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Quantifying the differential effect that the electrical stimulation of bovine carcasses has on pH, and color

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ABSTRACT

Electrical stimulation of carcasses is a procedure that is used to promote tenderness of meat. However it has also been shown to affect pH and meat color. To determine if bovine carcasses that receive electrical stimulation to improve their tenderness showed better values of pH, L*, a*, b*, C* and H* when compared with carcasses that were not stimulated, a comparison was done between 59 electrical stimulated and 79 non-stimulated carcasses, all of which were processed in a Federal inspected slaughterhouse, and electrical stimulation was administered according to the standard procedure performed by the slaughter plant and all data were obtained from the longissimus dorsi muscle 24 hours after slaughter, and the model used to estimate the differences was simple linear regression with dummy variables, due to the fact that the variable "electrical stimulation" is discrete. Beef pH levels in stimulated carcasses was 0.2 units lower ($P<0.01$), while the differences for a*, b*, C* and H* were 1.8, 1.9, 2.4 ($P<0.01$) and 3.2 ($P<0.5$) when compared to the results from non-stimulated beef In the case of L*, electrical stimulation had no statistical effect. Although a statistically significant effect of electrical stimulation on color was found, the results indicate that it cannot be considered a useful procedure to improve the colorimetric quality of beef because of its small size. However, in the case of pH the effect was found to be significant.

Key words: acidity, beef, colorimetrics, quality

Introduction

When purchasing meat, consumers consider color as a very important characteristic (NAM and AHN, 2003). To evaluate beef color, L*, a*, b*, C* and H* values are used

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(MANCINI and HUNT, 2005). L* measures luminosity and a* determines the amount of red, while b* measures yellow (LIU et al., 1996). Color intensity is quantified using chroma (C*), while the Hue angle (H*) measures the proportion of red and yellow.

It has been established that a close relationship exists between meat color and pH (WARRIS, 1996). This effect is due to the fact that when meat pH is high, proteins bind more intensely with water, causing muscle fibers to swell and the space between them becomes smaller. The outcome is that less water is available to reflect light so the meat appears darker (PAGE et al., 2001) and as a result consumer acceptability of the product is reduced. A study in Spain reported that meat with a pH above 5.8 sells between 30 and 60 % below its normal price (MACH et al., 2008). Similarly, research done in northwestern Mexico found that the price of beef with a pH higher than 5.8 was 10 % lower because of its color (LEYVA et al., 2012).

Furthermore, meat tenderness is also a characteristic that is considered important by consumers (DESTEFANIS et al., 2008). In order to improve meat tenderness, commercial abattoirs use electrical stimulation (ES) on carcasses (DEN HERTOG-MEISCHKE et al., 1997). However other meat quality traits are affected and these include the color and its stability (SIMMONS et al., 2008). To achieve the tenderizing effect an electrical current is applied using one of two methods: low voltage stimulation (50-120 V), or high voltage stimulation (300-1000 V) (TROY and KERRY, 2010).

The benefits of ES are a consequence of an increased pH decline, so that the onset of rigor mortis is accelerated as a result of faster glycolysis (FRANCO et al., 2009). The outcome of this acceleration is that tenderization begins earlier. In addition, stimulated bovine carcasses show higher L*, a*, b* values, which makes the beef brighter and more red when compared to non-stimulated beef (KLASTRUP et al., 1984).

Meat scientists consider that more research is required to measure the relationship between ES and meat quality (SIMMONS et al., 2008), and taking into account the importance of color as a quality trait of beef, the use of a quantitative model to measure the effect that ES has on L*, a*, b*, C* and H* may be considered to be of great importance for a better understanding of the relationship between the variables. As a result, the purpose of this study was to quantify the differential effect that electrical stimulation has on the color and pH of beef through the use of a regression model with a dichotomic independent variable.

