The performance and characteristics of carcass and breast meat of broiler chickens fed diets containing flaxseed meal

Tarek M. Shafey,1 Ahmed H. Mahmoud,2 El-Sayed Hussein,3 Gamal Suliman1
1Department of Animal Production, King Saud University, Riyadh, Saudi Arabia
2Department of Zoology, King Saud University, Riyadh, Saudi Arabia

Abstract

The effects of flaxseed meal (FSM) feeding on the performance (weight gain, feed intake and feed conversion ratio), carcass characteristics and pectoral muscles fillets [major (PMJ) and minor (PMN)] quality [shear force, pH and cooking water loss percentage (CWLP)] and colour [redness (a*), lightness (L*) and yellowness (b*)] were evaluated in a factorial design experiment with five graded levels of FSM (0, 20, 40, 60 and 80 g) and sex of broiler chickens from 21 to 39 days (d) of age. The addition of FSM to the diet did not affect the performance and carcass characteristics, but significantly (P<0.05) increased CWLP and reduced pH of the PMJ (80>20=0) and PMN (80>40>20=0 g FSM/kg) and PMJ and PMN (P<0.01) increased a* value of the PMJ (80=60>40 g FSM/kg). The male birds had significantly (P<0.01) higher performance, L* value of the PMN and lower a* value of the PMJ than females. The breast weight of males fed 20 g FSM/kg was significantly (P<0.05) higher than that of females. However, higher dietary levels of FSM/kg increased breast weight of females when compared with those of males. It was concluded that the addition of up to 80 g FSM/kg to the diet during 21 to 39 d did not affect the performance and carcass characteristics of broiler chickens, and that of 80 g FSM/kg increased CWLP and reduced pH of PMs. Sex of birds influenced the performance and characteristics of PMs.

Introduction

There are many factors that made the poultry industry become very successful in dominating the meat market. These factors include developing a wide range of chicken products that meet consumer demands for high quality products with emphasis on appearance, texture and juiciness. Broilers are the main type of chickens produced. The most common product of poultry slaughterhouses is the whole bird. However, during recent years there has been a shift from fresh, whole-bird sales to sales of cut-up bird parts and convenience products because these products have higher value (FAO, 2010). Chicken products taken from the breast are considered white meat. Breast meat makes up approximately 30% of the edible carcass meat and 50% of edible protein (Summers et al., 1988). Cutting up and further processing chicken adds value to the product and increase convenience to consumers. According to Butterworth (2010), whole bird sales represent a small percentage of the poultry meat market (only about between 10 and 30% depending on the country) and the most of chicken meat is sold as fillets, breast portions and cuts. The criteria for breast meat quality include colour, pH, water holding capacity, tenderness, and sensory acceptability (Van Laack et al., 2000; Barbut, 2009). The quality of broiler meat is becoming a major issue for the poultry industry.

There is very little information available in the literature on the relationship between dietary composition and meat quality of broiler chickens. Kristensen et al. (2002) found a relationship between diet and texture of meat. Also, Cisneros et al. (1996) and Smith et al. (2002) reported a relationship between feed and the colour of meat. The use of organic matter in free range chickens has been investigated by different authors (Castellini et al., 2002a, 2002b; Rizzi et al., 2007; Therkildsen et al., 2013). The main differences in meat quality between free-range and conventionally-reared chickens are related to colour, flavour, and texture. Also, antioxidants have been used to maximise growth and yield and to maintain or improve breast meat functional properties (Gladine et al., 2007; Jang et al., 2008). However, breast meat yield was little affected by diet composition (Summers et al., 1988).

