Effect of fat content on physical, microbial, lipid and protein changes during chill storage of foal liver pâté

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The effect of fat content (30%, 35% and 40%) on physical, microbial, lipid and protein changes, during chill storage, of foal liver pâté was studied. Microbial counts showed differences (P < 0.05) during storage time and among fat levels. Lightness and redness values gradually decreased over time, while yellowness increased during the whole period and displayed the highest values at the end of storage. The significant increase of protein carbonyls, during chill storage, of foal liver pâté reflects the intense oxidative degradation of the muscle proteins. The fat level presented significant differences in lipid oxidation, since foal pâtés with higher fat content (HF) showed significant higher TBARs values, compared to pâtés with lower fat content (LF) (0.54 vs. 0.46 mg MDA/kg pâtés; P < 0.001). Finally, NHI (non heme iron) increased during refrigerated storage of foal liver pâté, with the contents in the HF group being higher at all stages of storage (P < 0.05).

1. Introduction

Liver pâté is a cheap cooked meat product traditionally consumed around the world. In some countries (Spain, France, Germany and Denmark) these products are largely consumed (Fernández-López, Sayas-Barberá, Sendra, & Pérez-Alvarez, 2004; Martín, Antequera, Muriel, Pérez-Palacios, & Ruiz, 2009). The main ingredients used in the manufacture of liver pâté are meat industry by-products (backfat, liver and sometimes low category meat). These ingredients are a source of saturated fatty acids and provide a considerable proportion of the fat (between 25% and 45%) and energy contents, so this product presents some negative health concerns related to the high fat content and fatty acid profiles of animal fat.

Traditionally, pâté has been manufactured with goose or pork liver, although during recent years many new products, whose characteristics are more in line with health recommendations, have been launched on the market. These new products are based on a reduced fat content (Estévez, Ventanas, & Cava, 2005) and/or an improved fatty acid profile (Martín, Ruiz, Kivikari, & Puolanne, 2008; Martín et al., 2009).

Today’s consumers are health conscious and demand high quality food products. They require meat products with low fat and healthier fat composition, in view of cardiovascular disease or obesity. As a result of the above, modern consumers are willing to purchase new and stimulating experiences and this is where meat and meat products, from alternative species, can succeed (Lorenzo, Temperán, Bermúdez, Cobas, & Puriñños, 2012). At the same time, foal meat represents a good alternative as an ingredient in the elaboration of pâté. Previous studies reveal that foal meat is highly nutritious due to low fat and cholesterol levels, high protein, bioavailable iron and vitamin B contents, and a positive fatty acid composition, as well as a high content of unsaturated fatty acids (Franco, Rodríguez, Puriñños, Bermúdez, & Lorenzo, 2011; Lorenzo, Fuciños, Puriñños, & Franco, 2010; Lorenzo & Pateiro, 2013).

Regarding meat products, foal meat was used in the manufacture of dry-cured sausages obtaining excellent results (Lorenzo & Franco, 2012; Lorenzo, Montes, Puriñños, & Franco, 2012; Lorenzo, Temperán, et al., 2012).

In the manufacture of liver pâté, pork meat has been used as the main ingredient, although in some cases meat from other animal species, such as ostrich (Fernández-López et al., 2004) and goat (Dalmás, Bezerra, Morgano, Milaní, & Madruga, 2011) are also used. However, there are almost no studies concerning liver pâté manufactured with foal meat (Lorenzo & Pateiro, 2013). Furthermore, previous studies have demonstrated that the level of fat has an influence on the nutritional and sensory characteristics of these products (Estévez, Ventanas, & Cava, 2005; Estévez, Ventanas, Cava, & Puolanne, 2005). Thus, the objectives of the present study were to develop a value-added product, foal pâté, prepared using three different formulations in terms of fat content and to study its shelf life during refrigerated storage.

