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Article

Development and validation of a visual pattern for evaluating beef meat color in Mexico

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Abstract:

This study aimed to develop a visual scale for beef color evaluation. A total of 1,165 loins were analyzed 24 h *postmortem* in four slaughterhouses in Mexico. In each sample, it was determined color using a visual pattern and a spectrophotometer (CIELAB scale), taking a photograph of each loin. Seven categories were identified using the visual method (from very light red to very dark red), and the instrumental color variables (L*, a*, b*, C*, and h*) were used to create prediction models for the visual categories. The scale was constructed using L* as the sole predictor, as this model explained > 90 % of the observed variation. The pattern was illustrated with photos of the samples with an L* value within the 95 % confidence interval of the mean in each category, from very light red (48.1 <L*<48.8) to very dark red (32.7 <L*<33.4). The total color difference between the categories fluctuated between 2.8 and 5.5, which suggests that these are distinguishable with the naked eye. A trained sensory panel and a consumer panel, through tests, validated the scale. Trained panelists correctly rated the samples in 92.6 % of the evaluations. In meat with dark-cutting (DC) appearance, the trained panelists had 100 % hits, and the consumer panelists 85.3 %. The proposed visual pattern is supported by instrumental measurements and proved to be technically feasible for the evaluation of color in beef by trained personnel and consumers.

Key words: Beef, Bovine, Quality, Color, Visual, Instrumental, Pattern.

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Introduction

Fresh meat color is among the main quality attributes that influence the consumer buying decision(1,2). It is a fact that meat color defects cause significant economic losses, as they lead to a discount on meat prices(3-5). Therefore, color is one of the main attributes used to evaluate the quality of carcasses and meat in countries that are big traders, like the United States, Japan, Canada, and Australia(6-9). These assessment schemes are carried out using visual scales, which are highly correlated with the consumer buying decision(10). Furthermore, the early detection of these color defects allows the segregation of meat with an undesirable appearance and redirect it to manufacturing processes in which this attribute is less important(7).

Different countries develop visual patterns for meat color evaluation because this attribute is a multifactorial phenomenon. For example, factors like breed, production system, diet, and pre- and post-slaughter handling, which are different in each country, are relevant sources of meat color variation(11,12). Therefore, the use of these tools by the meat industry must follow scientific evidence originated from local herds. The latter is especially important in cattle, a species that usually presents a high variation in its quality attributes(13).

In Mexico, beef cattle production is among the most economically important livestock activities(14). Furthermore, beef is highly popular in the country, with an annual *per capita* consumption of 17.40 kg(15), however, there are no scientifically supported tools for the segregation of meat according to color. The Mexican standard for carcass classification includes color as one of the quality determining attributes(16). However, it proposes the use of a solid color scale from the Pantone system of just three levels, which are cherry-red, deep red, and dark red meat color. This scale is not representative of the whole range of hues that beef can have, nor does it describe the appearance associated with quality defects, like dark-cutting beef (DC). Moreover, this method does not consider that meat has an irregular surface, with muscular fibers in different directions, connective tissue, and intramuscular fat. Therefore, the use of photographic patterns is considered a better alternative for the subjective evaluation of meat color(17).

Despite some current private initiatives and several regional studies(18-22), so far, a visual pattern has not been developed to serve as a reference for the national industry. This situation represents a commercial disadvantage for local producers, who can receive economic penalties according to subjective evaluations from customers. Therefore, this study aims to develop and validate a visual pattern for beef meat color evaluation at an industrial scale in Mexico. This research hope to contribute to market organization and to improve communication between the different links of the value chain, as well as to generate a subjective evaluation method for meat color, based on scientific evidence, that will eliminate the deficiencies in the system considered in current regulations.

