American Journal of Food and Nutrition, 2013, Vol. 1, No. 2, 12-21
Available online at http://pubs.sciepub.com/ajfn/1/2/2

DOI:10.12691/ajfn-1-2-2

Organic and Conventional Chicken Meat Produced In Uruguay: Colour, Ph, Fatty Acids Composition and Oxidative Status

G. Castromán[1], M. del Puerto[2], A. Ramos[1,2], M.C. Cabrera[1,2], A. Saadoun[1,*]

[1]Fisiología y Nutrición, Facultad de Ciencias, Universidad de la República. Iguá. Montevideo, Uruguay
[2]Dpto. Producción Animal y Pasturas, Laboratorio de Calidad de Alimentos y Calidad de Productos, Facultad de Agronomía, Universidad de la República. Eugenio Garzón 809. Montevideo, Uruguay
*Corresponding author: asaadoun@fcien.edu.uy

Received April 2, 2013; Revised July 16, 2013; Accepted July 18, 2013

Abstract The organic chicken meat is present in the market and accepted by consumers in Uruguay. However, no information about its quality is available. The study of organic meat showed a higher lightness (L*) and lower yellowness (b*) than conventional chicken meat. For redness (a*), the results were inconclusive. Haem iron content was higher in organic meat and the lipids content was not different between organic and conventional meat. The fatty acids composition showed that the organic meat presented 31-34 %, 49-53 % and 12-14 % of saturated, monounsaturated and polyunsaturated fatty acids (PUFA), respectively. The limited uses of corn and soybean to fed organic chickens, probably explain the unexpected low level of PUFA in organic meat. The organic meat also showed a lower TBARs level and a similar level of protein carbonyl in comparison to the conventional one. Catalase presented a higher activity in organic meat compared to the conventional one. No differences were observed for superoxide dismutase and glutathione peroxidase.

Keywords: *organic meat, broiler meat, fatty acids, TBARs, SOD, GPx, catalase*

Cite This Article: Castromán, G., M. del Puerto, A. Ramos, M.C. Cabrera, and A. Saadoun, "Organic and Conventional Chicken Meat Produced In Uruguay: Colour, Ph, Fatty Acids Composition and Oxidative Status." *American Journal of Food and Nutrition* 1, no. 2 (2013): 12-21. doi: 10.12691/ajfn-1-2-2.

1. Introduction

The global tendency towards the consumption of differentiated poultry products has been growing steadily in the past years in Europe and the United States [1], with a consequent increase of the use of alternative poultry production systems such as the "Label Rouge" [2,3,4,5]. In Uruguay, consumers show a growing preference for meat from broilers reared under organic conditions, which is related to the perception of this meat as one produced in an environment friendly system that considers animal welfare and produces meat with good flavour and high nutritional levels [4,6]. Consequently, organic farms have been developed locally by poultry breeders to produce organic chicken for the Uruguayan market using standard fast-growing breeds [7]. These poultry breeders were part of the APODU [8], an association which groups all the animal and vegetal organic producers of the country. The members of this association must follow determined rules to produce organic products on governmental regulation [9].

The organic rearing system is generally reputed to reduce stress, increase welfare and comfort for birds [10]. This rearing system seems to be also associated with an improving sensory quality and enhancing the flavour of meat, as reported by Castellini [4] and Fanatico et al [11]. However, the organic chicken meat seems to generally have a higher level of oxidation expressed by TBARS indices in comparison to the conventional meat [4]. The oxidative processes are the most important non-microbial factors responsible for meat deterioration resulting in losses of both nutritional value and food quality. This leads to adverse changes in sensory properties such as appearance, texture and flavour, and a possible production of toxic compounds. [12,13,14,15,16]. Fortunately, the presence of naturally occurring antioxidant substances in chickens meat scavenge free radicals, such as the antioxidant enzymes superoxide dismutase (SOD), catalase and glutathione peroxidise (GPX), counterbalances the negative effect of oxidation.

In this investigation, two commercial products consisting of organic and conventional chicken meat, both available in the market of Uruguay, were evaluated. The study compared some meat quality parameters such as meat colour, pH, haem iron content, total lipids, fatty acids composition, TBARs, protein carbonyls, SOD, CAT and GPx activities.

2. Materials and Methods

2.1. Animals and Samples

Five carcasses from an organic system and five from a conventional one were obtained from a local broker in Montevideo (Uruguay). The ten carcasses (weight of approximately 2000g and 2500g for the organic and the conventional chicken, respectively) were transported to the laboratory in a refrigerated isotherm box and the left *Pectoralis major*, *Sartorius and Gastrocnemius* muscles were excised and used for immediate study of colour, pH at 3 and 24h post-mortem, and the haem iron content at 24h post-mortem. The right *Pectoralis major*, and *Gastrocnemius* muscles were also entirely excised, rapidly frozen at – 20ºC and stored at this same temperature in a sealed bag until being analysed for lipids, fatty acids composition, TBARS, Protein carbonyls, and enzymes activities.

2.2. Determinations of Colour and pH

The color parameters (L*, a*, b*) were measured in *Pectoralis major*, *Sartorius* and *Gastrocnemius* muscles using a colorimeter Minolta CR-10, based on the Cielab Colour System [17]. The pH at 3h post-mortem and the ultimate pH (at 24 h post-mortem) were measured in the same three muscles with a digital pH-meter LTlutron PH-201 (with automatic temperature compensation) equipped with a penetrating spear tip pH electrode (Model: PE-04HD).

2.3. Determination of Haem Iron Content

Haem iron content was determined as hemin, after extraction with acidified acetone solution, as previously described [18,19,20]. Hemin was quantified in a Genesys 6-UV spectrophotometer (Thermo Corporation, USA) at 640nm. Meat samples (1g) were finely chopped and macerated in 4.5ml of acidified acetone (acetone: HCl: water - 90:2:8) in glass tubes for 1 minute on reduced light to minimize the pigment fading during the extraction. The tubes were sealed to reduce evaporation and held for incubation at room temperature (20-22ºC) in the darkness for 1h. After incubation, the tube content was filtered from glass filter papers (Whatman GFA) and the absorbance of the filtrate was read at 640 nm. The haem iron content was calculated using the factor 0.0882µg iron / µg hematin [18]. All samples were analyzed in duplicate.

2.4. Determination of Total Lipid Content

Lipids were extracted by homogeneization of 2.5 g samples of wet *Pectoralis major* and *Gastrocnemius* muscles using an Ultra Turrax (IKA T18 Basic), at 26 000 rpm, with 50 ml of 2:1 Chloroform:Methanol solvent mixture [21]. The extraction solution was decanted overnight and the chloroform phase was eliminated by roto-evaporation. The lipids were weighted accurately at 0.1mg. The results were expressed as % of total lipids for each sample. All samples were analyzed in duplicate.

