroidal saponins have been commercialized as supplements for poultry, health foods for human consumption, and potential anti-cancer treatments. Therefore, the present review will critically shed light on the availability of different saponins and the influence on the production performance and immunopathology responses of poultry supplemented with different saponins extract. Information from this review will added knowledge on the usability of different saponins extracts which could be considered as a novel feed additive in the poultry industry.

Introduction

Poultry contributes significantly to nutrition and food security, providing protein, essential micro-nutrients, and energy to humans in short production cycles. Therefore, the poultry industry is rapidly growing particularly in developing countries (Bahri *et al.*, 2019). For instance, there is over 23 billion poultry around the world (Mottet and Tempio, 2017). Comparatively, the human population is now at 7 billion and with an annual growth rate 1.4%, it is expected to reach 9.7 billion by 2050 (Jenkins *et al.*, 2020). Despite the rapid growth, the broiler industry faces various issues in accordance with the rapidly increasing human population. To keep up with the demands, extensive work has been conducted by the combination of genetics improvement and feed enhancement to boost the feed conversion ratio (FCR) in broiler chickens. Despite its development, the broiler industry is facing many challenges such as disease outbreaks that could slow down its growth causing economic uncertainty and food security in the world (Chung *et al.*, 2019). The situation often worsens in the tropics due to the heat stress conditions that causes negative effects on the production performances of birds, consequently causing large economic damage to commercial

Please cite this article as Mohamed M. Alghirani, Eric Lim Teik Chung, Faez Firdaus Abdullah Jesse, Awis Qurni Sazili & Teck Chwen Loh. 2022. The Potential Use of Plant-Derived Saponins as a Phytobiotic Additive in Poultry Feed for Production and Health Advancement: A Comprehensive Review. Poult. Sci. J. 10(2): 215-226.

poultry farms (Ramiah *et al*., 2019; Chung *et al*., 2020a).

Although poultry is an important resource for nutrition and food security, it is one of the contributing factors affecting human health. The wide practice of antibiotics in animal feed will hasten the development of pathogens and normal flora's resistance to essential antimicrobials (Muaz *et al*., 2018). For instance, colistin antibiotic is broadly added to poultry diets for growth-promoting and disease prevention effects (Kempf *et al*., 2016). This antimicrobial drug is the last defense line against severe infection and is a common life-saving last resort medicine especially when patients are infected by superbugs. This will ultimately act as a source of transmission to humans leading to treatment failures and economic losses in livestock. Using in-feed antibiotics as a growth promoter is banned in developed countries due to their harmful effects on both humans and livestock (Gheisar and Kim, 2018). As a result, antibiotics should be replaced with other safe feed additives .

Due to the value of antibiotics as a bactericide and growth promoter in the poultry industry, there have been several attempts to explore a better alternative since a few decades ago (Hashemi and Davoodi, 2011). Gadde *et al*. (2017) stated that prebiotics, probiotics, phytobiotics, enzymes, symbiotics, toxin binders, organic minerals, organic acids, and oligosaccharides are the few potential substitutes for poultry. All these alternatives can enhance performance effectively and have some therapeutic use in veterinary medicine. Moreover, these substitutes are readily biodegradable, do not have adverse effects on the gut normal microflora, and do not cause drug resistance, carcinogenesis, and environmental pollution (Yadav *et al*., 2016).

Saponins

Saponins are bioorganic molecules that have at least one glycosidic linkage (C-O-sugar bond) between an aglycone and a sugar chain at C-3, which will be split into aglycone and sugar moiety when hydrolyzed. According to El Aziz *et al.* (2019), there are two chemically different partitions, part A the non-saccharide portion (the hydrocarbon skeleton portion without sugar chain) called sapogenin, genin, or aglycone, and part B (saccharide moiety) which has a different of pentoses or hexoses sugars. The non-saccharide part of isolated amorphous solid saponins has 27 to 30 carbon atoms and has a high molecular weight (El Aziz *et al.,* 2019). In addition, saponins can be further classified into three categories based on the type of sapogenin present including triterpenoid glycosides, steroid glycosides, and alkaloid glycosides (Abed El Aziz *et al.*, 2017; El Aziz *et al.,* 2019). Saponins can be found in at least 400 plant types and can be extracted from different parts of the plants like stem, root, seed, pericarp, bark, and shell (Lima *et al*., 2013). They present in a several forages like legumes, lupins, red clover, soybean, fodder plants, Lucerne, and ladino clover that are significant for livestock (Wina *et al*., 2005).

Considering the need for clean and safe poultry meat, plant secondary metabolites such as saponins are gaining consideration due to their promising properties on the general performance of monogastric animals including poultry (Chaudhary *et al*., 2018a). Saponins are related to the plant protection system and are mostly found in tissues that are more vulnerable to bacterial, fungal, or insect predation (Muniandy *et al*., 2020). According to Cardona-Álvarez *et al*. (2016) and Chung *et al*. (2018), saponins are also associated with the defense function of a plant, which acts as a protective chemical barrier protecting the plant against predators, and insects, and having adverse effects on herbivores. Attributable to the defense mechanism, saponins of some plants were found to be toxic and detrimental to certain species of livestock. For example, saponins intoxication results in photosensitization accompanied by degeneration of the liver and kidneys in ruminants grazing on *Brachiaria* pasture (Chung *et al*., 2018).

Nonetheless, steroidal saponins extracted from different plant sources are widely available as additives, supplements for human consumption, and possible anti-cancer medications. There is a gap of knowledge regarding the possible utilization and the effects of other saponins on the growth performance, carcass characteristics, meat quality, and plasma lipid profile in poultry under tropical conditions. Information from these studies will be added knowledge on the usability of alternative saponins that is vastly available and could be developed as a novel feed additive in the poultry sector. Therefore, this review paper will further discuss the production performance and immunopathology responses of poultry fed with different saponins extracts and concentrations.

Effect of saponins on the production performance of poultry

Growth performance

An optimum supplementation of saponins in feed can significantly influence production performances and lipid profiles in poultry (Chepete *et al.*, 2012; Ranjbar *et al.*, 2014; Su *et al.*, 2016; Alghirani *et al.*, 2021b). Some pharmaceutical companies are marketing saponins as feed improvement for poultry production. The growth-promoting effects of saponins like steroidal saponins in poultry could be due to their positive effect on the digestive tract through activation of digestive enzymes and enhancement of the gut histomorphology. These characteristics will then facilitate the absorption of nutrients and other substances (Cheeke, 2001). Besides, saponins have beneficial effects on broiler performance due to their impact as emulsifying agents affecting membrane permeability (Youssef *et al.*, 2021). They also have antimicrobial, anti-inflammatory, antioxidant, free-radical scavenging, and immune system enhancement activities which will improve the growth performance of broilers (Su *et al.*, 2016). It is considered a safe and non-toxic feed supplementation stimulating better weight gain, productivity, and growth in broiler chickens (Oleszek *et al*., 2001; Saeed *et al*., 2018). According to Miah *et al*. (2004), diets containing 75 mg/kg of exogenous saponins increased the body weight gain of commercial broiler chicks by 18.78% and 20.57% on days 21 and 42 respectively compared to the control group. Moreover, the feed intake and carcass quality of those broilers were also significantly improved. Supplementation of *Y. schidigera* saponins at 150 and 225 mg/kg in broiler chicks was also found to enhance the growth performance (Ranjbar *et al*., 2014). Another study showed an improvement in the growth parameters results of Arbor Acres broilers that were fed with a diet containing 100 mg/kg of *Y. schidigera* extract which contains more than 40% steroidal saponins (Su *et al*., 2016). Supplementation of *Y. schidigera* saponins in the broiler chick diet also showed an increase in body weight gain during the starter phase. This increase may be attribute to the positive impacts on the digestive tract (Saeed *et al*., 2018). Moreover, using *Y. schidigera* herb at different concentrations (50, 100, and 200 mg/kg) in laying hens also increased the growth performance during the laying phase with better weight gain while reducing ammonia production (Chepete *et al*., 2012). All these might be attributable to the characteristics of saponins, which could enhance the permeability of the intestine, and promote the uptake of nutrients.

