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The impact of overnight lairage on meat quality and storage stability of pork loin

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Abstract

Lairage, a part of the animal welfare practices, has been known to mitigate pre-slaughter stress in animals. However, research investigating the relationship between lairage and pork meat quality remains scarce. In this study, we conducted a comparative analysis of the physicochemical quality and storage stability of pork from pigs subjected to immediate slaughter (CON) and those provided with a 24 h lairage before slaughter (LRG) over a 7-day storage period. The loins from 20 castrated pigs in each group, respectively, were collected at 1, 3, 5, and 7 days and used for analysis of meat quality and storage stability, including pH, meat color, moisture, water holding capacity, drip loss, cooking loss, shear force, fatty acid composition, lipid oxidation, antioxidant activity, and electrical resistance. Overall, there were no significant differences in physicochemical meat quality parameters between CON and LRG groups. Similarly, no differences were observed in the storage stability of pork including 2-thiobarbituric acid reactive substances, 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity and electrical resistance. However, the proportion of unsaturated fatty acids was significantly higher in LRG compared to CON. In conclusion, 24 h lairage for castrated pigs had limited impact on meat quality and storage stability but led to an increase in the unsaturated fatty acid proportion.

Keywords: Animal welfare, Lairage, Pork, Meat quality, Storage stability

INTRODUCTION

Over the past 20 years, consumer demand for animal welfare has witnessed a substantial increase. Ethical consciousness among consumers has reached a point where they refuse purchasing products failing to meet their animal welfare standards [1]. Font-i-Furnols suggested that meat quality now encompasses socio-ethical values, including consideration like production system, animal welfare, and environmental impacts, with animal welfare emerging as an important factor influencing consumer

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Availability of data and material
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Authors' contributions
Conceptualization: Nam KC, Moon SS, Jung JH, Jo C.
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Formal analysis: Choi M, Lee D.
Methodology: Choi M, Lee D, Nam KC.
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Investigation: Choi M, Lee D.
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Ethics approval and consent to participate
The experiment was approved by the institutional animal care and use committee (IACUC) at Sunchon National University, Suncheon, Korea (SCNU IACUC-2020-12).

purchasing decisions [2]. Furthermore, it is widely known that preslaughter stress can exert adverse effects on meat quality parameters, such as ultimate pH and drip loss [3]. Consequently, effective control of preslaughter stress is imperative to ensure optimal meat quality [4]. Previous studies have shown that the implementation of animal welfare practices helps alleviate stress in animal as evidenced by indicators such as blood cortisol levels or heart rates [5,6,7]. As a result, the importance of animal welfare has been consistently emphasized.

Pigs are commonly known to be sensitive to stress [8]. Therefore, various forms of stress can significantly affect the quality of pork [9]. Many previous studies have consistently affirmed that stress experienced during the preslaughter period exerts adverse effects on pork quality. These effects include lower pH levels, reduced water holding capacity (WHC) and moisture content, along with higher drip loss, electrical conductivity, and L^* value [10,11,12]. For these reasons, it becomes evident that minimizing stress in domestic animals is significantly important. Accordingly, many studies have focused on developing strategies to alleviate the preslaughter stress [13,14,15].

Lairage, an important preslaughter handling process that provides a rest period for animals before they are slaughtered to reduce stress and fatigue that they may have experienced during transportation and therefore this process ultimately prevents quality deterioration [7]. Extensive research has been conducted on the effects of lairage on animal stress and meat quality, with a specific focus on the duration of lairage. Liste et al. suggested that lamb meat with 12 h lairage showed lower levels of cortisol, lactate, and glucose compared to meat without lairage [16]. Additionally, it exhibited higher WHC and lower b^* value. Díaz et al. showed similar results that suckling lamb with 24 h lairage had lower b^* value and higher WHC than lamb without lairage [17]. Moreover, they also indicated that, after five days of storage, the differences of meat color and WHC between the groups became reduced. Another previous study proposed that pre-slaughter fasting could be useful for increasing ultimate pH and lowering the possibility of pale, soft, and exudative (PSE) pork [18]. However, the existing literature usually did not consider the above aspects as the main arguments of the paper; instead, it predominantly focused on stress indicators like cortisol [19]. Therefore, there is scarce information regarding the relationship between meat quality and lairage, especially in pork. In addition, as mentioned before, while stress is influence on the composition of the pork, limited research explores the relationship between lairage and storage stability of pork.

