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PH POST-MORTEM ON POULTRY CARCASSES IN A SLAUGHTER LINE FOR INDUSTRIAL IDENTIFICATION OF PSE (PALE, SOFT, EXUDATIVE) AND NORMAL MEAT

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ABSTRACT

Background. Some quality defects can cause changes in the attributes of meat, among which we can highlight PSE (Pale, Soft and Exudative) meats. PSE results from a sudden drop in pH while the carcass is still at an elevated temperature. The identification of PSE meat has previously been done through the measurement of pH and *L** value (Luminosity). Studies suggest that a more accurate assessment of the kinetics of pH and temperature decrease needs to be conducted to better understand the etiology of PSE meat in poultry. The objective of this work was to obtain a glycolytic curve for normal meat and chicken PSE through the analysis of pH, *L**, and WHC (Water holding capacity).

Materials and methods. A glycolytic curve was obtained for normal meat and PSE through pH, *L** and WHC. Samples of breast fillets were obtained from carcasses immediately after sampling from the chiller, and the pH, temperature, and *L** were measured between the times of 1h35min and 25h35min postmortem (pm). The WHC analysis was performed at 25h35 pm.

Results. As of 8h35 pm, the pH values of the meat were found to have stabilized, with the pH of the PSE meat being 5.69 ±0.07, and of the regular meat being 5.93 ±0.09. The final pH (25h35min pm) was 5.98 ±0.06 and the *L** 57.30 ±2.39 for normal meat, while the result for the PSE meat was 5.72 ±0.06 for pH and 59.44 ±1.51 for *L**. The WHC results showed a difference between the normal chicken fillets and PSE, which were 67.19 ±3.13 and 64.45 ±2.66 respectively.

Conclusion. We conclude that under industrial conditions of slaughter, the resolution of *rigor mortis* occurs 8h35 pm.

Keywords: chicken, chiller, pH, lightness, water hold capacity, meat quality, glycolytic curve

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INTRODUCTION

During the year 2021, 14.329 million tons of chicken meat were produced in Brazil, generating a Gross Production Value about US$20 billion. Regarding the exports, they were 4.610 million tons, generating US$7.6 billion. In addition to the financial data being expressive, the consumption of this protein source is essential, and in that same year 45.56 kg were consumed per inhabitant (Ministério da Agricultura..., 2022). The success of the production and consumption of chicken meat in the country has mainly been attributed to the technological advancement of the sector. This includes the improvement in genetics, as well as management that has allowed the achievement of a better conversion rate and the reduction of fattening times with a consequent reduction in the price of meat and increased consumption (Moraes and Capanema, 2012).

The color, texture, and water holding capacity (WHC) of the chicken breast are important quality attributes and are associated with the pH decline before and after the onset of rigor mortis. The industry's challenge has been to supply consumers with meat products that are soft, juicy, and with a pleasant color and flavor (Fletcher, 2002). However, the tenderness of chicken meat has not been a problem for the industry, although some changes in color and WHC result in quality losses as they are considered to be undesirable characteristics. Poultry which undergoes changes in pH, color, and *postmortem* exudation is known as PSE meat (Pale, Soft and Exudative) (Olivo and Olivo 2006). The occurrence of these pale, soft, and exudative meats has been attributed to a sharp drop in pH while poultry carcasses are still at an elevated temperature (35°C) which causes the denaturation of myofibrillar and sarcoplasmic proteins (Barbut, 1997). The factors that influence the formation of PSE meat in birds can be attributed to pre-slaughter management (Zhang et al., 2012; Langer et al., 2010), to rearing systems (Carvalho et al., 2015), or to factors associated with the characteristics intrinsic to the skeletal striated musculature of these birds.

Strategies to reduce the occurrence of PSE meat in poultry were investigated by Guarniere et al. (2004) and Langer et al. (2010). The identification of PSE meat in poultry has been carried out by measuring pH and luminosity L^* (Droval et al., 2012; Kato et al., 2013; Soares et al., 2003), and the implementation of a PSE meat identification system can be of great importance for the poultry industry (Barbut, 1997). However, Eadmusik et al. (2011) suggested that a more accurate assessment of the kinetics of the pH decline associated with the temperature of poultry PSE meat after slaughter may mainly clarify the etiology of the problem in the slaughterhouse. However, all studies have been carried out in laboratories and not directly in slaughterhouses after pre-cooling in a chiller and maintenance in a cold room. If these parameters are determined in slaughterhouses, they can be better used to identify the main factors that can influence the slaughter of birds and the identification of PSE and normal meat.