In contrast, few researchers reported the negative or no impact of saponins supplementation in poultry (Alagawany *et al.*, 2016; Bera *et al.*, 2019). For instance, the inclusion of alfalfa saponins above 5% in poultry diets caused a lower growth rate in chicks and egg production of hens (Makkar *et al*., 2007). Pleger *et al.* (2020) also observed a decrease in broilers' feed intake and growth performance after supplementing the starter diet with alfalfa leaves. Furthermore, it has been observed that 0.5 g/kg of *Camellia* L. plant extract (CLE) containing high levels of triterpenoid saponins reduced broilers' feed intake and body weight on days 35 and 42, while 0.3 g/kg of CLE significantly decreased feed intake only on day 21 (Khalaji *et al.*, 2011). On top of that, Hassan (2013) reported that broiler diets containing 0.25% saponins-rich guar meal extract also significantly decreased the feed intake and body weight gain of broiler chicks suggesting saponins may possess growth inhibition effects. Furthermore, Annongu *et al.* (2014) found that supplementing *Moringa oleifera* seeds in broilers feed at 2.5, 5.0, and 7.5% resulted in decreased feed intake and body weight gain. All these could be attribute to the cyanogenic glycosides compound of saponins that causes bitterness astringency, and off-flavor thus leading to lower feed intake of those birds (McNeill *et al.*, 2004). A study on the effect of tea saponins' taste on poultry feed intake was conducted by Ueda *et al*. (2002) to confirm this hypothesis. There was no statistical difference in feed intake between the basal diet and the diet containing 0.5% saponins. Ueda *et al*. (2002) concluded that the reduction in feed intake due to tea saponin supplementation was associated with crop distention which could be due to the undigested ingesta that remained in this organ rather than the taste of saponins. Another study advocated that the taste of saponins is not the main factor responsible for the reduced feed intake (Ueda, 2001). In accord with this, Iji *et al.* (2004) stated that saponins have also been associated with decreased protein digestibility, which may delay the growth of chickens.

Serum cholesterol

Nonetheless, supplementing saponins from different sources was found to lower serum cholesterol levels despite not having significant changes in the growth performance (Matsuura, 2001). This could be due to the interactions of bile acids and saponins in the gut causing the formation of large mixed micelles that encourages cholesterol excretion. The deferring of intestinal absorption of nutritional fat via inhibiting pancreatic lipase activity could be led to a lower serum cholesterol concentration (Oakenfull, 1986). The reduction in total lipid and cholesterol may also be incurred by the diminishing influence of saponins extracts on hepatic 3-hydroxy-3-methylglutaryl coenzyme A (HMGCoA) reductase that is needed for cholesterol synthesis in the liver (Fujioka *et al.*, 2003; Ariana *et al*., 2011). Few studies reported that saponins decrease the bad cholesterol (LDL) specifically in the serum of both rodents and poultry (Matsuura, 2001). It was then established that saponins from different sources have the potential to lower the serum cholesterol level in broiler and layer chickens, thus producing healthier meat and eggs for the consumers (Matsuura, 2001; Afrose *et al*., 2010b). Some studies recommended supplementing purified saponins to chicken diets such as saikosaponin (triterpenoid saponins obtained from roots of *Bupleurum falcatum L.* and related plants), digitonin (steroidal saponins obtained from *Digitalis purpurea*), gypsophila, soybean, *Y. schidigera*, saponaria, alfalfa, fenugreek, chick pea, *Q. saponaria*, and garlic saponins can help reduce the serum lipid profile and in some cases liver parameters (Oakenfull and Sidhu, 1990; Matsuura, 2001).

According to Chaudhary *et al*. (2018b), the serum levels of total cholesterol, triglyceride, and LDL-cholesterol were significantly decreased in broiler breeders supplemented with 150 ppm of dietary soapnut (*Sapindus mukorossi*) shell powder rich in saponins.

On the other hand, Afrose *et al*. (2010a) reported a reduction of 23% of blood serum cholesterol and egg yolk cholesterol in laying hens supplemented with 75 mg/kg of Karaya saponins. Based on Qureshi *et al*. (1983), 0.25% of ginsenosides supplementation extracted from Wisconsin ginseng suppressed cholesterogenesis and lipogenesis in White Leghorn hens. Supporting this, Yan *et al*. (2011a) reported that adding 1 or 2% wild ginseng adventitious root meal to laying hens' diet also helps increased egg production and reduced serum cholesterol concentrations. In an unrelated study, administration of fenugreek seed (*Trigonella foenum graecum L.*) extracts containing steroid saponins at 12.5 mg/day per 300 g body weight increased food consumption and induced hypocholesterolemia in rats supporting the positive effect of saponins on reducing the plasma cholesterol level in animals (Petit *et al*., 1995).

Carcass traits

Saponins supplementation could help improve the carcass quality of chickens. The beneficial effect of saponins in poultry carcass could be due to its positive effects on gut health and nutrient absorption leading to improve body weight, since there is a strong relationship between body weight enhancement and carcass improvement (Ashour *et al.*, 2014, Alghirani *et al*., 2021a). In a study by Yan *et al*. (2011b), the use of wild ginseng adventitious root meal at 0.1% enhanced the growth performance in broilers, whereas supplementing at 0.2 and 0.3% induce a decrease in the breast muscle, abdominal fat, and serum cholesterol's 2-thiobarbituric acid reactive substances (TBARS) in broiler chickens. Besides, similar inhibitory properties on the abdominal fat were also observed in broiler chickens fed with thyme (*Thymus vulgaris*) (Al-Kassie, 2009; Abdulkarimi *et al*., 2011). Al-Kassie (2009) revealed that the addition of thyme oil at 200 ppm to the diets of broiler chickens caused a significant decrease in the abdominal fat percentage during the fatting period compared with the control diet. The result was consistent with Abdulkarimi *et al*. (2011), who proved that supplementing thyme saponins extract at 0.2, 0.4, and 0.6% to drinking water significantly decreased the accumulation of fat in the abdominal areas of broiler chickens, however, it lowered the plasma total cholesterol, LDL cholesterol, and the liver weight. This may be due to the presence of saponins in thyme that has an inhibitory effect on lipogenesis (Qureshi *et al*., 1983; Abdulkarimi *et al*., 2011). Abdominal broiler fat is considered a waste commodity in the poultry industry because it constitutes an extra cost during treatment as well as the loss of sales. These few studies proved that the introduction of saponins could reduce this form of waste. In a more recent study, 100 mg/kg of *Y. shidigera* saponins supplementation in commercial broilers was reported to improve growth performance, and carcass trait value, as well as enhance the breast and drumstick muscle quality (Alghirani *et al*., 2021b).