Flaxseed meal (FSM) is a by-product of the flaxseed (FS) oil extraction industry. It has a unique nutrient profile with high level of α-linolenic acid (ALA; Cunnane et al., 1989). Flaxseed meal could be of great interest to the poultry industry for enriching poultry products with high ALA content. The addition of FS to the diets of broiler and laying hens enriched meat and eggs with ALA, consequently improving the health status of poultry products (Ajuyah et al., 1991; Aymond and Van Elswyk, 1995; Anjum et al., 2013). A number of studies suggested that FSM can be included in the diets of broiler chickens (Mridula et al., 2011; Anjum et al., 2013). The addition of 50, 100 or 150 g FSM/kg to the diet of broiler chickens reduced body weight gain (BWG) and increased feed conversion ratio (FCR) without altering feed intake at 42 days of age (Mridula et al., 2011). However, Anjum et al. (2013) found that dietary level of 50, 100 or 150 g FSM/kg of broiler chickens reduced BWG, feed intake and increased FCR of chickens at 42 days of age. The objectives of this study were to further evaluate the influence of FSM levels in the finishing diet on the performance, carcass characteristics and quality of breast meat fillets of sexed broiler chickens.

Materials and methods

A total of 384, day old Ross broiler chickens were used in this experiment. The chicks were feather sexed, individually weighed and randomly sorted into 24 replicates of 8 birds each per sex. They were housed in electrically heated battery cages. Lighting was incandescent and continuous throughout the experimental period. Birds were fed a commercial starter diet (22% protein and 3100 ME kcal/kg) to 20
days of age. At 21 days of age, 125 birds of comparable weight of each sex were selected and randomly distributed into 25 replicates of five birds each and were randomly assigned to either one of the five finisher diets to 39 days of age. The diets were formulated to be iso-nitrogenous and iso-caloric and contained 5 levels of FSM (0, 20, 40, 60 and 80 g FSM/kg; Table 1). Feed and water were provided ad libitum. The body weight and feed consumption were recorded weekly. At the end of the experiment six birds per treatment per sex were randomly selected and processed at King Saud University to determine processing yields. Birds were weighed, killed by cervical dislocation after 9 h of feed and water deprivation, bled, scalded, defeathered in a rotary picker and eviscerated and abdominal fat were removed. Data from carcass weight, abdominal fat and cut parts (back, breast, wings, thighs and drumsticks) and edible offal (liver plus heart plus gizzard) were recorded. The pectoral muscles [(PMs), pectoralis major (PMJ) and pectoralis minor (PMN)] of the left side of the breast were dissected, weighed and the hydro-toralis minor (PMN) of the left side of the breast were dissected, weighed and the hydrogen ion concentration (pH) and colour quality were determined. The pH was measured using a microprocessor pH-meter (Model PH 211; Hanna Instruments, Woosocket, RI, USA). The pH meter was placed in incisions made with the tip of a knife in the cranial left side of the muscle. Three readings were taken and the mean value was calculated for PMJ and PMN for each carcass. The colour values of CIELAB Color System (1976), L* (lightness), a* (redness) and b* (yellowness), were determined using a Chroma meter (Konica Minolta CR-400; Konica Minolta, Tokyo, Japan). Readings were made in three different areas of the internal face of the cranial position of the PMs. The averages of the three values of the colour components were used in the statistical analyses. Immediately following the measurement of pH and colour quality, the PMs were frozen, and stored at -20°C prior to the determination of cooking water loss (CWL) and shear force (SF). The frozen PMs were thawed at 4°C for 24 h then placed in a commercial indoor counter top grill (Kalorik GR 28215; Kalorik, Miami Gardens, FL, USA) and cooked to an internal temperature of 70°C. The temperature was monitored by inserting a thermocouple thermometer probe (Ecocam Temp JKT; Eutech Instruments, Singapore) into the geometric center of the muscle. The muscles were weighed in semi-analytical scales (Mettler M P1210; Mettler-Toledo Ltd., Leicester, UK), before and after cooking to determine CWL percentage (CWL%) as the difference between the initial and final weights *100/initial weight. The cooked samples used for determining CWL were used to evaluate SF or tenderness evaluation according to Wheeler et al. (2005). They were cooled to room temperature (22°C), then five 2.0×1.0×1.0 cm pieces, with the longest length lengthwise to the muscle fibers, according to the methodology of Froning and Uijttenboogaart (1988). Shear force was determined as the maximum force (kg) perpendicular to the fibres using Texture Analyzer (TA-HD-Stable Micro Systems; Stable Micro Systems Ltd., Godalming, UK) equipped with a Warner-Bratzler attachment. The crosshead speed was set at 120 mm/min.

