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The Efficacy of Plant based Diets on Growth Potential, Energy Utilization, Nutrient Digestibility, Leg Bone Development and Litter Quality of Meat Chickens

Review Article

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ABSTRACT

Both plant and animal ingredients are used commonly to formulate balanced diets for poultry. Although many changes have been occurred in the genetics, nutrition and feeding of modern meat chickens, free selection and indiscriminate uses of feedstuffs for the non-ruminant animal diets can be hazardous due to the emerging threat of diseases outbreak via animal by-products. Besides this, many other concerns of including animal ingredients in poultry diets such as high price, zoonotic effects, ban on uses, food safety and product quality etc., encourage the poultry integrators to use merely vegetable feedstuffs for diet formulation excluding animal by-products. Exclusive use of plant ingredients into poultry diets might offer potential beneficial effects for optimizing poultry products. Poultry industry may be benefitted by using these cheap sources of vegetable ingredients for quality, safe and organic meat production. After all, most poultry integrators are looking for alternative ways to streamline production. This is why, currently the search for and the appropriate use of vegetable ingredients demand more research to explore their potential uses in poultry diets including other farm animals. However, despite the advantages of using vegetable feedstuffs in poultry diets, there are some associated problems that can affect the performance of meat chickens. So our current study is focused on to review these limitations of meat chickens fed vegetable-based diet, which include productivity, feed utilization and nutrient digestibility, leg bone health and litter quality of meat chickens.

KEY WORDS broiler chickens, digestibility, energy utilization, growth, leg bone health, litter quality, vegetable diets.

INTRODUCTION

The modern meat chickens are fast growing birds, and are efficient converter of feed nutrients to meat. The main objective of rearing meat chickens is to provide premium quality of animal meat for human consumption, and thus to meet the huge protein gap of the consumer world. To obtain quality meat or protein from animals such as meat chickens, a high quality, well-balanced diet is required to supply the birds. Proteins from animal sources, are known to have a well-balanced amino acids with higher biological values than vegetable protein. Optimum performance can be attained from meat chickens when the poultry are raised on diets formulated with animal protein diets (Hossain *et al.* 2013a; Hossain *et al.* 2011a; Hossain *et al.* 2015). However, vegetable proteins have considerable prospects in monogastric animal diets, because they are abundant naturally, cheap and the raw materials are easy to process with

low cost compared to animal proteins. Moreover, feed formulation using only vegetable ingredients can minimize the feed cost, ensure consumer's food safety, and can meet meat chicken nutrient requirement for rapid growth and health. Despite the advantages of plant feed materials, there are many constraints or challenges. These include anti-nutritive factors, poor protein quality, unbalanced amino acids, increased crude fiber, poor biological values, poor digestibility and so on (Tacon, 1992; Vieira *et al*. 2003; Hossain *et al*. 2011c). The challenges can be eliminated easily and nutritional status of plant-based diets can be improved substantially, when plant feedstuffs are well-processed, and are balanced with necessary nutrients including supplements.

Our recent studies on the nutritional quality of plant-based diets with or without the inclusion of supplements, animal proteins and so forth have been reported varying degree of success in terms of growth responses, feed utilization, digestibility, feed efficiency, bone development and litter quality. Meat chickens grown on diets exclusively with plant ingredients excluding animal meals may show satisfactory performance as long as right amount of protein and indispensable amino acids are incorporated in the rations. There is the possibility that diets formulated with the vegetable feedstuffs may be nutritionally inferior, and meat chickens fed solely on these formulations might respond negatively. Many attempts are being made to bring about radical changes in the diet formulation for poultry. Diets with no animal by-products have been investigated by many researchers, utilizing different combinations of plant proteins with or without supplementation of pro-nutrients, enzymes, probiotics, and synthetic amino acids (Baghel and Netke, 1987; Reddy and Eswaraiah, 1989; Reddy and Eswaraiah, 1991; Hossain *et al.* 2013a; Hossain *et al.* 2011a; Hossain *et al*. 2015). The inferences drawn from their research studies were widely variable, as the results were dependent upon the type of plant protein utilized, the combination of different feed sources, the level of inclusion in diets, and the amino acid profile of the protein mixtures used in the practical diets of meat chickens (Sadagopan *et al*. 1993). Therefore, the present study is undertaken to review on the different aspects of plant-based diets, and its impact on growth potential, nutrients utilization, feed digestibility, leg bone health and litter quality of meat-chickens for economic poultry production.