Considering the importance of converting muscle into meat, in this case chicken meat, to clarify the phenomenon and identify of PSE meat, the objective of this work was to build a glycolytic curve through temperature measurement, pH decline, color measurements L^* (Luminosity), and WHC in the industrial slaughter line immediately after *postmortem* to identify PSE and normal meat.

MATERIALS AND METHODS

The experiment was carried out in the winter at a poultry slaughterhouse located in the North of Paraná. The slaughterhouse works under Federal Inspection and performs the activities according to the rules established in Ordinance n°210 (Ministério da Agricultura…, 1998). The transport distance of the birds was approximately 90 km on paved roads, and the journey time from the farms to the refrigerator was an average of 1h30min. The birds fasted for 10 hours. Slaughter was carried out normally in the refrigerator line and in accordance with animal welfare standards. Forty poultry carcasses were collected at the exit of the pre-cooling chiller, with a *postmortem* time of 1h35 pm. The carcasses were from animals of the same batch, and all animals were females of the Cobb strain that were 50 days old. The carcasses were randomly selected and immediately after collection, they were boned to obtain the breast (*Pectoralis major* muscle) without bone and without skin. The chicken breasts obtained were identified with a numerical code using a white label that was fixed on the packaging of a plastic Ziploc bag.

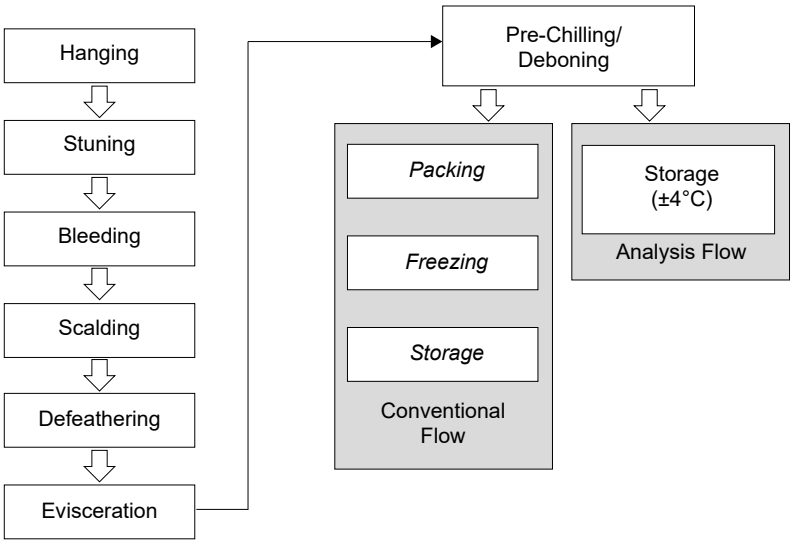

Fig. 1. Poultry slaughter in a commercial slaughterhouse: 1. Indicates the conventional flow chart where the chicken breasts were removed from the carcass, packaged, cooled, and stored at –20°C; 2. Indicates the flowchart of this experiment, whose chicken breasts were stored at 4°C in the slaughterhouse at 10 different times to perform the measurements of pH, temperature (°C), and *L**

The identified chicken breasts were placed in a cold chamber regulated at ±4°C in accordance with Brazilian legislation (Ministério da Agricultura…, 1998) at ten different time intervals (time 1 to time 10) for direct measurement of pH. The pH measurement was performed using a portable meter (Testo 0563 2051), previously calibrated with pH 7.0 and 4.0 buffers. The electrode was inserted into the cranial portion of the Pectoralis major muscle, and the median was taken at 25°C. The parameters *L**, *a**, *b**, *C**, and ΔE were obtained by computer vision system and a Konica Minolta colorimeter CR-400. The use of a cold room was the strategy adopted to allow simulation of the temperature drop closest to the conventional slaughter flow (Fig. 1) and at the same time to provide an adequate place to handle the samples for analysis. Each access time of the samples represented a period of maintenance of the respective sample in the cold room that started 1h35 pm (initial time) and ended after 25h35 pm. Therefore, the ten times sampled were: time 1 (2h35 pm), time 2 (3h35 pm), time 3 (5h35 pm), time 4 (8h35 pm), time 5 (11h35 pm), time 6 (14h35 pm), time 7 (17h35 pm), time 8 (20h35 pm), time 9 (23h35 pm), time 10 (25h35 pm).