In this regard, we hypothesized that lairage may enhance pork quality during storage and improve storage stability. Therefore, we aimed to examine the effects of overnight lairage on quality characteristics and storage stability-related properties during 7 days of storage by comparing samples of pigs without lairage.

MATERIALS AND METHODS

Animals and experimental design

The experimental design of the present study is described in Fig. 1. A total of 40 castrated pigs were raised in an animal-friendly farm, Cheil breeding stock farm (Incheon, Korea) until their live weight reached 30 kg. A stocking density of the farm was over 0.3 m^2 per animal. Then, they were transported to Yuunwoo animal welfare-friendly farm (Hwasung, Korea) and raised in four separate pens ensuring a stocking density of over 1 m^2 per animal until they reached the target weight of 110 kg. Each pen accommodated 10 pigs, with 5 of them undergoing an overnight lairage for 24 h without access to food, but with free access to water before being slaughtered (LRG). The pigs assigned to LRG were transported one day prior slaughter, while the other 5 pigs were slaughtered immediately upon arrival at the abattoir (CON). As a result, a total of twenty pigs were allocated

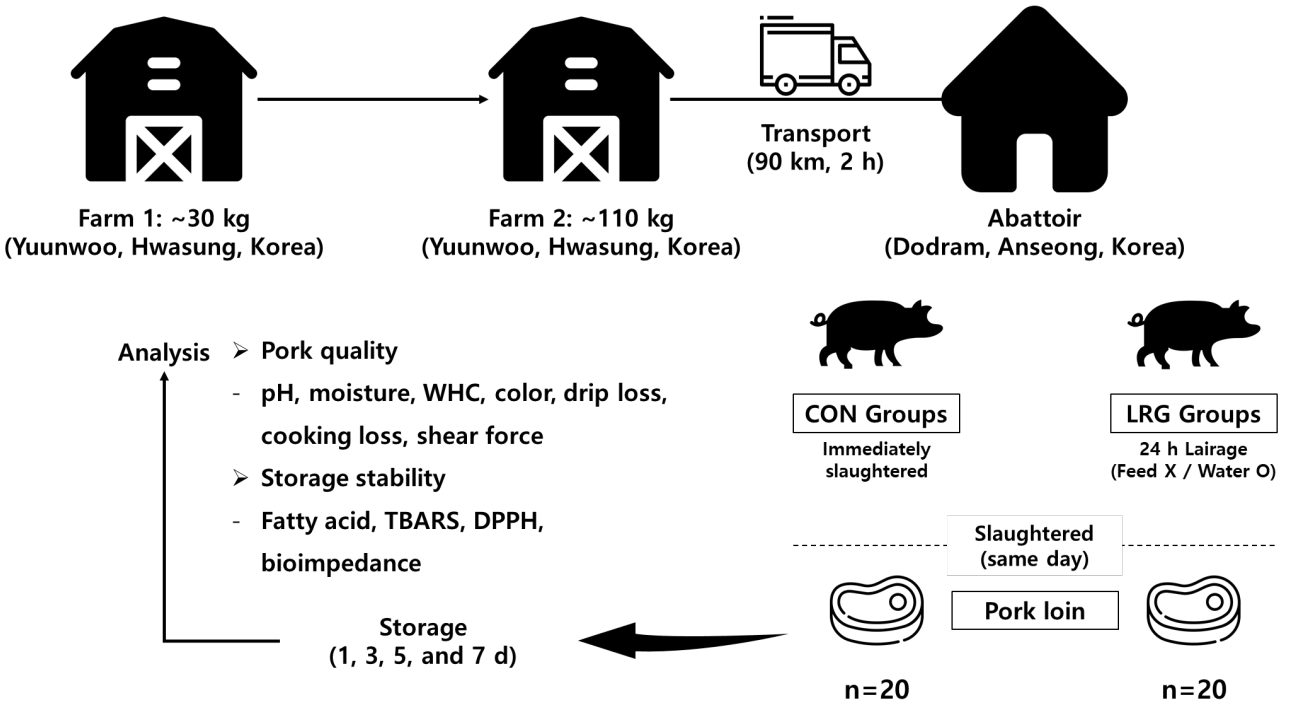

Fig. 1. A schematic diagram of the experiment design. On day 1, 20 pigs designated for the lairage (LRG) group were brought from the farm and held in a lairage area for 24 h. On day 2, 20 pigs designated for the control (CON) group were brought from the same farm to the abattoir directly. Both groups were slaughtered on the same day, and carcasses from each group were randomly selected and loin cuts from the carcasses were collected. Each loin cut was divided into four blocks and stored for 1, 3, 5, and 7 days and used for pork quality and storage stability analyses. WHC, water holding capacity; TBARS, 2-thiobarbituric acid; DPPH, 2,2-diphenyl-1-picrylhydrazyl.

to each treatment group. The abattoir (Dodram, Anseong, Korea) was approximately 90 km far from the farm, which took approximately 2 h for pig transportation. During transportation, the temperature was maintained in the enclosed truck at around 15℃–18℃ to minimize stress. The detailed information of carcasses is shown in Table 1. Both groups were slaughtered on the same day, and the loin cuts were collected, vacuum-packed, and transported to the laboratory in a cooler with ice both top and bottom. The loins were stored for 1, 3, 5, and 7 days to investigate the effect of storage on pork loin from CON and LRG. The experiment was approved by the institutional animal care and use committee (IACUC) at Suncheon National University, Suncheon, Korea (SCNU IACUC-2020-12).