Productivity of meat chickens fed plant-based diets

The response of body growth in fast-growing meat chickens has been considered as an initial parameter for estimating the bioavailability of essential nutrients of feeds, because meat chickens are an ideal assay material with a limited nutrient storage, high nutrient demand, and rapid growth rate (Ammerman, 1995). The optimum growth or better productivity of meat-chickens are dependent mostly on the protein requirement. The protein need of poultry diets is met by both animal and plant protein sources. Plant proteins are generally beset with low content of various amino acids with poor biological value. These characteristics of vegetable protein deteriorate the quality of diets, and thereby lower the productivity of the meat-chickens. Besides, diet formulation exclusively with all plant feedstuffs may increase dietary fiber and anti-nutritive level considerably, which in turn, might affect the performance of the birds to an extend. Poor growth performance and inferior feed efficiency of broiler chickens were encountered when the birds had an access to sole vegetable diets compared to animal protein diets (Hossain *et al.* 2013a; Hossain *et al*. 2011a; Hossain *et al*. 2015). The growth response of broilers may be influenced adversely by many factors including type of feeds, level of nutrients, protein or amino acid requirements, biological value, properties of protein sources, quality, dietary fiber level, anti-nutritional factors and so on (Hossain *et al*. 2014a). However, many other previous researchers observed positive growth responses of meat-chickens when the birds fed only plant-based diets (Cancherini *et al.* 2004; Bellaver *et al.* 2005; Omenka and Anyasor, 2010). Similar growth responses of broiler chickens were also observed by Vieira and Lima (2005), when the birds fed diets either animal protein or all-vegetable diets. Results tend to suggest that similar growth responses can be obtained, if the diet is formulated with similar nutrient composition, and the feed is free from any detrimental factors, and well-balanced with necessary nutrients.

Feed conversion ratio (FCR) or feed efficiency is considered as one of the most important criteria used for determining the performance of meat or layer chickens by the poultry industry. Dietary feed resources might affect the FCR of meat chickens adversely, when different feed sources are used in composition. However, different researchers have reported both positive and negative effects of plant and animal protein diets on the feed efficiency of broiler chickens. Higher rate of muscle protein and body weight gain was found in broilers fed the vegetable-based diets compared to feeds formulated with animal products (Omenka and Anyasor, 2010). Many researchers (Al-Ostwani *et al.* 2000; Cancherini *et al.* 2004) observed improved FCR when plant-based diets were fed to broiler chickens. Conversely, impaired FCR was observed in the broilers when the birds offered sole vegetable proteins diets compared to those birds fed the diets containing animal (fishmeal, poultry meat, bone meal and poultry visceral meal) proteins (Sadagopan *et al*. 1993; Cruz *et al.* 2009; Alali *et al.* 2011; Hossain *et al.* 2012c; Hossain *et al.* 2012d; Hossain *et al.* 2013a). The variation in FCR be-

tween vegetable protein and animal protein diets may have been due to complementary effects of well-balanced amino acids, better digestibility of protein or other nutrients.

Energy utilization of meat chickens on plant-based diets

Energy component plays a pivotal role in formulating diets for poultry. Feed costs represent a major cost in poultry production (about 70%), with dietary energy sources occupying the greatest portion (70 to 75% of the diets) (Vander Klis *et al*. 2010). Most of the dietary energy comes from plant sources in the form of starch from cereal grains. However, although vegetable ingredients are inexpensive, their exclusive use in non-ruminant animals diet is limited, because many nutritionists are still concerned about the quality issues and energy values of the feeds, as well as their mode of utilization. It is generally assumed that, bird's feed consumption is regulated mostly towards the satisfaction for energy requirement first; once this is met, after that they show less tendency to consume any more feeds, even if the requirements for other nutrients like protein, vitamins, or minerals have not been fulfilled (Singh and Panda, 1992). It emphasizes that, the energy content of the feeds plays a premier role in meat chicken production. Therefore, it is important to determine precisely energy utilization of diets containing vegetable sources, either for least-cost formulation purposes or for adapting feed supply to energy requirements of animals (Noblet, 2006).