Some beneficial and detrimental effects of using plant saponins as supplementation in the poultry diet are summarized in Tables 1 and 2. Studies using plant-based containing saponins instead of pure saponins extract were found to be detrimenntal to experimental animals. The negative results could be caused by other reasons such as low digestibility or the presence of other anti-nutritive factors in the diet. Besides, limited knowledge regarding the effect of saponins on the growth performance, carcass characteristics, meat quality, and plasma lipid profile in poultry reared under tropical environments warrants further investigation. Positive findings from these studies could eventually enhance the production performance of the poultry industry via saponins supplementation, which will eventually contribute to the food security of a country.

Effect of saponins on the health response of poultry

Blood parameters

The immune status of broilers can be determined through measuring the heterophils to lymphocytes (H/L) ratio in addition to other components of the blood (Chung *et al*., 2020b). According to some studies, dietary supplementation of saponins from different sources demonstrated no significant effect on the blood parameters such as hemoglobin, packed cell volume, glucose, creatinine, total protein, albumin, globulin, albumin to globulin (A:G) ratio, calcium, inorganic phosphorus, and the liver parameters of both broilers and broiler breeders (Chaudhary *et al.*, 2018b). Nevertheless, Chaudhary *et al*. (2018b) observed that broiler breeders fed with dietary soapnut saponins at 150 ppm showed a significant reduction of the serum corticosterone and H/L ratio signifying a better health performance. Saponins have the ability to stimulate and enhance humoral and cell-mediated immunity thereby providing resistance against protozoal, fungus, and bacterial diseases (Cheeke, 2001; Chaudhary *et al*., 2018b). This is because, saponins encourage the secretion of cytokines that trigger the cellular, and humoral immunity responses (Palatnik *et al*., 2004; Song and Hu, 2009). Jia *et al*. (2014) and Holmes *et al*. (2015) have proven that saponins can stimulate animal immune organs resulting in immune system fortification. This was confirmed through the measurement of interleukin-6 (IL-6), plasma gamma-interferon (IFN-8), interleukin 2 (IL-2), and tumor necrosis factor-alpha (TNF-α) plasma titers that are responsible in stimulating the immune response.

Table 1. The different effects of saponins supplementation on the growth and serum cholesterol of poultry

Plant / Saponins extract	Concentration	Effects	Reference
Exogenous saponins	75 mg/kg	Increase body weight gain, feed intake and carcass quality of commercial broiler chicks at all production stages.	Miah *et al*. (2004)
Yucca schidigera saponins	150 & 225 mg/kg	Enhance the growth performance in broiler chicks.	Ranjbar *et al*. (2014)
	100 mg/kg	Increase body weight gain and feed efficiency in Arbor Acres broilers.	Su *et al*. (2016)
	-	Improve better weight gain, productivity and growth in broiler chickens	Oleszek *et al*. (2001) and Saeed *et al*. (2018)
	-	Increase body weight gain during the starter phase in broiler chick	Saeed *et al.* (2018)
Yucca schidigera herb	50, 100, & 200 mg/kg	Better weight gain during the laying phases and reduce ammonia production in layers,	Chepete *et al*. (2012)
Alfalfa saponins	5%	Lower growth rate and egg production of laying chicks.	Makkar *et al*. (2007)
Camellia L. plant extract	0.3 & 0.5 g/kg	Significantly reduce feed intake and body weight of broilers	Khalaji *et al.* (2011)
Guar meal extract	0.25%	Decrease the feed intake and growth rate of broiler chicks	Hassan (2013)
Moringa oleifera seeds	2.5, 5.0, & 7.5%	Decreased feed intake and body weight gain of broilers	Annongu *et al.* (2014)
Tea saponins	0.5%	No significant changes in the feed intake of chicks.	Ueda (2001) and Ueda *et al*. (2002)
Purified saponins	-	Decrease the plasma and in some cases liver cholesterol concentrations in poultry.	Oakenfull and Sidhu (1990) and Matsuura (2001)
Soapnut (*Sapindus mukorossi*) saponins	150 ppm	Decrease serum levels of total cholesterol, triglyceride and LDL-cholesterol in broiler breeders.	Chaudhary *et al*. (2018b)
Karaya saponins	75 mg/kg	Reduced of 23% of blood serum cholesterol and egg yolk cholesterol in laying hens.	Afrose *et al*. (2010a)
Wild ginseng saponins (Ginsenosides)	0.25%	Inhibit cholesterogenesis and lipogenesis in layers.	Qureshi *et al*. (1983)
Wild ginseng adventitious root meal	1 & 2%	Reduced serum cholesterol concentrations in laying hens.	Yan *et al*. (2011a)

Table 2. The different effects of saponins supplementation on the carcass characteristics and meat quality of poultry

Plant / Saponins extract	Concentration	Effect	Reference
Wild ginseng adventitious root meal	0.1, 0.2, & 0.3%	Enhanced growth performance and decreased abdominal fat plus serum cholesterol in broiler chickens.	Yan *et al.*, (2011b)
Thymus vulgaris (Thyme) oil	200 ppm	Decrease the abdominal fat percentage in broilers.	Al-Kassie, (2009)
Thymus vulgaris (Thyme) extract	0.2, 0.4, & 0.6% in drinking water	Lower plasma total cholesterol, LDL cholesterol concentrations, liver weight and decrease abdominal fat weight in broilers.	Abdulkarimi *et al.*, (2011)
Yucca schidigera saponins extract	100 mg/kg	Improve growth performance, carcass values as well as breast and drumstick muscle quality in broilers.	Alghirani *et al.*, (2021b)

Vaccine adjuvants

Vaccination is a form of protection for poultry against endemic diseases and reduce risk of economic loss due to higher morbidity and mortality rates in affected farms (Chung *et al*., 2021). For instance, Quillaja saponins are commonly used for many years as veterinary vaccine adjuvants in oral and injected vaccines to stimulate immune responses (Palatnik *et al*., 2004). Likewise, Rajput *et al*. (2007) combined *Cochinchina momordica* seed extract with an inactivated H5N1 vaccine as an adjuvant in two weeks old chickens. On top of that, Berezin *et al*. (2008) formulated immunostimulating complex (ISCOMs) using purified saponins from *Glycyrrhiza glabra* and *Aesculus hippocastanum* as an adjuvant for *Eimeria tenella* for a possible vaccine development to control avian coccidiosis. A further study was conducted using *Gipsophila paniculata*, *Glycyrrhiza glabra,* and *Aesculus hippocastanum* saponins (Berezin *et al.*, 2010). Both studies confirmed that important immunostimulation and protection were achieved in chickens via immunization with ISCOMs containing purified saponins and native *E. tenella* antigens. The study concluded that ISCOMs may be used successfully to improve the effectiveness and safety of vaccines to prevent poultry diseases (Berezin *et al.*, 2010).

