Review Article

The Practical Application of Sunflower Meal in Poultry Nutrition

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Abstract | The benificial application of untraditional feedstuffs such as sunflower meal (SFM) in animal and poultry nutrition in developing countries has received considerable attention. SFM is a by-product of sunflower oil industry, and has been increasingly added to animal and birds diets. Moreover, SFM is potentially one of the most important protein source in the world. Nowadays, it is well known that feed represents the main cost of animal and poultry production and accounts about 75% of the total cost. The increasing feed ingredients price of poultry nutrition caused to look closely at agricultural by-products which are less cost than traditional ingredients. Thus, the waste residues of crops, vegetables and fruits after harvesting and processing could be used as sources of protein, energy and other nutrients in feeding animals and poultry. Reports from variuos laboratories on the using SFM as feed ingredient for poultry are discussed in this review. Based on the findings presented, SFM is an acceptable feed componentof poultry rations and can be fed at 25% in broiler and 20% in layer diets. However, replacement of soybean meal (SBM) with SFM may affect dietary inclusions of essential amino acids, and use of synthetic lysine may need to be increased. The high levels of SFM in poultry diets can be used successfully with appropriate diet formulation adjustments for energy and amino acids particularly lysine and methionine. This compilation with its valubale information would be beneficial for researchers, chemists, feed and food industry, and certainly could help to promote the usage of SFM in poultry production.

Keywords | Sunflower meal, Nutritive value, Antinutrional factors, Performance, Carcass traits, Digestibility, Digestive enzymes, Mortility rate, Poultry nutrition

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INTRODUCTION

Sunflower seeds (SFS) belongs to the genus of *Helianthus annuus* (Soliman et al., 1996; Canibe et al., 1999; San Juan and Villamide, 2001).The cultivated SFS is one of 67 species of genus *Helianthis* in the world (Flagella et al., 2002). The production of SFS reached 37.08 million tonne and thereby produced 15.22 million tonne of oil in the world (FAO, 2012). SFS are one of the major oilseeds produced in the world beside cotton seeds, soybeans and rapeseed (Salunkhe et al., 1992). This plant has been developed to become the second largest reserve of feed and protein source, the third most important source of consumed oil by huaman and animal, and fourth major oil seed in production (Lusas, 1985; Aboul Ela et al., 2000; Garcés et al., 2009).

Sunflower Meal (SFM) is commonly produced with 60-65% protein core (kernel) and 35-40% hull (shell). SFM contains about 30-34% of crude protein, 20-25% cellulose and 8-10% lignin (Sredanovic et al., 2012). As the result of such a high share of hulls in SFM, with about 50% cellulose and 25% lignin, the nutritive value of SFM is drastically reduced in animal and poultry nutrition (Delic, 1992; Attia et al., 1998; Slavica et al., 2006; Ali et al., 2011). Since, the key challenge of incorporation of SFM in broiler diets is the high fiber content in SFM (NRC 1994), which may negatively effects on growth performance and carcass yield, therefore certain exogenous enzymes such as beta-gluconase, phytase etc. may be added to broiler feeds containing SFM to aid fiber digestion including carbohydrases or to solubilize phytic phosphorus, consequently reducing their harmful effects on performance parameters of broiler (Raza et al., 2009). SFM can be used as a feedstuff to replace soybean meal (SBM) in poultry diets (Soliman, 1997). According to Lipiec (1991) SFM can be used in monogastric animal nutrition in the amount of 50 to 150 g/kg diet. A major factors of using SFM in poultry diets is a cheap price compared to SBM, also it is free from toxic molecules and anti-nutritional factors which may affect productive performance (Gheyasuddin et al., 1970; El-Barbary, 1997). SFM could be used profitably up to 200 g/kg of broiler diets with no adverse impacts on growth performance and feed utilization (Valdivie et al., 1982; El-Sherif et al., 1995). The higher inclusions of SFM at 85 and 100 % as a replacement for SBM were stated with laying hens (El-Sherif et al., 1997; El-Deek et al., 1999b; Rama Rao et al., 2009). Zatari and Sell (1990) and Vieira et al. (1992) found that the high amounts of SFM can be successfully used in diets of laying hen and broiler chicken if adequate concentrations of dietary metabolizable energy (ME) and lysine are provided. Vetesi et al. (1999) recorded that live body weight, feed conversion ratio, carcass value as well as egg production and hatchability percentages of geese and ducks did not significantly change even at 100% replacement of SBM with SFM. But, there are some restrictions/ limitations about using the high inclusion levels of SFM in poultry diets viz., high fiber content, low ME content, and low lysine content in SFM, these reasons may restrict its high incorporation level in broiler diets (Smith, 1968; Biesiada-Drzazga et al., 2010). It has been stated that SFM can be included in poultry diets at relatively high levels without any adverse impact on productive performance and egg quality criteria (Tsuzuki et al., 2003; Casartelli, et al., 2006; Rezaei and Hafezian, 2007).

