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ARTICLE

Effect of three different lairage times (0, 18 and 24 hours) on meat quality parameters in camels

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ABSTRACT Animal stress has frequently been linked to pre-slaughter operations, particularly the transportation and handling process. Therefore, it is assumed that an optimal lairage time before slaughter will exert positive effects on the animal's welfare and meat quality. However, the impact of this practice on camels is unknown. This study aimed to assess the influence of three lairage durations: 0 h (L0), 18 h (L18), and 24 h (L24) on the quality of camel meat. Ninety adult male camels aged 6 years were included in this study. *Longissimus lumborum* was sampled to analyze for muscle glycogen, muscle pH (45 min; 48 h), muscle temperature (45 min; 48 h), electrical conductivity (45 min; 48 h), drip loss (DL), cooking loss (CL), and thawing loss (TL). The L24 group had the lowest ($p < 0.05$) of muscle glycogen and the highest ultimate pH (48 h). Further, the L24 group had the lowest muscle temperature, electrical conductivity, drip loss, and thawing loss ($p < 0.05$). In conclusion, a lairage period of 24 h is recommended in the field conditions studied here for full recovery from stress response caused by the pre-slaughter process and for achieving better camel meat quality. **Acta Biol Szeged 67(2):187-195 (2023)**

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Introduction

The pre-slaughter period is as stressful for animals as the slaughter procedure itself (Dalla Costa et al. 2019; Clariget et al. 2021). Prior to slaughter, like other animal species, camels might experience various types of stressors that can compromise their welfare and final product quality (Tabite et al. 2019; El Khasmi 2024). Pre-slaughter stress is the culmination of a number of stressors, including transportation, novelty (new surroundings), fasting, loading, unloading, and stock density (El Khasmi et al. 2015). Several studies have been undertaken to ascertain the impact of the pre-slaughter stress on camel welfare and the quality of their meat (Barka et al. 2016; Lemrhamed et al. 2018; Tabite et al. 2019).

Previous studies have reported that stressful situations, especially during transportation, induce an increase in numerous blood parameters such as cortisol, glucose, creatine kinase, and blood lactate (Saeb et al. 2010; Lemrhamed et al. 2018). Meanwhile, it has been demonstrated that pre-slaughter stress was mostly associated with muscle glycogen depletion, which can affect the quality of the meat of camels (El Khasmi et al. 2010; Barka et al. 2016). Camels that are subjected to stressor challenges prior to slaughter may experience a high ultimate pH, electrical conductivity, drip loss, and lipid peroxidation (Barka et al. 2016; Tabite et al. 2019).

For other animal species, several researchers have reported that an adequate lairage time before slaughter can reduce the stress caused by pre-slaughter practices, allowing animals physiological recovery and, consequently, improving their meat quality. However, what is considered adequate varies (Dokmanović et al. 2016; Yalcintan et al. 2018; Biffin et al. 2020; Najafi et al. 2020). Nevertheless, the results reported in the previous studies regarding the optimum lairage duration prior to slaughter have shown a wide discrepancy, probably due to the complexity of behavioral and physiological responses.

In contrast to other species, no research has attempted to establish the ideal rest period at the slaughterhouse in terms of meat quality for dromedary camels. Therefore, this study aimed to determine the optimal lairage duration for obtaining top-quality camel meat.

Materials and methods

Study site and experimental conditions

This investigation was carried out from April 2022 to

June 2022 at the El Oued slaughterhouse, located in the southeast part of Algeria (latitude 33°22'16.823" N, longitude 6°50'52.686" E). The mean humidity throughout the study was 28.3%, and the mean temperature was 25.6 °C. The average rainfall and wind speed were 4.2 mm and 21.7 km/h, respectively.

Animals and treatments

This study was performed in accordance with the European ethical guidelines for animal handling (European directives EU 86/609-STE123 and 2010/63/EU). All procedures were undertaken in agreement with the local animal ethical committee guidelines. All observations were made under normal commercial abattoir practice conditions. All efforts were made to minimize animal stress and suffering during the study. The animals used in this experiment were handled gently.