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2. Materials and methods

2.1. Manufacture of the foal liver pâté

For this study, three different formulations of foal liver pâté were considered, differentiated in terms of fat content [30% fat (low fat; LF), 35% fat (medium fat; MF) and 40% fat (high fat; HF)]. The pâté were prepared in the pilot plant of the Meat Technology Center of Galicia (Ourense, Spain). Foal liver, foal meat (from the hind quarter, composed principally by gluteus medius, semitendinosus and semimembranosus muscles) and subcutaneous fat, from commercial slaughter pig, were used as the main ingredients in the manufacture of the pâté. 24 h before the manufacture, liver and foal meat were ground through a 10 mm diameter mincing plate in a cooled chopper (La Minerva, Bologna, Italy) at 4 °C and mixed with sodium chloride, sodium nitrite and ascorbate. This blend was kept under dark and refrigerated conditions. On the day of manufacture, the fat was chopped using the same conditions as for the meat and liver, and scalded with water at 65 °C. Then, the remaining ingredients were added, sodium caseinate to the scalded fat, and water, milk powder and potassium phosphate to the mixture prepared the previous day. Finally, both mixtures were blended to obtain a homogeneous raw paste. Liver pâté was packed in 150 g glass containers prior to thermal treatment (80 °C/30 min). Subsequently, the samples were cooled in a blast chiller (−21 °C/30 min) and stored in the dark, at 2 °C, for 5 months from the day of the manufacture. Pâté was analysed at 0, 30, 60, 90, 120 and 150 days of refrigerated storage (2 °C). Batches were manufactured in triplicate. In each sample point, a total of three foal liver pâtés of each batch were analysed.

2.2. Analytical methods

2.2.1. Microbial analysis

Ten grammes of foal liver pâté were aseptically placed into a sterile stomacher bag. This was then homogenised with 90 ml of sterile 0.1% peptone water in a masticator blender (IUL Instruments, Barcelona, Spain) for 2 min, at room temperature. For each sample, appropriate serial decimal dilutions were prepared in peptone water solution (0.1%) and duplicate 1 ml or 0.1 ml samples of appropriate dilutions were poured, or spread, onto total count and selective agar plates.

Total viable counts (TVC) were enumerated in Plate Count Agar (PCA; Oxoid, Unipath Ltd., Basingstoke, UK) and incubated at 30 °C for 48 h; psychrotrophic aerobic bacteria on Plate Count Agar (PCA; Oxoid, Unipath Ltd., Basingstoke, UK) after incubation at 7 °C for 10 days; lactic acid bacteria on the Man Rogosa Sharpe agar (Oxoid, Unipath Ltd., Basingstoke, UK) (pH 5.6), after incubation at 30 °C for 5 days; Enterobacteriaceae on Violet Red Bile Glucose agar (Merck, Darmstadt, Germany) after incubation at 37 °C for 24 h; and Pseudomonads spp. on Pseudomonads Selective Agar (Merck, Darmstadt, Germany) with Pseudomonads CFC Selective Supplement (Merck, Darmstadt, Germany) incubated at 25 °C for 48 h. For the Brochothrix thermosphacta enumeration, 0.1 ml sample of each dissolution was spread on the surface of STAA Agar Base (Oxoid, Unipath Ltd., Basingstoke, UK) with STAA Selective Supplement (Oxoid, Unipath Ltd., Basingstoke, UK) and incubated at 25 °C for 72 h. After incubation, plates with 30–300 colonies were counted. Counts were expressed as number of colony forming units (CFU)/g.

2.2.2. Physico-chemical analysis

The pH of samples was measured using a digital pH-meter (Thermo Orion 710 A+, Cambridgeshire, UK) equipped with a penetration probe. Colour measurements were carried out using a CR-200 colorimeter (Minolta Chroma Meter Measuring Head, Osaka, Japan). Three measurements were performance for each sample. CIELAB space: lightness, \( L^* \); redness, \( a^* \); yellowness, \( b^* \) were obtained. Before each series of measurements, the instrument was calibrated using a white ceramic tile.


2.2.3. Texture profile analysis (TPA)

The Texture Analyser (TA-XT.plus, Stable Micro Systems, Vienna Court, UK) was used to conduct TPA. Hardness (kg), cohesiveness, springiness (mm), gumminess (kg) and chewiness (kg mm⁻¹) were evaluated as previously evaluated in Lorenzo and Pateiro (2013).

2.2.4. Protein oxidation assessment

Protein carbonyls, as measured by the total carbonyl content, were quantified in foal pâté following the method described by Oliver, Ahn, Moerman, Goldstein, and Stadtman (1987). Protein concentration was calculated from absorption at 280 nm using bovine serum albumin (BSA) as a standard. The amount of carbonyls was expressed as nmol of carbonyl per milligramme of protein, using an adsorption coefficient of 21.0 mM⁻¹ cm⁻¹ at 370 nm for protein hydrazones.