Great efforts have been made to improve the nutrients bioavailability from different feedstuffs via supplementation of enzymes. Enzymes may not be produced with large concentrations by the birds, and thus are suggested to be added to poultry diets (El-Deek et al., 1999a). Since, SFM contains substantial concentrations of cell-wall material and a high level of fiber that could affect the nutritive value of this meal, the use of an exogenous enzyme may be justified to improve the accessibility of cell contents to digestive enzymes (Brenes et al., 2008). Recently, supplementation of enzymes in poultry feeds has considerably increased, but few investigations are available on the influences of enzyme on utilization of SFM in poultry. On the other hand, many authors (Rebolé et al., 1999; Kocher et al., 2000; Attia et al., 2003) have reported that commercial enzymes with various activities from pectinase, glucanase, xylanase and cellulose etc. did not result in significant improvements in broiler growth performance, but in some reports it was found beneficial effects on apparent metabolizable energy (AME) and feed efficiency values (Abbas et al., 1998; Mandal et al., 2005). The manuscript describes all the salient aspects of SFM viz., chemical composition, nutritive value, amino acids profile and anti-nutritional factors as well as its effect on growth and productive performance, carcass characteristics and quality, blood constituents, nutrient digestibility and bioavailability, intestinal enzyme activities and many useful and useless applications of this important meal in poultry nutrition. The information on SFM presented will be useful for researchers, chemists, feed and food industry and poultry industry.

NUTRIENT COMPOSITION OF SFM

Literature studies found various chemical compositions of SFM (Villamide and San Juan, 1998; Senkoylu and Dale, 1999). This variation may be due to different grain processing methods, as reported by Pinheiro et al. (2002). The high production of new kinds of high oil content SFS for oil production and increased trends in formulating poultry diets containing high levels of protein and energy, has promoted evaluation of SFS (Cheva-Isarakul and Tangtaweewipat, 1991).

The chemical analysis for the nutrient content of SFM stated by several authors is shown in Table 1. Since, chemical composition of SFM considerably varied; crude protein (CP) and dry matter (DM) values ranged from 26.41 to 40.30 and 88.00 to 93.80% with an average of 32.42 and 90.36%, respectively; while crude fiber (CF) percent ranged from 11.54 to 29.68% with an average of 21.39%. Moreover, ether extract (EE) content ranged from 0.40 to 18.78% with an average of 6.74% (Table 1). Processing methods of SFM seem to be the key factor affecting the results obtained. The wide range in chemical composition of SFM may be returned to extraction methods of oil from the seeds. In case of ash (total minerals) value of SFM, little variations were found between the literature findings (5.46 – 7.75%).

AMINO ACIDS PROFILE

Amino acids contents of SFM as reported by several researchers are shown in Table 2. Data of amino acid pattern of SFM showed that although it was limiting containing in lysine, methionine, cystine, and tyrosine, but it seemed to have good concentrations of arginine, glutamic acid and aspartic acid. The same result was reported by Klain et al. (1956) who stated that the supplementation of lysine improved the nutritive value of SFM.

Correspondingly investigation of many researchers (Thomas et al., 1965; Marinov et al., 1973; Singh and Prasad, 1979)

Table 1: Nutrient composition of SFM

Authors	DM%	CP %	EE %	CF %	Ash %
Afifi (1972)	90.11	32.42	1.49	23.37	5.91
Rad and Keshavarz (1976)	93.80	36.30	0.40	18.22	7.06
Samy (1979)	91.20	26.41	7.34	29.68	5.46
Singh and Prasad (1979)	91.60	36.00	1.50	18.33	7.75
Lee and Lee (1982)	90.10	28.40	7.40	20.30	6.30
Valdivie et al. (1982)	91.02	31.48	16.40	16.37	6.82
Abdel Malaak (1989)	88.56	40.30	-	18.00	-
Zatari and Sell (1990)	89.32	29.72	12.53	28.73	5.52
Dessouky (1996)	90.23	32.60	-	18.40	-
San Juan and Villamide (2001)	-	33.14	2.77	25.21	7.00
Rostagno et al. (2005)	89.09	31.40	-	23.00	-
Senkoylu and Dale (2006)	90.20	32.30	18.78	11.54	6.29
Nassiri Moghaddam et al. (2012)	88.00	30.00	2.50	21.20	-
Liu et al. (2015)	91.48	33.52	3.11	27.23	6.85
Average	90.36	32.42	6.74	21.39	6.49

Table 2: Amino acids profile of SFM (% DM)

Amino acids	Researchers								Average
	Klain et al. (1956)	Singh and Prasad (1979)	Valdivie et al. (1982)	Zhang and Parsons (1994)	Dessouky (1996)	San Juan and Villamide (2001)	Senkoylu and Dale (2006)	Liu et al. (2015)	
Indispensable amino acids, %									
Arginine	-	2.39	2.87	2.76	2.31	1.94	2.48	2.62	2.48
Histidine	0.95	0.41	0.99	0.83	0.78	0.78	0.77	0.93	0.80
Isoleucine	2.04	0.74	1.54	1.42	1.38	1.41	1.25	1.34	1.39
Leucine	2.65	1.85	2.31	2.35	2.31	2.03	2.02	2.09	2.20
Lysine	1.09	0.80	1.39	1.43	0.87	1.12	1.14	1.48	1.16
Methionine	0.91	0.32	0.61	0.57	0.62	0.70	0.68	0.75	0.64
Phenylalanine	1.82	2.04	1.71	1.61	0.62	1.30	1.44	1.39	1.49
Threonine	1.52	0.66	1.34	1.29	1.21	1.22	1.15	1.25	1.20
Tryptophan	-	-	-	-	-	-	0.41	0.37	0.39
Valine	2.17	0.84	1.85	1.87	0.42	1.68	1.58	1.76	1.49
Dispensable amino acids, %									
Alanine	3.34	-	1.75	-	1.96	1.35	-	1.62	2.16
Tyrosine	1.09	0.93	0.82	0.76	0.69	0.65	0.80	0.76	0.83
Proline	-	-	-	1.64	1.69	1.32	-	1.20	1.51
Serine	-	1.83	1.51	1.48	1.71	1.28	-	1.42	1.59
Aspartate	-	-	3.40	2.28	3.21	2.87	-	3.01	2.97
Cystine	-	-	0.61	0.56	0.59	0.53	0.66	0.56	0.59
Glutamine	6.98	-	6.85	7.21	7.20	6.14	-	6.80	7.00
Glycine	2.56	1.82	2.19	1.87	1.89	1.96	1.7 7	2.00	2.01

