Impact of feeding chromium supplemented flaxseed based diet on fatty acid profile, oxidative stability and other functional properties of broiler chicken meat

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Abstract A total of 240 broiler chicken of same hatch with uniform weight were used in a biological experiment with completely randomized design to investigate the effects of incorporating organic chromium (Cr) in flaxseed meal based diet on the fatty acid profile, oxidative stability and functional properties of broiler chicken meat. Five diets were formulated as per the recommendations of BIS (Nutrient requirements for poultry 13: 9863, Bureau of Indian Standards, New Delhi, 1992) in which flaxseed meal was used to replace 10% of soyabean in basal diet and four levels of Cr (0.0, 0.5, 1.0 and 1.5 mg/kg diet) as Cr-picolinate were used. The results revealed that flaxseed feeding significantly increased the percentage of unsaturated fatty acids, including MUFA, PUFA, ω -3, ω -6 fatty acids and ω -3: ω -6 and PUFA:SFA ratios, whereas, significant decline was seen in saturated fatty acids and no effect of Cr was observed on the fatty acid profile of broiler chicken. Flaxseed feeding significantly reduced the

cholesterol and fat percentage of meat, whereas, significant progressive reduction was observed with increasing Cr levels. The combination of 10% flaxseed with 1.0 mg Cr/kg diet increased the final pH of broiler meat. The addition of flaxseed significantly reduced water holding capacity, extract release volume and antioxidant potential of broiler meat, whereas, increasing Cr supplementation progressively increased them. Flaxseed feeding significantly increased the drip loss and lipid peroxidation of broiler meat, whereas, Cr supplementation decreased them. It was concluded that inclusion of 10% flaxseed and 1.5 mg Cr/kg diet results in desirable fatty acid profile, oxidative stability and functional properties of broiler chicken meat.

Keywords Chromium · Flaxseed · Broiler · Meat quality · Oxidative stability

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Introduction

Various medical reports during last decade has shown significant rise of cardiovascular diseases in India due to changing food habits of people and the curative measures of which are not economically viable for general masses. World-wide health professionals are emphasizing the need to increase intake of ω -3 polyunsaturated fatty acids (PUFA), while reducing trans-fatty acids, saturated fatty acids and cholesterol for reducing the incidence or prevention of coronary heart disease (Simopoulos 2002; Vos and Cunnane 2003). Since, there exists a close relationship between fatty acid profile of the poultry diet and that of deposited lipids in the tissues, efforts are taken to improve carcass composition with the inclusion of higher levels of flaxseed in the feed of broiler chicken because it is one of the most concentrated sources of PUFA, with moderate levels of monounsaturated fatty acids (MUFA) and low levels of saturated fatty acids (SFA). On the other hand, in recent years there has been considerable research interest in utilization of Cr in animal feed because of its beneficial effects on meat quality as a result of its potentiation of insulin sensitivity, like fat reduction and enhancement of protein content (Debski et al. 2004). Cr supplementation offers a non-nitrogenous way to improve carcass leanness in broilers and in turn reduces carcass fat.

Though, flaxseed feeding improves the fatty acid profile as result of increased unsaturation of broiler meat but compromises its oxidative stability by making it more prone to oxidative rancidity leading to the production of a secondary metabolite, malonaldehyde (MDA), an indicator of rancidity along with free fatty acids and other peroxides. However, in addition to its role in glucose and lipid metabolism, Cr also functions as an antioxidant which provides protection against lipid peroxidation (Anderson 2000). Thus, in this study, keeping in view the health related issues and the role played by flaxseed and Cr in alteration of fatty acid profile of broiler meat, its oxidative stability and other physico-chemical properties, the broiler chicken were fed diets containing flaxseed and Cr to assess their impact on the broiler meat quality.