Chicken breasts with values of *L** 24h ≥ 53 and pH ≤ 5.8 were identified as PSE and those with intermediate values 44 < *L** 24h < 53 and 5.8 < pH > 6.2 as normal according to the criterion used by Soares et al. (2003). In the PSE and normal chicken breasts pH, temperature (°C), and luminosity (*L**) were measured at the respective times 1 (2h35 pm) and 10 (25h35 pm) of refrigeration at 4°C. The chicken breasts at time 10 (25h35 pm) were separated to determine WHC. The pH and temperature measurements (°C) of refrigeration were performed in triplicate. To determine the pH, a contact potentiometer was used, whose readings were performed by insertion in the ventral cranial portion of the chicken breasts and as described by Kato et al. 2013. The *L** value was obtained using a Minolta colorimeter and immediately after determining the pH, the final value being the average of three measurements aligned and obtained on the ventral skull face (Kato et al., 2013).

The WHC (measured in triplicate) measure was determined according to Hamm (1961) and obtained after sub-sampling of 35 PSE and 35 normal chicken breasts, only at 25h35 pm. WHC was expressed in % and as follows: % WHC = [(final weight loss minus initial weight) / initial weight] multiplied by 100.

All analyses were performed in triplicate, and the results are expressed as the mean values ± standard deviation (SD). Analysis of variance (ANOVA) and Tukey's test for comparison of means at the 5% level of significance were conducted using Statistica® 10.0 (StatSoft, Inc., Tulsa, OK, EUA). The confidence level of the statistical tests was 95%.

RESULTS

Brazilian legislation, which is applied to all slaughterhouses registered under a federal inspection system, covering both the domestic and export markets, states that chicken carcasses immediately after the water chilling system leaves for pre-cooling must present a temperature equal to or below 7°C, with temperatures up to 10°C being tolerated, when they must be destined for immediate freezing. In this study, the average temperature obtained in the carcasses at the initial time (1h35 *postmortem*) was 6.3°C, demonstrating that it is in accordance with Brazilian legislation. After boning, the chicken breasts were stored and kept in a cold room (±4°C) in accordance with Brazilian legislation, which establishes temperatures between –1 and 4°C, with a maximum variation tolerance of one centigrade degree (Ministério da Agricultura…,1998).

Both the pH and L^* values (Fig. 2) of 40 chicken breasts were collected, and it was observed that 28.6% were classified as PSE. Regarding the measurement of the pH value at times 0 to 10h (Fig. 2), it was observed that the initial pH value (1h35 pm) for the chicken breasts with PSE was 6.59 ±0.17, with a final pH of 5.72 ±0.06.

In the present study and only after time 4 (8h35 pm), the pH values started to stabilize for normal chicken breasts and with PSE (Fig. 2). It can be observed that from time 4 (8h35 pm) there was still a small variation in the pH value from 5.69 to 5.72 and from 5.93 to 5.98 for PSE and normal chicken breasts, respectively.

At the initial time (1h35 pm), the brightness parameter (L^*) (Fig. 3) of the PSE (53.11 ±1.90) and normal (53.23 ±1.60) chicken breasts was similar. The L^* value (Fig. 3) at time 2 (3h35 pm) of the PSE and normal chicken breasts was 54.07 ±1.55 and 51.20 ±2.83, and at time 6 (14h35 pm) this value increased to 58.07 ±1.60 and 55.54 ±3.90, respectively. In the final measurements (25h35 pm) of the pH curves of the

Table 1. Water Retention Capacity (WHC) in PSE and normal chicken breasts measured at time 10 (25h35 pm)

Chicken breasts	% de WHC*
PSE	64.45 ±2.66[b]
Normal	67.19 ±3.13[a]

*Water holding capacity.
Averages followed by different letters in the column differ by t test (LSD) at the 5% significance level.