Measurements were made of BWG, feed intake, and FCR during the starter, finisher and entire experimental periods (1 to 20, 21 to 39 and 1 to 39 days of age, respectively), carcass composition and sensory analysis (pH, CWL, colour quality, CWLP and SF) of PMs at 39 days of age. Data collected were subjected to analysis of variance using GLM procedures (SAS, 2002). Where significant variance ratios were detected, differences between treatment means were tested using the least significant difference procedures.

### Results

The effects of feeding dietary level of FSM from 21 to 39 days of age on the performance and carcass characteristics of broiler chickens are shown in Tables 2 and 3, respectively. Dietary level of FSM did not affect BWG, feed intake, FCR, carcass weight, abdominal fat weight, and carcass composition of thigh, drumstick, wings, breast and back of chickens. Sex of bird significantly (P<0.01) influenced BWG, feed intake and FCR during the experiment (starter, finisher and entire periods, 1-

| Table 1. Composition of the experimental diets. |
|-------------------------------|---|---|---|---|---|
|                               | 0 | 20 | 40 | 60 | 80 |
| Ingredients, g/kg             |   |    |    |    |    |
| Wheat                         | 468.0 | 467.5 | 466.9 | 466.4 | 465.9 |
| Corn                          | 230.7 | 208.3 | 185.9 | 163.5 | 141.1 |
| Soybean meal                  | 231.0 | 227.3 | 223.6 | 219.9 | 216.2 |
| Corn oil                      | 14.8 | 14.5 | 14.5 | 14.5 | 14.5 |
| FS oil                        | 0.0 | 7.1 | 13.9 | 20.7 | 27.4 |
| FSM                           | 0.0 | 20.0 | 40.0 | 60.0 | 80.0 |
| Sand                          | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Limestone                     | 15.7 | 15.6 | 15.5 | 15.4 | 15.2 |
| Dicalciumphosphate            | 14.8 | 14.8 | 14.8 | 14.8 | 14.8 |
| Sodium chloride               | 2.3 | 2.3 | 2.3 | 2.3 | 2.2 |
| Sodium bicarbonate            | 5.8 | 5.8 | 5.8 | 5.7 | 5.7 |
| Magnesium oxide               | 1.5 | 1.5 | 1.4 | 1.4 | 1.3 |
| Premixc                       | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| DL-methionine                 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| L-lysine                      | 0.6 | 0.6 | 0.7 | 0.7 | 0.8 |

Analysis

| ME, kcal/kg               | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| CP (%)×6.25, g/kg         | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 |
| Lysine, g/kg              | 10.50 | 10.50 | 10.50 | 10.50 | 10.50 |
| Methionine+cysteine, g/kg | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 |
| Total phosphorus, g/kg    | 6.72 | 6.73 | 6.75 | 6.76 | 6.77 |
| Sodium, g/kg              | 2.90 | 2.90 | 2.90 | 2.90 | 2.90 |
| Potassium, g/kg           | 7.26 | 7.26 | 7.26 | 7.26 | 7.26 |
| Calcium, g/kg             | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Magnesium, g/kg           | 2.97 | 2.97 | 2.97 | 2.97 | 2.97 |
| Chloride, g/kg            | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 |
| Available phosphorus*, g/kg| 4.50 | 4.50 | 4.50 | 4.50 | 4.50 |