Materials and methods

Animals, experimental diets and design

Following a completely randomized design (CRD), day old straight run 240 broiler chicken of uniform body weight were distributed at random into 30 replicates with 8 chicks in each and housed in specially designed battery brooder cages for 6 weeks. Five dietary treatments (iso-caloric and

iso-nitrogenous) were formulated as per recommendation of BIS (1992) by using 10% flaxseed meal to replace soyabean in the basal diet and four levels of Cr (0, 0.5, 1.0 and 1.5 mg/kg diet) as Cr-picolinate. Each dietary treatment was allocated six replicates. The feeding and watering of birds was done ad libitum. From each replicate two birds were slaughtered for collection of meat samples.

Fatty acid profile of meat

The method of O'Fallon et al. (2007) was followed for preparation of fatty acid methyl esters (FAME) of thigh and breast meat samples separately. Fatty acid standard, containing 37 different fatty acid methyl esters was used and 0.5 μ l of standard was injected into GC to get the standard peaks. The fatty acid composition of the FAME was determined by capillary GC on a CP-6173, 60 mm $\times$ 0.25 mm $\times$ 0.20 mm capillary column (Varian) installed on a Thermo Scientific Ceres 800 plus gas chromatograph fitted with Automatic sampler, integrator and flame ionization detector. The initial oven temperature was set at 120 $^{\circ}$ C, held for 5 min, subsequently increased to 240 $^{\circ}$ C at a rate of 2 $^{\circ}$ C min $^{-1}$, and then held for 60 min. Nitrogen was used as the carrier gas at a flow rate of 1 ml/min. Both the injector and the detector were set at 260 $^{\circ}$ C. The split ratio was 30:1. Fatty acids were identified by comparing their retention times with the fatty acid methyl standards and were expressed as percentage of total fatty acids.

Physico-chemical properties of meat

Fat (percentage, dry basis) of breast and thigh meat was determined by using the Soxhlet extraction apparatus as described by AOAC (1995). The cholesterol estimation of meat was done separately for breast and thigh by using the method of Wybenga and Pileggi (1970). The pH of both fresh as well as refrigerated storage meat was measured as per the method devised by Trout et al. (1992). For the estimation of purge loss/drip loss, the frozen meat samples from thigh as well as breast were taken, weighed and recorded as the initial weight (W1). The weighed samples were placed into polyethylene bags, labeled and stored hanging at 4 $^{\circ}$ C for 24 h. The meat samples were weighed again and final weight (W2) was recorded. Drip loss was calculated as shown in the equation below:

$$\text{Drip loss (\%)} = \frac{W1 - W2}{W1} \times 100$$

The extract release volume (ERV) of both fresh and refrigerated stored breast and thigh meat samples was determined by the technique of Jay (1964). Water holding capacity (WHC) of meat samples was determined by the

method devised by Wardlaw et al. (1973) in fresh as well as stored meat. The Lovibond Tintometer colour (redness, yellowness and chroma) of breast and thigh meat samples was measured by Lovibond Tintimeter (Model F, Greenwich, UK).

$$\begin{aligned}\text{Redness} &= a^*, \text{Yellowness} = b^*, \text{Chroma} \\ &= (a^{*2} + b^{*2})^{1/2}\end{aligned}$$

Antioxidant parameters

ABTS assay (2, 2-azinobis-3-ethylbenzothiazoline-6-sulfonic acid) and DPPH assay (1, 1-diphenyl-2-picrylhydrazyl)

The spectrophotometric analysis of ABTS+ and DDPH radical scavenging activities of both breast and thigh meat samples was determined according to the method of Shirwaikar et al. (2006) and Kato et al. (1988), on fresh basis as well after 1 month of refrigerated storage, respectively.

Lipid peroxidation parameters

Thiobarbituric Acid reactive Substances (TBARS) value of breast, thigh and liver samples

The extraction method described by Witte et al. (1970) was used for determination of TBARS values of breast, thigh and liver samples on fresh basis as well after 1 month of refrigerated storage. TBARS value was calculated as mg malonaldehyde (MDA) per Kg of sample by multiplying O.D value with K-factor of 5.2.

Free fatty acid value

The method as described by Koniecko (1979) was followed for estimation of free fatty acid values of breast and thigh meat samples on fresh basis as well as after 1 month of refrigerated storage.

Peroxide value

The peroxide values of breast and thigh samples were measured as per the procedure described by Koniecko (1979) on fresh basis as well after 1 month of refrigerated storage.