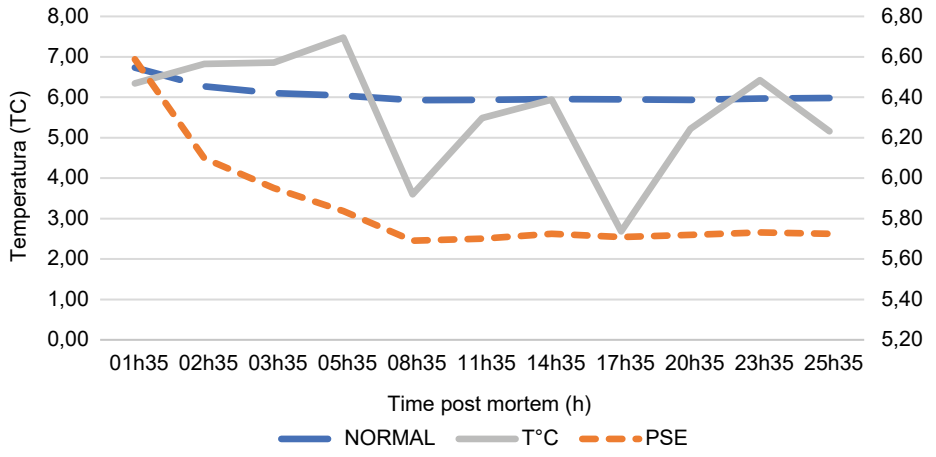

Fig. 2. pH curves of chicken breasts for classification as PSE (n = 9) and normal (n = 31) as a function of *postmortem* chilling temperature in a commercial slaughter line

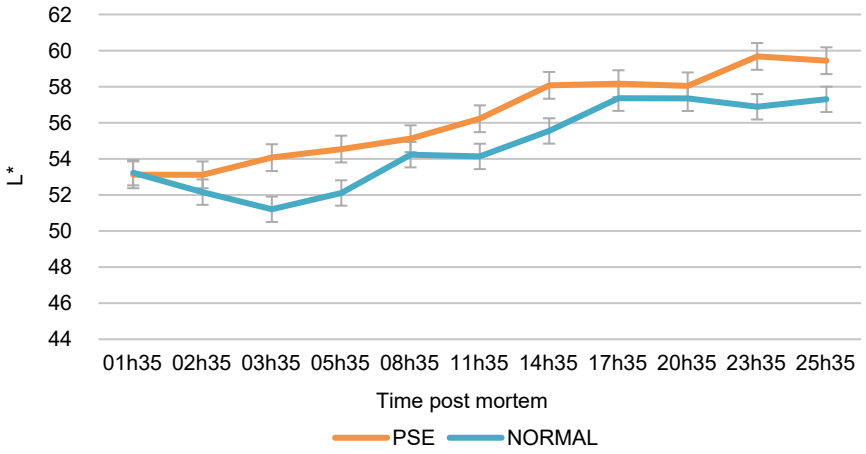

Fig. 3. Brightness values (L^*) of chicken breasts classified as PSE and normal as a function of *postmortem* time in a commercial slaughter line

PSE and normal chicken breasts (Fig. 2), pH values of 5.72 ±0.06 and 5.98 ±0.06 and values of L^* of 59.44 ±1.51 and 57.30 ±2.39, respectively, were found.

The WHC of the chicken breasts with PSE was lower than the normal ones (Table 1), which indicates that the muscle structure of the breasts with PSE showed greater water loss.

DISCUSSION

During this work, the stored chicken breasts were kept under refrigeration temperatures that varied from 6.3 to 5.2°C. This greater oscillation of temperatures in the chicken breasts occurred as a result of the moments when the samples were manipulated to determine the pH and L^* values. These breast samples were also influenced when still hot as they were placed in the refrigeration chamber, so there was a variation in temperature with the entry of new samples into the chamber. Among the external factors that occurred until rigor mortis set in, temperature was the most important and had the greatest influence on pH and L^* determinations. With the reduction in temperature during refrigeration, glycolysis and consequent drop in pH may have occurred more slowly, as described by Hamoen et al. (2013) and Kuffi et al. (2018).

The percentage of chicken breasts classified as PSE was close (27.5%) to that described by Freitas et al. (2018), who carried out an experiment during the winter whose ambient temperature varied between 10.6 and 18.4°C. Similar results (27.2%) were obtained by Langer et al. (2010), whose temperature varied between 12 and 15°C.