2.2.5. Lipid oxidation assessment

Lipid stability was evaluated using the method proposed by Vyncke (1975). Thiobarbituric acid reactive substances (TBARs) values were calculated from a standard curve of malonaldehyde with 1,1,3,3 tetraethoxypropane (TEP) and expressed as mg MDA/kg sample.

2.2.6. Analysis of non-heme iron

The non-heme iron (NHI) was determined by the ferrozine method (Purchas, Simcock, Knight, & Wilkinson, 2003). Concentrations were obtained using a standard curve from 0 to 5 mg of iron/l made with ferrous sulphate heptahydrate (Panreac Química S.L.U.,

Table 1

| Chemical composition (%) of foal liver pâté with different fat levels (mean ± standard deviation of nine replicates). |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Foal liver pâté                                 | SEM                                             | P-value                                         |
| Low fat (LF)                                    | Medium fat (MF)                                 | High fat (HF)                                  |
| Moisture (%)                                    | Fat (%)                                         | Protein (%)                                    |
| 54.0 ± 2.24a                                    | 23.2 ± 0.92b                                   | 16.2 ± 0.58a                                   |
| Fat (%)                                         | 53.3 ± 0.83da                                   | 15.5 ± 0.26b                                   |
| Protein (%)                                     | 52.5 ± 0.86a                                   | 15.0 ± 0.59b                                   |
| Ash (%)                                         | 3.25 ± 0.20a                                    | 3.26 ± 0.06a                                   |

\*\*Means in the same row not followed by a common superscript letter are significantly different (\*P < 0.05; Duncan test). SEM: standard error of mean.
Barcelona, Spain). All samples were assayed in duplicate. The results were expressed in mg/100 g of pâté.

2.3. Statistical analysis

For the statistical analysis of the results, an analysis of variance (ANOVA) of one way using IBM SPSS Statistics 19.0 program (IBM Corporation, Somers, NY, USA) was performed for all variables in the study. The least squares mean (LSM) were separated using Duncan’s t-test. All statistical test of LSM were performed for a significance level $P < 0.05$. Correlations between variables were determined by correlation analyses using the Pearson’s linear correlation coefficient with the above statistical software package mentioned.

3. Results and discussion

3.1. Effect of fat content on evolution of microbial counts during storage of foal liver pâté

Changes in microbial counts during chilled storage of foal liver pâtés of the three different fat contents are shown in Fig. 1. In general, microbial counts showed differences ($P < 0.05$) during storage time and among fat levels. Initial TVC (day 0) were very low (below 1.5 Log CFU/g) and remained low during the first 2 months of storage (less than 3 Log CFU/g) in all groups. Our initial TVC values after the thermal treatment were lower than those reported by other authors in this kind of product (Delgado-Pando, Cofrades, Rodríguez-Salas, & Jiménez-Colmenero, 2011; Delgado-Pando, Cofrades, Ruiz-Capillas, Tríki, & Jiménez Colmenero, 2012) and in comminuted meat products (Kao & Lin, 2006; López-López, Cofrades, & Jiménez-Colmenero, 2009). After 2 months of storage, we observed a different evolution in TVC among the three groups, since the low fat (LF) batch remained stable till the end of chilled period, while medium fat (MF) and high fat (HF) groups showed a significant increase ($P < 0.001$) reaching the maximum values after 5 months of storage (average values of 5.29 and 5.57 Log CFU/g for MF and HF groups, respectively). At 3–5 months of storage, no significant differences were observed between MF and HF samples. These results are consistent with the thermal treatment applied (80 °C/30 min) and the storage conditions (in hermetically-sealed containers without air contact at 2 °C), which considerably limit microbial growth. According to Spanish legislation (Regulation EC 1441/07, DOUE L322/12, 2007) the limit established for bacterial counts is $10^6$ CFU/g; the spoilage can be detected, mainly due to odour, in most foods with more than 6 Log CFU/g (Dainty & Mackey, 1992). Therefore, the shelf-life of foal liver pâtés could be extended up to 5 months of storage.

On the other hand, the evolution and counts of aerobic bacteria, psychrotrophic bacteria and lactic acid bacteria (LAB) was similar within each of the three batches (see Fig. 1) although some differences were observed. After 3 months of storage, microbial counts obtained from LF groups were always significantly lower ($P < 0.05$) than the other ones; thus we can say that there was a relationship between microbial population and product formulation. These results are in disagreement with those reported by Delgado-Pando et al. (2011, 2012), who observed that there was no clearly identifiable relationship between microbial population and product formulation in pork liver pâté, reformulated by reducing fat content and/or replacing the pork backfat with oil in water emulsion and konjac.