reported that lysine is considered the most limiting amino acid in SFM protein. Green et al. (1987) pointed out that true digestibility of most essential amino acids in SFM were similar to or greater than those of SBM exceptionally lysine amino acid which was more digestible in SBM (87.9%) than in SFM (72.2%). In this connection, Dessouky (1996) reported that SFM is high in some amino acids such as aspartic, arginine and glutamic contents and low in others like lysine, tyrosine, methionine and cystine contents. Moreover, the previous author added that lysine seemed to be the first limiting amino acid of SFM.

NUTRITIVE VALUE OF SFM FOR POULTRY

Several researchers determined/measured the metabolizable energy (ME) and nutrient digestibility of SFM (Rodrı´guez et al., 1998; San Juan and Villamide 2001; Georgieva et al., 2014). Lautner and Zenisek (1964) stated that the ME of SFM was 7.97 MJ/Kg. Regarding the evaluation of crude protein in SFM, Rathowski (1971) reported that the digestibility values of crude protein for rapeseed meal, peanut meal, SBM and SFM were 58, 82, 90 and 94%, respectively. In this experiment, results showed that the net protein utilization of rapeseed meal, peanut meal, SBM and SFM were 56, 43, 55.5 and 60.5% respectively. Additionally, Eklund et al. (1971) found that the protein efficiency ratio (PER) of SFM was 2.16 which improved to 3.3 after lysine supplementation. A study by Rose et al. (1972) evaluated two different samples of SFM as a substitute for SBM in laying hen diets. They found that the values of ME were 9.21 and 8.94 MJ/Kg on dry matter basis for two seed meals.

Rad and Keshavarz (1976) reported that the ME of SBM being 2500 Kcal/kg was higher than that of SFM which ranged between 1800 and 2100 Kcal/kg. Also, the authors found that the net protein value (NPV) of SFM decreased by increasing the processing temperature. In addition, SFM diet supplemented with lysine improved the NPV of SFM to be higher than that of SBM diet (64.75% vs. 55.23%).Otherwise, Samy (1979) found that the value of ME in SFM expressed in Kcal/Kg was 2486. Valdivie et al. (1982) found that SFM contains ME between 6.27 and 9.19 MJ/Kg according to type of hulling and fat removing process industrially used. The nitrogen-corrected apparent metabolizable energy (AME_n) value of full fat sunflower seed was lower than 18.71 MJ/kg and 17.67 MJ/kg reported by Rodriguez et al. (1998) and Rodriguez et al. (2005), respectively.

Green et al., (1987) stated that groundnut and sunflower meals were similar in true digestibility of most essential amino acids but lower than that of SBM. Generally, according to the NRC (1994) SFM contains 32% CP, 1.1% EE, 24% CF and 1543 ME per Kcal/Kg. on the other hand; Dessouky (1996) concluded that the ME content in SFM was 1651 Kcal/kg DM.

Gross energy value of SFM equal to gross energy of SBM (4501 vs. 4508 kcal/kg) and is higher than that of cottonseed meal (4401 kcal/kg). These values for gross energy will vary due to the amount of residual oil and hulls after processing (Nadeem, et al., 2005). The values of AME_n in SFM were 1.458, 1.458 and 1.481 kcal/kg in guinea fowl, cockerels and quails, respectively (Mandal et al., 2005). The values AMEn of the diets and SFM were decreased with increasing inclusion level of SFM from 0 to 270 g/kg in broiler diets. Also, in this trend, the dietary AME_n amounts were regressed against the incorporated levels of SFM by using linear and quadratic models (Nassiri et al., 2012).

ANTI-NUTRITIONAL FACTORS OF SFM

SFM is a good source of crude protein average 32.42%, but the presence of polyphenolic compounds restricts its use in feed animal and poultry. Chlorogenic acid (CGA) is the major molecule of polyphenolic compounds in SFM as demonstrated by many researchers (Leung et al., 1981; Pedrosa et al., 2000). Sabir et al. (1974), Lusas (1985) and Salem (1990) reported that the percent of CGA is 70% of total phenolic constituents in SFM. Irrespective of CGA, SFM contains other phenolic compounds such as caffeic, rosmarinic and ferulic acids, as well as myricetin and rutin, all these compounds present in quantities of less than 0.15 ppm. De Leonardis et al. (2005; 2006) reported that phenolic compounds of SFS included seven molecules like chlorogenic, caffeic, protocatechuic, o-cinnamic, ferulic and syringic acids. CGA is a phytochemical molecule which is the ester of caffeic acid (CA) and quinic acid (QA). Also, CA and QA are found in sunflower polyphenolic compounds with CGA. The concentrations of CGA, QA and CA isolated from SFM samples were 2.70, 0.38 and 0.20 %, respectively.