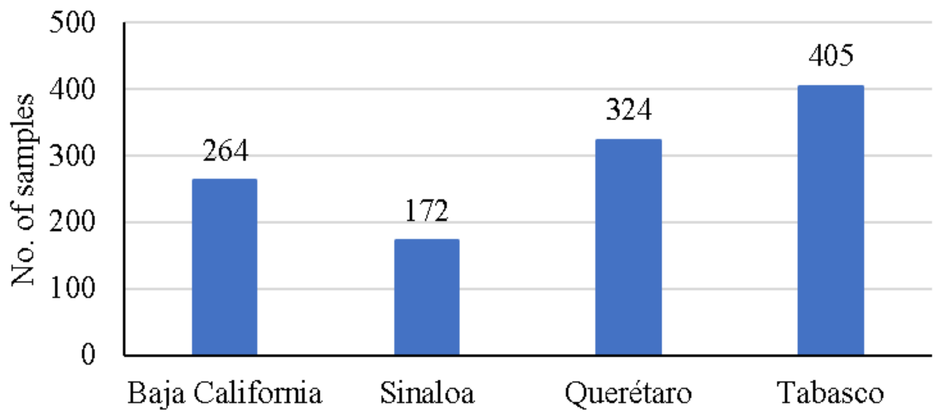
Material and methods

Sampling scheme

The slaughterhouses that participated in the study were selected using a non-probability sampling plan, based on the following criteria: 1) companies located in one of the three ecological-livestock areas of Mexico (arid and semiarid, wet tropics, and dry tropics); 2) carcass halves are cut between the twelfth and thirteenth ribs; 3) the company is a Federal Inspection Type (TIF) slaughterhouse, and 4) availability of working areas with technical lighting and space conditions, access to primary cuts, and cutting area with a refrigeration temperature of 6-8 ºC.

According to these criteria, four TIF slaughterhouses were selected, located in Baja California, Sinaloa, Querétaro, and Tabasco states, in which a total of 1,165 samples were analyzed (Figure 1). Before color evaluation, meat was exposed to oxygen for 30 min; this created a much slower working rate compared to the process flow. Therefore, it was not possible to analyze all the carcasses processed in one day. The goal was to take at least 170 carcasses per slaughterhouse, which was the minimum sample size determined, considering a confidence level of 95 %, an accuracy of 0.5 units in the instrumental color variables, and a variance of 10.69, estimated from preliminary tests. Thus, using the equation $n = \frac{Z_{\alpha}^2 * S^2}{d^2}$, it was obtained a sample size of 164, which was rounded to 170. However, in order to obtain the highest possible variation, in each establishment, all the loins that could be collected in an 8-hour shift for 3 or 4 days were analyzed. Therefore, the actual sample size per slaughterhouse fluctuated between 172 and 405, according to the slaughter volume in each establishment.

Figure 1: Number of loin samples analyzed in TIF slaughterhouses of four Mexican states between November 2012 and July 2013



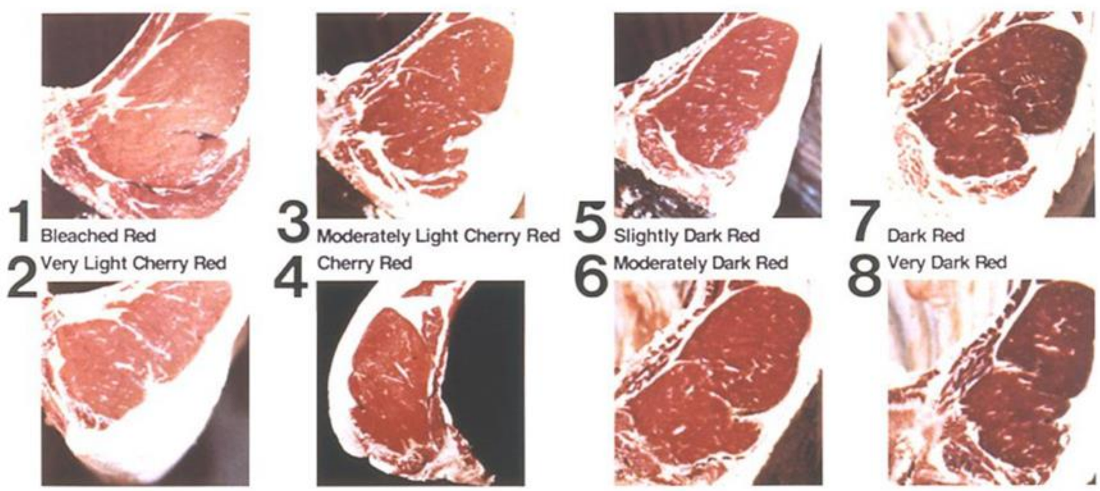
The population of animals from which the data were obtained was made up, in about 80%, of non-castrated entire males, the remaining percentage were females. As the research was carried out on slaughterhouses, it was not always possible to know the age at slaughter. However, in a sample of around 300 animals in which this data was available, 86 % were 24-mo-old or less. Overall, this was the age expected for the studied sample, considering previous reports that document the preponderance of young bulls in the beef cattle slaughter population in Mexico(23).