pH

A meat sample (2 g) was mixed with 18 mL of distilled water and homogenized using a homogenizer (Polytron PT10-35 GT, Kinematica AG, Luzern, Switzerland) at 11,000 rpm for 60 s. The homogenates were filtered using a Whatman No. 4 filter paper (Whatman PLC, Kent, UK)

Table 1. The carcass characteristics and fat content of the pigs with no (CON) or 24 h lairage (LRG)

Treatment	Backfat depth (mm)	Carcass weight (kg)	Fat content (%)
CON	22.20[b]	88.05	3.38
LRG	23.25[a]	89.50	3.36
SEM[1)]	0.297	0.611	0.233

[1)]Values are presented as n = 40.

[a,b]Different letters within the same column indicate significant difference ($p < 0.05$).

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and the pH of each filtrate was measured using a pH meter (SevenExcellence™, Mettler Toledo International, Schwerzenbach, Switzerland). Before measurement, the pH meter was calibrated using standard buffers with pH values of 4.01, 7.00, and 9.21.

Meat color

Meat color was measured using a colorimeter (CM-5, Konica Minolta Sensing, Osaka, Japan). Before measurement, the sample was exposed to air for 30 min to bloom, and the instrument was calibrated using a standard white plate. The illuminant was D65 and the standard observer was set to 10°, and the meat color was measured using a plate with a diameter of 30 mm. The results were expressed as Commission Internationale d'Eclairage (CIE) L*, a*, and b*, which represent lightness, redness and yellowness, respectively. Each sample was measured three times and its average value was used as one replicate.

Moisture content

The moisture content was measured according to the AOAC method with some modification. The weight of a pre-dried aluminum dish was measured and three grams of meat sample was placed on the dish. The sample was then dried in a dry oven at 104℃ until it reached a constant weight, and then transferred to the desiccator. The weight of the dried sample with the dish was measured. The moisture content was calculated as a percentage using the following equation:

$$\text{Moisture}(\%) = \frac{(P_0 + M_0) - P_1}{M_0} \times 100$$

where M_0 represents the weight of the sample. P_0 and P_1 represent the weight of the dish before drying and the weight of the dish with sample after drying, respectively.

Water holding capacity

Five grams of the sample were centrifuged at 1,000×g for 10 min at 5℃ (Combi-514R, Hanil, Daejeon, Korea). The weight of the meat sample was then measured, and the WHC was calculated using the following equation:

$$WHC(\%) = \frac{M \times S_1}{M \times S_0} \times 100$$

where M represents the value for moisture content, S_0 represents the initial sample weight, and S_1 represents the weight of the sample after centrifugation.