FSM, flaxseed meal; FS, flaxseed; ME, metabolisable energy; CP, crude protein. The composition of vitamins and minerals in the premix (per ton of diet): vitamin A, 6,000,000 IU; vitamin D, 1,500,000 IU; vitamin E, 20,000 IU; vitamin K, 1000 mg; vitamin B1, 1 mg; vitamin B2, 3000 mg; vitamin B6, 2000 mg; vitamin B12, 10 mg; niacin, 20,000 mg; folic acid, 500 mg; pantothenic acid, 5000 g; biotin, 50 mg; antox- idant, 60,000 mg; cobalt, 100 ppm; copper, 500 ppm; iodine, 500 ppm; iron, 20,000 ppm; manganese, 40,000 ppm; selenium, 100 ppm; zinc, 30,000 ppm. Available phosphorus was calculated on the basis of 30% availability of phosphorus in plant products.
20, 21-39 and 1-39 days of age, respectively), and (P<0.05) carcass weight of birds without altering carcass characteristics or abdominal fat at the end of the experiment. The male birds had a significant (P<0.01) heavier BWG and a higher feed consumption than those of the females birds during the experiment. However, FCR of the male birds was significantly (P<0.01) lower during the starter period and higher during the finisher and entire periods of the experiment than those of the female birds. There was a significant (P<0.05) interaction between dietary level of FSM and sex of birds on breast weight. The weight of breast of male birds fed 20 g FSM/kg was significantly (P<0.05) higher than that of female birds. However, dietary level of 40, 60 and 80 g FSM/kg increased the weight of breast in female birds when compared with those of male birds.

The effects of dietary level of FSM on the characteristics (pH, CWLP, tenderness, and colour) of the PM fillets (PMJ and PMN) of broiler chickens are shown in Tables 4 to 6, respectively. In PM fillets, the addition of the FSM to the diet of broiler chickens significantly (P<0.05) increased CWLP (80>20=0, and

Table 2. Performance of sexed broiler chickens fed diets with graded levels of flaxseed meal from 21 to 39 days of age.

| Treatment | 1-20 | 21-39 | 1-39 |
|-----------|------|-------|------|
| Age, day  | BWG, g | Feed intake, g | FCR | BWG, g | Feed intake, g | FCR | BWG, g | Feed intake, g | FCR |
| FSM, g/kg |       |        |      |       |        |      |       |        |      |
| 0         | 653.2 | 868.9  | 1.33 | 1395.3 | 2486.7 | 1.78 | 2048.5 | 3355.6 | 1.64 |
| 20        | 651.9 | 867.6  | 1.33 | 1352.6 | 2402.1 | 1.78 | 2004.5 | 3269.7 | 1.63 |
| 40        | 651.3 | 875.6  | 1.35 | 1342.4 | 2380.1 | 1.77 | 1994.1 | 3256.0 | 1.63 |
| 60        | 653.9 | 970.5  | 1.33 | 1372.5 | 2423.3 | 1.76 | 2029.1 | 3293.8 | 1.62 |
| 80        | 659.1 | 878.6  | 1.33 | 1345.2 | 2381.5 | 1.77 | 2004.3 | 3260.1 | 1.63 |
| SEM       | 9.2   | 9.4    | 0.02 | 23.1    | 44.0   | 0.03 | 26.7    | 44.2    | 0.02 |
| Sex       |       |        |      |        |        |      |        |        |      |
| Male      | 686.7 | 890.1  | 1.30 | 1408.5 | 2581.6 | 1.84 | 2095.2 | 3471.7 | 1.65 |
| Female    | 621.2** | 854.5** | 1.38** | 1315.8** | 2247.5** | 1.71** | 1936.9** | 3102.4** | 1.60** |
| SEM       | 5.8   | 6.0    | 0.01 | 14.6    | 26.6   | 0.02 | 16.9    | 27.9    | 0.01 |
| Source of variation |       |        |      |        |        |      |        |        |      |
| FSM       | ns    | ns     | ns   | ns      | ns     | ns   | ns      | ns     | ns |
| Sex       | **    | **     | **   | **      | **     | **   | **      | **     | ** |
| FSM×sex   | ns    | ns     | ns   | ns      | ns     | ns   | ns      | ns     | ns |

BWG, body weight gain; FCR, feed conversion ratio [=feed intake (g)/weight gain (g)]; FSM, flaxseed meal. Birds were fed a commercial starter diet (22% protein and 3100 metabolisable energy, kcal/kg). **Significantly different (P<0.01); ns, not significant (P>0.05).