The study was performed based on a replicated design with 90 clinically healthy male camels (30 camels for each treatment). The camels were from the Sahraoui population (6 years old and 323.45 ± 5.09 kg live weight) and were randomly selected for this study. All the animals originated from the same farm and were subjected to the same management practices. The animals were intensively housed and raised under one feeding strategy without any variations in terms of feeding management. The diet fed at the farm was composed of dry hay straws and barley concentrates. The animals were given access to feed and water *ad libitum* during the experiment. All of the animals were starved for 12 hours (for sanitary reasons) prior to being transported to the abattoir for slaughter.

At the same time of each day (early evening), the camels were transported to the abattoir under similar conditions. The camels were moved from the farm to the abattoir by walking them over a distance of 7 km (2–3 h approximately). The transportation was undertaken consciously to prevent additional stress to the animals. Upon arrival at the slaughterhouse, the camels were carefully handled by the same trained person and calmly put in a holding area as one group with a solid fence and a concrete floor. During the lairage period, the stocking density was 10–15 m^2 per animal. The animals had access to water, but no feed. All the precautions were taken to avoid stress from contact and mixing with unfamiliar subjects.

Based on the length of the lairage period, the camels were separated into three groups: 0 h (L0), 18 h (L18), and 24 h (L24). For slaughter, the camels were calmly guided to the slaughter room to be slaughtered in accordance with the standard Halal practice without any prior stunning.

Meat quality measurements

Muscle sampling

Immediately after the slaughter process and veterinarian examination, a sample of *Longissimus lumborum* (approximately 250 g) was collected within 30 min post-mortem from the right side of each carcass. The muscle samples were transferred to the laboratory at 4 °C for 10 min in zippered plastic bags. On arrival, the connective tissue and fat were eliminated and the lean meat was divided into five parts for each muscle: the first one for glycogen content determination, the second one for the analysis of pH, temperature, and electrical conductivity, the third for the determination of drip loss, the fourth one for the measurement of cooking loss, and the fifth one for the assessment of thawing loss.

After that, the samples to be used for the glycogene content determination were immediately placed in the freezer at -30 °C until the analysis. The other meat portions were kept apart in plastic bags and refrigerated at a temperature of 4 °C. The pH, temperature, and electrical conductivity assessments were performed at 45 min and 48 h after slaughter, while the analysis of water-holding capacity parameters was performed after the ultimate pH was reached (48 h post slaughter in camel species).

Measurement of physico-chemical parameters

Muscle glycogen content was measured using the methods mentioned by Dreiling et al. (1987). For this, muscle samples (approximately 2 g) were taken from each *longissimus lumborum* muscle collected during the study. The muscle samples were completely homogenized for 30–45 sec using a mechanical tissue disruptor after being thoroughly homogenized with 10 ml of cold 7% perchloric acid. The supernatant was collected after centrifugation at 15 000 g and 0-4 °C, decanted, and stored for glycogen analysis. About 1.3 ml of a solution containing 2.6 g of potassium iodide (in 10 ml of distilled water) and 0.26 g of iodine and 100 ml of saturated $CaCl_2$ were combined in order to create the iodine color reagent. About 0.4 ml of tissue extract or glycogen standard was mixed with 2.6 ml of the reagent. The concentration of glycogen was measured spectrophotometrically at 460 nm using a UV–visible light spectrophotometer (Jenway Model 6705) and a commercial glycogen assay kit (Sigma-Aldrich, MAK016, USA). The results were expressed as millimoles of glycogen content per kilogram of muscle (mmol/kg).

The pH and the temperature of muscle samples were determined using a portable pH meter (Hanna waterproof pH meter, Model Hi 99163, Romania). The pH meter was placed straight into the muscles at a uniform depth (1.5 cm). The readings were recorded in triplicates. Before taking the measurements, the pH meter was calibrated

Table 1. Least square means (±SE) and significance levels of meat physico-chemical parameters in relation to different lairage times.