CGA causes an observable reduction in the digestibility and bioavailability of the protein content of sunflower, on the other hand, CGA is a vital compound of the hydroxycinnamates, components that are ubiquitous in plants and have interesting biological properties, such as antioxidant activities (Clifford, 2000; Žilić et al., 2010). But from another point of view, the phenolic compounds including CGA which presented in SFM were not toxic as stated by Sosulski et al. (1972) which reported that there are no known toxic impacts for CGA in SFM. On the other hand, the CGA in SFM causes a brown and green discoloration in feeds at alkaline pH (González-Pérez et al., 2002). The phenolic compounds in SFM are stated till now to be not toxic for farm animals. However, CGA could become a key barrier to its utilization in feed products as forming color factors but not as a toxic component. Also, the average value of CGA in SFM was found to be 2.27% (Dessouky, 1996). Treviño et al. (1998) did not detect any adverse effect of CGA on the nutritive value of the diet in broiler chickens. Luckett et al. (1999) isolated from sunflower seeds a peptide with 14 amino acids, termed sunflower trypsin inhibitor (SFTI-1), which could also have a negative effect on the performance. Methionine and choline addition are needed to counteract the harmful effect of CGA when SFM is used in the poultry and animal diet (Swick, 1999).

EFFECT OF PROCESSING ON THE NUTRITIVE VALUE OF SFM

The methods of processing of SFM seem to be the key factor affecting its nutritive value (Clandinin and Robble 1950). Also, theses authors found that treating sunflower seed with excessive temperature reduced the protein quality. Moreover, Alexander and Hill (1952) pointed out that dry heating of SFM at 121°C caused marked destruction of some amino acids such as lysine in the meal. On the contrary, methionine amino acid was unaffected by the heat treatment. The nutritive value of protein in SFM increased with decreasing the processing temperature (Morrison et al., 1953).

SFM processed at 155°C in the cooker and 144°C in the conditioner had less available tryptophan, lysine and arginine than that produced at 111 and 122°C in the cooker and conditioner, respectively (Renner et al., 1953). On the same context, Rad and Keshavarz (1976) studied the nutritional value of SFM which was processed at 105-125°C in the cooker and at 80-130°C in the conditioner. The authors noted that the metabolizable energy (ME), net protein value (NPV) and available lysine of SFM decreased with increasing the processing temperature. On the other hand, Zhang and Parsons (1994) revealed that true digestion coefficients of amino acids in SFM decreased when autoclaving time increased. Where, the digestibility values of lysine in SFM were 86, 54, 43 and 35% when SFM autoclaved for 0, 30, 60 and 90 minute, respectively. According to Ravindran and Blair (1992) and San Juan and Villamide (2000) high temperature associated with mechanical pressing damages the protein, destroys amino acids, and decreases their availability.

SFM was exposed to 1000 W microwave irradiation for six minutes resulted in increase in vitro gas production parameters and improvement of nutritive value such as metabolizable energy, organic matter digestibility and short chain fatty acids content of sunflower meal. This method can be used as cost effective method for improvement of nutritional value of oil seed meals (Maheri-Sis et al., 2011).

SFM IN FEED

BROILER CHICKENS

Growth Performance

Several studies have been reported to evaluate the use of SFM at different inclusion levels in broiler diets (Waldroup et al., 1970; Levic et al., 1998; Sredanovic et al., 2005; Abbas and Yagoub, 2008; Peric et al., 2010). Feed efficiency gradually decreased with SFM diet compared to corn soybean diet. Also, in this study, supplementation of lysine to SFM diet improved feed conversion but did not quite restore it to that given by the corn soybean diet. Moreover, SFM could successfully replace one-third of SBM, while replacing two-thirds of SBM by SFM, slightly depressed the growth rate of broiler chickens (Afifi 1972). A study of Ologhobo (1991) confirmed the negative effect of feed conversion efficiency by feeding broiler chickens on diets substituting SFM for SBM at 50, 75 and 100% levels. While, substituting SFM for SBM at 50, 75 and 100% decreased body weight gain of broiler chickens for 8 weeks. On the other hand, Rad and keshavarz (1976) stated that about 50% of SBM protein could be replaced by SFM protein without drastic effect on growth rate of broiler chicks. This is equal to the use of 17.5% SFM in the diet which supplies 7% of the dietary protein. Lee and Lee (1982) confirmed the findings by Valdivie et al., (1982) and observed no significant difference in feed efficiency of Shaver broiler chickens fed diets containing 50, 100, 150 or 200 g/kg of SFM till 56 days of age.

Increasing SFM up to 250 g/ kg diet supplemented with lysine and methionine supported equal or better weight gain of broiler chickens than the control diet ($P < 0.01$). However, the worst value of feed conversion ratio was recorded with the diet containing SFM 250 g /kg diet (Musharaf 1991). The findings of SFM inclusion in broiler diets are controversial. The inclusion of 10 or 20% SFM significantly decreased body weight gain. Daghir et al. (1980), Lee and Lee (1982) and Abid et al. (1990) used SFM successfully in broiler chicken diets up to 20% without adverse impact on growth rate.

Live body weight and body weight gain as well as feed intake and feed conversion of growing Japanese quail were not statistically ($P>0.05$) influenced by inclusion SFM (35, 50 and 65 g/kg diet) levels (Christaki et al., 1994). Jackson and Dalibard (1995) evaluated the performance of broilers fed diets containing SBM, SFM and canola meal, and all diets formulated based on CP or ideal protein. The same authors found that the replacement of SBM by SFM did not compromise broiler performance when the diet was formulated on ideal protein basis.