Table 3. Carcass composition of sexed broiler chickens fed diets with graded levels of flaxseed meal from 21 to 39 days of age.

| Treatment | Live weight, g | Carcass weight, g | Live body weight, kg | Eviscerated carcass, kg |
|-----------|----------------|-------------------|----------------------|------------------------|
| FSM, g/kg | Abdominal fat | Neck | Edible offal | Eviscerated carcass | Thighs | Drums | Wings | Breast | Back |
| 0         | 2140.8         | 1557.6 | 6.3 | 24.1 | 41.5 | 726.7 | 136.1 | 106.7 | 40.2 | 320.7 | 97.0 |
| 20        | 2035.6         | 1453.6 | 8.1 | 24.5 | 43.0 | 713.7 | 126.1 | 103.7 | 41.1 | 301.0 | 105.8 |
| 40        | 2089.3         | 1501.7 | 8.1 | 23.7 | 40.3 | 717.5 | 129.1 | 103.3 | 40.1 | 313.8 | 106.3 |
| 60        | 1967.7         | 1399.0 | 7.1 | 27.0 | 41.7 | 710.1 | 121.5 | 105.2 | 44.2 | 318.5 | 97.0 |
| 80        | 2010.6         | 1438.9 | 7.7 | 22.6 | 41.3 | 714.9 | 122.6 | 109.3 | 41.4 | 321.0 | 102.7 |
| SEM       | 84.8           | 67.3   | 0.75 | 1.8 | 1.1 | 6.24 | 6.1 | 2.6 | 1.7 | 6.9 | 3.9 |
| Sex       |                |        |      |      |      |      |      |      |      |      |      |
| Male      | 2147.6         | 1530.8 | 7.2 | 24.7 | 41.1 | 722.2 | 126.2 | 107.7 | 41.0 | 315.6 | 100.9 |
| Female    | 1945.1*        | 1406.3* | 7.7 | 24.0 | 42.1 | 711.1 | 127.9 | 103.6 | 41.9 | 319.4 | 103.1 |
| SEM       | 53.6           | 42.5   | 0.5 | 1.1 | 0.7 | 3.9 | 3.9 | 1.7 | 1.1 | 4.4 | 2.5 |
| Source of variation |        |        |      |      |      |      |      |      |      |      |      |
| FSM       | ns             | ns     | ns   | ns   | ns   | ns   | ns   | ns   | ns   | ns   | ns |
| Sex       | *              | *      | ns   | ns   | ns   | ns   | ns   | ns   | ns   | ns   | ns |
| FSM×sex   | ns             | ns     | ns   | ns   | ns   | ns   | ns   | ns   | ns   | *    | ns |

FSM, flaxseed meal. *Edible offal, liver weight+heart weight+gizzard weight; **Significantly different (P<0.01); ns, not significant (P>0.05).
Discussion

Results from the performance of chickens indicated that the addition of FSM to the diet of broiler chickens from 21 to 39 days of age did not influence BWG, feed intake and FCR. These results are in agreement with previous reports which showed that the addition of 80 g FSM/kg to the diets of broiler chickens did not adversely affect weight gain and FCR (Leeson and Summers, 1997; Ajuyah, 1991). Also, Alzueta et al. (2003) found that diets with 80 or 160 g FS/kg did not influence feed consumption of broilers from 1 to 23 days of age. However, these results were partly in agreement with Mridula et al. (2011) who reported that the addition of 50, 100 or 150 g FSM/kg to the diet did not influence feed consumption, but dietary level of 50 and 150 g FSM/kg significantly reduced weight gain and feed efficiency, protein efficiency ratio and increased energy efficiency ratio of broiler chickens during 4 to 6 weeks of age. The poor growth performance of chickens fed the 50 and 150 g FSM/kg diets was related to the reduction in the digestibility of feed and protein. However, the effect of 100 g FSM/kg diet was intermediate. Also, Najib and Al-Yousef (2011) found that increasing dietary level of FS above 50 g/kg in broiler diets increased feed intake, FCR and decreased body weight. It has been suggested that including FS up to 120-150 g/kg in broilers diets could improve the omega-3 fatty acid content of the meat without impair-