Pseudomonas spp. and B. thermosphacta were not detected on any of the three groups of foal liver pâtés analysed till 5 months of storage (data not shown). At this time of storage, the highest values were observed in samples from MF group with mean values of 4.2 and 3.5 Log CFU/g for Pseudomonas spp. and B. thermosphacta, respectively. These results showed that the thermal treatment applied was effective for the three formulations assayed. Finally, no Enterobacteriaceae were detected (data not shown), either initially or throughout storage (5 months) in pâtés formulated with different fat contents. These results are in agreement with those obtained by Delgado-Pando et al. (2011) and Fernández-López et al. (2004) for similar products. Thermal treatment seems to be enough to inactivate the microorganisms of this family.

3.2. Effect of fat content on the physical properties during storage of foal liver pâté

The chemical composition of foal liver pâtés with different fat levels is presented in Table 1. As expected, the differences in formulation produced significant differences in the proximate composition of the pâtés. Table 2 shows the physical properties of foal liver pâtés of the three different fat contents during the storage time. Variations in pH values are of little quantitative relevance ($P > 0.05$). The values obtained (6.67–6.89) were slightly higher...
Colour parameters were significantly ($P < 0.05$) affected by fat content (Table 2). These results were expected because the colour of pâtés is closely related to the colour properties of raw material used for the formulation (Estévez, Ventanas, Cava, et al., 2005) and therefore, changes in the proportions of the ingredients might lead to different colour properties. The results of the present study indicated that higher contents of fat and lower of meat, increase lightness and reduce redness in the liver foal pâté samples. In this sense, HF foal pâté samples showed higher lightness than LF foal pâté samples (54.21 vs. 52.97; $P > 0.05$, respectively, at 0 days of storage). A reduction of fat levels (and increased added meat) favours the appearance of dark colouring (higher redness and lower lightness). LF foal pâté samples were redder than HF foal pâté samples (CIE $a^*$-values: 9.27 vs. 8.06, $P = 0.001$ at 0 days of storage).

Colour characteristics of foal liver pâtés significantly ($P < 0.05$) changed during the whole display (see Table 2). These modifications in instrumental colour measurements can be considered as noticeable since the total colour difference ($D_0–150$) values were higher than 2 (Francis & Clydesdale, 1975). Lightness (CIE $L^*$-values) gradually decreased over time in three batches studied. At day 150, higher CIE $L^*$-values were measured in HF foal pâté samples than on other ones (53.2 vs. 52.0 vs. 50.4, $P < 0.05$, for HF, MF and LF groups, respectively). A similar evolution was observed for redness (CIE $a^*$-values) and after 150 days of storage, the higher CIE $a^*$-values were found for LF foal pâté group (5.20 vs. 4.20 vs. 3.41, $P < 0.01$, for LF, MF and HF batches, respectively). Finally, the CIE $b^*$-values increased during the storage period showing the highest values at the end of storage in the batches LF and MF. Our results are in agreement, with those reported in previous studies, on the colour changes during chill storage of liver pâté and other cooked products (Estévez & Cava, 2004; Estévez, Ventanas, & Cava, 2006; Fernández-Ginés, Fernández-López, Sayas-Barberá, Sendra, & Pérez-Alvarez, 2003; Ganho, Morcuende, & Estévez, 2010).

The decrease of redness values during storage time have been described in cooked meats subjected to refrigerated and frozen storage (Georgantelis, Blekas, Katikou, Ambrosiadis, & Fletrouis, 2007). To explain the discolouration of cooked meats, Fernández-Ginés et al. (2003) suggested that colour deterioration, during storage time of cooked meats, is explained by the oxidative degradation of certain nitroso pigments. On the other hand, protein radicals and other protein oxidation products are known to induce lipid oxidation (Viljanen, Kivikari, & Heinonen, 2004) and hence, heme pigments in pâté could also be affected by their pro-oxidant action. This is partially in agreement with the findings in this study, where the Pearson correlation test indicated that the carbonyl content was negatively related to $a^*$ values ($r = 0.766, P < 0.01$) and positively correlated to CIE $b^*$-values ($r = 0.685, P < 0.01$). According to Estévez and Cava (2004), the oxidative degradation of the denatured-globin and the oxidative cleavage of the hematin pigment would lead to the release of iron from the heme molecule, causing the eventual discoloration of the pâté.