2.5. Fatty Acid Quantification

Each sample of extracted lipids, approximately 40 mg, was converted to methyl esters [22]. The lipids were dissolved in 2ml of hexane and 4 ml of 2 M KOH in methanol were added. The mixture was vortexed for two minutes, centrifuged at 1000 g for 10 minutes at 4ºC, and the hexane phase, which contains the methylated fatty acids, was separated to be injected in the chromatograph. The fatty acid composition of each sample was determined twice by gas chromatography using a Clarus 500 Gas Chromatographer (Perkin Elmer Instruments) equipped with a FID detector. The column was a 100m CPsil-88 (Varian, Netherland) and the temperature program was 1 min at 90ºC, to 180ºC (rate 30ºC by min) and maintained for 20 min. After that, the temperature was raised to 220ºC (rate of 20ºC by min) and maintained for 10 min. One µl sample was injected by an autosampler (Perkin Elmer, USA) using the split method with a valve opening at 30sec post-injection. A fixed vented flow of 50% was determined to drain the solvent excess. The carrier gas was H_2 (99.99995 %) at a flow rate of 2ml/min, The FID flame was maintained by H_2 and air at a flow rate of 45ml/min and 350ml/min, respectively. The calibration and the peak determinations were based on authentic standards fatty acids from Sigma-Aldrich (St Louis USA). The results were expressed for each fatty acid as g/ 100 g total detected fatty acids.

2.6. Determination of Lipid and Protein Oxidation

Lipid oxidation was determined by the method of Lynch and Frei [23] with some modifications. Samples of 1.5g were homogenized with the extraction buffer (0.15 M KCl, 0.02 M EDTA and 0.30 M BHT) using an Ultra Turrax (IKA T18 Basic) at 12000 rpm for 1min. Two assay tubes containing 4ml of the homogenate were frozen at -20ºC for further use in protein carbonyls assay and determination of protein content. The same procedure without adding the sample was followed for the blank. Four ml of the homogenate were centrifuged at 2000 g for 10min at 4ºC and 1 ml of the supernatant was incubated with 1 ml of a TBA-TCA solution (35 mM TBA and 10 % TCA in 125mM HCl), in a boiling water bath for 30min. Afterwards, the assay tubes were cooled in ice for 5min and kept at room temperature for another 45 min. Two ml of n-butanol was added and, after centrifugation at 3000 g for 10 min, the supernatant was extracted and its absorbance was measured at 535 nm. MDA concentration was calculated using the molar extinction coefficient of MDA (156,000 M^{-1} cm^{-1}). Results were expressed as mg of MDA per kg of fresh meat.

Protein oxidation level was assayed using a method previously described [24]. The frozen samples separated the day prior to TBARS assays were thawed and let stand for 15min at room temperature and finally vortexed for 10 seconds. Two 2ml aliquots of the samples were put in different glass tubes (sample and corresponding blank), kept in ice and afterwards centrifuged at 3000 g for 10 min at 4ºC. Two ml of 2M HCl and 2ml of a DNPH solution (20 mM DNPH in 2M HCl) were added to the blank and sample tubes, respectively. These tubes were incubated at room temperature for 1 h, vortexed 5 seconds every 10min; then 2ml of 20 % TCA were added to all the tubes. Those tubes were kept at room temperature for another 15min and vortexed for 5 seconds every 5min. These tubes were then centrifugated at 2000g for 10min. Pellets were washed three times with 4ml of ethanol:ethyl acetate (1:1), centrifuged each time, to eliminate traces of

DNPH. Then, pellets were dissolved with 6ml of 6M guanidine HCl with 20 mM KH_2PO_4, incubating at room temperature for 15 min and vortexed for 5 seconds every 5 min. Afterwards they were centrifuged at 2400 g for 10 min and the absorbance of the supernatant was measured at 370 nm. The concentration of the DNPH was calculated using the DNPH molar extinction coefficient (22000 M^{-1} cm^{-1}). Results were expressed as nM of DNPH per mg of protein.

2.7. Superoxide Dismutase and Catalase Activities

An unique sample extraction was made for both enzymes activity measurements. Samples of 2.3-2.5 g frozen meat were homogenized with 26 ml of extraction buffer (0.15 M KCl and 0.79 M EDTA pH 7.4), using an Ultra Turrax (IKA T18 Basic) at 12000 rpm for 1 min. The homogenate was centrifuged 10 min at 9000 g at 4 ºC. The supernatant was extracted and used to determine SOD and catalase activities.

For the total SOD activity determination, the incubation mixture was prepared as follows: 2850µl of 50mM phosphate buffer (pH 8.2), 75µl of supernatant and 75µl of 10mM pyrogallol. This method is based on the inhibition of pyrogallol autooxidation by SOD, and is showed by the increase in absorbance at 340 nm recorded on 10 seconds intervals during 2 minutes. The results are expressed as IU and IU per gram of fresh meat. An IU was defined as the SOD activity needed to inhibit 50 % of pyrogallol auto-oxidation [25,26].

Catalase activity determination was done using the method described by Aebi [27]. It measures the disappearance of H_2O_2 reflected by the decrease in the absorbance at 240 nm during a period of 210 s recorded every 30 s. The incubation mixture contained: 2820 µl of extraction buffer, 90 µl of the above mentioned supernatant and 90 µl of 6.56 mM H_2O_2. Results were expressed as µmoles H_2O_2 min^{-1} per gram of fresh meat and as nM H_2O_2 min^{-1} per mg of protein.

2.8. Glutathione Peroxidase Activity

The method followed for this determination was previously described [28,29]. Samples of 5g frozen meat were homogenized with 25ml of extraction buffer (50 mM KH_2PO_4 and 0.5mM EDTA), using an Ultra Turrax (IKA T18 Basic) at 18000 rpm for 1 min. The homogenate was centrifuged at 2000g for 2min at 4ºC and the supernatant was filtered. A supplementary aliquot of 4 ml was saved at 4ºC for further protein determination assay. The composition of the assay mixture was 50 mM KH_2PO_4 buffer, 0.5mM EDTA, 1mM reduced glutathione (SIGMA-ALDRICH G4251), 0.15 mM NADPH (SIGMA N1630 or Fluka 93220), 1.5 U glutathione reductase (SIGMA G3664), 0.15 mM H_2O_2 and 1mM NaN_3 (SIGMA S-2002). The incubation mixture was prepared as follows: 1980µl of assay mixture and 20µl of filtered sample. Glutathione oxidase activity was measured at 22ºC, based on the recording of oxidation of NADPH reflected by the diminution of absorbance at 340 nm of the incubation mixture every 30sec through a period of 3min. Glutathione peroxidase activity was expressed as µmoles of oxidized NADPH min^{-1} per gram of fresh meat and as nM min^{-1} per mg of protein. The concentration of the NADPH was calculated using the NADPH molar extinction coefficient at 22ºC (6300 $M^{-1}cm^{-1}$).

2.9. Determination of Protein Content

Assessment of protein content for enzymes activities determination was done using the method described by Stoscheck [30]. BSA (SIGMA) used as standard, was dissolved in the corresponding assay buffer. Absorbance were measured at 280 nm with the use of a spectrophotometer Genesys 6 (Thermo, USA) and using quartz cells.