Table 4. Quality and colour characteristics of pectoralis major fillets of sexed broiler chickens fed diets with graded levels of flaxseed meal from 21 to 39 days of age.

| Treatment | CWLP | SF | pH | Colour quality |
|-----------|------|----|----|----------------|
|           | L*   | a* | b* |
| FSM, g/kg |      |    |    |                |
| 0         | 26.24 | 2.70 | 6.19 | 45.30, 3.22   |
| 20        | 26.95 | 3.27 | 6.16 | 45.42, 3.58   |
| 40        | 27.92 | 3.96 | 6.05 | 46.81, 4.22   |
| 60        | 38.32 | 3.33 | 6.09 | 45.87, 4.35   |
| 80        | 30.41 | 3.46 | 5.59 | 45.27, 4.06   |
| SEM       | 1.08  | 0.30 | 0.06 | 0.60, 0.28   |
| Sex       |      |    |    |                |
| Male      | 28.54 | 3.01 | 5.94 | 46.08, 3.75   |
| Female    | 27.39 | 3.28 | 6.08 | 45.36, 3.42   |
| SEM       | 0.69  | 0.19 | 0.04 | 0.38, 0.17   |
| Source of variation |      |    |    |                |
| FSM       | *    | ns  | ** | ns              |
| Sex       | ns   | ns  | *  | ns              |
| FSM×sex   | ns   | ns  | ns | ns              |
| CWLP cooking loss percentage; SF, shear force; L*, lightness; a*, redness; b*, yellowness; FSM, flaxseed meal. *Means within column followed by different superscripts are significantly different (P<0.05). **Significant (P<0.01); ns, not significant (P>0.05).

Table 5. Quality and colour characteristics of pectoralis minor fillets of sexed broiler chickens fed diets with graded levels of flaxseed meal from 21 to 39 days of age.

| Treatment | CWLP | SF | pH | Colour quality |
|-----------|------|----|----|----------------|
|           | L*   | a* | b* |
| FSM, g/kg |      |    |    |                |
| 0         | 25.86 | 2.03 | 5.83 | 47.91, 3.71   |
| 20        | 27.30 | 1.93 | 5.90 | 48.54, 3.28   |
| 40        | 25.62 | 2.07 | 5.69 | 47.82, 3.18   |
| 60        | 27.26 | 2.14 | 5.73 | 48.12, 4.10   |
| 80        | 31.69 | 1.88 | 5.37 | 48.04, 3.72   |
| SEM       | 1.29  | 0.17 | 0.08 | 0.76, 0.27   |
| Sex       |      |    |    |                |
| Male      | 27.81 | 2.15 | 5.68 | 49.17, 3.33   |
| Female    | 27.61 | 1.87*| 5.69 | 47.04*3.84    |
| SEM       | 0.82  | 0.11 | 0.05 | 0.48, 0.17   |
| Source of variation |      |    |    |                |
| FSM       | *    | ns  | ** | ns              |
| Sex       | ns   | *   | ns  | *              |
| FSM×sex   | ns   | ns  | ns  | ns              |
| CWLP cooking loss percentage; SF, shear force; L*, lightness; a*, redness; b*, yellowness; FSM, flaxseed meal. *Means within column followed by different superscripts are significantly different (P<0.05). **Significant (P<0.01); ns, not significant (P>0.05).
ing performance too much (Pekel et al., 2009; Najib and Al-Yousef, 2011). Factors that may influence the performance of chickens on FS include processing of FS and age of the bird. Leeson and Summers (1997) suggested that grinding of FS before mixing could increase the digestion by chickens. Also, Shen and Chavez (2003) found that pelleting improved feed intake and growth of broilers compared with birds fed whole, ground, or autoclaved FS at 100g/kg diet. Gonzalez-Esquerra and Leeson (2000) reported that roosters had higher AMEn values than those of broiler chickens (3560-3654 vs 2055-2118 kcal/kg for roaster vs broiler birds, respectively) when diets containing 100 g FSM/kg diet were fed. Differences in the preparation of FS or FSM and age of birds among various studies may have contributed to differences in the performance of chickens.