The relative speed of broilers' body growth compared to other poultry species is mainly dependent on the efficient utilization of nutrients to produce body tissues, deposit fat and protein in the carcass (Leeson *et al*. 1996). It is reported that higher energy deposited as protein in the birds fed conventional or animal protein diets (Hossain *et al*. 2012c; Hossain *et al*. 2012d). The trend of protein and fat deposition in the body may be influenced by many factors including nutrition, genotype, sex, environmental condition, and body weight or degree of maturity of birds (Havenstein *et al*. 1994; Wiseman and Lewis, 1998; Decuypere *et al*. 2003).

Metabolizable energy (ME) and net energy (NE) are the determinant factors to measure energy availability and utilization for non-ruminant animals. The ME is commonly accepted and widely used to compare energy values of available feedstuffs for poultry. Variation in gross chemical composition between grains may affect the digestibility of feed energy to a great extend (Black, 2001). The capacity of cereal grains to contribute energy to birds varies widely between and within grain species. This variation in energy value may arise from chemical or physical properties and botanical origin of individual feed components. A recent study reported that the ME value was similar between treatments when broiler fed on vegetable or conventional diets, but the ME and fat intakes were reduced in the birds fed on plant-based diets (Hossain *et al*. 2012c; Hossain *et al*. 2012d), as shown in Table 1. Besides, energy retention as fat (RE_f) and as protein (REp) also reduced in the same diet (Table 2). The ME intake of birds may have been reduced due to a high fiber contents and presence of anti-nutritive factors (ANFs) contained in the vegetable protein diets (Barteczko *et al*. 2008; Warenham *et al*. 1994).

Nutrient digestibility of meat chickens on plant-based diets

Unlike ruminant animals, poultry has different process of digestion, absorption and assimilation of ingested feed materials. Poultry diets based only on the vegetable materials tend to increase fiber level, which result in reduced nutrient digestibility and impaired performance of the birds. Poor digestibility of feeds often results in reduced efficient nutrient utilization as well. The poor performance of meat chickens fed all-vegetable diets could be partly due to poor nutrient utilization and low nutrient digestibility of plant-based diets (Hossain *et al.* 2013a).

Similar digestibility values of energy (gross energy and starch) were observed by a recent study conducted by Hossain *et al.* (2013a), when meat chicken fed vegetable or animal protein diets. However, although many factors such as pelleting, enzyme supplementation, technological treatments, chemical and physical nature of the feed materials etc., might also affect the digestibility of feed energy to an extend (Svihus *et al.* 2004; Noblet, 2006; Hossain *et al.* 2012b; Hossain *et al*. 2014b).

Apart from energy, protein is also an important nutrient required inevitably for the proper growth and development of the meat chickens. The physical and nutritional characteristics of the major muscle (Pectoralis) of broiler chickens can be improved by nucleotide supplementation in broiler diet. The higher protein digestibility was found in the birds fed animal protein diets than those of vegetable protein diets (Hossain *et al.* 2012a; Hossain *et al*. 2013a).

The major factors limiting the use of these vegetable proteins in feeds are the presence of naturally growing anti-nutritive factors (ANFs) including NSPs, tannins, trypsin inhibitors, phytic acids etc., which have detrimental impact on nutrient digestibility and absorption (Gatel, 1994; Smits and Annison, 1996).

Besides these, the chemical and physical protein characteristics, nature of protein and amino acids, dietary fiber contents, processing method etc., might affect the digestibility of feed proteins (Mahmoudnia *et al.* 2011). Vieira *et al*. (2003) and Vieira and Lima (2005) reported that nutrient digestibility of vegetable-based diets was comparatively lower (3.4%) than that of conventional or diets mixed with animal proteins.