Statistical analysis

For each treatment two samples were taken from each of the six allocated replicates for data collection. The data obtained from the experiment were subjected to analysis of

variance for a completely randomized design, using the GLM procedure (SPSS software-17), by the methods of Snedecor and Cochran (1989). The significant mean differences were tested as per Duncan multiple range test (DMRT) as described by Duncan (1955) with significance level defined at $P < 0.05$.

Result and discussion

Fatty acid profile

The results have shown significant differences among the treatments both in breast and thigh meat (Table 1). Significantly higher percentages of palmitic acid and stearic acid and lower percentages of fatty acids like oleic acid, linoleic acid, eicosanoic acid, linoleic acid and eicosatrienoic acid were observed in treatment T1 as compared to other treatments, which were almost similar to each other. Further, higher SFA (%) and lower MUFA, PUFA, ω -3 PUFA, ω -6 PUFA, ω -3: ω -6 ratio and PUFA:SFA ratio were observed in T1 as compared to other treatments, which were almost similar to each other. These results clearly suggested that flaxseed feeding increased the percentage of UFA, including MUFA, PUFA, ω -3, ω -6 fatty acids and ω -3: ω -6 and PUFA:SFA ratios, whereas, significant decline was seen in SFA. However, no effect of increasing Cr levels was observed on fatty acid profile of broiler chicken. The higher percentage of UFA in meat can be attributed to higher proportion of UFA in flaxseed which undergoes faster absorption in the gut without any significant bio- hydrogenation, unlike ruminants. The results of the present study can be corroborated with the results of Mridula et al. (2015) who observed that the ALA content in both breast and thigh tissues was increased significantly with increasing levels of flaxseed meal in broiler diet, whereas, in contrast Linoleic acid content decreased. Rahimi et al. (2011) reported that incorporation of flaxseed and canola seed in the diet significantly increased the proportions of the ω -3 PUFA in the form of ALA, along with the increase of PUFA and PUFA:SFA ratio. Anjum et al. (2013) have reported that feeding flaxseed significantly increased breast ω -3 fatty acid levels, primarily ALA (18:3 n-3) and eicosapentaenoic acid (C20:3 n-3). Similarly, Abdulla et al. (2015) observed that the supplementation of the diets with linseed/flaxseed oil significantly increased C18:3 ω -3, ω -3: ω -6 ratio, UFA:SFA ratio, and PUFA:SFA ratio. Though, the literature citing the effect of Cr feeding on fatty acid profile of the broiler chicken meat is not available, researches on other species are available. Similar to our results, Nejad et al. (2016) in Holstein steers, Jackson et al. (2009) in swine, Lambertini et al. (2004) in

Table 1 Effect of chromium supplemented flaxseed based diet on fatty acid profile of broiler chicken meat

Fatty acids	Thigh					Breast				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Myristic acid (C14:0)	0.64	0.67	0.72	0.53	0.67	0.65	0.57	0.55	0.59	0.54
Palmitic acid (C16:0)	27.47	23.12	23.40	21.22	22.50	28.91	23.77	22.11	22.56	23.47
Palmitolic acid (C16:1)	3.44	4.39	3.66	4.12	3.68	3.99	3.07	3.11	4.34	3.70
Stearic acid (C18:0)	11.43	3.81	5.26	3.42	4.74	17.11	10.46	10.15	8.83	9.85
Oleic acid (C18:1) ω -9	32.95	37.10	36.78	37.95	36.61	30.13	35.51	36.19	35.78	35.02
Linoleic acid (C18:2) ω -6	17.67	21.23	20.47	22.51	22.46	15.12	19.26	20.23	19.94	20.06
Eicosanoic acid (C20:1) ω -9	1.39	3.11	3.25	3.63	3.91	1.19	3.13	3.11	3.74	2.76
Linolenic acid (C18:3) ω -3	1.33	2.94	2.71	2.97	2.91	0.36	1.12	1.01	1.07	1.14
Behenic acid (C22:0)	ND	ND	ND	ND	ND	ND	0.34	0.28	0.31	0.34
Eicosatrienoic acid (C20:3) ω -3	1.03	1.73	1.54	1.68	1.59	0.69	1.49	1.54	1.47	1.54
Lignoceric acid (C24:0)	2.65	1.89	2.21	1.96	0.94	1.85	1.29	1.73	1.37	1.58
SFA (%)	42.19	29.50	31.59	27.14	28.84	48.52	36.43	34.82	33.66	35.78
MUFA (%)	37.78	44.60	43.69	45.71	44.20	35.31	41.70	42.40	43.86	41.48
PUFA (%)	20.03	25.90	24.72	27.16	26.96	16.17	21.87	22.78	22.48	22.74
ω -3 PUFA (%)	2.36	4.67	4.25	4.65	4.50	1.05	2.61	2.55	2.54	2.68
ω -6 PUFA (%)	17.67	21.23	20.47	22.51	22.46	15.12	19.26	20.23	19.94	20.06
ω -3:n6 Fatty acid ratio	0.134	0.220	0.207	0.207	0.200	0.069	0.135	0.126	0.127	0.134
PUFA:SFA ratio	0.475	0.878	0.782	1.001	0.935	0.333	0.600	0.654	0.668	0.636