Materials and methods

The study was undertaken in December and February at a Federal Inspected Plant located in Mexicali, Mexico. The plant operates from Monday through Saturday between 7:00 am and 3:00 pm and slaughters 35 to 45 animals/ hour. The animals that are slaughtered are mostly crosses between European races and zebu. Although the plant routinely applies electrical stimulation, the data were obtained in a period when an increased workload resulted in a group of carcasses not receiving electrical stimulation. A total of 138 carcasses were studied, 59 of which received ES, and 79 were not stimulated. Twenty-four hours after slaughter, the carcass was chilled between 0 and 2 ºC and pH, L*, a*, b*, C* and H* measurements were taken from the *Longissimus dorsi* muscle between the 11^{th} and 12^{th} ribs (SOTELO et al., 2008). pH values were obtained using a DeltaTRAK ISFET pH 101 punction potenciometer (DeltaTRAK, Inc., Pleasanton, CA., E.U.A.), while L*, a*, b* and H values were measured on the surface of the muscle using a Minolta CM-2002 spectrophotometer (Minolta Camera Co., Ltd, Japan) with a specular component, a D_{65} illuminant and a 10^0 observer. C* was calculated using $(a^{*2} + b^{*2})^{0.5}$ and H* was obtained using the formula $tang^{-1}(b^*/a^*)$ (MARÍA et al., 2003; PATTEN et al., 2008). The mean of the three measurements taken from each carcass was used for the estimation.

The carcasses were electrically stimulated within a three minute period after slaughter, using a Jarvis Es-4 electric stimulator. An electrical discharge of between 15 to 17 volts was applied for 15 seconds by means of electrodes placed on both sides of the neck.

To estimate the effect that ES has on pH and the colorimetric variables, ordinary least squares (OLS) were used to estimate six models, all of which had ES as the independent variable, while for each of the models the dependent variables were pH, L*, a*, b*, C*, and H*.

Due to the fact that ES was considered as a qualitative variable, which was given a 1 value when the electrical stimulation was applied and 0 when it was not stimulated, a linear regression model with ES as a dummy variable was used to obtain the regression coefficients (BROOKS, 2008). All estimations were done using Megastat for Excel version 10.1.

The following model was employed to estimate the regression coefficients:

$y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 D_i + u_j$ (1)

Where:

β_0 = constant

β_1 and β_2 = coefficients

D_i = dummy variable

u_j = disturbance

If D took the value of cero then the result is model 1, if D = 1, then the constant is different from β_0 and is equal to $(\beta_0 + \beta_1)$, so inclusion of the dummy variable changes the value of the intercept (ASTERIOU and HALL, 2007).

Results

The results from the OLS estimation obtained from the six models, all of which considered ES as the independent variable are presented in Table 1.

Table 1. Estimated coefficients obtained by OLS and carcass means for each of the six models

variable	Co-efficient	Standard error	Significance	Mean (ES Carcasses)	Mean (non-ES carcasses)
pH	$\beta_0 = 5.9$	0.02	**		5.9
	$b_1 = -0.20$	0.02	**	5.7	
L*	$\beta_0 = 37.84$	0.44	**		-
	$\beta_1 = 1.00$	0.53	NS	-	
a*	$\beta_0 = 10.60$	0.35	**		10.6
	$\beta_1 = 1.88$	0.43	**	12.5	
b*	$\beta_0 = 5.88$	0.39	**		5.9
	$\beta_1 = 1.78$	0.46	**	7.7	
C*	$\beta_0 = 12.11$	0.47	**		12.1
	$\beta_1 = 2.37$	0.57	**	14.5	
H*	$\beta_0 = 25.97$	1.12	*		25.9
	$\beta_1 = 3.24$	1.35	**	29.2	

*P<0.05; ** P< 0.01; NS: not significant

In the case of the OLS model used to estimate the effect ES has on pH, it was found that non stimulated carcasses had a mean pH value of 5.9 (β_0) and that when the carcass was stimulated the mean pH value was 0.19 units lower (β_1). The average pH value for ES carcasses was calculated by adding the mean value of pH for the non-stimulated carcasses to the additional effect that ES has on pH. In this study, the mean pH value for non-stimulated carcasses was 5.9 and considering that β_1 is negative, it was found that the mean value for pH in ES carcasses was 5.7.