As expected, the manufacture of foal pâté with increasing fat levels resulted in products with modified textural properties (Table 2). The fat reduction produced an increase of hardness ($0.22$ vs. $0.26$ vs. $0.37$ kg; $P < 0.001$ for HF, MF and LF groups, respectively), chewiness ($0.11$ vs. $0.13$ vs. $0.19$ kg mm; $P = 0.001$ for HF, MF and LF groups, respectively) and gumminess ($0.11$ vs. $0.14$ vs. $0.21$ kg; $P < 0.001$ for HF, MF and LF groups, respectively). This behaviour is coherent with the data previously reported by Estévez, Ventanas, and Cava (2005) in liver pâté and by Ayo, Carballo, Solas, and Jimenez-Colmenero (2008) in Frankfurters, who observed that the fat reduction causes increased hardness.
Textural properties of foal liver pâté were affected by storage time (see Table 2). After 150 days of chill storage, hardness significantly \((P < 0.001)\) increased 54.1%, 76.9% and 77.3% in HF, MF and LF groups, respectively; while chewiness also significantly \((P < 0.001)\) increased 68.4%, 61.5% and 72.7% in HF, MF and LF groups, respectively. These results are in agreement with those reported by other authors on liver pâté (Estévez et al., 2006; Fernández-López et al., 2004). Although loss of moisture during storage could explain the increase of hardness in foal liver pâté, this is not applicable to the present study, since the chemical composition of the foal liver pâté was identical at day 0 and day 150 (refrigerated) (data not shown). On the other hand, oxidative damage to proteins has an impact on protein solubility, leading to the aggregation and complex formation due to cross link formation (Karel, Schaich, & Roy, 1975). It is plausible that protein oxidation could lead to an increase of hardness in foal liver pâté through the formation of protein carbonyls, the loss of protein functionality and the formation of cross links between proteins. The positive correlation between carbonyl content and hardness \((r = 0.494, P < 0.01)\) in the present study seems to support this hypothesis.

3.3. Effect of fat content on protein and lipid oxidation during storage of foal liver pâté

Results from the analysis of the effect of fat level on the oxidative deterioration of the proteins, from foal liver pâtes during the storage, are shown in Fig. 2. At day 0, the carbonyl contents were higher in pâté with LF (14.70 nmol carbonyls/mg protein) as compared to those with MF (12.4 nmol carbonyls/mg protein) and HF content (11.5 nmol carbonyls/mg protein) \((P < 0.001)\). The amount of carbonyls from protein oxidation significantly \((P < 0.001)\) increased during chill storage in LF, MF and HF foal liver pâté; an increase which was significantly higher in HF foal liver pâtes than in LF group \((\Delta\text{ carbonyls “HF”}: 31.9; “MF”: 24.7 and “LF”: 8.45; \(P < 0.001)\). The increase of protein carbonyls show that muscle proteins in foal liver pâté are susceptible to oxidative reactions leading to carbonyl gain.

Results of this study suggest that protein oxidation mainly occurred from day 120 to day 150, with the highest amount of carbonyls being detected at the end of the storage time (see Fig. 2). The large amount of protein carbonyls observed at 150 days of storage (23.2, 37.1 and 43.4 nmol carbonyls/mg protein, for LF, MF and HF batches, respectively) denotes more intense oxidative reactions than previously found on raw pork and beef subjected to chill storage (Lund, Hviid, & Skibsted, 2007; Lund, Lametsch, Hviid, Jensen, & Skibsted, 2007). In our study, mincing and the temperatures applied during thermal treatment (80 °C/30 min) could have enhanced protein oxidation in the foal liver pâté. Heating degrades myoglobin, causing the release of iron, which is believed to increase its pro-oxidant potential in cooked meats (Kristensen & Purslow, 2001). On the other hand, the disruption of the tissues leads to the release of pro-oxidants naturally present in the muscle and enhances the incorporation of oxygen in the system. Requena, Chao, Levine, and Stadtman (2001) showed that NHI was the main
initiator of protein oxidation in cooked meat systems. This is in agreement with findings in this work, since we observed a positive correlation between the carbonyl content and NHI content \((r = 0.867, P < 0.01)\).