SFA saturated fatty acids, MUFA monounsaturated fatty acids, PUFA polyunsaturated fatty acids, ND not detected

rabbits did not observe any modification in the fatty acid composition as a result of Cr supplementation.

Physico-chemical properties

The results presented in Table 2 reveal that cholesterol content of thigh meat was significantly ($P < 0.01$) higher in treatment T1 and T2 and significantly lower in T4 and T5, whereas, T3 was having intermediate value. Similarly, the breast cholesterol content was significantly ($P < 0.01$) highest in T1 followed by T2 and lowest in T5 followed by T4; and T3 was intermediate to them. The thigh fat (%) was significantly ($P < 0.01$) highest in T1 followed by T2 and lowest in T5 followed by statistically similar T4, with T3 yielding intermediate value. The breast fat (%) of T1 was significantly ($P < 0.01$) highest followed by statistically similar T2 value and lowest in T5 and T4 with T3 statistically similar to T2, T4 and T5. So the results indicated that addition of 10% flaxseed caused decline of both cholesterol and fat of meat, though significant only in case of breast cholesterol and thigh fat (%). Cr supplementation caused progressive decline of both cholesterol and fat of meat, though not significant in case of breast fat (%). This decline of fat and cholesterol content can be attributed to increased UFA in meat which undergoes rapid oxidation reactions as compared to their saturated counter parts. The flaxseed may also exert its effect by increasing intraluminal

viscosity which hinders micelle formation and thus diminish lipid uptake and also inhibit re-uptake of bile acids causing increased hepatic synthesis of bile acids from cholesterol in the liver, thereby reducing it level in the body. Cr is reported to improve the insulin sensitivity of tissues, causing enhanced deposition of dietary protein and carbohydrate in the muscle cells as compared to fat. These results are in agreement with the findings of Ajuyah et al. (1991), Abdulla et al. (2015) and Murakami et al. (2010) who reported significant decrease of lipids/cholesterol in broiler meat due to the addition of flaxseed/flaxseed oil supplementation in broiler diets. Similarly, Duraisamy et al. (2013) reported the decline of breast cholesterol content of broilers fed diets containing more UFA than SFA. However, in contrast, Rahimi et al. (2011) have observed no effect on fat content of breast and thigh muscles either by feeding flaxseed or canola seed meals. Similar to the present findings (Toghyani et al. 2012; Choct et al. 2005) have reported significant reduction of muscle fat in broilers as a result of Cr supplementation. Krolczewska et al. (2005) have reported marked reduction in breast and thigh cholesterol up on Cr supplementation in broiler chicken. Also, Ibrahim et al. (2010) and Debski et al. (2004) have reported significant reduction in cholesterol and fat percentage of muscles up on organic Cr supplementation. However, in contrast, Kim et al. (1995)

Table 2 Effect of chromium in flaxseed based diet on cholesterol, fat percentage, pH and colour values of broiler chicken meat