Table 1 Metabolizable energy (ME) of diets, intake of gross energy (GEI), metabolizable energy (MEI), protein and fat of different diets fed to broilers

Item	Treatments[1]				SEM
	SBM75	Can75	SBM50	Can50	
ME (MJ/kg)	12.3	12.1	12.3	12.3	0.05
GEI (MJ/bird)	15.8^{c}	17.5^{b}	19.3^{a}	18.8^{a}	0.13
MEI (kJ/d/bird)	567.9^{b}	592.0^{b}	686.6^{a}	672.2^{a}	4.79
Protein intake (g/b)	48.0	44.7	49.9	49.1	1.30
Fat intake (g/b)	50.6^{c}	63.7^{b}	65.2^{b}	71.7^{a}	0.47

[1] SBM75 and Can75 denote vegetable protein diets whereas SBM50 and Can50 are conventional or animal protein diets (Hossain *et al.* 2012d).
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 2 Energy retention as fat (RE_f) and as protein (REp), and efficiencies of energy (ME), fat and protein use towards energy retention

Energy retention	Treatments[1]				SEM
	SBM75	Can75	SBM50	Can50	
RE_f (kJ/d)	131.8^{b}	123.0^{b}	161.3^{a}	160.0^{a}	4.09*
REp (kJ/d)	142.5^{b}	130.1^{b}	176.9^{a}	169.5^{a}	4.01**
Efficiencies of energy utilization					
K_{RE}	0.46	0.45	0.48	0.49	0.013
K_{REp}	0.25	0.22	0.26	0.25	0.006
K_{REf}	0.23	0.21	0.23	0.24	0.006

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
[1] SBM75 and Can75 denote vegetable protein diets whereas SBM50 and Can50 are conventional or animal protein diets (Hossain *et al.* 2012d).
* (P<0.01) and ** (P<0.05).
SEM: standard error of the means.

Hossain *et al.* (2013a) observed 6.8% lower protein digestibility of meat chickens when the birds fed plant-based diets than those fed on conventional diets containing animal protein (Table 3). However, although properly processed cereals and oilseed meals might have little or almost devoid of residual effects of ANFs, the complex structure, chemical or physical natures of plant-based diets might hinder the birds from getting full nutritional benefits from the feeds, by suppressing their digestibility and efficient nutrient utilization (Hossain *et al.* 2013a).

Leg bone or skeletal development and quality of meat chickens on plant-based diets

Modern meat chickens are very susceptible to leg problems, compared to other species of poultry. Birds with increased number of leg problems are culled from the flock or downgraded at slaughter (Kestin *et al.* 1999). Weak bones result in breaking during processing and lower meat grade. Also weak legs often result in reduced feed intake, which affect weight gain including product quality (Orban *et al.* 1999). The prevalence of leg problems of broiler chickens may be affected by numerous factors, including feed sources, nutrient density, dietary protein sources or levels, deficiency of specific nutrients, especially vitamins and minerals in broiler diets (Bilgili *et al.* 2006; Brickett *et al.* 2007).

The incidence and severity of leg problems in the fast-growing meat chickens are of great concern, both from product quality and animal well-being points of view. However, broiler feet has a great demand in the Asian market. Meat chickens grown exclusively on plant-based feeds excluding animal by-products or growth promoter have also a great demand in European and other markets. The regulation of European Union (CEC, 2000) suggests that animal meat should be produced without using animals–by products to meet the rising demand of the consumers. However, it is noticed that the yield of grade A broiler feet reduces, when the meat chickens produce on diets excluding any animal proteins or animal by-products (Eichner *et al.* 2007). The increased exclusion of animal protein from diets will exasperate this problem (Hossain *et al.* 2011b). Broiler chickens resulted in poor bone breaking strength or poor leg bone health, when the birds fed on only plant-based diets (Hossain *et al.* 2011b; Hossain *et al.* 2013a), as shown in Table 4. The poor leg health of broilers on the plant feed diets might have been due to anti-nutritional effect of the plant feeds. Phytate is a common and prominent anti-nutritive factor in all the plant feedstuffs, which forms mineral-phytate bond, and makes the nutrients unavailable in the feeds (Rutherfurd *et al.* 2002; Al-Kaiesy *et al.* 2003; Akande *et al.* 2010). In view of forgoing, it is explicit that leg bone quality, hard structure or skeletal formation of animal, the provision of micronutrient (minerals and vitamins) in broiler diets is undeniable. Although vegetable feedstuffs are a good sources of vitamins and minerals, but some anti-nutritive factors (e.g. phytic acid) present in these ingredients make them unavailable affecting the proper growth and development of the bone structure. So inorganic minerals or vitamins and minerals premix, exogenous enzymes may be supplemented in the practical diets of broiler chickens for meeting their optimum requirement, and for better performance and leg bone development of the meat chickens.