Drip loss and cooking loss

Drip loss was calculated by measuring the ratio of weight loss before and after storage [20]. Cooking loss was calculated by measuring the weight difference before and after heating a sample (30 mm × 50 mm × 10 mm; width × length × height) until its core temperature reached 75℃ using water bath. The calculation formula is as follows:

$$\text{Cooking loss}(\%) = \frac{C_0 - C_1}{C_0} \times 100$$

where C_0 is the initial weight of the sample and C_1 is the weight of the sample after cooking.

Warner-Bratzler shear force

The sample was cut into a size of 40 mm × 50 mm × 10 mm (width × length × height), then cooked until the core temperature of the sample reached 75℃. After that, the sample was re-cut into a size of 10 mm × 20 mm × 10 mm (width × length × height) to make the shape accurate and consistent [21]. The Warner-Bratzler blade was attached to a texture analyzer (TA-XT2, Stable Micro System, Surrey, UK) and the muscle fiber direction of the sample was placed perpendicularly to the blade to measure the shear force. The instrumental condition was set to pre-test speed 2.0 mm/s, test speed 2.0 mm/s, and post-test speed 5.0 mm/s. The shear force was expressed as kgf.

Fatty acid composition

Fatty acid composition of the meat sample was measured according to O'Fallon et al. and Uyen et al. with some modification [22,23]. The sample (1 g) was mixed with 0.7 mL of 10 N KOH and 6.3 mL of methanol and placed in a constant-temperature water bath at 55℃. The mixture was vigorously shaken every 30 min for 1 h and 30 min. After cooling in ice water for 1–2 min, 0.58 mL of 24 N H_2SO_4 was added to the samples and the mixture was shaken again every 30 min for 1 h and 30 min while being heated in the constant-temperature water bath at 55℃. After cooling in ice water, 3 mL of hexane was added, and the mixture was centrifuged at 3,000×g for 5 min using a Combi-514R centrifuge (Hanil) to separate the fatty acid methyl esters. The upper layer was transferred to a vial using a Pasteur pipette, injected into the gas chromatograph equipped with the HP-88 column (60 m × 0.2 mm × 250 μm) and a flame ionization detector (Agilent 7890 series, Agilent Technologies, Wilmington, DE, USA). The injector was set to a split ratio of 25:1 with a temperature of 250℃, and the temperature of the detector was set to 250℃. A high-purity mixture of air, H_2, and He was used as a carrier gas with a flow rate of 400 mL/min for air and 40 mL/min for H_2.

2-Thiobarbituric acid reactive substances

The sample (5 g) was mixed with 15 mL of distilled water in a 50 mL test tube and homogenized. Then, 1 mL of the homogenate was transferred into a disposable test tube, and 50 μL of 7.2% butylated hydroxytoluene in ethanol (w/v) and 2 mL of 20 mM thiobarbituric acid (TBA) in 15% trichloroacetic acid (TCA) solution (w/v) were added into the tube. The mixture was thoroughly vortexed and incubated at 95℃ in a water bath for 15 min, and cooled for 10 min. The mixture was mixed again, and centrifuged at 2,265×g at 5℃ for 15 min (Combi-514R, Hanil). The absorbance of the supernatant was measured at 531 nm. Distilled water (1 mL) and TBA/TCA solution (2 mL) were mixed together to be used as a blank. The TBARS value was expressed as mg malondialdehyde (MDA) per kg of meat sample.