Parameters	Lairage time			*p*-value
	L0 (n = 30)	L18 (n = 30)	L24 (n = 30)	
Muscle glycogen (mmol/kg)	38.17 ± 1.64[a]	32.24 ± 1.43[b]	30.15 ± 1.31[c]	< 0.001
pH45 min	6.81 ± 0.05	6.92 ± 0.03	6.96 ± 0.03	0.062
pH48 h	5.52 ± 0.06[a]	5.76 ± 0.03[b]	5.85 ± 0.03[c]	0.001
MT45 min (°C)	25.04 ± 0.28[a]	22.03 ± 0.30[b]	20.11 ± 0.27[c]	< 0.001
MT48 h (°C)	14.52±0.22[a]	12.50 ± 0.18[b]	11.16 ± 0.19[c]	< 0.001
EC45 min (mS/cm)	3.90 ± 0.12[a]	3.42 ± 0.10[b]	3.17 ± 0.08[c]	< 0.001
EC48 h (mS/cm)	9.55 ± 0.26[a]	8.20 ± 0.25[b]	7.54 ± 0.20[c]	< 0.001

L0 group: slaughtered without lairage; L18 group: subjected to 18 hours of lairage before slaughter; L24 group: subjected to 24 hours of lairage before slaughter. MT: muscle temperature. EC: electrical conductivity. Means with different superscripts within a row are significantly different ($p < 0.05$).

using pH 4.00 and pH 7.00 standard buffer solutions.

Electrical conductivity meter (Model Hanna EC 215) outfitted with an electrode of the four rings HI 76303 was used to measure the electrical conductivity (mS/cm).

Measurement of water-holding capacity parameters

Drip loss was calculated using the method outlined by Honikel (1998). At 48 h post slaughter, the meat samples were weighed and suspended in a plastic bag by a nylon cord in order to prevent the meat from coming into contact with the bag's interior surface. The samples were kept in a refrigerator for 48 h at 4 °C. The meat samples were reweighed after storage, and the drip loss % was determined. Using the following formula, the results were reported as the drip loss %

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Drip loss % = [muscle weight before storage (at 48 h) - muscle weight after storage (at 96 h) / muscle weight before storage (at 48 h)] × 100.

For determination of the cooking loss, weighed meat samples (at 48 h post slaughter) were placed in plastic food packaging polyethylene bags and cooked in a water bath at 70 °C for 90 min (Honikel 1998). The samples were cooked, allowed to cool for 30 min at room temperature, then slightly dried with blotting paper before being reweighed. The recorded weight variations were expressed as follows:

Cooking loss % = [muscle weight before cooking (at 48 h) - muscle weight after cooking / muscle weight before cooking (at 48 h)] × 100.

The approach described by El-Rammouz et al. (2004) was used to calculate the thawing loss. At 48 h after slaughter, the samples were put in plastic bags with liquid ethanol that was chilled at 4 °C and then frozen at 0 °C for 36 h. The samples were defrosted for 12 h at 4 °C. Using the following formula, the thawing loss was calculated as the percentage of weight loss after freezing.

Thawing loss % = [muscle weight before thawing (at 48 h) - muscle weight after thawing / muscle weight before thawing (at 48 h)] × 100.

Statistical analysis

Statistical analysis was undertaken using the SPSS Statistics package (Version 27.0). The data are presented in the tables as mean and standard error (SE). The data were analyzed using a model that considered lairage duration as a possible source of variation. The data were analyzed by the One-way ANOVA or the Kruskal-Wallis test after evaluating for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests and for homogeneity using the Levene's test. If the effect of lairage duration was significant,multiple comparisons among the groups (one–one) were performed using the independent-samples T test or Mann-Whitney U test. A probability level (p) of 5% was considered significant.