These results of the initial and final pH at times of 0 to 10h are contradictory to those described by Wilhelm (2010), whose measurements were performed in the laboratory and away from the slaughterhouse, where the samples did not show differences between the initial (01h30) and final (24h) pH of 5.81 and 5.77, respectively. Still, under the same conditions of pH measurements also taken in the laboratory, Soares et al. (2003) described different results for this experiment, whose pH values were 6.17 ±0.04 and 5.86 ±0.05 at 15min pm for chicken breasts subjected to thermal and non-normal stress, respectively, indicating that in this period the phenomenon of chicken breasts with PSE was already established.

In a study by Kuffi et al. (2018) in cattle which addressed the enzymatic kinetics of cuts of meat at two different temperatures to accompany the pH drop as well as its stabilization, the authors reported that temperature was a determining factor for the action of glycolytic enzymes to act in the tissue. They also reported that the conversion of glycogen and, consequently, the drop in pH, varied significantly with the type of cooling, but only during the initial hours. Thus, they concluded that the cooling rate was decisive, with lower temperatures decreasing the rate of pH decline. Dransfield and

Sosnicki (1999) also commented that the temperature was critical for *postmortem* events in poultry carcasses, where with an increase in temperature of 10°C (in the region of 30°C), protein denaturation increases by 20 times. Thus, the potential detrimental effect of the PSE defect of the fast-growing lines can be partially offset by increasing the carcass cooling rate.

The time of onset of pH stabilization (Fig. 2) was similar to that described by Pedrão et al. (2014), whose final pH value of chicken carcasses subjected to refrigeration after 8h35 pm was 5.86. They investigated the effects of cooling on the speed of glycolysis and the development of PSE in chicken meats, which is also dependent on multifactorial causes and the management of the slaughter process, mainly including the refrigeration system used.

At the initial time (1h35 pm), the brightness parameter (L^*) of the PSE (53.11±1.90) and normal (53.23 ±1.60) chicken breasts was similar. These results indicated that the color development of the chicken breasts had not yet stabilized as expected since the naturally occurring enzymatic reactions were still in full activity in the striated and skeletal muscles. These statements can be related to information provided in work carried out by Hamoen et al. (2013), who discuss the interactions of pH with changes that directly affect meat quality. It was observed (Fig. 3) that over time, the color stability of PSE and normal chicken breasts occurred slowly, although the luminosity of the chicken breasts with PSE was greater. The stability in the color of the chicken breasts depends on the conversion of the muscles into meat associated with the stability of the activities of the enzymes of the muscle tissues that establish the condition of PSE and normal meat (Pedrão et al., 2014).

The L^* value at time 2 (3h35 pm) of the PSE and Normal chicken breasts increased at time 6 (14h35 pm). When characterizing the incidence of PSE in chickens in the commercial slaughterhouse at 3h00pm, Woefel et al. (2002) described that the value of L^* was 60.41, which was higher than that observed in the present study. These L^* values were different from those described by Barbut et al. (2005), who in the same period of time found that the luminosity L^* was 57.70 and 49.71 for PSE and normal chicken meat, respectively.

However, the pH value (5.72) at the same time evaluated for meat with PSE was similar to the present study. The different L^* values for PSE and normal chicken breasts (Fig. 3) and those described by Woefel et al. (2002) and Barbut et al. (2005) were difficult to compare since color is a multifactorial characteristic and is mainly associated with free water of the muscular structure. Other factors may also intervene in the L^* values, such as slaughter age (Petracci et al., 2004), season (Petracci et al., 2004), creating system (Carvalho et al., 2017), time / cooling temperature (Bressan and Beraquet, 2004), and other factors. However, in the PSE chicken breasts, the variation in the value of L^* over the pm period (Fig. 3) follows a classic and standard curve with a higher value than normal chicken breasts.