2,2-Diphenyl-1-picrylhydrazyl radical scavenging activity

The meat sample (2 g) was mixed with 18 mL of distilled water and homogenized at 11,000 rpm for 1 min using a homogenizer (Polytron PT10-35 GT, Kinematica AG). The homogenate was then centrifuged at 2,265×g for 10 min (Combi-514R, Hanil). After centrifugation, 0.4 mL of the supernatant was mixed with 1.6 mL of distilled water and 2 mL of 0.2 mM DPPH in methanol solution. The mixture was incubated at room temperature for 60 min in the dark, and the absorbance of the sample was measured at 517 nm. Ascorbic acid was used as a reference and distilled water absorbance was also measured for control. Lastly, the DPPH radical scavenging activity was calculated using the following formula:

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$$\text{DPPH radical scavenging activity}(\%) = \frac{\text{Absorbance of Control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100$$

Electrical resistance

Each sample's electrical resistance was measured using an RCL electric bridge (630A automatic RCL meter with an adaptor PM 9542A, Philips, Hamburg, Germany). The measurement was performed by inserting a probe (YL-69, Jiexing, Guangdong, China), which is a soil moisture sensor, into the center of the sample to obtain the impedance (Z, Ω) value. The measurement was repeated three times to obtain the mean value.

Statistical analysis

The results were analyzed via one- and two-way analysis of variance using SAS 9.4 (SAS Institute, Cary, NC, USA). Tukey's multiple test was used to determine the significant differences between sample groups at $p < 0.05$.

RESULTS AND DISCUSSION

Comparative analysis of the physicochemical characteristics of immediate slaughte and 24 h lairage before slaughter groups

We conducted a comparative analysis of the differences in the physicochemical quality of the CON and LRG groups over a 7-day storage period, including pH, meat color, moisture, WHC, drip loss, cooking loss, and shear force (Table 2).

pH

There were no significant differences in pH between the CON and LRG groups during five days of storage, but on day 7, the LRG group showed significantly higher pH compared to CON ($p < 0.05$) (Table 2). The overall pH values of pork were within an average pH range of pork loin (from 5.5 to 5.8) which was reported by Warner et al., indicating that lairage did not directly affect the incidence of PSE or Dark Firm Dry (DFD) meat [24]. It was hard to find any research comparing samples that underwent no lairage before slaughter and those with a 24 h lairage (long period lairage). However, the previous study compared short and long period lairage indicated that there was no significant difference observed in the ultimate pH of pork between short (8 min to 2.7 h) and extended period lairage (14 h to 21.5 h) [9]. Furthermore, Fernandez et al. and Śmiecińska et al. reached similar conclusions, finding no significant difference in pH between groups subjected to short lairage and those with an extended lairage period [25,26]. This suggests that the pork production system can accommodate an overnight lairage period as a pre-slaughter method, followed by the findings outlined in the earlier paper by Miranda-de la Lama et al. [27].

The pork samples were stored for days 1-7 to simulate retail condition, and during storage, the meat pH within each group did not differ significantly during seven days of storage. Importantly, meat pH is strongly correlated with other physicochemical quality attributes such as meat color and WHC [28]. Therefore, the similar pH value between both groups might lead to the similar meat color and WHC observed in our study. Meanwhile, as Liste stated, lairage could reduce the levels of cortisol, lactate, and glucose [16]. These are stress metabolites, and if their blood levels are high, it leads to excessive postmortem muscle metabolism and lowers the pH level [29]. However, since there was no difference in this study, further research is needed from a metabolite perspective.

Table 2. Changes in the physicochemical traits of pork loin from the pigs with no (CON) or 24 h lairage (LRG) during seven days of storage