Some researchers have consistently reported positive growth performance and feed utilization results when SFM is added to broiler chicken rations. Findings from an early study by Salih and Taha (1989) showed that live body weight and body weight gain as well as feed intake and feed efficiency were similar in all treatments when broiler chickens fed diets contained different levels of SFM 0, 10, 20 or 40%. Zatari and Sell (1990) fed broiler chickens with

0, 100 or 200 of SFM /kg diet from 1 to 42 days of age. Findings from this study suggest that the inclusion of 100 or 200 g of SFM per kg diet improved feed efficiency. El-Zubeir and Ibrahim (1991) and Ibrahim and El-Zubeir (1991) found that feed intake and feed conversion efficiency of broiler chickens were similar in all investigated groups contained up to 30% SFM. Also, growth parameters (body weight gain, feed intake, and feed conversion efficiency) revealed that SFM can be used in broiler chicken rations up to 30% with no adverse impact on growth rate (Rajesh et al., 2006).This difference may be attributed to the quality of the SFM processing or variety of the birds or animal used (Campbell et al., 1989).

Studies involving the use of SFM have confirmed, and recommended that the high levels of SFM can be used effectively in broiler diets (Senkoylu and Dale, 1999). El-Sherif et al. (1995) demonstrated the possibility of replacing SBM with SFM up to 70% in broiler chickens diets during grower and finisher stages and supplemented with methionine, lysine and fat without adverse impacts on growth performance. The treated and untreated form of SFM in broiler diets had no drastic effects on body weight, also no significant adverse impact was observed on growth rate and feed conversion ratio of broiler chickens at 28 or 49 days of age (Desouky 1996).

There were no significant differences in body weight gain, feed intake and feed utilization among the birds fed the control diet and those fed on diets with increasing amount of hulled full-fat sunflower seed from 50 to 250 g/kg diet (Rodriguez et al., 1998). Kocher et al. (2000) indicated that commercial enzyme products had some effects in diets containing high concentrations of SFM. Birds fed the SFM-based diets had a significant ($P<0.001$) higher growth rate and AME and a lower feed conversion ratio (FCR) than those fed the canola meal diets. The addition of enzymes to either CM or SFM-based diets had no significant effects on growth performance and AME. Moreover, Swain et al. (1996) reported that performance of broiler chickens was improved in high-CF sunflower cake with multi-enzyme supplementation. Also, Cowan et al. (1999) found an improvement in broiler performance due to supplementation of pectinase enzyme in SFM-based diets. On the contrast, Mushtaq et al. (2006) noted that enzyme addition through 2 week after hatch had no remarkable impact when used in SFM-based diets.

Arija et al. (1998) and Suresh et al. (2000) reported no adverse effects from including up to 50 and 120 g/kg, respectively, of sunflower seed hulls in broiler diets. SFM can be used in broiler chicken diets at levels up to 140 g/kg without adverse effects on performance or other parameters (Nassiri et al., 2012).

Feed intake of birds ranged from 420 to 520g/week with increasing levels of SFM from 0% to 75%, respectively. Moreover, feed efficiency and body weight gain were unaffected by the dietary SEM inclusions during the fattening period. Thus, SFM can replace SBM and groundnut cake up to 75% level without adverse impacts on growth performance of broiler chickens (Adejumo and Williams 2006).

Previous studies investigating the impacts of the use of SFM meal as a replacement for SBM show inconsistent results. The inclusion of SFM resulted in worse broiler performance in some studies (Abdelrahman et al., 2007; Peric et al., 2010). Also, these results are supported by Mandal et al. (2006) who found that the inclusion of SFM in broiler diets decreased growth performance in terms of poor feed efficiency and growth rate. However, Mandal et al. (2003) showed that inclusion of undecorticated SFM at 0, 50 and 100 g/kg in broiler chicken diets replacing part of SBM had no significant impact on weight gain and feed consumption throughout the fattening period (starter and finisher).

On the other hand, in others studies, the inclusion of SFM up to 20% (El-Sherif et al., 1997; Tavernari et al., 2008) or at even higher concentrations (Rama Rao et al., 2006; Mushtaq et al., 2009) did not have any adverse effects on live body weight or body weight gain. According to Furlan et al. (2001) SFM, in replacement of SBM, can be added up to 30%, where feed intake and body weight gain were improved by 13.17 and 12.04%, respectively), with no detrimental effects on growth performance. On the same context, Senkoylu and Dale (2006) did not observe any significant effect on broiler performance when up to 28% SFM was included in the diet. Also, the previous authors used the residue SFM cold-pressing, which contains 32.3% CP and 18.78% EE compared to SFM. Tavernari et al. (2009) did not find body weight gain differences in broilers fed diet contained up to 20% SFM, while feed intake was inversely proportional to SFM dietary level. On the other hand, Pinheiro et al. (2002) reported that SFM inclusion higher than 12% reduced body weight gain and feed intake of broiler, but the best feed intake value achieved when SFM was not added to the diet. Some studies stated that high inclusions of SFM up to 20% in grower and finisher broiler diets had no impact on feed conversion ratio (Aftab 2009; Peric et al., 2010).