In accordance with the studies above, saponins help raise cytokine production and activate natural immunity as well as stimulate humoral and cellular immunity. The result was consistent with Sahoo *et al*. (2016), who found that antibody concentrations against Newcastle Disease (ND) virus in broiler chicks were notably increased in the *Y. schidigera* extract group on days 7 and 14 post-vaccination. Additionally, supplementation of *Y. schidigera* from 100 to 200 mg/kg in layer diets can enhance the immune system by increasing IgG and IgM concentrations (Alagawany *et al*., 2016; Saeed *et al*., 2018). Alternatively, saponins from Panax ginseng were also found to enhance both B and T cell-mediated immune responses. Administration of Panax ginseng saponins sequestered from ginseng leaves and stems at 5 mg/kg through drinking water considerably enhanced the antibody reactions to immunity against Avian influenza (AI), ND, and Infectious bursal disease (IBD) vaccination by stimulating IgA producing cells of chickens' tissues (Zhai *et al*., 2011; Zhai *et al*., 2014). Another study was conducted to estimate the impact of ginseng stem-leaf saponins (GSLS) on the immune response to a bivalent inactive vaccine of AI and ND in immunosuppressed chickens via cyclophosphamide treatment. The study concluded that GSLS supplemented in drinking water at 2.5, 5, and 10 mg/kg for 7 days improved the vaccination efficacy in immunosuppressed chickens (Yu *et al*., 2015b). Moreover, GSLS significantly improved serum antibody response to inactivated H5N1 and H9N2 vaccinations in chickens (Jiang *et al*., 2012; Landy *et al*., 2012). Panax ginseng has a high value to be utilized as herbal medicines; however, its high cost restricts its development for animal use (Zhai *et al*., 2014).

Antioxidant effect

Amazingly, plant saponins also comprise antioxidant activity to prevent, delay, and protect cells against oxidative damage. Besides improving vaccination efficacy, Yu *et al*. (2015a) described that GSLS can also be a promising agent against oxidative stress in poultry. The result of supplementing poultry with GSLS in drinking water indicated that the treatment groups expressively subdued cyclophosphamide-induced oxidative stress by improving the total antioxidant capacity, organ functions, amount of ascorbic acid, glutathione, α-tocopherol by increasing the action of catalase, glutathione peroxidase, and total superoxide dismutase while reducing the protein malondialdehyde and carbonyl content. The result was consistent with Chi and Catchmark (2017), who administered tea saponins at 5 mg/kg in drinking water for 7 days after broilers were immunized with live ND and IB vaccines. These two studies concluded that GSLS and tea saponins could be developed as a potential agent against oxidative stress for the poultry industry (Yu *et al*., 2015a; Chi and Catchmark, 2017).

Antiprotozoal & antifungal effects

Simultaneously, saponins are an example of phytobiotics that have a positive influence on several pathogens including protozoa and fungi. Saponins such as steroidal and triterpenoid saponins from different plant sources contain toxic effects against protozoa. This toxicity property against protozoa seems to be common and nonspecific by affecting the cell membranes. Specifically, saponins from both Quillaja and Yucca were found to bind cholesterol in the animal cell membranes that modify the membrane structure and function. Attributable to the cholesterol-binding activity, Quillaja saponins are commercially used in the crop industry as a nematocidal agent (McAllister *et al*., 2001). As a result, this activity of saponins could also be utilized in the treatment of protozoal infections in livestock including poultry (Francis *et al*., 2002). Alternatively, *Sesbania grandiflora* leaves extracts containing saponins, tannin, phenol, flavonoid, and alkaloid may also serve as an effective helminticide against *Ascaridia galli* at the concentrations of 0.1 to 1 mg/mL in poultry birds (Raza *et al*., 2016). Apart from that, saponins were also found to be effective against fungi (Delmas *et al*., 2000; Wang *et al*., 2000). In a study conducted by Kim *et al*. (1998), *Kalopanax pinctus* saponins extract demonstrated specific and strong antifungal activity towards *Cryptococcus neoformans* and *Candida albicans* in humans. Similar results were obtained by Shimoyamada *et al*. (1998), who reported that saponins extracted from *Asparagus officinalis* leaves contain antifungal activities at concentrations of 0.5 to 8.0 mg/mL depending on the type of fungus. Also, *Y. schidigera* saponins can eliminate some dermatophytic, film-forming, and food-deteriorating yeasts and fungi (Miyakoshi *et al*., 2000). Although saponins extracts were found to be effective against fungus, no information is available regarding the application of saponins against fungal problems in poultry birds.

Table 3. The different effects of saponins supplementation on the health performance of poultry

Plant / Saponins extract	Concentration	Effect	Reference
Soapnut (*Sapindus mukorossi*) saponins	150 ppm	Reduced the serum corticosterone and H/L ratio in broiler breeders.	Chaudhary *et al*. (2018b)
Quillaja saponins	-	Vaccine adjuvants in oral and injected vaccines.	Palatnik *et al*. (2004)
Cochinchina momordica seed extract	-	Adjuvant for H5N1 vaccine in chickens.	Rajput *et al*. (2007)
Glycyrrhiza glabra and *Aesculus hippocastanum* saponins	-	Adjuvant for *E. tenella* vaccine in chickens.	Berezin *et al*. (2008)
Gipsophila paniculata, Glycyrrhiza glabra, and *Aesculus hippocastanum* saponins	-	Adjuvant for *E. tenella* vaccine in chickens.	Berezin *et al*. (2008)
Yucca schidigera extract	-	Increased the antibody titers against Newcastle Disease (ND) virus in vaccinated broiler chicks.	Sahoo *et al*. (2016)
	100 to 200 mg/kg	Enhanced the immune system by increasing levels of immunoglobulin (IgG and IgM) in layers.	Alagawany *et al*. (2016) and Saeed *et al*. (2018)
Panax ginseng saponins	5 mg/kg in drinking water	Significantly improved the immune responses to vaccination against AI, ND, and IBD in chickens.	Zhai *et al*. (2011) and Zhai *et al*. (2014)
Ginseng stem-leaf saponins (GSLS)	2.5, 5, & 10 mg/kg in drinking water	Improved the vaccination efficacy in immunosuppressed chickens.	Yu *et al*. (2015b)
	-	Improved serum antibody response to inactivated H5N1 or H9N2 vaccines in chickens	Jiang *et al*. (2012) and Landy *et al*. (2012)
	2.5, 5, & 10 mg/kg in drinking water	Inhibited cyclophosphamide-induced oxidative stress in chickens.	Yu *et al*. (2015a)
Tea saponins	5 mg/kg in drinking water	Increased the total antioxidant capacity, catalase, total superoxide dismutase glutathione peroxidase, glutathione, α-tocopherol, and ascorbic acid.	Chi and Catchmark (2017)
Sesbania grandiflora leaves extract	0.1 to 1 mg/mL	Effective anthelmintic activity against *Ascaridia galli* in poultry birds.	Raza *et al*. (2016)
Saponins extracts	-	Generally contain antifungal activities.	Kim *et al*. (1998), Shimoyamada *et al*. (1998) and Miyakoshi *et al*. (2000)
Yucca schidigera extract	10% in media	Useful effects on the constitution of microflora in the intestinal tract.	Katsunuma *et al*. (2000)
	30% saponins	No antibacterial activity against the gram-negative bacteria.	Hassan *et al*. (2010)
Guar meal extract	100% saponins	Exhibited antibacterial activity against S. typhimurium, *E. coli,* and *S. aureus.*	Hassan *et al*. (2010)
Quillaja extract (triterpenoid)	8 to 10% saponins	Exhibited antibacterial activity against *S. typhimurium*, *E. coli,* and *S. aureus.*	Hassan *et al*. (2010)
Soybean extract (triterpenoid)	95% saponins	Negative antibacterial activity.	Hassan *et al*. (2010)