Trait	Treatment	Storage period (d)				SEM[1]
		1	3	5	7	
pH	CON	5.70	5.68	5.70	5.68^{b}	0.018
	LRG	5.74	5.74	5.76	5.74^{a}	0.028
	SEM[2]	0.026	0.025	0.023	0.020	
CIE L*	CON	55.72^{X}	54.61^{Y}	56.11^{aX}	56.98^{X}	0.389
	LRG	54.85^{X}	54.12^{Y}	55.45^{bX}	56.44^{X}	0.409
	SEM	0.368	0.361	0.390	0.428	
CIE a*	CON	15.89^{YZ}	16.76^{X}	16.39^{XY}	15.19^{Z}	0.194
	LRG	15.80^{YZ}	16.91^{X}	16.18^{Y}	15.29^{Z}	0.159
	SEM	0.181	0.158	0.126	0.206	
CIE b*	CON	5.40	5.37	5.83	5.93	0.168
	LRG	5.56	5.21	5.61	5.68	0.153
	SEM	0.136	0.104	0.167	0.217	
Moisture (%)	CON	74.11^{Y}	74.82^{X}	74.00^{aY}	73.73^{Y}	0.174
	LRG	73.61^{Y}	74.53^{X}	73.26^{bY}	73.51^{Y}	0.196
	SEM	0.191	0.188	0.158	0.201	
WHC (%)	CON	69.19^{X}	64.28^{Y}	63.53^{Y}	63.18^{Y}	0.975
	LRG	69.32^{X}	65.06^{XY}	62.57^{Y}	61.35^{Y}	1.164
	SEM	0.717	1.104	1.115	1.279	
Drip loss (%)	CON	-	3.81^{Y}	6.42^{X}	7.47^{X}	0.369[3]
	LRG	-	3.36^{Y}	5.99^{X}	7.05^{X}	0.381[3]
	SEM	-	0.289	0.397	0.426	
Cooking loss (%)	CON	20.74^{Z}	25.33^{Y}	27.93^{X}	24.58^{Y}	0.479
	LRG	21.06^{Z}	24.99^{Y}	28.07^{X}	24.46^{Y}	0.466
	SEM	0.260	0.502	0.610	0.448	
Shear force (kgf)	CON	5.70^{X}	4.19^{Y}	3.54^{YZ}	3.02^{bZ}	0.178
	LRG	6.01^{X}	4.38^{Y}	3.66Z	3.32^{aZ}	0.174
	SEM	0.259	0.177	0.130	0.091	

[1]Values are presented as n = 80.

[2]Values are presented as n = 40.

[3]Values are presented as n = 60.

[a,b]Different letters within the same column indicate significant difference ($p < 0.05$).

[X–Z]Different letters within the same row indicate significant difference ($p < 0.05$).

WHC; water holding capacity.

Meat color

There were no significant differences in any of the L*, a*, and b* values between CON and LRG groups at all storage periods ($p > 0.05$) except for L* value on day 5, where CON showed higher value than LRG ($p < 0.05$) (Table 2). Within the CON group, the L* value decreased on day 3 but then increased on day 5, while the a* value increased on day 3 and decreased on day 7. The b* value showed no significant changes throughout the storage period in CON. Conversely, in the LRG group, the L* value decreased on day 3, then increased on day 5. Regarding the a* value of LRG, it increased on day 3 but gradually decreased on days 5 and 7. Similar to CON, the b* value in LRG showed no significant changes during the storage period. Furthermore, a two-way ANOVA (Table 3) revealed that the presence of lairage only had a significant effect on L* value, while storage time significantly affected all meat color traits in both in CON and LRG. These findings align with a

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Table 3. Meat color of pork loin in relation to lairage and storage period

Trait	Lairage (L)		SEM	Storage period (D)				SEM	*p*-value		
	CON[1)]	LRG		1 d	3 d	5 d	7 d		L	D	L×D
CIE L*	55.86^{X}	55.22^{Y}	0.200	55.29^{YZ}	54.37^{Z}	55.78^{XY}	56.71^{X}	0.282	0.025	*	0.964
CIE a*	16.06	16.05	0.089	15.84^{Y}	16.84^{X}	16.29^{Y}	15.24^{Z}	0.125	0.918	*	0.732
CIE b*	5.63	5.52	0.080	5.48^{XY}	5.29^{Y}	5.72^{X}	5.81^{X}	0.114	0.306	0.006	0.563

[1)]CON, the pork loin without any lairage process; LRG, the pork loin with 24-hour lairage.

[2)]Values are presented as n = 160.

[X-Z]Different letters within the same row indicate significant difference ($p < 0.05$).

*$p < 0.0001$.

previous study, which compared the meat qualities of pigs subjected to four different lairage times (0 h, 3 h, 8 h, and 24 h) [30]. Their study found that the initial L* value was higher in 0 h lairage group than in 24 h lairage group, which was in accordance with our results on day 5. However, the initial a* value was lower in 0 h group. Lastly, the b* value did not show significant difference between 0 h and 24 h groups, which corresponds to our result. In another study, the L* value and a* value of pork loin between 2 h and overnight lairage groups were not significantly different [31].