Treatment	T1	T2	T3	T4	T5	Pooled SEM	P value
Flaxseed (%)	0	10	10	10	10		
Chromium (mg/Kg)	0	0	0.5	1.0	1.5		
Cholesterol (mg/100g)							
Thigh	100.23 ^c	97.00 ^c	85.33 ^b	73.07 ^a	71.32 ^a	2.519	$P < 0.01$
Breast	116.17 ^d	99.17 ^c	92.05 ^{bc}	84.12 ^{ab}	82.67 ^a	2.586	$P < 0.01$
Fat (%)							
Thigh	12.42 ^d	10.75 ^c	9.08 ^b	7.83 ^{ab}	7.42 ^a	0.402	$P < 0.01$
Breast	6.75 ^c	5.92 ^{bc}	5.25 ^{ab}	4.42 ^a	4.33 ^a	0.211	$P < 0.01$
pH							
Fresh meat	5.954	5.996	6.018	6.008	5.893	0.023	NS
Refrigerated stored	5.917 ^a	5.920 ^a	5.891 ^a	6.000 ^b	5.854 ^a	0.014	$P < 0.01$
Redness (a)							
Breast	1.92	1.78	1.94	1.62	1.60	0.098	NS
Thigh	2.58	3.40	2.98	2.38	3.08	0.129	NS
Yellowness (b)							
Breast	1.50 ^a	2.58 ^b	2.88 ^b	3.92 ^c	2.98 ^b	0.183	$P < 0.01$
Thigh	2.08 ^a	3.02 ^b	2.98 ^b	3.88 ^c	3.70 ^c	0.144	$P < 0.01$
*Chroma							
Breast	2.44 ^a	3.15 ^{ab}	3.50 ^{bc}	4.29 ^c	3.43 ^{bc}	0.163	$P < 0.01$
Thigh	3.38 ^a	4.59 ^b	4.24 ^b	4.56 ^b	4.83 ^b	0.138	$P < 0.01$

Redness = a*, Yellowness = b*, Chroma = $(a^{*2} + b^{*2})^{1/2}$, * Colour values

Values bearing different superscripts within the row differ significantly; NS nonsignificant

reported no significant effect of Cr supplementation on carcass fat.

No effect of flaxseed feeding and Cr supplementation was found on pH of fresh meat, whereas, the pH of meat after 1 month of storage, in treatment T4 was significantly ($P < 0.01$) higher as compared to other treatments. In general, in case of tintometer colour scores, significantly ($P < 0.01$) lowest scores of yellowness (b*) and chroma were observed in T1 and highest in T4, whereas, no changes were observed in redness (a*) values. The results indicate that flaxseed feeding had no effect of pH of meat, whereas, it increased the b* and chroma; and 1.0 mg Cr/kg diet yielded highest pH after 1 month of refrigerated storage and highest values of b* and chroma of both breast and thigh. However, these observations were in contrast to the findings of Tarek et al. (2014) who reported increase of pH with increasing flaxseed levels. Further, Anjum et al. (2013) and Betti et al. (2009) reported that pH and broiler meat color characteristics were not affected by flaxseed feeding to broiler birds. Similarly, Krolczewska et al. (2005) observed no effect of Cr supplementation on pH of muscles, whereas, in contrast they observed that breast muscles as well as leg muscles were characterized by significantly lower ($P < 0.05$) colour parameters in the group fed 500 µg Cr/kg as compared to 300 µg Cr/kg and control groups.