Results

The effect of lairage time on the meat physico-chemical indicators is shown in Table 1. Most of the studied parameters were significantly influenced by the lairage time, except the musculaire pH measured at 45 min (pH_{45min}), which was not affected among the treatment groups ($p > 0.05$). Muscle glycogen, temperature, and electrical conductivity measured at different *post-mortem* times (45 min and 48 h) were significantly lower in the group subjected to a lairage time of 24 h as compared with other treatments (L0 and L18), whereas the ultimate pH($pH_{\mu 48h}$) was significantly lower in the group that was not subjected to lairage (L0).

Table 2 shows the variation in terms of meat water-

Table 2. Least square means (±SE) and significance levels of meat water holding capacity parameters in relation to different lairage times.

Parameters	Lairage time			*p*-value
	L0 (n = 30)	L18 (n = 30)	L24 (n = 30)	
Drip loss (%)	5.71 ± 0.21[a]	4.68 ± 0.16[b]	4.27 ± 0.12[c]	< 0.001
Cooking loss (%)	37.17 ± 0.73	35.21 ± 0.70	34.83 ± 0.87	0.077
Thawing loss (%)	23.16 ± 0.33[a]	19.48 ± 0.24[b]	17.47 ± 0.15[c]	< 0.001

L0 group: slaughtered without lairage; L18 group: subjected to 18 hours of lairage before slaughter; L24 group: subjected to 24 hours of lairage before slaughter. Means with different superscripts within a row are significantly different ($p < 0.05$).

holding capacity parameters according to the lairage time. Except for cooking loss, which did not differ significantly with lairage times, the levels of drip and thawing loss tended to be significantly lower in the L24 group as compared with L0 and L18 groups. On the other hand, the highest values ($p < 0.05$) of the previous parameters were recorded in the L0 group.

Discussion

It is commonly established in previous studies that stress endured by animals during the pre-slaughter process may induce a rapid drop in muscle glycogen stores (Ferguson and Warner 2008; Li et al. 2018). Thus, the significant decrease in glycogen content observed in the present study during lairage can be explained by a depletion in muscle glycogen related to emotional and physical stress experienced during transportation. Prior to slaughter, the hypothalamic-pituitary-adrenal axis is activated, which results in a release of cortisol and catecholamines, which immediately stimulates muscle and hepatic glycogen mobilization, leading to a decrease in the muscle glycogen levels (Ferguson and Warner 2008). In agreement with our results, El Khasmi et al. (2010) demonstrated that short-term pre-slaughter transport can lead to a drastic depletion of glycogen in camel muscles. Furthermore, Barka et al. (2016) highlighted a significant decrease in glycogen content with an increase in transportation distance. Also, Biffin et al. (2020) studied the effect of two different resting times (overnight vs 7 days) on muscle glycogen levels of alpaca (*Vicunga pacos*) and stated that an extended resting period could induce a significant decrease in glycogen reserves. These previous authors attributed their results to the increased stressors within the novel resting environment. On the other hand, Sterten et al. (2010) believe that muscle glycogen drop during the pre-slaughter process may be a consequence of fasting throughout lairage. After some hours of transportation and feed withdrawal, animals are presumed to need more energy in order to restore their energy balance and consequently to adapt to novel resting situations (Del Campo et al. 2021). Thus, glycogen reserves after a longer fasting period could probably be the primary source of energy available for animals.

In our study, lairage duration had no significant effect on the initial pH measured at 45 min, which is probably related to the short time of pH measurement post slaughter. Indeed, it seemed that this short time was not sufficient for a pronounced variation to appear in this trait. In this context, Barka et al. (2016) have indicated that the drop in pH was primarily due to the conversion of glycogen into lactic acid and, subsequently, an accumulation of lactate in the muscles. On the other hand, previous study has reported that, due to the presence of humps and their fewer glycolytic enzymes, camels have a high gluconeogenesis capacity, which is characterized by a slower glycolytic pathway compared to other animal species. In fact, these unique specificities may cause a slower glycogen degradation and a decrease in the post-mortem pH drop rate (Soltanizadeh et al. 2008). In addition, Abdelhadi et al. (2012) suggested that post-slaughter pH drop in camel meat was remarkably slower than that in beef and attributed their findings to the different properties of muscle fibers in the two species.