2.10. Statistical Analysis

Data were analyzed using NCSS (NCSS, 329 North 100 East, Kaysville, UT 84037, USA) software, running the GLM procedure followed by the Tukey-Kramer multiple comparison test. All data within the same variable, from each production system were compared using one-way ANOVA procedure. The significance level was established at $p < 0.05$. All values are reported as mean ± standard error of the mean (SEM).

3. Results

3.1. Colour and pH

The colour determination showed for lightness (L*) a system main effect ($p < 0.001$), a muscles main effect ($p < 0.001$) and a time effect ($p < 0.05$). The organic chicken meat showed a higher L* than the conventional one. Within the same muscle and time, at 3 and 24 hours post-mortem the *Pectoralis major* and *Gastrocnemius* muscles of organic chickens showed a higher L* than the *Sartorius* muscle. For conventional chicken meat, at 3 hours post-mortem the L* showed that *Gastrocnemius* > *Pectoralis major* > *Sartorius* (Table 1). At 24 hours post-mortem, the L* of the *Sartorius* muscle showed that *Gastrocnemius* = *Pectoralis major* > *Sartorius* (Table 1).

For the redness (a*), the results showed a system ($p < 0.001$) and a muscle ($p < 0.001$) main effect, but not a time effect. At 3 but not at 24 hours *post-mortem*, the organic chicken meat showed a higher a* than the conventional ones (Table 1). Within the same muscle and time, the a* showed for organic meat that at 3 hours post-mortem *Sartorius* > *Gastrocnemius* > *Pectoralis major* (Table 1). The conventional chicken showed a* results as follow *Gastrocnemius* = *Sartorius* > *Pectoralis major*. At 24 hours post-mortem the a* in organic chicken meat showed that *Sartorius* > *Pectoralis major* = *Gastrocnemius*. For conventional ones, the results for a* showed differences as follow *Gastrocnemius* > *Pectoralis major* = *Sartorius* (Table 1).

For yellowness (b*), the results showed a system ($p < 0.001$) and a time ($p < 0.001$) main effects, but not a muscle effect (Table 1). The values of b* were lower in organic meat than in conventional meat, both at 3 and 24 hours post-mortem. Independently to the production system and muscles, the value of b* were lower at 3 than at 24 hours post-mortem. Within the same muscle and time, no difference between the three muscles was detected (Table 1).

Table 1. Color of meat at 3 hours and 24 hours *post mortem* in three muscles of organic and conventional chicken

	Hours post-mortem			
	3		24	
Muscles	Organic	Conventional	Organic	Conventional
L*				
Pectoralis major	55.5 ±1.5a	51.9 ±0.51b	57.7 ±1.2a	53.3 ±0.6[a]
Sartorius	51.3 ±1.0b	48.5 ±0.78c	53.1 ±0.8b	49.5 ±0.4b
Gastrocnemius	56.2 ±0.7a	54.6 ±0.58a	57.6 ±0.5a	53.2 ±0.4a
		Signification		
Main effects	System :		Muscles :	Time :
a*				
Pectoralis major	1.38 ±0.24c	0.74 ±0.25a	0.69 ±0.25b	1.28 ±0.26b
Sartorius	4.34 ±0.44a	1.76 ±0.15b	3.29 ±0.81a	2.91 ±0.21b
Gastrocnemius	2.93 ±0.23b	2.03 ±0.41b	2.19 ±0.28ab	3.61 ±0.4[a]
		Signification		
Main effects	System :		Muscles :	Time : NS
b*				
Pectoralis major	15.1 ±0.6a	17.1 ±0.3a	16.9 ±0.5a	19.7 ±0.5a
Sartorius	15.3 ±0.4a	17.3 ±0.5a	16.7 ±0.6a	19.1 ±0.6[a]
Gastrocnemius	14.6 ±0.5a	17.6 ±0.8a	15.6 ±0.5a	20.2 ±0.8a
		Signification		
Main effects	System :		Muscles : NS	Time :

Values are means (n=5) ± SEM. L*= lightness, a*= redness, b*= yellowness.
Main effects signification: *= $p < 0.05$. ***= $p < 0.001$, NS= not significant.
Within the same production system and time pos-mortem, different letters means significant differences ($p < 0.05$).

The pH showed a system main effect ($p < 0.0001$) but not a muscle nor a time effect. The pH was higher at 3 and 24 hours in the chicken meat of conventional system in comparison to the chicken meat of organic system (Table 2).

Table 2. Values of meat pH at 3 hours and 24 hours (ultimate pH) *post-mortem* in three muscles of organic and conventional chicken.

	Hours post-mortem			
	3		24	
Muscles	Organic	Conventional	Organic	Conventional
Pectoralis major	6.03 ±0.01	6.22 ±0.08	5.98 ±0.09	6.09 ±0.05
Sartorius	6.12 ±0.02	6.18 ±0.05	6.02 ±0.06	6.16 ±0.03
Gastrocnemius	6.00 ±0.03	6.14 ±0.06	6.02 ±0.06	6.12 ±0.03
		Signification		
Main effects	System		Muscle NS	Time NS

Values are means (n=5) ± SEM. Main effects signification: ****= $p < 0.0001$, NS=not significant.

3.2. Haem Iron Content

The results for haem iron content showed a system ($p < 0.01$) and a muscle ($p < 0.001$) main effect (Figure 1). Within the same production system, both in organic and conventional chicken meat, *Pectoralis major* showed a lower ($p < 0.05$) content of haem iron in comparison to *Sartorius* and *Gastrocnemius* muscles (Figure 1).

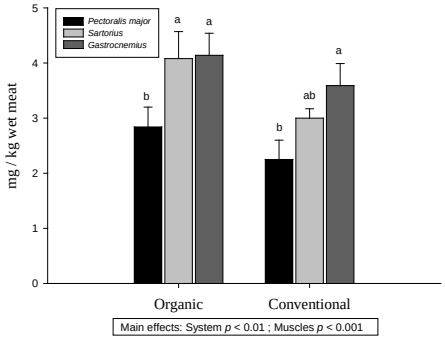

Figure 1. Haem iron determined at 24 hours post mortem in three muscles of chickens produced on organic and conventional rearing system. Bars are mean ± SEM (n=5). Different letters at the top of the bars means significant differences ($p < 0.05$)

3.3. Lipid and Fatty Acid Composition

The lipid content showed a muscle main effect ($p < 0.002$) but not a system main effect (Figure 2). However, independently of the production system, the *Gastrocnemius* muscle showed more lipids ($p < 0.05$) than the *Pectoralis major* muscle (Figure 2).