After the final measurements (25h35 pm) of the pH curves of the PSE and normal chicken breasts, the pH values were similar to Woefel et al. (2002), with values of pH (5.76) and L^* (59.81) in chicken breasts with PSE from an industrial slaughterhouse, though they were measured at 24h pm and under different conditions than in the present study. Droval et al. (2012) described an L^* value of 59.20 ±1.97 of chicken breasts with PSE, which was similar to the present study. The L^* value (Fig. 3) of chicken breasts with PSE (59.44 ±1.51) was higher than normal ones (57.30 ±2.39) as expected, and the same was also observed by Bianchi, Fletcher, and Smith (2005); Woefel et al. (2002); and Droval et al. (2012).

The PSE meat had a lower pH than the normal meat (Fig. 2) due to the higher concentration of calcium in the muscle (Soares et al., 2003), with a consequent increase in the activity of proteolytic enzymes affecting muscle integrity and impairing the functionality of proteins (Wilhelm et al. 2010). To time 4 (8h35 pm), it was observed (Fig. 2) that the pH value remained practically constant, indicating that there was a stability of the enzymatic reactions with conversion of the muscle into meat, and thus, a better pH condition was defined for the PSE meat in relation to the normal meat. The pH stability was also observed by Pedrão et al. (2014) and Soares et al. (2003), who measured the pH at 8h35min and 15 min pm, respectively. However, these measurements were performed on samples from different refrigerators that were transported to a laboratory far from the collection sites, whose conditions were different from this study.

Zhu et al. (2011) pointed out that early in the *postmortem* process of chickens, temperature influenced

the rapid degradation of ATP and glycogen, thus inducing a high rate of lactate formation and a drop in pH. The rate of temperature drop in the *postmortem* process of turkeys contributed significantly to the loss of functionality of the meat protein (Rathgeber et al., 1999). In this way, it became evident that the *postmortem* temperature conditions to which the carcasses or meat are exposed are decisive in slowing down the activities of enzymes and reducing the formation of PSE meat. Kuffi et al. (2018) also obtained data similar to the pH decline compared to lower temperatures, which also highlights that after the first few hours *postmortem*, the pH decrease is even slower. The same was observed in the data obtained in this experiment. According to Carvalho et al. (2019), higher *postmortem* temperatures accelerate the muscle glycolytic process. These same authors reported in previous data (Carvalho et al., 2017) that chicken breasts kept at 37°C showed high glycolytic speed, which consequently affected the WHC and the change in the luminosity of these meats, since the pH was lower at higher temperatures in *postmortem* carcasses.

The WHC of chicken breasts with PSE was lower than the normal ones. Similar WHC results for chicken breasts with PSE have also been described by Droval et al. (2012), Kato et al. (2013), and Ribeiro et al. (2015). Kato et al. (2013) evaluated WHC in commercial branded chicken carcasses that showed lower pH values, and Ribeiro et al. (2015) used chicken breast fillets with PSE from different strains of birds and the same slaughter conditions as in the present study. Protein denaturation is more extensive in meat with PSE than meat classified as normal and directly influences the retention of intracellular water that can be exudated, resulting in a lower WHC value compared to normal meat (Barbut et al., 2005). There is a direct correlation between the temperature at which the rigor is established, the shear force (Bekhit et al., 2007), and the WHC, which in turn depends linearly on the final pH. According to Josell et al. (2003), between the pH range of 5.2 and 5.7, it can be seen that the loss of water increases with the decrease in pH and may develop a meat with less juiciness.

Different slaughter and processing conditions directly affect the speed of muscle meat processing reactions and, consequently, the development of abnormal meat. In chickens under commercial slaughter conditions, rigor mortis is resolved after 8h35 *postmortem*, unlike conditions set in the laboratory on an experimental scale. Based on the data obtained, we suggest discussing the so-called conditions for the development of PSE meat since the classic definition of the phenomenon, which is a rapid drop in pH with the carcass still hot, above 35°C, should be revised in order to be applied to a commercial slaughter line as the carcasses are kept at low temperatures.

CONCLUSION

Different slaughter and processing conditions directly affect the speed of muscle meat processing reactions and, consequently, the development of abnormal meat. In chickens under commercial slaughter conditions, rigor mortis is resolved after 8h35 *postmortem*, unlike conditions used in the laboratory on an experimental scale. Based on the data obtained, we suggest discussing the conditions for the development of PSE meat since the classic definition of the phenomenon, which is a rapid drop in pH with the carcass still hot, above 35°C, should be revised in order to be applied to a commercial slaughter line as the carcasses are kept at low temperatures.

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