The results (Table 3) pertaining to WHC and ERV of breast and thigh meat, both in fresh and stored condition, revealed significantly ($P < 0.01$) lowest values in T2 followed by T3, and highest values in T5 followed by T1. However, the differences were not significant in case of ERV of thigh meat after 1 month of storage. The drip loss (%) of breast and thigh meat was significantly ($P < 0.01$) lowest in treatment T5 and highest in T2. However, the difference between T1 and T2 was not significant in case of drip loss of breast meat. All other treatments yielded intermediate values. These results indicate that flaxseed feeding decreased WHC and ERV of broiler meat and Cr feeding progressively increased them, whereas, reverse effect was found on drip loss. These negative effects of flaxseed may be attributed to its ability to increase the unsaturated fatty acid content of broiler meat which makes it more prone to oxidation. This oxidation may generate free radicals leading to protein denaturation, thus exerting their negative effect on WHC, ERV and drip loss of broiler meat. On the other hand, one possible mechanism of action of Cr having positive effect on WHC, ERV and drip loss of broiler meat might be improved insulin sensitivity of tissue, causing enhanced deposition of dietary protein and carbohydrate in the muscle cells as compared to fat. However, not enough literature is available citing the effects of flaxseed and Cr feeding in broilers on the WHC,

Table 3 Effect of chromium in flaxseed based diet on WHC, ERV and drip loss of broiler chicken meat

Treatment	T1	T2	T3	T4	T5	Pooled SEM	<i>P</i> value
Flaxseed (%)	0	10	10	10	10		
Chromium (mg/Kg)	0	0	0.5	1.0	1.5		
<i>Water holding capacity (WHC)</i>							
Fresh meat							
Thigh	73.8 ^{cd}	62.7 ^a	67.2 ^{ab}	70.7 ^{bc}	78.3 ^d	1.262	<i>P</i> < 0.01
Breast	88.3 ^{bc}	79.3 ^a	80.7 ^{ab}	82.8 ^{abc}	89.5 ^c	1.373	<i>P</i> < 0.05
Refrigerated stored							
Thigh	60.3 ^{bc}	48.0 ^a	54.7 ^{ab}	62.0 ^{bc}	67.8 ^c	1.734	<i>P</i> < 0.01
Breast	73.3 ^c	59.0 ^a	65.3 ^{ab}	71.2 ^{bc}	75.7 ^c	1.450	<i>P</i> < 0.01
<i>Extract release volume (ERV)</i>							
Fresh meat							
Thigh	27.8 ^{ab}	24.8 ^a	28.3 ^{ab}	31.0 ^b	35.8 ^c	0.838	<i>P</i> < 0.01
Breast	31.7 ^{bc}	27.7 ^a	30.0 ^b	32.2 ^{bc}	33.8 ^c	0.496	<i>P</i> < 0.01
Refrigerated stored							
Thigh	25.8	22.5	23.8	25.3	27.2	0.555	NS
Breast	27.0 ^b	24.2 ^a	26.2 ^{ab}	27.7 ^{bc}	29.5 ^c	0.466	<i>P</i> < 0.01
<i>Drip loss</i>							
Fresh basis							
Thigh	6.97 ^b	8.22 ^d	7.39 ^c	6.78 ^b	4.40 ^a	0.306	<i>P</i> < 0.01
Breast	6.90 ^{bc}	8.35 ^c	6.88 ^{bc}	5.49 ^{ab}	4.06 ^a	0.350	<i>P</i> < 0.01

NS nonsignificant

Values bearing different superscripts within the row differ significantly

ERV and drip loss (%) of broiler chicken meat except for one contrasting observation of Betti et al. (2009) who reported that drip loss was not significantly affected by feeding different levels of flaxseed (10 and 17%) to broiler birds.

Antioxidant parameters

DPPH and ABTS (% inhibition) values of meat reveal the free radical scavenging ability of the meat. The results (Table 4) have shown no dietary effects on DPPH values of fresh breast and thigh meat, whereas, after 1 month of refrigerated storage significantly ($P < 0.01$) lowest values were observed in treatment T2 which was similar to T3 and T4; and highest values were seen in T5 which was similar to T1. These findings suggest that feeding flaxseed decreased, whereas, Cr increased the DPPH values of broiler meat. Similarly, the ABTS values of breast meat, fresh as well as refrigerated stored, were found significantly ($P < 0.01$) lower in treatment T2 as compared to other treatments. It suggests that flaxseed feeding decreased, whereas, Cr feeding had no effect on ABTS values of breast meat of broiler chicken. No effect was found on ABTS values of thigh meat. It was concluded from the results that flaxseed feeding has negative effect on the anti-oxidant parameters, whereas, Cr feeding causes improvement of these parameters, but these anti-oxidant