The 80 g FSM/kg diet reduced pH value and increased CWLP in the PM fillets (PMJ and PMN) without altering the tenderness of meat. Additionally, the negative correlation between FSM and pH and the positive correlation between FSM and CWLP would suggest that dietary FSM influenced the pH and CWLP of PM fillets. Aaslyng et al. (2003) reported a significant effect of pH on cooking loss. Poultry meat with low pH has been associated with low water-holding capacity, which results in increased cook-loss and drip loss (Froning et al., 1978; Barbut, 1993; Northcutt et al., 1994). It seems that the increase in CWLP may be attributed to the decline in pH value of PM fillets of chickens fed the high dietary levels of FSM. These results may suggest that the lower pH value of PM from broiler chickens fed high FSM diets could influence storage and sensorial quality because of the positive effects on microbial development and juiciness. Low pH value of meat has been reported to increase shelf-life (Allen et al., 1997). These results are in agreement with Lopez-Ferrer et al. (2001) and Polawska et al. (2011) who reported that tenderness of PM was not influenced by the addition of FSM to the diet of chickens and emus, respectively. However, Mridula et al. (2011) reported that the addition of FSM for up to 150 g/kg diet of broiler chickens did not influence appearance, colour, tenderness or flavor of breast meat. Whilst the effect of dietary FSM on pH value of PM is in contrast with Polawska et al. (2012) who reported that pH of muscles from emu fed diets with high FS

### Table 6. Pearson correlation coefficients and probabilities of quality and colour characteristics of pectoralis major and minor muscles of broiler chickens fed flaxseed meal diets.

|          | PMJ          |          |          |          |          |          |
|----------|--------------|----------|----------|----------|----------|----------|
|          | FSM | CWLP | SF | pH | L* | a* | b* |
| FSM      | 1.000 | | | | | | |
| CWLP     | 0.38837 | 1.000 | | | | | |
| SF       | 0.19407 | 0.21211 | 1.000 | | | | |
| pH       | -0.35324 | -0.22871 | -0.20847 | 1.000 | | | |
| L*       | 0.02606 | 0.14131 | -0.18250 | -0.05937 | 1.000 | | |
| a*       | 0.0152 | 0.6787 | 0.4969 | 0.0340 | 0.16901 | 1.000 | |
| b*       | -0.19882 | -0.03937 | -0.10771 | -0.10482 | 0.0152 | 0.6787 | 1.000 | |
|          | PMN          |          |          |          |          |          |
|          | FSM | CWLP | SF | pH | L* | a* | b* |
| FSM      | 1.000 | | | | | | |
| CWLP     | 0.37177 | 1.000 | | | | | |
| SF       | -0.02472 | 0.23299 | 1.000 | | | | |
| pH       | -0.28415 | -0.20228 | -0.26453 | 1.000 | | | |
| L*       | -0.00801 | 0.19815 | 0.18495 | 0.13105 | 1.000 | | |
| a*       | 0.09311 | 0.16876 | 0.06449 | -0.09372 | -0.35146 | 1.000 | |
| b*       | -0.07745 | -0.03879 | 0.04393 | -0.05572 | 0.35793 | -0.02027 | 1.000 | |

PMJ, pectoralis major muscle; PMN, pectoralis minor muscle; FSM, flaxseed meal; CWLP, cooking weight loss percentage; SF, shear force; L*, lightness; a*, redness; b*, yellowness. Sixty pieces of pectoralis major and minor were considered.
were higher than those of the control.