Antibacterial effect

In addition, saponins from different plant sources have different antibacterial properties. For instance, the *Y. schidigera* plant consists of antimicrobial properties attributable to the high concentration of saponins (Matusiak *et al*., 2016). Referring to Avato *et al*. (2006), *Y. schidigera* saponins have different effects on the types of bacterial growth isolated from the animal intestinal through *in vitro* testing. Based on a study by Katsunuma *et al*. (2000), *Lactobacillus rhamnosus*, *L. plantarum*, *Escherichia coli*, *Enterococcus hirae*, *Bifidobacterium thermophilum*, *Streptococcus bovis*, and *Bifidobacterium longum* grew well on the media containing 10% *Y. shidigera* extract. Other strains include *Fusobacterium necrophorum*, *F. varium*, *Bacteroides fragilis*, *Clostridium perfringens*, *C. sporogenes*, *C. innocuum*, *Veillonella parvula*, *Eubacterium aerofaciens*, *Propionibacterium acnes*, *Peptococcus asaccharolyticus*, *Selenomonas ruminantium*, *Megasphaera elsdenii,* and *Ruminococcus productus* did not grow on the media containing 10% *Y. shidigera* saponins. The study concluded that *Y. shidigera* saponins have useful effects on the constitution of microflora in the intestinal tract (Katsunuma *et al*., 2000). Conversely, Hassan *et al*. (2010) stated that guar meal and Quillaja have better antibacterial effects against *Salmonella typhimurium*, *E. coli,* and *Staphylococcus aureus*. From this study, both guar meal and commercial Quillaja saponins containing 100% and 8 to 10% saponins extract respectively had the highest hemolytic and antibacterial activities. Yucca extract containing 30% saponins had no antibacterial activity against the gram-negative bacteria whereas soybean saponins extract demonstrated negative antibacterial activity against any bacterial strain although contains almost 95% saponins. Briefly, the high amount of saponins extracted from various plant sources consists of different antibacterial activities, which are dependent on the saponins concentration and the type of bacteria present.

In summary, there is another usage of plant saponins in addition to growth stimulants in the poultry diet (Table 3). From the studies mentioned above, saponins were found to stimulate the immunopathology responses and contained some anti-microbial activities. Then again, complete information on the effect of saponins supplementation on the blood profiles of poultry under hot and humid weather has yet to be discovered. Filling the gap of knowledge from these studies could convince the industry to practice saponins confidently as an alternative feed additive instead of using antibiotics and other synthetic drugs for growth promoters and disease prevention. As a consequence, poultry products will be free from drug residues contributing to better food safety for human consumption.

Conclusion

It can be concluded that saponins from various sources and at different concentrations could be offered as an antibiotic alternative due to their growth promoting, immunity enhancer, and antimicrobial properties. However, there is no precise and consistent information regarding the usage of saponins in poultry. The inclusion levels of saponins extract or plant-containing saponins at 50 to 200 mg/kg in poultry diets were found to be beneficial for growth performance and health enhancement. Whereas, lower concentrations at 2.5 to 10 mg/kg could be added into the drinking water to attain similar effects. Ironically, high levels of supplementation at 0.1 to 5% were reported to improve the quality of meat and egg but have no unfavorable effect on growth performance. Therefore, more studies and research are needed to shed light on the usage of this plant extract as well as the optimum concentration, which could eventually be used effectively as an additive in poultry feed.

Acknowledgement

The authors would like to thank the Ministry of Higher Education, Malaysia for providing funds for some of the studies conducted in this review. The project was funded by the Fundamental Research Grant Scheme (FRGS), (Grant no: FRGS/1/2020/WAB04/UPM/02/1).

References

Abdulkarimi R, Daneshyar M & Aghazadeh A. 2011. Thyme (*Thymus vulgaris*) extract consumption darkens liver, lowers blood cholesterol, proportional liver and abdominal fat weights in broiler chickens. Italian Journal of Animal Science, 10: 100-105. DOI: 10.4081/ijas.2011.e20

Abed El Aziz M, Ashour A, Madbouly H, Melad AS & El Kerikshi K. 2017. Investigations on green preparation of heavy metal saponin complexes. Journal of Water and Environmental Nanotechnology, 2: 103-111. DOI: 10.22090/JWENT.2017.02.005

Afrose S, Hossain MS & Tsujii H. 2010a. Effect of dietary karaya saponin on serum and egg yolk cholesterol in laying hens. British Poultry Science, 51: 797-804. DOI: 10.1080/00071668.2010.526924

Afrose S, Hossain MS, Maki T & Tsujii H. 2010b. Effects of karaya saponin and *Rhodobacter capsulatus* on yolk cholesterol in laying hens. British Poultry Science, 51: 409-418. DOI: 10.1080/00071668.2010.495469

Alagawany M, El-Hack ME & El-Kholy MS. 2016. Productive performance, egg quality, blood constituents, immune functions, and antioxidant parameters in laying hens fed diets with different levels of *Yucca schidigera* extract. Environmental

Science and Pollution Research, 23: 6774-6782. DOI: 10.1007/s11356-015-5919-z

Alghirani MM, Chung ELT, Jesse FFA, Sazili AQ & Loh TC. 2021a. Could phytobiotics replace antibiotics as feed additives to stimulate production performance and health status in poultry? an overview. Journal of Advanced Veterinary Research, 11: 254-265. DOI: AVR/article/view/810

Alghirani MM, Chung ELT, Sabri DSM, Tahir MNJM, Kassim NA, Kamalludin MH, Nayan N, Jesse FFA, Sazili AQ & Loh TC. 2021b. Can *Yucca schidigera* be used to enhance the growth performance, nutrient digestibility, gut histomorphology, cecal microflora, carcass characteristic, and meat quality of commercial broilers raised under tropical conditions? Animals, 11: 2276. DOI: 10.3390/ani11082276

Al-Kassie GA. 2009. Influence of two plant extracts derived from thyme and cinnamon on broiler performance. Pakistan Veterinary Journal, 29: 169-173.