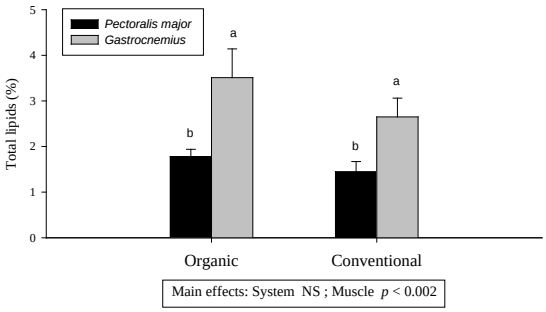

Figure 2. Total lipids content in two muscles of chickens produced on organic and conventional rearing system. Bars are mean ± SEM (n=5). Different letters at the top of the bars means significant differences ($p < 0.05$). NS= not significant

For fatty acids composition, a main effect for the production system has been obtained for almost all the

detected fatty acids, except C16:0, C18:3n6 and C20:5n3 (Table 3). A muscles main effect has been observed only for C16:0, C16:1, C18:0, C18:3n3 and C20:3n6 (Table 3). When the different classes of fatty acids were considered, it appears that the organic chicken meat showed a higher ($p < 0.001$) content of monounsaturated fatty acids and a lower ($p < 0.001$) content of polyunsaturated fatty acids (Table 3). Furthermore, the n-6 and the n-3 fatty acids family both showed a lower ($p < 0.001$) contents in organic chicken meat (Table 3). No effect of production system was detected for the saturated fatty acids. This last class of fatty acids, showed only a muscle main effect ($p < 0.01$), having the *Gastrocnemius* muscle more saturated fatty acids than the *Pectoralis major* one (Table 3).

Table 3. Fatty acids composition of meat in two muscles of chickens produced on organic and conventional rearing system

Fatty acids	Rearing system				Main effects signification	
	Organic		Conventional			
	(g/100 g Fatty acids)					
	Pectoralis major	*Gastrocnemius*	*Pectoralis major*	*Gastrocnemius*	System	Muscles
C14:0	1.09 ±0.09	0.95 ±0.08	0.46 ±0.03	0.33 ±0.05	***	NS
C14:1	0.23 ±0.03	0.16 ±0.07	0.08 ±0.01	0.05 ±0.02	***	NS
C16:0	21.45±0.69	22.49 ±0.51	20.04±0.15	21.62±0.79	NS	*
C16:1	5.87 ±0.58	4.63 ±0.56	2.66±0.23	1.49 ±0.21	***	**
C18:0	9.29 ±0.60	10.52 ±0.72	10.28±0.74	12.82 ±0.96	*	*
C18:1	46.25±1.07	44.47 ±1.69	29.42±1.15	27.27 ±1.63	***	NS
C18:2n6	9.22 ±0.94	9.85 ±0.96	28.89±0.92	24.29 ±1.94	***	NS
C20:0	0.05±0.003	0.04 ±0.01	0.08±0.006	0.09 ±0.02	***	NS
C18:3n6	0.07 ±0.01	0.06 ±0.009	0.12 ±0.01	0.08 ±0.02	NS	NS
C20:1	0.82 ±0.14	0.58 ±0.04	0.23 ±0.03	0.17 ±0.02	***	NS
C18:3n3	0.47 ±0.06	0.36 ±0.05	2.00 ±0.13	1.27 ±0.26	***	**
C20:3n6	0.07 ±0.01	0.15 ±0.03	0.35 ±0.04	0.66 ±0.11	***	**
C20:3n3	0.54 ±0.11	0.72 ±0.13	nd	nd	***	NS
C20:4n6	1.33 ±0.39	1.89 ±0.57	2.56 ±0.57	4.76 ±1.20	**	NS
C20 :5n3	0.09 ±0.03	0.13 ±0.03	0.14 ±0.02	0.25 ±0.08	NS	NS
C22:4n6	0.26 ±0.07	0.33 ±0.10	0.45 ±0.11	0.75 ±0.18	*	NS
C22 :5n3	0.29 ±0.07	0.17 ±0.05	0.45 ±0.09	0.96 ±0.25	***	NS
C22 :6n3	0.16 ±0.05	0.30 ±0.07	0.77 ±0.22	1.85 ±0.53	***	NS
Unidentified	2.45 ±0.10	2.19 ±0.29	1.03 ±0.10	1.29 ±0.21	***	NS
SFA	31.88±0.74	34.00±0.62	30.86±0.76	34.86±1.51	NS	**
MUFA	53.16±1.63	49.84±2.16	32.38±1.38	28.98±1.85	***	NS
PUFA	12.49±1.43	13.95±1.66	35.72±0.64	34.87±1.58	***	NS
n-6	10.95±1.29	12.28±1.58	32.36±0.65	30.54±1.31	***	NS
n-3	1.54±0.19	1.67±0.16	3.36±0.21	4.33±0.65	***	NS

Values are means ± S.E.M (n=5), nd= not detected, SFA= Saturated fatty acids, MUFA= Monounsaturated fatty acids, PUFA= Polyunsaturated fatty acids. Main effects signification: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, NS= not significant.

3.4. Lipid and Protein Oxidation

For TBARS the results showed a system ($p < 0.0001$) main effect but not a muscle main effect. The organic chicken meat presented a lower TBARS level than the conventional one (Figure 3).

For protein carbonyls, neither a system nor a muscle main effect was observed (Figure 4).

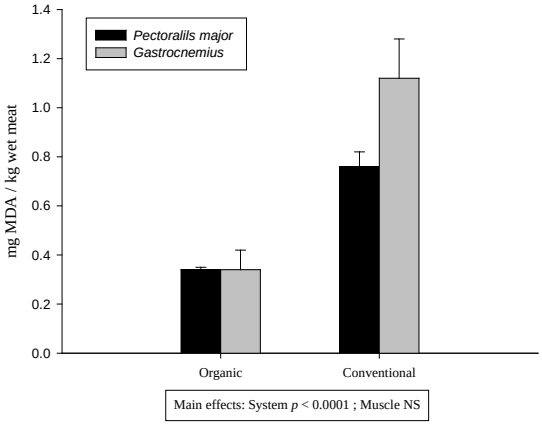

Figure 3. TBARS in two muscles of chickens produced on organic and conventional rearing system. Bars are mean ± SEM (n=5). NS= not significant

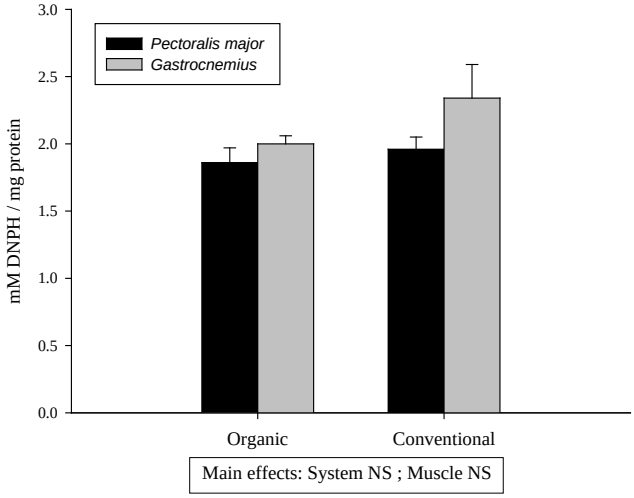

Figure 4. Protein carbonyls content in muscles of chickens produced on organic and conventional rearing system. Bars are mean ± SEM (n=5). NS= not significant

3.5. Anti-oxidative Enzyme Activities

The superoxide dismutase activity expressed both as U/g wet meat and U, showed neither a system effect nor a muscle effect (Figure 5).