The colour of meat is considered to be the most important quality attributes of meat product for consumer acceptance. Higher values of L*, a* and b* indicated lighter, redder and yellower meat, respectively. Dietary FSM influenced the colour quality of the PMJ fillets, without altering the colour quality of PM. The FSM diet was associated with an increase in the redness and a decline in the pH of the PMJ fillets. These changes would contribute to the acceptability of PMJ fillets. The negative correlation between L* and a* values in the fillets of PMJ and PMN was in agreement with Bihan-Duval et al. (1999) who reported a negative correlation between L* and a* values in the PMJ when they measured meat quality parameters 24 h postmortem. The negative correlation between pH and a* in the PMJ fillets found in this study is in agreement with Allen et al. (1998) and Qiao et al. (2001) who reported a significant positive correlation between ultimate pH and a* values. However, the researchers measured pH and colour traits 24 h after slaughter in groups of breast fillets with different colour intensity. The positive correlation between L* and b* found in the PMN fillets and not in the PMJ would suggest that the fillets of PMN tended to be paler when compared with PMJ. The correlation between lightness and yellowness and the relatively higher values of lightness and yellowness of PMN when compared with those of PMJ could be attributed to a lower pigment content of the meat. It is well recognised that haem pigments concentration in muscles largely influences the appearance of poultry meat (Fletcher, 2002). The negative correlation between redness and lightness in the PMJ and PMN is in agreement with Sirri et al. (2009) who found that positive correlations found between total haeme pigments concentration and meat redness and the negative correlation between total haeme pigments concentration and lightness.

Results from this study suggest that sex of birds influenced characteristics of PMJ and PMN differently. Female birds had a higher pH value in the PMJ fillets, and tender, lighter and redder PMN fillets than those of male birds. Sex of birds did not influence CWLP and yellowness in PMJ and PMN fillets. These findings are not in agreement with Souza et al. (2011) who reported that meat samples of male broilers of Cobb strain showed higher redness and lower yellowness values as compared to females. In contrast, Ngoka et al. (1982) reported no effect of sex on pH, water holding capacity, cook loss, or colour quality of turkey breast muscle. Also, Northcutt et al. (2001) reported no difference in breast fillet shear values between sexes of broilers at 51 days of age. Froning et al. (1978) studied colour attributes of the PMJ of turkeys as affected by age, gender, and genetic strain. There are many factors that influence the characteristics and quality of poultry meat. These factors include growth rate, size of bird, genetic background and age of bird. Differences in these studies may be attributed to any of these factors.

The correlations between dietary FSM and characteristics of PM and correlations among characteristics of PM of sexed chickens identify the advantage of sexing the birds. Results indicate that sex of birds did not only influence the relationship between dietary FSM and PM characteristics but also the correlations among characteristics of PM. These correlations identify the importance of dietary FSM as a factor in the characteristics of PM of sexed chickens. In the male birds, there was a positive correlation between dietary FSM and CWLP, and a negative correlation between CWLP and pH in the PMJ fillets; and positive correlations between dietary FSM and CWLP, and L* and b*, and negative correlation between CWLP and pH in the PMN fillets. In female birds, there were significant positive correlations between dietary FSM and a*, CWLP and SF and negative correlation between pH and a* in the PMJ fillets.

Conclusions

It is concluded that the addition of up to 80 g FSM/kg to the diet of broiler chickens from 21 to 39 days of age did not influence BWG, feed intake, FCR and tenderness of PMJ fillets (PMJ and PMN), but reduced pH value and increased CLNP. The negative and positive correlations between dietary FSM and characteristics of PM fillets of pH and CWLP, respectively, improved the characteristics. In addition, dietary FSM increased the redness of the PMJ fillets, without altering the colour quality of PMN fillets. Sex of birds influenced the characteristics of PMJ fillets without influencing the relationship between dietary FSM and PM characteristics. Female birds had a higher pH value in the PMJ fillets, and tender, lighter and redder PMN fillets than those of male birds. The lower pH value of PM from broiler chickens fed high FSM diets could influence storage and sensorial quality. However, more research is needed in this area. The association of dietary FSM with the increase in redness and the decline in pH of the PMJ fillets would contribute to the acceptability of PMJ fillets.

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