Annongu A, Karim OR, Toye AA, Sola-Ojo FE, Kayode RMO, Badmos AHA, Alli OI & Adeyemi KD. 2014. Geo-Assessment of chemical composition and nutritional evaluation of *Moringa oleifera* seeds in nutrition of broilers. Journal of Agricultural Science, 6: 119. DOI: 58f788840f7e9bfcf93bdd41

Ariana M, Samie A, Edriss MA & Jahanian R. 2011. Effects of powder and extract form of green tea and marigold, and-tocopheryl acetate on performance, egg quality and egg yolk cholesterol levels of laying hens in late phase of production. Journal of Medicinal Plants Research, 13: 2710-2716. DOI: 10.5897/JMPR.9000537

Ashour EA, Alagawany M, Reda FM & Abd El-Hack ME. 2014. Effect of supplementation of *Yucca schidigera* extract to growing rabbit diets on growth performance, carcass characteristics, serum biochemistry and liver oxidative status. Asian Journal of Animal and Veterinary Advances, 11: 732-742. DOI: 10.3923/ajava.2014.732.742

Avato P, Bucci R, Tava A, Vitali C, Rosato A, Bialy Z & Jurzysta M. 2006. Antimicrobial activity of saponins from *Medicago sp*.: structure-activity relationship. Phytotherapy Research, 20: 454-457. DOI: 10.1002/ptr.1876

Bahri S, Ariffin A & Mohtar S. 2019. Critical review on food security in Malaysia for broiler industry. International Journal of Academic Research in Business and Social Sciences, 9: 869-876. DOI: 10.6007/IJARBSS/v9-i7/6186

Bera I, Tyagi PK, Mir NA, Tyagi PK, Dev K, Sharma D & Mandal AB. 2019. Dietary supplementation of saponins to improve the quality and oxidative stability of broiler chicken meat. Journal of Food Science and Technology, 56: 2063-2072. DOI: 10.1007/s13197-019-03683-z

Berezin VE, Bogoyavlenskiy AP, Tolmacheva VP, Makhmudova NR, Khudyakova SS, Levandovskaya SV & Aleksyuk PG. 2008. Immunostimulating complexes incorporating *Eimeria tenella* antigens and plant saponins as effective delivery system for coccidia vaccine immunization. Journal of Parasitology, 94: 381-386. DOI: 10.1645/GE-1289.1

Berezin VE, Bogoyavlenskyi AP, Khudiakova SS, Alexuk PG, Omirtaeva ES, Zaitceva IA & Fetterer RH. 2010. Immunostimulatory complexes containing *Eimeria tenella* antigens and low toxicity plant saponins induce antibody response and provide protection from challenge in broiler chickens. Veterinary Parasitology, 167: 28-35. DOI: 10.1016/j.vetpar.2009.09.045

Cardona-Álvarez J, Vargas-Vilória M & Paredes-Herbach E. 2016. Clinical and histopathological study of the phototoxic dermatitis in Zebu calves in grazing of *Brachiaria decumbens*. Revista MVZ Córdoba, 21: 5366-5380. DOI: 10.21897/rmvz.603

Chaudhary SK, Bhar R, Mandal AB, Rokade JJ, Jadhav SE, Kannan A & Gopi M. 2018a. Effect of dietary soapnut (*Sapindus mukorossi*) shell powder on selected stress indices, lipid profile and litter quality in broiler breeders. Animal Nutrition and Feed Technology, 18: 311-320. DOI: 10.5958/0974-181X.2018.00029.X

Chaudhary SK, Rokade JJ, Aderao GN, Singh A, Gopi M, Mishra A & Raje K. 2018b. Saponin in poultry and monogastric animals: A review. International Journal of Current Microbiology and Applied Sciences, 7: 3218-3225. DOI: 10.20546/ijcmas.2018.707.375

Cheeke PR. 2001. Actual and potential applications of *Yucca schidigera* and *Quillaja saponaria* saponins in human and animal nutrition. Recent Advances in Animal Nutrition, 13: 115-126. DOI: 10.1007/978-94-015-9339-7_25

Chepete HJ, Xin H, Mendes LB, Li H & Bailey TB. 2012. Ammonia emission and performance of laying hens as affected by different dosages of *Yucca schidigera* in the diet. Journal of Applied Poultry Research, 21: 522-530. DOI: 10.3382/japr.2011-00420

Chi K & Catchmark JM. 2017. Enhanced dispersion and interface compatibilization of crystalline nanocellulose in polylactide by surfactant adsorption. Cellulose, 24: 4845-4860. DOI: 10.1007/s10570-017-1479-3

Chung ELT, Alghirani MM, Kamalludin MH, Nayan N, Jesse FFA, Wei OTA, Stephen MAFMH, Reduan MFH & Loh TC. 2021. Do different vaccination regimes affect the growth performance, immune status, carcass characteristics and meat quality of broilers?

British Poultry Science, 62: 32-37. DOI: 10.1080/00071668.2020.1817327

Chung ELT, Kamalludin MH, Jesse FFA, Reduan MFH, Ling LW, Mahzan NM, Henipah NNMMA, Loh TC & Idrus Z. 2020a. Health performance and blood profile changes in commercial broilers supplemented with dietary monocalcium phosphate. Comparative Clinical Pathology, 29: 573-579. DOI: 10.1007/s00580-019-03085-9

Chung ELT, Kamalludin MH, Jesse FFA, Reduan MFR, Loh TC & Idrus Z. 2019. Effect of monocalcium phosphate supplementation on the growth performance, carcass characteristic, gut histomorphology, meat and bone quality of broiler chickens. Pertanika Journal of Tropical Agricultural Science, 42: 1237-1250.

Chung ELT, Nayan N, Kamalludin MH, Alghirani MM, Jesse FFA, Kassim NA, Azizi A, Reduan MFH & Loh TC. 2020b. The effects of alkaline and rainwater on the production and health performance of commercial broilers under tropical conditions. The Thai Journal of Veterinary Medicine, 50: 53-61.

Chung ELT, Predith M, Nobilly F, Samsudin AA, Jesse FFA & Loh TC. 2018. Can treatment of *Brachiaria decumbens* (signal grass) improve its utilisation in the diet in small ruminants? a review. Tropical Animal Health and Production, 50: 1727-1732. DOI: 10.1007/s11250-018-1641-4

Delmas F, Di Giorgio C, Elias R, Gasquet M, Azas N, Mshvildadze V & Timon-David P. 2000. Antileishmanial activity of three saponins isolated from ivy, α-hederin, β-hederin and hederacolchiside A1, as compared to their action on mammalian cells cultured in vitro. Planta Medica, 66: 343-347. DOI: 10.1055/s-2000-8541

El Aziz MMA, Ashour AS & Melad ASG. 2019. A review on saponins from medicinal plants: chemistry, isolation, and determination. Journal of Nanomedicine Research, 8: 282-288. DOI: 10.15406/jnmr.2019.07.00199

Francis G, Kerem Z, Makkar HP & Becker K. 2002. The biological action of saponins in animal systems: a review. British Journal of Nutrition, 88: 587-605. DOI: 10.1079/BJN2002725

Fujioka T, Kondou T, Fukuhara A, Tounou S, Mine M, Mataki N, Hanadaa K, Ozaka M, Mitani K, Nakaya T, Iwai T & Miyakawa H. 2003. Efficacy of a glycyrrhizin suppository for the treatment of chronic hepatitis C: a pilot study. Hepatology Research, 26: 10-14. DOI: 10.1016/S1386-6346(02)00332-7

Gadde U, Kim WH, Oh ST & Lillehoj HS. 2017. Alternatives to antibiotics for maximizing growth performance and feed efficiency in poultry: a review. Animal Health Research Reviews, 18: 26-45. DOI: 10.1017/S1466252316000207

Gheisar M & Kim IH. 2018. Phytobiotics in poultry and swine nutrition–a review. Italian Journal of Animal Science, 17: 92-99. DOI: 10.1080/1828051X.2017.1350120

Hashemi SR & Davoodi H. 2011. Herbal plants and their derivatives as growth and health promoters in animal nutrition. Veterinary Research Communications, 35: 169-180. DOI: 10.1007/s11259-010-9458-2