Live body weight, body weight gain and feed consumption of broiler chickens were reduced in the diet contained high oleic acid sunflower seeds (HOASS) at 250 g /kg diet, compared with the control diet. On the other hand, the diet contained 150 g of HOASS /kg diet did not affect performance during the period from 4 to 21 d of age (Brenes et al., 2008). Also, the addition of enzymes (lipase or phospholipase or its combination) at the inclusion level of 1 g/kg to the broiler diets containing HOASS (150 g/kg diet) increased body weight gain and feed consumption and improved feed conversion ratio compared with the un-supplemented HOASS diet. On the contrary, the addition of 250 g of HOASS/kg in the diets caused a negative effect on broiler performance. Feed intake and feed conversion ratio were significantly improved when broiler chickens were fed different inclusions of full fat sunflower seed in the starter (1-3 wk of age) and finisher (3-7 wk of age) diets (Salari et al., 2009).

The inclusion levels of SFM at 6 and 8% in grower diet of broilers had no effects on growth parameters, while at 10% and 16% in finisher diet, body weight gain was statistically affected (P<0.05). Body weight gain significantly improved with dietary enzyme mixture (cellulase, β-glucanase, and xylanase) at 0.01% through the entire experimental period. Neither SFM nor enzyme supplementation had any effect on feed consumption (Horvatovic et al., 2015).

Carcass Characteristics

Ozen and Erdem (1992) replaced SBM by SFM in younger chicken diets at levels of 0, 25, 50, 75 and 100 during period 4-8 weeks of age. They did not found any significant differences between groups in the percentages of dressing, abdominal fat and edible parts. On the contrary, Ologhobo (1991) observed that substituting SFM for SBM at levels 50, 75, and 100% decreased the percentages of carcass, dressing and total edible meat. On the other hand, El-Sherif et al. (1995) replaced SBM with 5, 10 or 15% SFM in broiler diets during period 19 to 45 days of age and observed that carcass % had significantly differed among the groups. The differences in abdominal fat amount and carcass components among the groups were not significant. Quail carcass traits, including carcass yield, carcass weight and giblet weight (heart, liver and gizzard weight) were not statistically affected (P>0.05) by the SFM inclusion in quail diets (Christaki et al., 1994). Studies by Niemiec et al. (1996) observed that slaughter performance of chicken broilers was improved with diet contained SFM.

Fouzder et al. (2000) concluded that dressing traits, as measured by dressing % and blood, feather, giblets, abdominal fat, head and shank weights were not significantly affected (P<0.05) by the quail diets contained different levels of SFM (25, 50, 75 or 100% instead of SBM).Contrarily, Brenes et al. (2008) found that the addition of 250 g of HOASS/kg in the diets caused a negative effect on digestive organ sizes of broiler chickens (relative liver weight, relative duodenum, jejunum, ileum, and ceca lengths) compared to the control diet. Moreover, the same authors pointed out the addition of enzymes such as lipase and phospholipase or its combination at the level of 1 g/kg to broiler diets contained HOASS (150 g/kg diet) increased the relative weight of pancreas, liver and spleen as well as the relative lengths of duodenum, jejunum, ileum and ceca compared with the un-supplemented HOASS diet during the period from 4 to 21 d of age. On the contrary, the addition of 250 g of HOASS/kg in the diets caused a negative effect on digestive organ sizes.

Salari et al. (2009) found that the percentages weight of gizzard, breast, thigh, gastrointestinal tract and abdominal fat were not affected by dietary treatments which contained different levels of full fat sunflower seed; while, liver weight % was decreased significantly (P<0.05). Araújo et al., (2011) pointed out that use of sunflower meal up to 15% in the broiler diets did not influence growth performance and carcass and yields during period 22 to 42 days of age. Increasing dietary inclusion of SFM with enzyme blend supplementation reduced body weight gain and deteriorated feed conversion. The inclusion of SFM (0, 8, 16, and 24%) in broiler diets negatively influenced performance and carcass parameters (Araújo et al., 2014).

Neither SFM nor exogenous enzymes had any effect on broiler carcass parameters during the fattening period (Horvatovic et al., 2015).These results are in agreement with reports from other researchers, who also did not find any response of SFM or exogenous enzymes on carcass parameters (Tavernari et al., 2008; Mushtaq et al., 2009). In the work of Saleh et al. (2005) supplementation of cellulase to corn soya diet of broiler significantly reduced abdominal fat. However, some results suggested that enzyme addition improved carcass yield (Omojola and Adesehinwa, 2007). The use of exogenous enzymes in poultry diets with a high SFM inclusion concentrations resulted in better carcass percentage (Khan et al., 2006).

Blood Constituents

The inclusion of HOASS in the diet increased plasma uric acid (P<0.01), cholesterol (P<0.001), and glucose (P<0.001) concentrations by 5, 20, and 15%, respectively, and reduced (P<0.001) serum lactate dehydrogenase and creatine phosphokinase concentrations by 6 and 16%, respectively, compared with those fed the control diet. Moreover, the addition of exogenous enzymes (1g/kg diet) to broiler diets contained HOASS (150 g/kg diet) increased blood constituents such as plasma uric acid, calcium, serum lactate dehydrogenase, phosphokinase, total protein concentration, plasma cholesterol and glucose compared with the un-supplemented HOASS diet during the period from 4 to 21 d of age. On the other hand, the addition of 250 g of HOASS/kg in the diets caused a negative effect on blood parameters (Brenes et al., 2008).