It is well-documented in previous reports that the ultimate pH can affect numerous meat features such as tenderness, cooking time, water-holding capacity, flavor, color, and drip loss (Abdelhadi et al. 2017). As observed in our study, the lairage time significantly influenced the ultimate pH values; owing to longer lairage time, glycogen reserves were exhausted and greater ultimate pH values were installed. Most researchers have stated that the ultimate pH of camel meat is principally related to the glycogen content of muscle at the slaughterhouse (Soltanizadeh et al. 2008; Abdelhadi et al. 2017). Lower initial muscle glycogen contents may induce slower rates of the anaerobic glycolysis pathway, which result in a decrease in the production of lactic acid and a reduced rate of post-mortem pH drop (Soltanizadeh et al. 2008). It is clear in our study that the carcasses of L24 camels showed typical pH drop rate and meat quality traits. The lowest ultimate pH values found in the group without lairage (L0) suggest that camels of this group were more

stressed at slaughter than the others (L18 and L24), which may be due to pre-slaughter stress experienced, especially during transportation. In this study, the negative influence of lairage presumably occurred in the shorter lairage group mainly because the animals were not given enough time to adjust to their new environment. Furthermore, these lowest ultimate pH values in the L0 group could be attributed to the increased muscle metabolism just before slaughter associated with higher cortisol concentration, suggesting intense physical activity. Barka et al. (2016) reported that there was significant exhaustion of glycogen stores and a remarkable increase in pHu in camel muscles as the distance to the slaughterhouse increased. In contrast, other authors did not find any significant effect of transportation stressors for 2 h on the ultimate pH of camel muscles (El Khasmi et al. 2010). On the other hand, carcasses obtained from animals held for longer lairage durations exhibited a better rate of pH decrease and greater meat quality, indicating that a lairage time of 24 hours should be necessary, as it can allow physiological recovery and improve meat quality traits such as ultimate pH. Sufficient lairage time in favorable conditions, especially at night, likely permits the animal to rest and recuperate from stressors experienced during preslaughter practices. Unlike other livestock species, very little data are available on the ultimate pH–lairage time relationship in camels. In this context, according to El Khasmi et al. (2010) and Biffin et al. (2020), the ultimate pH of camel species did not differ significantly after a resting period of 10 hours and 7 days.

In our study, rest time had a pronounced influence on muscle temperature measured at different points post slaughter. The group slaughtered without rest registered higher initial (at 45 min) and final temperatures (at 48 h) than the other groups. This increase in muscle temperature might be attributed to the rise in body temperature induced by the physical activity associated with the transportation method used in the present investigation. In this respect, some authors observed an increase in the rectal temperature value of camels at the end of transportation (Lemrhamed et al. 2018). In addition, Elgioushy et al. (2020) demonstrated that there was a significant elevation in the body temperature of camels subjected to physical exercise. In the current study, it is presumed that the group that was not subjected to lairage prior to slaughter might show a faster rigor mortis development accompanied by an increased meat temperature, and lower ultimate pH value. The variation in the previous indicators suggested that stressful practices before the slaughter were associated with intense muscle metabolism and, subsequently, rapid onset of rigor mortis (Dokmanović et al. 2015). Stressful conditions before slaughter increase the muscle metabolic activity continually after death, which leads to an increase in the rate of glycolysis and, consequently, a higher temperature in muscles (Dokmanović et al. 2016; Driessen et al. 2020). On the other side, the lowest levels of muscle temperature at different sampling times observed in our study in the group subjected to a lairage duration of 24 h might be a consequence of the beneficial effect of this extended period.