Table 3 Ileal digestibility of gross energy, protein and starch by chicks on different diets

Item	Treatments[1]				SEM
	SBM	CAN	SMF	CMF	
Gross energy	0.77	0.77	0.78	0.77	0.058
Protein	0.77[b]	0.76[b]	0.81[a]	0.80[a]	0.007*
Starch	0.97	0.97	0.97	0.96	0.003

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
[1] SBM and CAN denote vegetable protein diets whereas SMF and CMF are animal protein diets (Hossain *et al*. 2013a).
* (P<0.01).
SEM: standard error of the means.

Table 4 Bone (right tibia) traits and quality of broiler chickens

Item	Treatments[1]				SEM
	SBM	CAN	SMF	CMF	
Length of bone (mm)	62.9[c]	64.7[b]	65.7[b]	67.1[a]	0.37*
Weight of bone (g/kg body weight)	3.5	3.4	3.6	3.7	0.07
Width of bone (mm)	11.5	11.3	11.9	11.6	0.12
Breaking strength (kg/bone/bird)	21.5[c]	28.2[ab]	31.3[a]	30.0[a]	1.05*

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
[1] SBM and CAN denote vegetable protein diets whereas SMF and CMF are animal protein diets (Hossain *et al*. 2013a).
* (P<0.01).
SEM: standard error of the means.

Litter quality of meat chickens on plant-based diets

Litter or bedding material is used in the poultry house to provide comfortable environmental condition. Good litter condition usually results in better production. High litter moisture level, excreta moisture, drinking water etc., may deteriorate the quality of the litter materials. Apart from these, ammonia level emanating from excreta and pH may also worsen the environmental conditions, and thus affect bird health and productivity. Ammonia can cause abundant pollution in broiler houses, and it may have a great impact on poultry welfare (Kristensen and Wathes, 2000). Ammonia is produced during the decomposition of uric acid and the efficiency of this conversion is directly related to the level of litter moisture. Growth depression and increase feed conversion in broilers may take place when ammonia levels exceeded 25 ppm in the broiler house.

Many dietary factors such as dietary protein level, electrolytic balance, ionophores, cereal contents, fibrous ingredients, legumes, and non-starch polysaccharides (NSPs) are associated with excreta or litter moisture and their quality (Smith *et al*. 2000; Murakami *et al*. 2001; Francesch and Brufau, 2003). Excreta moisture of broilers may be affected by the frequency of water consumption of the birds, which in turn, may be influenced by any alteration in dietary feedstuffs. The NSP contents of vegetable diets arising from soybean and canola meals, can affect digestion of other nutrients by attracting water and contributing increased litter moisture (Francesch and Brufau, 2004). Furthermore, vegetable ingredients, particularly soybean meal, can contain more potassium than the animal by-products (NRC, 1994; Vieira and Lima, 2005). Potassium is known to increase water consumption which leads to improved moisture level in the excreta of broilers (Murakami *et al*. 2001), and thus result in sticky litter.

Smith *et al*. (2000) showed that 0.1% increase in dietary potassium level led to increase in excreta moisture content by 1.2% in laying hens.

Environmental condition may be worsened by the excessive moisture defecated from the birds, and it leads to predisposing challenges of microbial infection to the birds. In addition, the carbohydrates available in the vegetable protein soybean are poorly digested (Parsons *et al*. 1980; Pierson *et al*. 1980), and these can stimulate for increase bacterial growth in the litter.

Broilers fed diets with only plant feed sources contributed a higher amount of moisture and ammonia in their excreta as reported by several researchers (Vieira and Lima, 2005; Eichner *et al*. 2007; Hossain *et al*. 2012a; Hossain *et al*. 2013a).

This excess moisture affects the litter quality adversely, and leads to an increased risk of development of footpad dermatitis and other diseases.

CONCLUSION

Meat-chickens on plant-based diets only can be reared successfully with a minimal intervention. From the review it is assumed that the key productive performance of the meat-chicken can be optimised as long as the birds fed on plant-based diets balanced with necessary nutrient including supplementation. Vegetable feedstuff has a considerable potential to reduce feed cost, if cheap ingredient like plant ingredients are selected and used for the diet formulation of non-ruminant animals such as poultry. Modern meat chicken production is now very competitive, and a small variation in the efficiency of nutrient digestibility and utilization of the supplied feedstuffs to the birds, can be economically lucrative and viable.

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