The estimated β_1 coefficients for b*, a*, C* (P<0.01) and H* (P<0.05) were statistically significant and positive, and when they were added to their correspondent β_0 values, the mean of a* in the stimulated carcasses was 12.5, for b* 7.7, in the case of C* the estimated mean was 14.5 and the mean obtained for H* was 29.2.

In the case of L* it was found that ES was not statistically significant. It was assumed that there was no effect on luminosity when the carcass received ES.

Excluding the case of pH, the rest of the confidence intervals (Table 2) obtained for all statistically significant coefficients show upper limit differential values that when added to β_0 are too small for the colorimetric variables to be placed inside a normal range However, the pH interval results support the theory that ES has a strong positive effect on this variable, due to the fact that even when the upper limit is added to β_0 the pH value is 5.7, which is considered acceptable.

Table 2. β_1 confidence intervals (0.95) for pH, a*, b*, C* and H*

Variable	Lower limit	Upper limit
pH	-0.25	-0.15
a*	1.04	2.73
b*	0.87	2.70
C*	1.25	3.49
H*	0.57	5.91

Discussion

The results obtained by this study for pH contradict similar studies, which found no differences in electrically stimulated Longissimus toracis and *Semimembranosus* muscles 24 hours after slaughter (DEN HERTOG-MEISCHKE et al., 1997). Opposite results have been reported indicating that applying ES to bovine carcasses for 60 seconds reduces pH by 0.05 units (SIMMONS et al., 2008). Similar results have been seen on deer meat, which showed a pH reduction of 0.07 units on the Longissimus dorsi muscle after ES was applied (WIKLUND et al., 2008). Reductions in pH were also found in camel meat when it was submitted to ES, where pH decreased 0.13 units in carcasses from animals between one and two years of age (KADIM et al., 2009). The variation in the reports may be a consequence of the type of ES, since as a result of the use of low voltage stimulation, pH reduction is accelerated in the Longissimus dorsi muscle of cattle within 10 hours post mortem (HOLLUNG et al., 2007). This pH acceleration has also been reported in sheep meat when high voltage is applied (YUAN et al., 2013).

Previous studies performed in the region found a 34 % incidence of DFD meat (SOTELO et al., 2008) and considering that this problem decreases the price of the affected meat, then the reducing effect that ES has on pH should be considered as a procedure that may help to maintain the price of locally produced beef.

It is important to consider that the effect of ES on pH is more related to the duration of the stimulus than to the method employed (TROY and KERRY, 2010). It also been shown that the way in which ES and the chilling method are combined influences the quality of meat, so that when a low voltage ES is combined with rapid chilling, the quality traits of beef are enhanced (LI et al., 2010).

In the case of color, the increase of a* found by this study is consistent with what has been reported by other researchers, who have found that ES beef shows a more intense red color 24 hours after slaughter (EIKELENBOOM et al., 1985). Similar results were found in lamb's meat 48 hours after slaughter (POULIOT et al., 2012). The results obtained for b* are similar to reports from other researchers who found a statistically significant relationship between this variable and ES (McKENNA et al., 2003). However, there are also reports that contradict the findings of this study where it was found that ES does not have an effect on L*, a*, b* (TIMAR, 2007).

The results of this study related to color are attributed mainly to the effect that ES has on pH. The reason for this is that there is an inverse relationship between pH and a*, b* and L* (PAGE et al., 2001). It is important to consider that the beneficial effects of ES on the color variables included in this study were very small, and a reason for this may be thenumber of factors that influence the effect that ES has on meat.

Voltage, timing and the duration of the electric stimulus have an effect on the results of ES (TIMAR, 2007). Other important factors are: the length of the chilling process (STRYDOM et al., 2005) and the muscle fiber type (KADIM et al., 2009).

Furthermore it also important to contemplate that in this study all the measurements were taken 24 hours post slaughter and to take into account the fact that in electrically stimulated beef (LI et al., 2011) and lamb´s meat (TOOHEY et al., 2008) color stability is not maintained for long periods, so it is possible to assume that the beneficial effect of ES will not be noticeable by consumers.