parameters did not differ among different Cr levels. The negative effects of flaxseed can be attributed to its ability to increase the UFA content of broiler meat, making it more prone to oxidation which results in more free radical generation. The exact physiological action of chromium that results in reduction of fat portion due to increased carcass leanness is not clear. One possible mechanism of action might be improved insulin sensitivity of tissues, causing enhanced deposition of dietary protein and carbohydrate in the muscle cells as compared to fat. No literature is available suggesting the impact of flaxseed and Cr feeding on the anti-oxidant parameters of the broiler meat.

Lipid peroxidation parameters

The lipid peroxidation parameters (Table 5) revealed that no significant differences were observed in free fatty acid and peroxide values of fresh breast and thigh meat. However, after 1 month of refrigerated storage, significantly ($P < 0.01$) highest values were observed in treatment T2 as compared other treatments. Moreover, these two parameters did not exhibit differences among different Cr levels. Similarly, significantly ($P < 0.01$) highest TBARS values of breast, thigh and liver, both in fresh and stored condition, were observed in treatment T2 and lowest in T1 followed by T5 and T4. All these observations suggested that flaxseed feeding increased, whereas, Cr feeding decreased

Table 4 Effect of chromium in flaxseed based diet on antioxidant and lipid peroxidation parameters of broiler chicken meat

Treatment	T1	T2	T3	T4	T5	Pooled SEM	P value
Flaxseed (%)	0	10	10	10	10		
Chromium (mg/Kg)	0	0	0.5	1.0	1.5		
<i>DPPH (% inhibition)</i>							
Fresh meat							
Breast	25.1	22.3	23.6	22.6	20.6	0.689	NS
Thigh	19.1	17.1	18.2	17.9	17.8	0.481	NS
Refrigerated stored							
Breast	16.4 ^b	11.0 ^a	11.5 ^a	11.6 ^a	16.7 ^b	0.318	<i>P</i> < 0.01
Thigh	12.6 ^c	8.9 ^b ^a	10.4 ^b	11.1 ^b	12.6 ^c	0.737	<i>P</i> < 0.01
<i>ABTS (% inhibition)</i>							
Fresh meat							
Breast	89.7 ^b	86.9 ^a	91.4 ^b	90.2 ^b	90.1 ^b	0.423	<i>P</i> < 0.01
Thigh	84.6	78.3	66.5	79.7	73.4	2.129	NS
Refrigerated stored							
Breast	86.7 ^b	86.0 ^a	87.1 ^b	86.8 ^b	86.8 ^b	0.105	<i>P</i> < 0.01
Thigh	71.2	70.3	64.5	69.8	68.7	0.904	NS

DPPH 1, 1-diphenyl-2-picrylhydrazyl; *ABTS* 2, 2-azinobis-3-ethylbenzothiazoline-6-sulfonic acid

NS Nonsignificant; Values bearing different superscripts within the row differ significantly

Table 5 Effect of chromium in flaxseed based diet on lipid oxidation parameters of broiler chicken meat