Our results, at 90 days of storage, are similar to those reported by Estévez and Cava (2004), who noticed values of 22.5 nmol carbonyls/mg protein in liver pâté. Finally, these results are in agreement with those found for lipid oxidation and indicate the possible relationship between protein and lipid oxidation. From the Pearson correlation test, it was found that TBARs values were positively related \((P < 0.01)\) to the carbonyls content \((r = 0.472)\).

The oxidative stability of the three batches of foal liver pâté studied throughout the storage time was evaluated by determining the 2-thiobarbituric acid-reactive substances (TBARs) index (Fig. 3). The fat level significantly influenced the lipid oxidation since HF pâté showed significantly higher TBARs values, compared to LF \((0.54 \text{ vs. } 0.46 \text{ mg MDA/kg pâté}; \ P < 0.001)\). Significant changes \((P < 0.001)\) were detected in the MDA content between day 0 and day 90 for pâté from LF \((\text{from } 0.04 \text{ mg MDA/kg pâté to } 0.44 \text{ mg/kg pâté})\), MF \((\text{from } 0.05 \text{ mg MDA/kg pâté to } 0.48 \text{ mg/kg pâté})\) and HF \((\text{from } 0.05 \text{ mg MDA/kg pâté to } 0.51 \text{ mg/kg pâté})\) batches and the highest increase occurred between day 60 and day 90 of storage \((\Delta \text{ TBARS } “HF”: 0.44; “MF”: 0.42; and “LF”: 0.38)}\). The increase in TBARs index is in agreement with those reported by Estévez and Cava (2004), and this increase could be explained by the equilibrium between the prooxidant and antioxidant factor in pâté. From these maximum values, a significant \((P < 0.0001)\) drop was observed until the end of the storage reaching final average values of 0.15, 0.16 and 0.19 mg MDA/kg pâté, for LF, MF and HF groups, respectively. This final drop was already observed in other meat products and could be attributed to the instability of the malonaldehyde (Melgar, Sanchez-Monge, & Bello, 1990).

### 3.4. Effect of fat content on non-heme iron level during storage of foal liver pâté

The evolution of NHI content of foal liver pâté from the three different fat contents during the storage is shown in Fig. 4. As it can be observed, NHI increased significantly \((P < 0.001)\) during refrigerated storage from 1.01 to 1.89 mg/100 g pâté, 1.14 to 2.02 mg/100 g pâté and 1.14 to 2.23 mg/100 g pâté, for LF, MF and HF groups, respectively. Foal liver pâté manufactured with a high fat content had a significantly higher amount of NHI than LF batch during the whole display \((P < 0.05)\). Our results are in agreement with those reported by Estévez and Cava (2004) and Estévez et al. (2006), who observed an increase of NHI content during the refrigerated storage of liver pâté.

Closely associated to the development of oxidative reactions in meats and cooked products, the breakdown of the heme molecule and the subsequent release of iron from the porphyrin ring has been reported. According to Miller, Gómez-Basauri, Smith, Kanner, and Miller (1994) the increase of NHI during refrigerated meat is a reflection of the degradation of the heme molecule. The results of this study showed a relationship between protein oxidation and the release of iron from the heme molecule. In fact, the release of iron mainly occurred after 90 days of storage \((\Delta \text{ NHI } “HF”: 0.56; “MF”: 0.44; and “LF”: 0.49; from day 90 to day 150)\) when the great increase in protein oxidation was also detected. Estévez and Cava (2004) observed a significant correlation between TBARs values and NHI content during refrigerated storage of liver pâté. Results from this study are in good agreement since NHI content significantly correlated to TBARs values \(r = 0.441, P < 0.01)\), to carbonyls \((r = 0.867, P < 0.01)\), and to storage time \((r = 0.941, P < 0.01)\). These positive correlations suggest that the oxidative degradation of some particular proteins such as the myoglobin could promote the deterioration of the heme group and the subsequent release of iron.

### 4. Conclusions

In conclusion, the storage of foal liver pâté led to a series of changes, mainly in fat and meat pigments, thereby reducing the quality of the product. The decrease of fat content on foal liver pâté revealed it enhanced the oxidative stability of proteins, significantly reducing the increase of non-heme iron during chill storage. From the microbial point of view, the shelf-life of foal liver pâté could be extended up to 5 months of storage. Further studies should evaluate the use of antioxidant to control colour and lipid and protein oxidation changes.

### References