In our study, it is clear that camels that were not subjected to lairage prior to slaughter had significantly higher electrical conductivity values compared with those that rested for 18 and 24 h. This result could be due to the stress generated by the transportation procedure. In consistence with our findings, Tabite et al. (2019) found that the cortisol concentrations were positively correlated with electrical conductivity in camel muscles. Driessen et al. (2020) have reported that increased physical activity or acute stress immediately prior to slaughter was commonly associated with a higher muscle metabolic activity, which results in an accelerated rate of glycolysis and, consequently, a rise in the electrical conductivity levels. In the same context, Correa et al. (2014) have hypothesized that the locomotory muscles are more susceptible to fast glycogen depletion following physical exercise, which is accompanied by a higher rate of post-slaughter glycolysis in the first hours after slaughter. Another possible explanation for the increase of electrical conductivity in animals that were not subjected to any lairage time (L0) could be muscular fatigue and exhaustion during transportation. In fact, muscle damage can lead to alterations in the cell membrane integrity and, consequently, affect the change of electrolytes between the extra- and intra-cellular compartments (Żywica et al. 2018). Membrane disorder permits the flow of intra- and extra-cellular liquid, which increases fluid content within the muscle, resulting in an increase in electrical conductivity (Saelin et al. 2017). On the other hand, the significant decrease in electrical conductivity in the group subjected to a longer lairage period (L24) could be related to physiological recovery, which reveals that the animals of this group may have lower susceptibility to ante-mortem stress. On the other hand, Rybarczyk et al. (2017) demonstrated that the carcasses of animals exposed to a prolonged fasting time prior to slaughter (24 instead of 18 h) showed higher technological meat traits, such as lower electrical conductivity values. Furthermore, Sterten et al. (2010) have reported a 19% reduction in the glycolytic potential of the *longissimus thoracis* muscle in pigs who fasted for 26.5 h compared with others who fasted for a period of 17.5 h.

In our study, it was evident that drip loss was greater in the animals that were not held in lairage (L0); this finding could be related to the pre-slaughter stress experienced by camels during transport, which is clearly reflected by the significant increase in the most studied

parameters in the animals of this group. This explanation is in agreement with the findings of Tabite et al. (2019), who reported a significant positive correlation between pre-slaughter stress and drip loss in camels. On the other hand, Dokmanović et al. (2016) have hypothesized that the higher drip loss found after short lairage duration can be closely attributed to the increase in muscle metabolic activity. In addition, the higher values of drip loss in the L0 group might be a result of the physical activity in the form of travel to the slaughterhouse, which results in an increase in muscle metabolism and undesirable development of rigor mortis. In the present study, it seemed that the animals from the group without any lairage time showed a faster acidification rate after slaughter than the other treatments and that lower pH levels are obtained in the muscle when the carcass temperature is still high. In fact, this hypothesis was clearly supported by the observed association between the lowest pH and the highest muscle temperature values recorded at 48 h *post* slaughter in this group. The association of high temperature and low pH during *post-mortem* might cause excessive denaturation of myofibrillar and sarcoplasmic proteins, reducing the water-holding capacity (Adzitey and Nurul 2011). This occurs because myofibrillar constituents expel the resulting liquid into the extracellular compartment, which increases in volume and reveals a poor water-holding capacity (Adzitey and Nurul 2011). On the other hand, the significant decrease in drip loss in the groups subjected to lairage periods (L18) and (L24) in the present study confirm that this practice may allow camels to recuperate from the pre-slaughter stress and, consequently, improve their meat quality. Dokmanović et al. (2015) suggested that the lower drip loss observed in the muscles after long lairage could be a result of excessive muscle glycogen depletion and greater meat pH value, which leads muscles to release less water. Furthermore, Rybarczyk et al. (2017) have reported that the drip loss levels in meat were clearly related to the fasting time prior to slaughter. On the whole, the beneficial effect of extended lairage and fasting time prior to slaughter on drip loss values may be explained by the slower post-slaughter glycolysis rate induced by the post-mortem exhaustion of muscle energy reserves (Matyba et al. 2021). In a recent study involving alpaca (*Vicunga pacos*), researchers observed that drip loss was greater in animals who rested for 7 days in lairage than those who rested overnight (Biffin et al. 2020). In line with the previous studies, Najafi et al. (2020) recently found that lambs that are not subjected to lairage before slaughter present the least water-holding capacity in *Longissimus* muscle than those held for 12 and 24 h.