The catalase activity expressed by g of wet meat showed a system ($p < 0.02$) and a muscle ($p < 0.001$) main effect (Figure 6). Also, when catalase activity was

expressed by mg of protein, the results showed a system ($p < 0.01$) and a muscle ($p < 0.001$) main effect (Figure 6). In all cases, the organic chicken showed more catalase than the conventional ones. Furthermore, the *Pectoralis major* muscle showed a lower activity of catalase ($p < 0.05$) than *Gastrocnemius* muscle in both production systems (Figure 6).

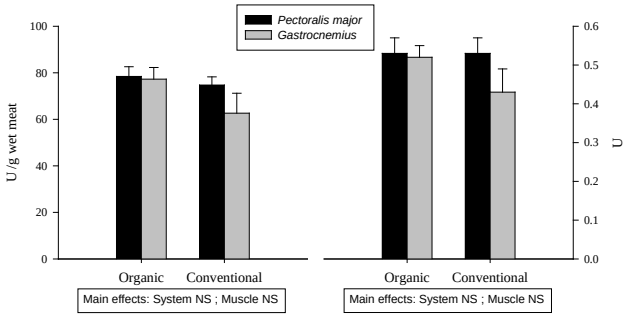

Figure 5. SOD activity in two muscles of chickens produced on organic and conventional rearing system. Bars are mean ± SEM (n=5). NS= not significant

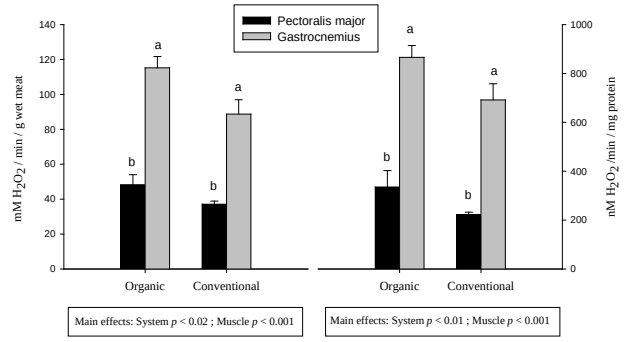

Figure 6. Catalase activity in muscles of chickens produced on organic and conventional rearing system. Bars are mean ± SEM (n=5). Different letters at the top of the bars means significant differences ($p < 0.05$)

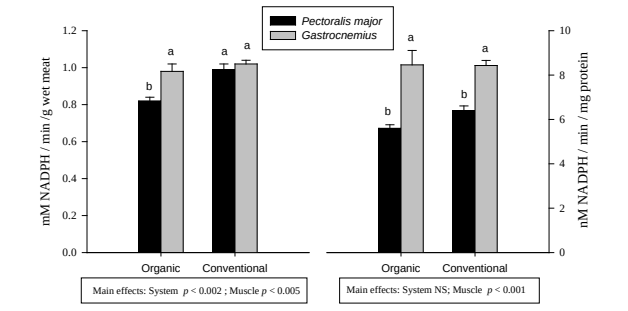

Figure 7. GPx activity in muscles of chickens produced on organic and conventional rearing system. Bars are mean ± SEM (n=5). Different letters at the top of the bars means significant differences ($p < 0.05$). NS= not significant

The GPx activity expressed by g of wet meat showed both a main effect of the production system ($p < 0.002$) and a muscle ($p < 0.005$) main effect (Figure 7). When the results were expressed by mg of protein only a muscle ($p < 0.001$) main effect was observed, but not a production system effect (Figure 7). However, both in organic and conventional production system, the *Pectoralis major* muscle showed a lower ($p < 0.05$) activity of GPx than *Gastrocnemius* muscle (Figure 7)

4. Discussion

In Uruguay, chicken meat is well accepted by consumers and takes a great part of the regime at all ages. The positive healthy image of the chicken meat, both organic and conventional, is associated principally with its nutritional composition related to its lower fat content and the presence of polyunsaturated fatty acids (PUFA). The affordable price of this kind of meat in the market makes it very attractive. The poultry market in Uruguay commercializes, for both organic and conventional systems, eviscerated carcasses of animals weighing between 1800 and 2600 g obtained from animals reared during 49-56 days. The carcasses of free-range or organically produced chickens were generally lighter than the conventional ones [4,31]. In Uruguay, as in other countries, the organic chicken meat has been directed towards consumers who are interested in the respect of animal welfare and the potential human health quality attribute associated to the organic chicken meat. However, the appearance and the texture of meat remain equally critical to the final selection of the product and the ultimate acceptance of the cooked product.

4.1. Colour, pH and Haem Iron Content

In the present investigation the L* showed higher values in organic meat, compared to conventional meat, at 3 hours and 24 hours post-mortem. Those values could be considered close to the threshold of pale meat for the broiler breast meat produced in Italy [32]. However, another investigation [33] considered a L* of 60 a limit for a pale meat in the poultry breast meat. Thus, it seems that there is not a value of L* which could be established as a standard threshold to discriminate unequivocally between pale and normal poultry meat. The pale poultry meat with a high L* was often associated with a low ultimate pH, generally below 5.70, in comparison to the normal meat. Of course, those results [32,33] were from breast meat, but a similar consideration could be assumed for Sartorius and Gastrocnemius muscles evaluated in the present investigation. In the report of Swatland [34], the subjective selection of pale and dark breast meat of conventionally produced 6 weeks-old chicken, conducted to the observation that a pH of 5.91 ± 0.12 and 6.36 ± 0.25 corresponded to a pale and a dark meat, respectively. Furthermore, in this same work, the low pH corresponded to a higher light reflectance, while the higher pH corresponded to a lower reflectance, both cases associated with the microstructure of the muscle fibres. In the present investigation, the recorded ultimate pH showed values ranged between 5.98-6.12 in organic meat and 6.09-6.22 in conventional one. In conclusion, It seems unlikely that the organic muscles evaluated in the present investigation could be considered as pale meat in regard to the relation between the L* values and the ultimate pH. Overall in our investigation, the L* showed higher values in organic meat and the ultimate pH showed lower values in organic meat, both compared to the conventional meat. For the redness (a*) the comparison between muscles showed that the *Pectoralis major* seems to be the muscle with the lower redness in comparison to the other two studied muscles. This result was in agreement to the observation reported by others [4,35] and could probably be associated

with a lower level of haem iron in meat detected in the present investigation, in both production systems. Haem iron is a highly associated component of the red colour in poultry meat [36]. However, the variations of a* between the two production systems were not clear. Then, taken together, the comparison between organic and conventional meat showed, in the present investigation, an opposite result. Indeed, the a* at 3 hours post-mortem were, overall, higher in organic meat, while the a* at 24 hours post-mortem were higher in conventional meat. Moreover in the present investigation, the conventional meat showed, at 24 hours post-mortem, a lower level of haem iron in comparison to the organic meat. Thus, the implication of iron pigment in poultry meat cannot be sufficient to explain the difference in redness between organic and conventional meat.