The variability of results that have been described may arise from differences in the design of the experiments. Nevertheless, they may also be a consequence of the large numbers of factors that affect the color of meat, and also considering that excessive stimulation may adversely affect meat quality (SIMMONS et al., 2008) It is important to identify the differences in the response characteristics of individual carcasses as an element for improvement in the search for more predictable outcomes of ES. Studies show that when excessive stimulation of carcasses is combined with high temperatures, a possible outcome is pale, soft exudative meat (PSE). This is due to the very rapid decline in pH during the early part of the postmortem period (TROY and KERRY, 2010)

It is also relevant to take stress into account during the pre-slaughter period, the reason for this being that there is increasing evidence to indicate that factors present during this period affect meat quality (FERGUSON and WARNER, 2008).

The results of this study indicate that ES of bovine carcasses has a sufficiently significant lowering effect on pH for it to reach acceptable levels, and also a positive effect on color. These findings are explained by the negative correlation that other studies have found between pH, L*, a*and b* (WULF and WISE, 1999) but although in this trial the effect of ES on a*, b*, C* y H*, was statistically significant, the differences were small.

When assessing meat, qualitative variables play an important role, so the use of models that include this type of variables is highly recommended. The effect that ES has on meat color and pH was measured using a linear regression model that included a dummy variable, and taking into account the fact that the interpretation of the coefficients and test statistics represents no difficulty, this category of models may be considered a useful tool when evaluating the quality of meat.

The outcomes of this research indicate that ES cannot be considered as a practical procedure to improve the colorimetric quality of beef, however a study done in Spain (FRANCO et al., 2009) found significant differences for L*, a*, b* and C* between stimulated and non-stimulated beef, which suggests that low voltage stimulation is recommended, not only to improve the tenderness of meat, but also to improve its color.

Considering the results of this study and the relation of slaughterhouse practices have with pH in beef (MACH et al., 2008), precautions should be taken during the pre-slaughter period to maintain pH levels below 5.8, so that better results in beef color may be achieved.

The benefits ES has on tenderization have been clearly established. However, in the case of beef color, the quantitative effect that this stimulation has is not clear, this conclusion arises as an outcome of the different results reported by published studies. More research that focuses on the quantitative measurement of the relationship between color and ES is needed, because at present all that is known is that electrically stimulating a carcass will not negatively affect beef color and that in some cases it may result in a noticeable improvement in this important quality trait, but few measurement of the effects have been made.

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SÁNCHEZ, E., C. PÉREZ, A. BARRERAS, F. FIGUEROA, B. HERRERA: Mjerenje različitog učinka električne stimulacije na pH i boju mesa goveđih trupova. Vet. arhiv 86, 149-158, 2016.

SAŽETAK

Električna stimulacija na trupovima zaklanih životinja postupak je kojim se poboljšava mekoća mesa. No, pokazalo se da taj postupak utječe i na pH odnosno boju mesa. Radi utvrđivanja dovodi li električna stimulacija upotrijebljena za poboljšanje mekoće mesa i do poboljšanja vrijednosti pH, L*, a*, b*, C* i H*, provedena je usporedba između 59 električno stimuliranih i 79 nestimuliranih trupova obrađenih u klaonici pod federalnom inspekcijom. Primijenjen je standardni postupak električne stimulacije, a svi podaci utvrđeni su za mišić longissimus dorsi, 24 sata nakon klanja. Uvažavajući da je električna stimulacija diskretna varijabla, za procjenu razlika korišten je model jednostavne linearne regresije s kodirajućom varijablom. Razina pH goveđeg mesa u električno stimuliranim trupovima bila je 0,2 jedinice niža (P<0,01), dok su razlike za a*, b*, C* i H* bile 1,8; 1,9; 2,4 (P<0,01) i 3,2 (P<0,5) veće u usporedbi s rezultatima za meso iz nestimuliranih trupova. U slučaju L*, električna stimulacija nije imala statistički dokazan učinak. Iako je ustanovljen statistički značajan učinak električne stimulacije na boju mesa, zbog male veličine tog učinka stimulacija se ne može uzeti u obzir za poboljšanje kolorimetrijske kvalitete govođeg mesa. Međutim, u slučaju pH taj je učinak bio izraženiji.

Ključne riječi: kiselost, govedina, kolorimetrija, kvaliteta