Moisture and water holding capacity

The moisture content was not significantly different between CON and LRG groups throughout the whole storage period except for day 5, where CON had a significantly higher value than LRG ($p < 0.01$) (Table 2). In CON group, the highest moisture content was observed on day 3, with no significant differences noted on the other days. Similarly, in LRG, the highest value was also observed on day 3, with no significant differences on the other days.

Similarly, there were no significant differences in WHC were observed throughout the entire storage period. In CON group, the WHC was the highest at the initial storage day, with no significant differences between days 3, 5, and 7. Conversely, in LRG, the highest value of WHC was observed on day 1 but gradually decreased, showing significant differences on days 5 and 7. The distribution of water within the muscle tissue includes both intra-myofibrillar and extra-myofibrillar spaces of the cells, causing changes in the intracellular structure that directly impact the WHC. Moreover, as postmortem rigor progresses, the space within the myofibrils decreases gradually, leading to the extrusion of water and resulting in a higher drip loss.

Drip loss and cooking loss

Both drip loss and cooking loss did not show significant differences throughout the entire storage period between CON and LRG (Table 2). In CON group, drip loss significantly increased from day 3 to day 5 ($p < 0.05$), while cooking loss showed a significant increase over the storage period, reaching its highest value on day 5, followed by a significant decrease on day 7. Similar trends in the changes of drip loss and cooking loss were observed in LRG. Drip loss is closely related with pH and WHC [28,32]; higher pH and WHC resulted in less drip loss. Hence, the similar pH and WHC values observed in both CON and LRG groups likely contributed to the absence of significant difference in drip loss and cooking loss.

Warner-Bratzler shear force

Except for day 7 where CON showed a lower value than LRG ($p < 0.05$), there were no significant difference in the shear force value between CON and LRG ($p > 0.05$) (Table 2). In CON group, the shear force decreased gradually from 5.70 on the initial day of storage to 3.02 on day 7 ($p <$

0.05). Similarly, in LRG, the shear force also showed a gradual decrease from 6.01 on day 1 to 3.32 on day 7 during storage ($p < 0.05$). Both groups exhibited a decrease in shear force values with increasing storage days, which can be attributed to the degradation of Z-disks in myofibrillar structures and the weakening of actin-myosin interactions caused by enzymes which are present in the meat [33,34].

Overall, the effect of lairage on the physicochemical meat quality attributes was not significant in this study.

Differences in fatty acids composition on lairage duration

Overall, there were no significant differences in the fatty acid composition between CON and LRG (Table 4). According to the previous study, differences in fatty acid composition were observed depending on the stress genotype of pigs [35]. In the study, the stress-positive pigs had the lower percentages of the C14 and C16 fatty acids (C14:0, C16:0, and C16:1), but higher

Table 4. Fatty acid composition (%) of pork loins with no (CON) or 24 h lairage (LRG)

Variables	CON	LRG	SEM[1)]
$C_{10:0}$	0.13	0.12	0.003
$C_{12:0}$	0.11	0.11	0.002
$C_{14:0}$	1.55	1.47	0.330
$C_{16:0}$	24.91	24.32	0.228
$C_{16:1}$	3.31	3.33	0.092
$C_{18:0}$	12.07	11.63	0.218
$C_{18:1}$	42.99	43.94	0.604
$C_{18:2}$	9.69	9.61	0.395
$C_{18:3}$	0.70	0.70	0.020
$C_{20:2}$	0.32	0.31	0.009
$C_{20:3}$	0.25	0.25	0.016
$C_{20:4}$	1.84	1.92	0.164
$C_{20:5}$	0.04	0.05	0.003
$C_{22:6}$	0.04	0.04	0.003
$C_{24:1}$	0.32	0.35	0.026
Total	98.26	98.14	0.193
SFA	38.76	37.65	0.394
UFA	59.49^{Y}	60.49^{X}	0.339
MUFA	46.62	47.62	0.626
PUFA	12.88	12.87	0.550
UFA/SFA	1.54^{Y}	1.61^{X}	0.025
n-6/n-3	11.50	11.45	0.481
n-6	11.84	11.84	0.542
n-3	1.03	1.03	0.021
AI	0.53^{X}	0.50^{Y}	0.008
TI	1.19^{X}	1.14^{Y}	0.018
P/S	0.33	0.34	0.017

[1)]Values are presented as n = 30.