Our results did not reveal any significant effect of lairage duration on cooking loss levels. These findings were in accordance with those of various studies on other livestock species that demonstrated that cooking loss was unaffected by lairage time (Gajana et al. 2013; Li et al. 2018; Yalcintan et al. 2018). Rybarczyk et al. (2017) reported that the fasting time prior to slaughter did not induce any significant variations between 18- and 24-hour feed withdrawal groups in terms of cooking loss. This insignificant effect of lairage time on cooking loss in the previous multiple reports might be attributed to the drastic cooking conditions attenuating this effect. Several other authors have stated that cooking loss is not significantly influenced by pre-slaughter treatments which have a great ability to induce higher stress levels, such as transport conditions (Gajana et al. 2013), handling practice (Oliveira et al. 2018), and physical exercise (Permana et al. 2020). In this context, Biffin et al. (2020) noted that meat from alpaca (*Vicunga pacos*) stored in lairage for 7 days showed higher cooking loss levels than those of overnight lairage. In fact, the longer lairage period applied by the previous authors compared with that in our study might be a possible explanation for the contradictory results between the two studies.

In the present study, the lairage duration had a significant effect on thawing loss. Hence, the greater levels of thawing loss observed in the animal group slaughtered immediately after transport than others could be ascribed to the transportation stress. This hypothesis is supported by Tabite et al. (2019), who found that higher pre-slaughter stress level was significantly associated with weak water-holding capacity in camel muscles. This also concurs with Gajana et al. (2013), who reported that a longer transportation time and traveled distance might cause an increase in thawing loss values. It is well known that a rise in physical activity or physiological stress in livestock animals throughout pre-slaughter handling and transportation leads to altered muscle metabolism and, subsequently, an increase in the glycolysis rate, especially during the early post-mortem time (Oliveira et al. 2018). Indeed, these changes might lead to a low meat pH, which can result in poor water-holding capacity (Ekiz et al. 2012; Huang et al. 2018; Najafi et al. 2020). According to Vermeulen et al. (2015), a lower pH owing to lactic acid leads to increased protein denaturation within the muscle, which results in lower water-holding capacity levels. The interaction between lairage and water-holding capacity in alpaca (*Vicunga pacos*) meat was recently investigated by Biffin et al. (2020), who noted that a longer lairage period (7 days vs. overnight) might induce a significant deterioration of the water-holding capacity. On the other hand, the lowest values of thawing loss in this study were observed after a longer lairage duration (24 hours) than after shorter ones, which might indicate that this rest period had a pronounced effect in terms of physiological

recovery, and it could alleviate stress induced by pre-slaughter handling practices and improve the meat quality. Besides, another possible explanation of this finding could be the extended fasting time in animals submitted to long lairage. This suggestion was supported by Rybarczyk et al. (2017), who reported lower thawing loss levels in pigs who fasted for 24 hours than those for 18 hours.

Conclusion

The results of this study indicate that lairage time before slaughter has a significant influence on several meat quality parameters. It appears that camels slaughtered without any lairage time are more stressed at the time of slaughter than those subjected to a lairage duration of 18 and 24 hours. An extended lairage period before slaughter has beneficial effects on the final product quality. Therefore, we can conclude that lairage for 24 hours is needed in the field conditions studied here to allow camels to recover from stress induced by pre-slaughter practices. On the whole, the determination of adequate lairage time depends on the pre-slaughter process. For this reason, lairage time should be adjusted according to the stressors. Otherwise, excessively short or long lairage periods might induce acute or chronic stress, which could compromise animal welfare and reduce meat and carcass quality.

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