For the yellowness (b*), organic meat showed lower values compared to the conventional meat at 3 and 24 hours post-mortem. Although the values of b* were close between the two kinds of meat, these differences could be explained by the diet differences between the organic and the conventional system. The conventional system used a diet largely based on corn which acts as a natural pigment to ensure the carcass yellowness, while the organic system used only a reduced amount of Non-genetically Modified corn. In Uruguay the no-GMO organic corn is rare and expensive [37], so only a limited amount of this corn is used (< 10 %) for the organic poultry production system. To compensate this, the organic producers included dried alfalfa to obtain an adequate grade of yellowness of the carcasses [38]. In the scientific literature, the values of b* were highly variable depending on the level of yellowness required by the market. In Uruguay the consumers prefer a yellow carcass. The values of b* observed in the present investigation were in the same order those observed in another report [35], but higher than those reported by other authors [4,39], both working on Ross poultry breed, the same one used in our investigation.

4.2. Lipid and Fatty Acid Composition

The total lipids content of the two muscles showed no difference between the two production systems. However, the *Gastrocnemius* muscles showed, as expected [40-42], a higher content in lipids than the *Pectoralis major* for both organic and conventional system.

The results of the fatty acids composition showed an unexpected difference between the meat from the organic system and the meat from the conventional one. Indeed, when the total fatty acids were grouped by class, it appears that the polyunsaturated fatty acids (PUFA) showed a dramatic difference between the two production systems. The pectoralis major and the Gastrocnemius muscles in organic system contain 12.49 % and 13.95 % of PUFA, respectively, while the same muscles in the conventional system showed levels of 35.72 % and 34, 87 %, respectively. Within the PUFA class, the n-6 fatty acids showed a level of 2.5 to 3 times more in conventional meat than in organic one. These results could probably be explained by the difference of the diet offered to the animals in the two systems. In the conventional production system, the diet was based mainly on corn and soybean. As linoleic acid is a typical polyunsaturated fatty acid present in corn and soybean, this probably explains why the meat of conventional chickens contained three times more of this fatty acid in comparison to the organic chickens."

Also, the n-3 fatty acids showed a level 2 to 2.6 times more in conventional than in organic meat. In particular, the high level of docosapentahexaenoic acid (DPA) and the docosahexadecanoic acid (DHA) observed in the conventional system can be explained by the use of fish meal in the diet offered to the animals. In the organic meat, the presence of total n-3 fatty acids (particularly DPA and DHA) could probably be explained by the inclusion of grass and dry alfalfa in the diet. This explanation has been previously suggested for organic and conventional chicken production system [4,43], and it has also been reported in other non-ruminant animals [44,45].

In the same time, the organic meat showed a higher level of monounsaturated fatty acids (MUFA), mainly oleic and palmitoleic fatty acids in the two muscles, in comparison to the conventional meat. Furthermore, *Gastrocnemius* showed, independently of the production system, a higher level of MUFA in comparison to the *Pectoralis major*. Finally, no differences were observed for the saturated fatty acids (SFA) in the two muscles for both production systems.

The fatty acids composition of organic meat should be considered nutritionally insufficient for humans in regard to the PUFA content. The main advantage of chicken meat is the interesting level of pufa in comparison to others usual meats such as beef, lamb and pig [46]. However, this positive aspect of chicken meat is absent in the organic meat evaluated in the present investigation.

4.3. Lipid and Protein Oxidation

The meat from the organic system showed a level two or three more times lower than the corresponding muscles of the conventional system. However, no difference between muscles was detected. Although the organic meat evaluated in the present investigation, could be considered as much more stable than the conventional meat in regard to the level of TBARs, the fatty acids composition can probably explain this result in great part. The organic meat showed in one part a reduced level of PUFA, the main target of oxidation process in meat, and in another part a higher level of MUFA, mainly oleic acid, which helps greatly in the lipid stability of all kinds of meat and other foods. The TBARS observed in our investigation, in both systems, were lower than those reported in another investigation [4] and higher than those reported by other authors [35,42,47]. The protein oxidation showed no difference between muscles and system. The protein oxidation damage in meat affects amino acidic residues causing a loss of the protein functionality affecting their nutritional and organoleptic functionality [48,49]. Reports which studied the protein oxidation of chicken meat are very sparse in the scientific literature to compare with our results [16,50]. However, our results showed that the organic production system did not cause a major protein oxidation of the two studied muscles in comparison to the conventional one.

4.4. Anti-oxidative Enzyme Activities

The activity of SOD showed no difference between *Pectoralis major* and *Gastrocnemius* muscles nor between

production systems, in the two result expression mode. Unfortunately, data on SOD in chicken meat, independently of the production system, cannot be sourced in the scientific literature for comparison.

To the contrary, the catalase activity in *Pectoralis major* muscle was lower than in *Gastrocnemius* muscle in the two production systems. Our results agree with those of Jahan et al. [47], who found that catalase activity was higher for chicken meat from an organic production system. Furthermore, other investigation [13,51], found a higher catalase activity in thigh meat in comparison to breast meat. The research done in human skeletal muscle, before and after exercise, showed a significant increase of catalase activity after a moderate physical training. [52]. Thus, chicken reared under the organic production system conditions have access to outdoor and grass paddocks, and enter the pens only to sleep, so they spend the day walking. Even though this exercise of walking cannot be considered as physical training, it can be considered as a chronic moderate exercise compared to the very low mobility of chicken in the conventional system. So, it could be possible to attribute the higher catalase activity we found in organic chicken muscle meat to the exercise they do. Furthermore, the catalase activity was higher in *Gastrocnemius* muscles which has an oxidative metabolism and lower in the *Pectoralis major* muscle which has a glycolitic metabolism. In this sense, our results agree with those of Jenkis & Tengi [53], who found that oxidative muscles present higher catalase activity than glycolytic ones.

SOD and catalase act in concert to counteract the oxidative processes in meat, by the transformation of H_2O_2 into H_2O and O_2. The two enzymes are the first line defence antioxidants. A third enzyme which also participates in that first line of defence is the GPx. In the present investigation, the GPx showed different results depending how its activity was expressed, i.e. by g of meat or by mg of proteins. When the results were expressed by g of meat, the organic meat showed a lower activity compared to the conventional one. Also the *pectoralis major* muscle showed a lower activity than the *Gastrocnemius* one. However, no difference was observed for the same muscle in the conventional system. When the activity of GPx was expressed by mg of protein, no difference between the two production systems were observed. However, the *Pectoralis major* muscle showed a lower activity of GPx in comparison to *Gastrocnemius* muscle, in both organic and conventional systems. This agrees with the results of Daun & Åkesson [15], who found that GPx activity was significantly higher in oxidative muscles of chicken, duck and turkey when compared to glycolytic ones. Indeed, it is generally considered that oxidative muscles have higher GPx activities than glycolytic ones [54].