Alkaline phosphatase activity, phosphorus, calcium, glucose, triglyceride, total protein, high and low density lipoprotein concentrations were not significant affected by inclusion of full-fat SFS at levels of 70, 140, and 210 g/kg in the broiler diet (Salari et al., 2009). A similar trend was reported by Selvaraj et al. (2004), using the inclusion of different levels of full-fat SFS in broiler diets, stated not statistically effect on blood parameters of poultry. Furthermore, Cheve-Isarakul and Tangtaweewipat (1991) observed the inclusion of SFS in the poultry diets had no impact on serum cholesterol concentration. However, Rama Rao et al. (2004) found that the serum levels of LDL cholesterol decreased in chickens receiving high-fiber diets. While, the plasma parameters including total protein, albumin, globulin etc. were generally stable in the diets which contained SBM replaced progressively by SFM at 0%, 25%, 50% and 75% throughout the growing period and values of these parameters were within normal bench marks for poultry (Adejumo and Williams, 2006).

Nutrient Digestibility and Intestinal Enzyme Activities

The digestion coefficients of OM, CP, EE and CF were not statistically differed (P<0.05) among the dietary treatments due to the inclusion of SFM. Compared with the control group, chicks fed diets incorporated with 2.5 and 5% of SFM showed significantly (P<0.05) lower digestion coefficients of NFE, being 82.47 and 82.42%, respectively (Ali, 1999). Kalmendal et al. (2011) revealed a beneficial impact of increased dietary inclusion of SFM on ileal digestibility of CP, and EE, despite the lower energy digestibility and DM.

The addition of 250 g of HOASS/kg in the diets caused a negative effect on fat and protein digestibilities. However, the inclusion of HOASS at 150 g/kg improved some of these parameters and amino acid digestibilities. Where, the inclusion of HOASS (250 g/kg) in broiler diet reduced (P<0.001) fat digestibility by 7% and amylase and lipase activities by 22 and 19%, respectively, compared with those fed the control diet. The addition of lipase and phospholipase enzymes at the inclusion level of 1 g/kg to the broiler diets containing HOASS at 150 g/kg diet improved fat digestibility compared with the control diet during the period from 4 to 21 d of age. The inclusion of enzymes in the HOASS diet increased (P<0.001) fat digestibility and amylase and lipase activities by 5, 53, and 58%, respectively, compared with the un-supplemented HOASS diet. The greatest response in fat digestibility and digestive enzyme activities was obtained with the combination of lipase plus phospholipase (Brenes et al., 2008).

The reduction in the amylase and lipase pancreatic activities by the birds fed the HOASS diet could be due to the adsorption of lipase and bile salts to the fiber present in the seed. Schneeman (1978) reported that the availability of enzymes such as lipase could be limited by their absorption into fibers such as xylan, cellulose, wheat bran, and rice bran. Evidence of this effect has also been observed in vitro by Lairon et al. (1985) with wheat bran. Almirall et al. (1995) reported the specific lipase activity to be decreased in broiler chickens after feeding barley. In fact, Arija et al. (1998) showed a consistently greater activity of lipase in birds fed increasing concentrations of dehulled full-fat sunflower seeds in the diets, probably because of the reduction of fiber content in their seeds. The activities of digestive enzyme including protease and α-amylase in chick digesta were not significantly influenced by the different levels of full fat sunflower seed (Salari et al., 2009). But, SFM significantly increased digesta viscosity in the ileum, while addition of exogenous enzyme to diet decreased viscosity of digesta particularly in the treatments with SFM level. The digesta viscosity increased from the upper to the lower digestive tract (Horvatovic et al., 2015). This phenomenon may be attributed to the impact of the concentration of compounds such as crude fiber that produce the high viscosity through the digestion process or probably due to the increased hydration of those compounds (Boros et al., 1998).

In a subsequent study, Tavernari et al. (2009) observed that dry matter digestibility and coefficients of Ca and P were improved in broiler chickens fed diets with SFM supplemented with exogenous enzymes. On the contrary, Kocher et al. (2000) did not observe any influences of enzyme supplementation in diets contained SFM. One explanation for this discrepancy in results is that different sunflower varieties or cultivars varying in chemical composition were used in the experiments. High SFM concentrations in broiler chicken diets need to the addition of high oil or dry fat levels in order to compensate the low energy level of SFM. Indeed, oil is one of the most expensive ingredients in poultry diets (Araújo et al., 2014).

Viability Rate

Early research results reported by Afifi (1972) did not found any significant trend between different groups in mortality rate, when used SFM as a substitute for SBM on weight basis at levels of 0, 6, 12 and 18% of broiler diets during the growing period. Moreover, Valdivie et al. (1982) used SFM at 0 and 20% in broiler diet and found that viability rate did not significantly differ between groups. Chrappa et al. (1987) noted that the administration of SFM to broiler diets had no adverse effect on mortality rate.

Salih and Taha (1989) found that mortality rate was the same in all treatment groups fed on diets containing SFM at levels of 0, 100, 200 or 400 g/Kg. Also, ChevaIsarakul and Tangtaweewipat (1991) showed that there was no significant effect of SFM 0, 15, 20, 25 and 30% on mortality rate in broiler chickens. On the same context, the inclusion of SFM in the raw or autoclaved form had no effect on broiler chickens mortality rate (Dessouky 1996). Ali (1999) did not show any significant (P<0.05) impact due to the inclusion of SFM in broiler diets on the mortality rate of chicks during the fattening period.