[X,Y]Different letters within the same row indicate significant difference ($p < 0.05$).

SFA, saturated fatty acid; UFA, unsaturated fatty acid; MUFA, monounsaturated fatty acid; PUFA; polyunsaturated fatty acid; AI, atherogenic index; TI, thrombogenicity index; P/S, ratio of PUFA to SFA.

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proportion of C18:0 acid than in the stress-negative pigs. In present study, although the percentage of an individual fatty acid did not show any significant difference, the sum of unsaturated fatty acids was significantly higher in LRG compared to CON. As a result, LRG showed significantly lower atherogenic index (AI) and thrombogenicity index (TI) compared to CON. It has been known that unsaturated fatty acids have various effects on cancer, diabetes, cardiovascular disease and even on cognitive function [36]. Furthermore, lower values of AI and TI indicate better nutritional lipid quality as these indexes indicate the reduced probability of the incidence of atherosclerotic and thrombus formation, respectively [37]. Therefore, it could be interpreted that overnight lairage might have some positive impact on human health to some extent.

Comparative analysis of the storage stability of pork from lairage

Lastly, to examine the differences in storage stability between CON and LRG during storage, we measured parameters including TBARS as an index of the degree of lipid oxidation, DPPH radical scavenging activity, and electrical resistance, which is known to be effective in freshness prediction [38]. For this analysis, it was only measured at day 1 and day 7, representing the initial and final day of whole storage for comparing changes in storage stability.

TBARS values were significantly higher on day 7 compared to day 1 in both the CON and LRG groups, with no significant difference between the two groups (Table 5). On the other hand, DPPH radical scavenging activity showed no significant differences between days 1 and 7 within each group, and similarly, no significant difference observed between the two groups. These findings suggest that a 24 h lairage did not significantly influence on the oxidation of meat.

According to Zhang et al., the tissue structure or cellular morphology of meat during storage can impact electrical parameters, and therefore electrical resistance holds potential predicting meat freshness like total volatile basic nitrogen (TVB-N) value [38]. In CON group, the electrical resistance decreased significantly from day 1 to 7 (Table 5). Similarly, in LRG, there was a significant decrease in electrical resistance from day 1 to day 7, with no significant difference between the two groups. Therefore, considering the results of TBARS, DPPH, and electrical resistance, it appears that overnight lairage did not show a significant effect on storage stability of pork.

Previous studies have suggested that overnight lairage may lead to more frequent instances of fighting among pigs and increased occurrence of skin blemishes [39]. Additionally, it was proposed

Table 5. Changes in the TBARS, antioxidant activity, and electrical resistance of pork loin from the pigs with no (CON) or 24 h lairage (LRG) during seven days of storage

Trait	Treatment	Storage period (d)		SEM[1)]
		1	7	
TBARS (mg MDA/kg)	CON	0.17^{Y}	0.21^{X}	0.004
	LRG	0.18^{Y}	0.21^{X}	0.003
	SEM	0.004	0.003	
DPPH radical scavenging activity (%)	CON	48.88	48.55	0.788
	LRG	49.44	49.09	1.117
	SEM	1.021	0.909	
Electrical resistance (Auto [Ω])	CON	205.60^{X}	117.82^{Y}	5.740
	LRG	203.00^{X}	118.45^{Y}	4.465
	SEM	7.143	1.367	

[1)]Values are presented as n = 40.

[X,Y]Different letters within the same row indicate significant difference ($p < 0.05$).

TBARS, 2-thiobarbituric reactive substances; MDA, malondialdehyde; DPPH, 2,2-diphenyl-1-picrylhydrazyl.

that the optimal lairage time for pigs could be between 1 and 3 h [40]. Although significant differences were not observed in most quality indicators between CON and LRG groups in the present study, the results could contribute to the establishment of more strategic conditions for animal welfare in pig production. In addition, it may be advisable to consider exploring the effect of a variety of lairage periods from short to long periods in future studies.

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