5. Conclusion

The results of the present investigation showed that the organic chicken meat as produced in Uruguay has a good oxidative stability. However, this meat cannot be considered adequate for the consumers in regard to its nutritional value, at least for PUFA contents. Although the high value of the organic meat resides in its safety in regard to chemical residue and welfare of the animals, it's also indispensable that the nutritional value of this kind of meat must be ensured for the consumers. The notion of nutritional security has to be strongly considered in the case of organic chicken meat. Most of the regulations which are worldwide applied, generally insist much on what kinds of food have to be banned and what kinds of chemical treatment have to be conducted to preserve the meat from possible contamination. However, these same regulations do not define in anyway, what kind of adequate nutritional composition is required in the meat for the consumers. There is no doubt that organic chicken meat has to be equally safe than nutritive. This particular point should be considered in future official regulations for organic chicken meat production. A similar viewpoint has been emitted by Castellini [55].

In the specific case of Uruguay, the banned use of GMO food and the limited availability of no-GMO corn and soybean [37] exacerbated the difficulty of the feed formulation to produce organic chicken meat, but this situation could be done in other parts of the world. It seems important in Uruguay to stimulate the emergence of rules which regulate and monitor the nutritional composition of the organic meat or any other specially produced chicken meat to ensure nutritional security for the consumers. On the other hand, the organic chicken producers have to innovate in their feeding strategy, choosing other PUFA OGM-free source available in the country or the region, such as the chia, the horse fat or the well known linseed [56,57,58].

Statement of Competing Interests

The authors have no competing interests'.

References

[1] Fanatico, A. C., Pillai, P. B., Cavitt, L. C., Emmert, J. L., Meullenet, J. F. and Owens, C. M., Evaluation of slower-growing broiler genotypes grown with and without outdoor access: Sensory attributes. *Poultry Science* 85, 337-343. 2006.

[2] ATTRA. Alternative Poultry Production Systems and Outdoor Access http://attra.ncat.org/attra-pub/poultryoverview.html#appendix http://attra.ncat.org/organic.html (accessed 2011/03/30). 2010a.

[3] ATTRA, Label rouge: Pasture-based poultry production in France. http://www.attra.ncat.org/attra-pub/PDF/labelrouge.pdf (accessed 2011/03/30). 2010b.

[4] Castellini, C., Mugnai, C. and Dal Bosco, A., Effect of organic production system on broiler carcass and meat quality. Meat Science 60, 219-225. 2002.

[5] ITAB, http://www.itab.asso.fr/downloads/fiches-elevage/cahier-poulets-web.pdf (accessed 2011, march 29). 2009.

[6] Fanatico, A. C., Pillai, P. B., J. L. Emmert, J. L. and Owens, C. M., Meat quality of slow- and fast-growing chicken genotypes fed low-nutrient or standard diets and raised indoors or with outdoor access. Poultry Science 86, 2245-2255. 2007.

[7] Meluzzi, A., Sirri, F., Castellini, C., Roncarati, A., Melotti, P. and Franchini, A., Influence of genotype and feeding on chemical composition of organic chicken meat. Italian Journal of Animal Science 8, 766-768. 2009.

[8] APODU, http://www.cebra.com.uy/presponsable/fortalecimiento-institucional/acuerdos-con-organizaciones/apodu. (Accessed on 2011/01/15). 2010.

[9] Rapal, http://webs.chasque.net/~rapaluy1/organicos/articulos/decreto_certificacion.pdf. 2008.

[10] Tuyttens, F., Heyndrickx, M., De Boeck, M., Moreels, A., Van Nuffel, A., Van Poucke, E., Van Coillie, E., Van Dongen, S. and Lens, L., Livestock Science 113,123-132. 2008.

[11] Fanatico, A. C., Cavitt, L.C., Pillai, P. B., Emmert, J. L. and Owens, C. M., Evaluation of slower-growing broiler geneotypes grown with and without outdoor access: Meat quality. *Poultry Science* 84, 1785-1790. 2005.

[12] Gray, J. I.; Gomaa, E. A. and Buckley, D. J., Oxidative quality and shelf life of meats. *Meat Science* 43, 111-123. 1996.

[13] Rhee, K. S., Anderson, L. M. and Sams, A. R., Lipid oxidation potential of beef, chicken and pork. *Journal of Food Science* 61, 8-12. 1996.

[14] Morrissey, P. A., Sheehy, P. J. A., Galvin, K., Kerry, J. P. and Buckley, D.J., Lipid stability in meat and meat products. *Meat Science* 49, S73-S86. 1998.

[15] Daun, C. and Åkesson, B., Comparison of glutathione peroxidase activity, and of total and soluble selenium content in two muscles from chicken, turkey, duck, ostrich and lamb. *Food Chemistry* 85, 295-303. 2004.

[16] Fellenberg, M.A. and Speisky, H., Antioxidants: their effects on broiler oxidative stress and its meat oxidative stability. *World's Poultry Science Journal* 62, 53-70. 2006.

[17] Cielab Colour System, *Commission International de l´Eclairage*. Paris: CIE Publication. 1976.

[18] Hornsey, H. C., The colour of cooked cured pork. 1. Estimation of the nitric oxide-haem pigments. *Journal of the Science of Food and Agriculture* 7, 534-541. 1956.

[19] Clark, E. M., Mahoney, A. W. and Carpenter, C. E., Heme and Total Iron in Ready-to-Eat Chicken. *Journal of Agriculture and Food Chemistry 45*, 124–126. 1997.

[20] Lombardi-Boccia, G, Martinez-Dominguez, B., Aguzzi, Altero and Rincon-Leon, F., Optimization of heme iron analysis in raw and cooked red meat. *Food Chemistry* 78, 505-510. 2002.

[21] Folch, J., Lees, M. and Sloane-Stanley, G. H., A simple method for the isolation and purification of total lipides peptides from animal tissues. *Journal of Biological Chemistry* 226, 497-509. 1957.

[22] Ichihara, K, Shibahara, A, Yamamoto, K. and Nakayama, T., An improved method for rapid analysis of the fatty acids of glycerolipids. *Lipids* 31, 535-539. 1996.

[23] Lynch, S. M. and Frei, B., Mechanisms of copper- and iron-dependent oxidative modifications of human low density lipoprotein. *Journal of Lipid Research* 34, 1745-1753. 1993.

[24] Mercier, Y., Gatellier, P. and Renerre, M., Lipid and protein oxidation in vitro, and Antioxidant potential in meat from Charolais cows finished on pasture or mixed diet.*Meat Science* 66, 467-473. 2004.

[25] Marklund, S. and Marklund, G., Involvement of the superoxide anion radical in the autooxidation of pyrogallol and a convenient assay for superoxide dismutase. *European Journal of Biochemistry* 47, 469-474. 1974.

[26] Gatellier, P., Mercier, Y. and Renerre, M., Effect of diet finishing mode (pasture or mixed diet) on antioxidant status of Charolais bovine meat. *Meat Science* 67, 385-394. 2004.

[27] Aebi, H., Catalase *in vitro*. *Methods in Enzymology* 105, 121-126. 1984.

[28] Günzler, A. and Flohé, L., *Glutathione Peroxidase*. In Greenwald, R. A. (ed). CRC
Press Inc Boca Raton, Florida, USA, Vol. 1, 1985. 285-290.