Hassan SM, Byrd JA, Cartwright AL & Bailey CA. 2010. Hemolytic and antimicrobial activities differ among saponin-rich extracts from guar, quillaja, yucca, and soybean. Applied Biochemistry and Biotechnology, 162: 1008-1017. DOI: 10.1007/s12010-009-8838-y

Hassan SM. 2013. Effects of guar meal, guar gum and saponin rich guar meal extract on productive performance of starter broiler chicks. African Journal of Agricultural Research, 8: 2464-2469. DOI: 10.5897/AJAR2013.6875

Holmes SE, Bachran C, Fuchs H, Weng A, Melzig MF, Flavell SU & Flavell DJ. 2015. Triterpenoid saponin augmention of saporin-based immunotoxin cytotoxicity for human leukaemia and lymphoma cells is partially immunospecific and target molecule dependent. Immunopharmacology and Immunotoxicology, 37: 42-55. DOI: 10.3109/08923973.2014.971964

Iji PA, Khumalo K, Slippers S & Gous RM. 2004. Intestinal function and body growth of broiler chickens on maize-based diets supplemented with mimosa tannins and a microbial enzyme. Journal of the Science of Food and Agriculture, 84: 1451-1458. DOI: 10.1002/jsfa.1816

Jenkins DG, Haberl H, Erb KH & Nevai AL. 2020. Global human "predation" on plant growth and biomass. Global Ecology and Biogeography, 29: 1052-1064. DOI: 10.1111/geb.13087

Jia ZY, Xie X, Wang XY & Jia W. 2014. Comparative study of main components of ginseng on immune function of rats. China Journal of Chinese Materia Medica, 39: 3363-3366.

Jiang W, Liu Y & Zheng H. 2012. Immune regulation of avian influenza vaccine in hens using '*Hypericum perforatum*' L. methanol extraction. Plant Omics, 5: 40.

Katsunuma Y, Nakamura Y, Toyoda A & Minato H. 2000. Effect of *Yucca shidigera* extract and saponins on growth of bacteria isolated from animal intestinal tract. Nihon Chikusan Gakkaiho, 71: 164-170. DOI: 10.2508/chikusan.71.164

Kempf I, Jouy E & Chauvin C. 2016. Colistin use and colistin resistance in bacteria from animals. International Journal of Antimicrobial Agents, 48: 598-606. DOI: 10.1016/j.ijantimicag.2016.09.016

Khalaji S, Zaghari M, Hatami KH, Hedari-Dastjerdi S, Lotfi L & Nazarian H. 2011. Black cumin seeds, Artemisia leaves (*Artemisia sieberi*), and *Camellia L.* plant extract as phytogenic products in broiler diets and their effects on performance, blood constituents, immunity, and cecal microbial population. Poultry Science, 90: 2500-2510. DOI: 10.3382/ps.2011-01393

Kim DW, Bang KH, Rhee YH, Lee KT & Park HJ. 1998. Growth inhibitory activities of kalopanaxsaponins A and I against human pathogenic fungi. Archives of Pharmacal Research, 21: 688-691. DOI: 10.1007/BF02976758

Landy N, Ghalamkari GH & Toghyani M. 2012. Evaluation of St John's Wort (*Hypericum perforatum L.*) as an antibiotic growth promoter substitution on performance, carcass characteristics, some of the immune responses, and serum biochemical parameters of broiler chicks. Journal of Medicinal Plants Research, 6: 510-515. DOI: 10.5897/JMPR11.1371

Lima FG, Haraguchi M, Pifster JA, Guimarães VY, Andrade DF, Ribeiro CS & Fioravanti MCS. 2013. Weather and plant age affect the levels of steroidal saponin and *Pithomyces chartarum* spores in Brachiaria grass. The International Journal of Poisonous Plant Research, 2: 45-53.

Makkar HP, Siddhuraju P & Becker K. 2007. Saponins, in: Methods in molecular biology: plant secondary metabolites, 93-100 (Totowa, Humana press). DOI: 10.1007/978-1-59745-425-4_1

Matsuura H. 2001. Saponins in garlic as modifiers of the risk of cardiovascular disease. The Journal of Nutrition, 131: 1000-1005. DOI: 10.1093/jn/131.3.1000S

Matusiak K, Oleksy M, Borowski S, Nowak A, Korczyński M, Dobrzański Z & Gutarowska B. 2016. The use of *Yucca schidigera* and microbial preparation for poultry manure deodorization and hygienization. Journal of Environmental Management, 171: 50-59. DOI: 10.1016/j.jenvman.2016.01.007

McAllister TA, Annett CB, Cockwill CL, Olson ME, Wang Y & Cheeke PR. 2001. Studies on the use of *Yucca schidigera* to control giardiosis. Veterinary Parasitology, 97: 85-99. DOI: 10.1016/S0304-4017(01)00394-6

McNeill L, Bernard K & MacLeod M. 2004. Food intake, growth rate, food conversion and food choice in broilers fed on diets high in rapeseed meal and pea meal, with observations on sensory evaluation of the resulting poultry meat. British Poultry Science, 45: 519-523. DOI: 10.1080/00071660412331286235

Miah MY, Rahman MS, Islam MK & Monir MM. 2004. Effects of saponin and L-carnitine on the performance and reproductive fitness of male broiler. International Journal of Poultry Science, 3: 530-533. DOI: 10.3923/ijps.2004.530.533

Miyakoshi M, Tamura Y, Masuda H, Mizutani K, Tanaka O, Ikeda T & Yamasaki K. 2000. Antiyeast steroidal saponins from *Yucca schidigera* (Mohave Yucca), a new anti-food-deteriorating agent. Journal of Natural Products, 63: 332-338. DOI: 10.1021/np9904354

Mottet A & Tempio G. 2017. Global poultry production: current state and future outlook and challenges. World's Poultry Science Journal, 73: 245-256. DOI: 10.1017/S0043933917000071

Muaz K, Riaz M, Akhtar S, Park S & Ismail A. 2018. Antibiotic residues in chicken meat: global prevalence, threats, and decontamination Strategies: a review. Journal of Food Protection, 81: 619-627. DOI: 10.4315/0362-028X.JFP-17-086

Muniandy KV, Chung ELT, Jaapar MS, Hamdan MHM, Salleh A & Jesse FFA. 2020. Filling the gap of *Brachiaria decumbens* (signal grass) research on clinico-pathology and haemato-biochemistry in small ruminants: a review. Toxicon, 174: 26-31. DOI: 10.1016/j.toxicon.2019.12.158

Oakenfull D & Sidhu GS. 1990. Could saponins be a useful treatment for hypercholesterolaemia? European Journal of Clinical Nutrition, 44: 79-88.