Treatment	T1	T2	T3	T4	T5	Pooled SEM	P value
Flaxseed (%)	0	10	10	10	10		
Chromium (mg/Kg)	0	0	0.5	1.0	1.5		
<i>Free fatty acid value (%)</i>							
Fresh meat							
Breast	0.104	0.090	0.090	0.085	0.104	0.003	NS
Thigh	0.085	0.080	0.085	0.071	0.066	0.004	NS
Refrigerated stored							
Breast	0.158 ^a	0.225 ^b	0.167 ^a	0.158 ^a	0.160 ^a	0.007	<i>P</i> < 0.01
Thigh	0.160 ^a	0.202 ^b	0.160 ^a	0.169 ^a	0.150 ^a	0.005	<i>P</i> < 0.01
<i>Peroxide value (meq/kg)</i>							
Fresh meat							
Breast	1.159	1.323	1.231	1.279	1.175	0.039	NS
Thigh	1.303	1.408	1.365	1.412	1.340	0.034	NS
Refrigerated stored							
Breast	1.108 ^a	1.475 ^b	1.297 ^{ab}	1.223 ^a	1.153 ^a	0.037	<i>P</i> < 0.01
Thigh	1.309 ^a	1.811 ^b	1.598 ^{ab}	1.477 ^a	1.366 ^a	0.055	<i>P</i> < 0.05
<i>TBARS value (mg MDA/kg)</i>							
Fresh meat							
Breast	0.133 ^a	0.297 ^c	0.222 ^b	0.190 ^{ab}	0.146 ^a	0.014	<i>P</i> < 0.01
Thigh	0.152 ^a	0.308 ^c	0.249 ^{bc}	0.204 ^{ab}	0.162 ^{ab}	0.017	<i>P</i> < 0.01
Liver	0.183 ^{ab}	0.301 ^c	0.216 ^b	0.183 ^{ab}	0.147 ^a	0.012	<i>P</i> < 0.01
Refrigerated stored							
Breast	0.260 ^a	0.430 ^c	0.384 ^{bc}	0.322 ^{ab}	0.264 ^a	0.018	<i>P</i> < 0.01
Thigh	0.369 ^a	0.504 ^c	0.437 ^b	0.394 ^{ab}	0.354 ^a	0.014	<i>P</i> < 0.01
Liver	0.338 ^a	0.496 ^c	0.409 ^b	0.349 ^a	0.327 ^a	0.014	<i>P</i> < 0.01

TBARS, thio-barbituric acid reactive substances; *MDA* malonylaldehyde

NS nonsignificant; values bearing different superscripts within the row differ significantly

the lipid peroxidation of the broiler meat. The increased lipid peroxidation due to flaxseed can be attributed to its ability to increase the UFA content of meat which undergoes rapid oxidation as compared to SFA. It is also suggested that antioxidant effect of Cr under stress is related to inhibition of epinephrine resulting from the inulinotropic effect of Cr. The unsaturated lipids readily undergo oxidation to produce peroxides and aldehydes, which are responsible for the reduction in storage quality that is often associated with poultry meat with an enhanced PUFA content (Leskanich and Noble 1997). The reason is the first step of lipid oxidation, which involves the removal of hydrogen from a methylene carbon in the fatty acid. This removal of hydrogen becomes easier as the number of double bonds in the fatty acid increases, which is why polyunsaturated fatty acids are particularly susceptible to oxidation. Therefore, increasing the degree of unsaturation of muscle membranes reduces the oxidative stability of the muscle. To our knowledge, there is no published literature available suggesting the impact of flaxseed and Cr feeding on the free fatty acid and peroxide values of the broiler meat. However, the results of the present study related to TBARS values are in agreement with the observations of Abdulla et al. (2015), Anjum et al. (2013), Rahimi et al. (2011) and Betti et al. (2009) who found that TBARS value of broiler meat increases with increasing levels of flaxseed in diet. Similar to the findings of present study, Toghyani et al. (2012) and Rao et al. (2016) reported that lipid peroxidation of broiler meat decreased after Cr supplementation in broiler diets. Also, Sahin et al. (2010) reported decreased MDA levels of muscles and liver in Japanese quail due to Cr supplementation.

Conclusion

The study revealed that the diet containing flaxseed caused a significant increase of UFA content particularly ω -3 and ω -6 fatty acids, with consequent decline of SFA content in broiler chicken meat. Flaxseed feeding reduced the meat cholesterol and fat content, whereas, progressive reduction was observed with increasing Cr levels in feed. The combination of 10% flaxseed with 1.0 mg Cr/kg diet increased the final pH of broiler meat. The addition of flaxseed caused significant reduction of WHC, ERV and antioxidant potential of broiler chicken meat, whereas, increasing chromium levels progressively increased them. Flaxseed feeding significantly increased drip loss and lipid peroxidation of broiler chicken meat, whereas, Cr supplementation decreased them. Based on these results it was concluded that inclusion of 10% flaxseed and 1.5 mg Cr/kg diet is optimum for desirable meat quality of broiler chicken.

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