[29] De Vore, V. R. and Greene, B. E., Gluthatione peroxidase in post-rigor bovine *semitendinous* muscle. *Journal of Food Science* 47, 1406-1409. 1982.

[30] Stoscheck, C. M., Quantification of protein. *Methods in Enzymology* 182, 50-68. 1990.

[31] Wang, K.H., Shi, S.R., Dou, T.C. and Sun, H.J., Effect of a free-range raising system on growth performance, carcass yield, and meat quality of slow-growing chicken. *Poultry Science* 88, 2219-2223. 2009.

[32] Petracci, M., Betti, M., Bianchi, M. and Cavani, C., Color variation and characterization of broiler breast meat during processing in Italy. *Poultry Science* 83, 2086-2092. 2004.

[33] Van Laack, R.L.J.M., Liu, C.H., Smith, M.O. and Loveday, H.D., Characteristics of pale, soft, exudative broiler breast meat. *Poultry Science* 79, 1057-1061. 2000.

[34] Swatland, H. J., How pH causes paleness or darkness in chicken breast meat. *Meat Science* 80, 396-400. 2008.

[35] Husak, R. L., Sebranek, J.G. and Bregendahl, K., A survey of commercially available broilers marketed as organic, free-range and conventional broiler for cooked meat yields, meat composition, and relative value. *Poultry Science* 87, 2367-2376. 2008.

[36] Boulianne, M. and King, A. J., Biochemical and color characteristics of skinless boneless pale chicken breast. *Poultry Science* 74, 1693-1698. 1995.

[37] Galeano, P., Martinez Debat, C., Ruibal, F., Franco Fraguas, L. and Galvan, G. A., Cross-fertilization between genetically modified and non-genetically modified maize crops in Uruguay. *Environmental Biosafety Research*, DOI:10.1051/ebr/2011100. 2011.

[38] Castañeda, M. P., Hirschler, E. M. and Sams, A. R., Skin Pigmentation Evaluation in Broilers Fed Natural and Synthetic Pigments. *Poultry Science* 84, 143-147. 2005.

[39] Mourao, J.L., Pinheiro, V.M., Prates, A.M., Bessa, R.J.B., Ferreira, L.M.A., Fontes, C.M.G. and Ponte, P.I.P., Effect of dietary dehydrated pasture and citrus pulp on the performance and meat quality of broiler chickens. *Poultry Science* 87, 733-743. 2008.

[40] O'Keefe, S. F., Proudfootb, F. G. and Ackman, R. G., Lipid oxidation in meats of omega-3 fatty acid-enriched broiler chickens. *Food Research Internationa* 28, 417-424. 1995.

[41] Mourot, J. and Hermier, D., Lipids in monogastric animals meat. *Reproduction Nutrition development* 41, 109-118. 2001.

[42] Bianchi, M., Ferioli, F., Petracci, M., Caboni, M. F., and Cavani, C., The influence of dietary lipid source on quality characteristics of raw and processed chicken meat. *European Food Research Technology* 229, 339-348. 2009

[43] Ponte, P. I. P., Prates, J. A. M., Crespo, J. P., Crespo, D. G., Mourao, J. L., Alves, S. P., Bessa, R. J. B., Chaveiro-Suarez, M. A., Ferreira, L. M. A. and Fontes, C. M. G. A., Improving the lipid nutritive value of poultry meat through the incorporation of a dehydrated leguminous-based forage in the diet for broiler chicks. *Poultry Science* 87, 1587-1594. 2008.

[44] Muriel, E., Ruiz, J., Ventanas, J. and Antequera, T., Free-range rearing increases (n-3) polyunsaturated fatty acids of neutral and polar lipids in swine muscles. *Food Chemistry* 78, 219-225. 2002.

[45] Forrester-Anderson, I.T., McNitt, J., Way, R. and Way, M., Fatty acid content of pasture-reared fryer rabbit meat. *Journal of Composition and Analysis* 19, 715-719. 2006.

[46] Saadoun, A. and Cabrera, M. C., A review of the nutritional content and technological parameters of indigenous sources of meat in South America. *Meat Science* 80, 570-581. 2008.

[47] Jahan, K., Paterson, A. and Spickett, C. M., Fatty acid composition, antioxidants and lipid oxidation in chicken breasts from different production regimes. *International Journal of Food Science and Technology* 39, 443-453. 2004.

[48] Mercier, Y., Gatellier, P., Viau, M., Remington, H. and Renerre, M., Effect of dietary fat and vitamin E on colour stability and on lipid and protein oxidation in turkey meat during storage. *Meat Science* 48, 301-318. 1998.

[49] Gatellier, P., Mercier, Y., Rock, E. and Renerre, M., Influence of dietary fat and vitamin E supplementation on free radical production and on lipid and protein oxidation in turkey muscle extracts. *Journal of Agricultural and Food Chemistry*, 48, 1427-1433. 2000.

[50] Liu, G. and Xiong, Y.L., Contribution of lipid and protein oxidation to rheological differences between chicken white and red muscle myofibrillar proteins. *Journal of Agricultural and Food Chemistry* 44, 779-784. 1996.

[51] Pradhan, A.A., Rhee, K.S. and Hernandez P., Stability of catalase and its potential role in lipid oxidation in meat. *Meat Science* 54, 385-390. 2000.

[52] Parise, G., Phillips, S.M., Kaczor, J.J. and Tarnopolsky, M.A., Antioxidant enzyme activity is up-regulated after unilateral resistance exercise training in older adults. *Free Radical Biology and Medicine* 39, 289-295. 2005.

[53] Jenkins, R.R. and Tengi, J., Catalase activity in skeletal muscle of varying fibre types. *Experientia* 37, 67-68. 1981.

[54] De Vore, V.R. Colnago, G.L., Jensen, L.S. and Greene, B.E., Thiobarbituric acid values and glutathione peroxidase activity in meat from chickens fed a selenium-supplemented diet. *Journal of Food Science* 48, 300-301. 1983.

[55] Castellini, C., Organic poultry production system and meat characteristics, in *XVIIth European Symposium on the Quality of Poultry Meat*. Doorwerth, The Netherlands. 47-52. May 2005.

[56] Lopez-Ferrer, S., Baucells, M. D., Barroeta, A. C., Galobart, J. and Grashorn, M. A., n-3 enrichment of chicken meat. 2. Use of

precursors of long-chain polyunsaturated fatty acids:Linseed oil. *Poultry Science* 80, 753-761. 2001.

[57] Cabrera, M. C., Saadoun, A., Grompone, A., Pagano, T, Salhi, M., Olivero, R. and del Puerto, M., Enriching the egg yolk in n-3 fatty acids by feeding hens with diets containing horse fat produced in Uruguay. *Food Chemistry* 98, 767-773. 2006.

[58] Coates, W. and Ayerza, R., "Chia (*Salvia hispanica* L.) seed as an n-3 fatty acid source for finishing pigs: Effects on fatty acids composition and fat stability of the meat and internal fat, growth performance, and meat sensory characteristics". *Journal of Animal Science* 87, 3798-3804. 2009.