LAYING HENS

Productive Performance

Several studies have been reported to evaluate the use of SFM at different inclusion levels in layer diets. In most of these studies, SFM was able to replace 50-100% of the SBM protein without adversely affecting the productive performance of laying hens (Rose et al., 1972; Deaton et al., 1979; Zhu et al., 1983; Michel and Sunde, 1985; Kashani and Carlson, 1988; Aguillera et al., 1989; Francesh et al., 1995). McNaughton and Deaton (1981) pointed out that SFM could be included in layer dies up to 30%, subsequently replacing 100% of the SBM without drastic effect on live body weight, egg weight or egg production. While, feed consumption increased as the dietary incorporated rate of SFM increased. Similar findings were obtained by Vieira et al. (1992) who noted that feed efficiency decreased as the SFM content was increased in layer diets. Intake of nutrients by layers fed on low energy diets with high CF contents over 8.9% (corresponding to 26% SFM) was not sufficient to maintain high rates of egg production.

Diets formulated from SFM or SFM plus groundnut meal (50:50) produced better responses in parameters of feed intake and feed efficiency as well as egg number and egg weight than diets with only groundnut meal as a main protein source (Singh and Prasad, 1979). Additional research by Uwayjan et al. (1983) observed that the inclusion of 30% SFM in layer diets did not affect feed conversion ratio, while feed consumption and laying rate were reduced, which might have been attributed to the increase in the fiber content of the diet.

Inclusion of SFM up to 15% in layer diets did not show any adversely affect feed intake, feed conversion ratio, egg production (Mirza and Sial 1992). High CP of SFM (44%) can successfully replace SBM plus fish meal in layer diets with equal quantities of lysine and metabolizable energy (Serman et al., 1997) and up to 85% of SBM in a lysine+ methionine and energy supplemented diet (El-Sherif et al., 1997).

Likewise, using a high fiber of SFM in a layer diet (36% crude protein and 24% fiber) up to 30% statistically decreased feed efficiency while egg weight, egg production, egg shell strength and mortality rate were not affected. But, intestines and gizzards were enlarged (Deaton et al., 1979). Mandlekar (1992) also reported that feed efficiency was significantly decreased with SFM diets. These results reported that layers tend to consume more feed to maintain the same rate of egg production when the diets contain high levels of SFM. This effect may be associated with increased bulk density which caused by the high CF content of the SFM (Nir et al., 1994; Jensen, 1998).

Arija et al. (1998) and Suresh et al. (2000) reported no adverse effects from including up to 50 and 120 g/kg, respectively, of sunflower seed hulls in broiler diets. SFM can be used in broiler chicken diets at levels up to 140 g/kg without adverse effects on performance or other parameters (Nassiri et al., 2012).

The above results suggest that SFM can be successfully used to replace SBM in layer diets without adversely affecting productive performance. Laying hen strains appear to tolerate higher dietary CF content up to 12% at both breeder and layer stages compared to broiler chickens. This result seems reasonable because laying hens have a more developed digestive system in terms of gut capacity. Supplementation of lysine to layer diets contained SFM does not appear to be as critical as in broiler diets because their lysine requirement is much lower. For egg weight, egg production and egg mass, methionine is the first limiting amino acid (Elliot, 1998; Alagawany et al., 2014; Alagawany and Abou Kasem 2014).

Egg Quality and Egg Composition

Inclusion of SFM up to 15% in layer diets did not show any adversely affect yolk index and Haugh unit score, but shell thickness was increased with SFM diet (Mirza and Sial, 1992). Likewise, using a high fiber of SFM in a layer diet (36% crude protein and 24% fiber) up to 30% egg shell strength was not affected (Deaton et al., 1979). In this contact, Tsuzuki et al. (2003) reported no impact of inclusion levels of SFM on Haugh unit or yolk color values. Nevertheless, Karunajeewa et al. (1989) found that birds fed diets containing SFM laid eggs with lower Haugh unit percentages than did birds fed SFM with or without addition of sunflower oil.

No significant differences ($P>0.05$) were observed among treatment groups in the productive performance and egg quality criteria (egg weight, shell strength, egg specific gravity, shell thickness, shell color, shell percentage, yolk percentage, albumen percentage, yolk color and Haugh units) as well as the levels of saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids in yolks of laying hens, when layer fed diets contained 0, 8.26, 16.52, and 24.84% SFM replacing SBM (Shi et al., 2012). However, Results from this study reported that the percentage of C17:0 and levels of egg yolk cholesterol of layers in the experimental groups were lower than those of layers in the control group ($P < 0.05$).

CONCLUSION

Based on findings of the researches and studies discussed in this review it can be reported that SFM can be a highly acceptable feed ingredient for poultry. SFM may provide a rich source of crude protein (32% at least), crude fiber, amino acids, energy, minerals, etc. in poultry rations. This literature review highlights that the chemical composition, amino acid profile, anti-nutritional factors and nutritive value of SFM and its use as a protein source with SBM in broiler and layer diets. Also, this review focused on the beneficial and adverse effects of SFM on performance parameters, feed utilization, nutrient absorption, carcass and egg quality traits as well as nutrient digestibility, digestive enzyme activities and mortality rate. Current recommended maximum dietary levels for SFM are 15-20% for broilers and layers and but the higher levels of SFM can be used successfully with appropriate diet formulation with adjustments for energy and amino acids particularly lysine and methionine. When formulating diets with SFM, digestible amino acids should be used especially for lysine, threonine and sulfur amino acids. Using high levels of SFM in poultry diets will change the amino acid profile, crude fiber and energy contents as well as the amounts of feedstuffs/ingredients being used.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

AUTHOR'S CONTRIBUTION

Mahmoud Alagawany, Mayada Ragab Farag and Mohamed Ezzat Abd El-Hack collected literatures and wrote the manuscript. Kuldeep Dhama performed the final check.

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