Oakenfull DG. 1986. Aggregation of saponins and bile acids in aqueous solution. Australian Journal of Chemistry, 39:1671-1683. DOI: 10.1071/CH9861671

Oleszek W, Sitek M & Stochmal A. 2001. Resveratrol and other phenolics from the bark of *Yucca schidigera Roezl*. Journal of Agricultural and Food Chemistry, 49: 4392-4396. DOI: 10.1021/jf001056f

Palatnik DE, Sousa CB, Santos WR, Casas CP, Paraguai DE, Souza E, Tinoco LW, Da Silva BP, Palatnik M & Parente JP. 2004. Protective vaccination against murine visceral leishmaniasis using aldehyde-containing *Quillaja saponaria* sapogenins. Vaccine, 22: 2470-2479. DOI: 10.1016/j.vaccine.2004.01.072

Petit PR, Sauvaire YD, Hillaire-Buys DM, Leconte OM, Baissac YG, Ponsin GR & Ribes GR. 1995. Steroid saponins from fenugreek seeds: extraction, purification, and pharmacological investigation on feeding behavior and plasma cholesterol. Steroids, 60: 674-680. DOI: 10.1016/0039-128X(95)00090-D

Pleger L, Weindl PN, Weindl PA, Carrasco LS, Leitao C, Zhao M, Schade B, Aulrich K & Bellof G. 2020. Effects of increasing alfalfa (*Medicago sativa*) leaf levels on the fattening and slaughtering performance of organic broilers. Journal of Animal Physiology and Animal Nutrition, 104: 1317-1332. DOI: 10.1111/jpn.13353

Qureshi AA, Abuirmeileh N, Din ZZ, Ahmad Y, Burger WC & Elson CE. 1983. Suppression of cholesterogenesis and reduction of LDL cholesterol by dietary ginseng and its fractions in chicken liver. Atherosclerosis, 48: 81-94. DOI: 10.1016/0021-9150(83)90019-9

Rajput ZI, Xiao CW, Hu SH, Arijo AG & Soomro NM. 2007. Improvement of the efficacy of influenza vaccination (H5N1) in chicken by using extract of *Cochinchina momordica* seed (ECMS). Journal of Zhejiang University-Science A, 8: 331-337. DOI: 10.1631/jzus.2007.B0331

Ramiah SK, Awad EA, Mookiah S & Idrus Z. 2019. Effects of zinc oxide nanoparticles on growth performance and concentrations of malondialdehyde, zinc in tissues, and corticosterone in broiler chickens under heat stress conditions. Poultry Science, 98: 3828-3838. DOI: 10.3382/ps/pez093

Ranjbar Z, Shariatmadari F & Torshizi MA. 2014. Effect of different levels of yucca extract and antibiotic on growth performance, immune response and blood factors of broiler chickens. Iranian Journal of Medicinal and Aromatic Plants Research, 30: 675-680. DOI: 20173172991

Raza A, Muhammad F, Bashir S, Aslam B, Anwar MI & Naseer MU. 2016. *In-vitro* and in-vivo anthelmintic potential of different medicinal plants against *Ascaridia galli* infection in poultry birds. World's Poultry Science Journal, 72: 115-124. DOI: 10.1017/S0043933915002615

Saeed M, Arain MA, Naveed M, Alagawany M, El-Hack MEA, Bhutto ZA & Chao S. 2018. *Yucca schidigera* can mitigate ammonia emissions from manure and promote poultry health and production. Environmental Science and Pollution Research, 25: 35027-35033. DOI: 10.1007/s11356-018-3546-1

Sahoo SP, Kaur D, Sethi AP, Saini AL & Chandra M. 2016. Effect of dietary supplementation of *Yucca schidigera* extract on the performance and litter quality of broilers in winter season. Animal Nutrition and Feed Technology, 16: 475-484. DOI: 10.5958/0974-181X.2016.00043.3

Shimoyamada M, Ikedo S, Ootsubo R & Watanabe K. 1998. Effects of soybean saponins on chymotryptic hydrolyses of soybean proteins. Journal of Agricultural and Food Chemistry, 46: 4793-4797. DOI: 10.1021/jf980694j

Song X & Hu S. 2009. Adjuvant activities of saponins from traditional Chinese medicinal herbs. Vaccine, 27: 4883-4890. DOI: j.vaccine.2009.06.033

Su JL, Shi BL, Zhang PF, Sun DS, Li TY & Yan SM. 2016. Effects of yucca extract on feed efficiency, immune and antioxidative functions in broilers. Brazilian Archives of Biology and Technology, 59. DOI: 10.1590/1678-4324-2016150035

Ueda H, Takagi A, Katou K & Matsumoto S. 2002. Feeding behavior in chicks fed tea saponin and quinine sulfate. The Journal of Poultry Science, 39: 34-41. DOI: 10.2141/jpsa.39.34

Ueda H. 2001. Short-term feeding response in chicks to tea saponin. The Journal of Poultry Science, 38: 282-288. DOI: 10.2141/jpsa.38.282

Wang Y, McAllister TA, Yanke LJ & Cheeke PR. 2000. Effect of steroidal saponin from *Yucca schidigera* extract on ruminal microbes. Journal of Applied Microbiology, 88: 887-896. DOI: 10.1046/j.1365-2672.2000.01054.x

Wina E, Muetzel S & Becker K. 2005. The impact of saponins or saponin-containing plant materials on ruminant production: A Review. Journal of Agricultural and Food Chemistry, 53: 8093-8105. DOI: 10.1021/jf048053d

Yadav AS, Kolluri G, Gopi M, Karthik K & Singh Y. 2016. Exploring alternatives to antibiotics as health promoting agents in poultry-A review. Journal of Experimental Biology, 4: 368-383. DOI: 10.18006/2016.4(3S).368.383

Yan L, Meng QW, Ao X, Wang JP, Jang HD & Kim IH. 2011a. Evaluation of dietary wild-ginseng adventitious root meal on egg production, egg quality, hematological profiles and egg yolk fatty acid composition in laying hens. Livestock Science, 140: 201-205. DOI: 10.1016/j.livsci.2011.03.033

Yan L, Meng QW, Lee JH, Wang JP & Kim IH. 2011b. Effects of dietary wild-ginseng adventitious root meal on growth performance, blood profiles, relative organ weight and meat quality in broiler chickens. Asian-Australasian Journal of Animal Sciences, 24: 258–263. DOI: 10.5713/ajas.2011.10222

Youssef IM, Männer K & Zentek J. 2021. Effect of essential oils or saponins alone or in combination on productive performance, intestinal morphology and digestive enzymes' activity of broiler chickens. Journal of Animal Physiology and Animal Nutrition, 105: 99-107. DOI: 10.1111/jpn.13431

Yu J, Chen Y, Zhai L, Zhang L, Xu Y, Wang S & Hu S. 2015a. Antioxidative effect of ginseng stem-leaf saponins on oxidative stress induced by cyclophosphamide in chickens. Poultry Science, 94: 927-933. DOI: 10.3382/ps/pev055

Yu J, Shi FS & Hu S. 2015b. Improved immune responses to a bivalent vaccine of Newcastle disease and avian influenza in chickens by ginseng stem-leaf saponins. Veterinary Immunology and Immunopathology, 167: 147-155. DOI: 10.1016/j.vetimm.2015.07.017

Zhai L, Li Y, Wang W & Hu S. 2011. Enhancement of humoral immune responses to inactivated Newcastle disease and avian influenza vaccines by oral administration of ginseng stem-and-leaf saponins in chickens. Poultry Science, 90: 1955-1959. DOI: 10.3382/ps.2011-01433.

Zhai L, Wang Y, Yu J & Hu S. 2014. Enhanced immune responses of chickens to oral vaccination against infectious bursal disease by ginseng stem-leaf saponins. Poultry Science, 93: 2473-2481. DOI: 10.3382/ps.2014-04056