Color measurement

Color measurements, both visual and instrumental, were carried out following the American Meat Science Association guidelines(24). Readings were made at 24 h *postmortem* in the cutting and deboning area of each TIF slaughterhouse, with a controlled room temperature of 6 to 8 ºC. The complete loins (*Longissimus dorsi* muscle), recently separated from the carcass and with a temperature not higher than 3 ºC, were collected. The selected loins were left to rest for 30 min on a stainless-steel table, with the loin eye area between the twelfth and thirteenth ribs exposed to air, to allow optimal oxygenation of myoglobin before the readings.

The visual color evaluation was performed under standardized conditions. As a light source, it was used a photographic quality Osram incandescent lamp with an intensity of 150 foot candles (1,614 luxes) and a color temperature of 3,200 ºK, placed at a 45° angle concerning the surface of the chop. A professional photographer took high-resolution photos of each loin chop evaluated; for this purpose, was used a 12-megapixel Nikon D300S camera with a Sigma 24-70 f. 2.8 zoom lens. Photographs were taken against a black background to eliminate color differences associated with the meat surface. The photographs function as illustrative images of the different hues of the meat, which could be included in the visual color scale that was being developed. Subsequently, using the United States eight-level color pattern for beef (Figure 2)[9], an experienced researcher performed the visual color evaluation in order to have a preliminary reference about the number of possible visual categories in the studied sample.

Figure 2: Visual scale for color evaluation in beef carcasses developed in the United States of America[9]



For instrumental measurements, was used a Hunter MiniScan EZ 4500L spectrophotometer with a 45/0 geometry and a port size opening of 25 mm (Hunter Associates Laboratory, Inc, Reston, Virginia, United States). The instrument was configured as follows: A/10° illuminant/observer combination and specular component excluded. Furthermore, the instrument was remotely operated using the program OnColor QC Lite, version 6 (CyberChrome, Inc., New Paltz, New York, United States) for computer data capture. Calibrations were performed before starting measurements and after every 100 readings or after 1 hour (whichever occurred first), using the black trap and white tile supplied by the manufacturer. From each loin chop, four readings were obtained, and their average was used to calculate the lightness (L*), redness (a*), yellowness (b*), hue (h*), and Chroma (C*) of each loin chop in the CIELAB scale. Along with these data, we also collected the spectral curves, which constitute the color footprint and were necessary for the professional impression of the scale.

Data analysis and visual scale conformation

For the statistical analysis was used the Statgraphics XV Centurion software for Windows (Statpoint, Inc., The Plains, Virginia, United States). The means of the color instrumental values were compared between the quality categories visually assigned. For this, a one-way analysis of variance (ANOVA) was performed using the Generalized Linear Model (GLM) procedure. As a result of the different number of observations per level, when significant differences were found, the means were discriminated using the Bonferroni multiple comparison procedure.

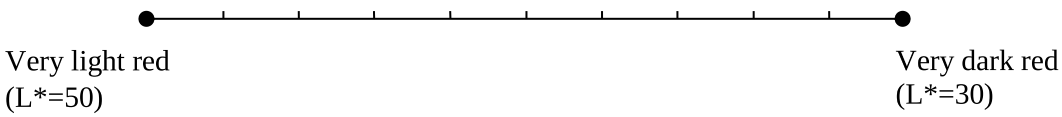
Different prediction models were tested to construct the scale, by means of the GLM procedure, using the visual category as the dependent variable and different combinations of the instrumental variables and their interactions as explicative variables (See Table S1 in Supplementary Information). Among the generated models, the one that explained the highest percentage of the observed variation between visual categories was chosen, which turned out to be the one that uses L* as the only explicative variable. Therefore, 95 % confidence intervals of L* were constructed within each visual category. To illustrate the scale, we selected the photographs that corresponded to L* loin chop values within the confidence interval of the mean in each category.

Lastly, it was necessary to determine if the categories could be differentiated visually. For this, it was calculated the total color difference (ΔE^*_{ab}), which is the sum of the modular differences of L*, a*, and b* between two samples: ($\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$). The greater the ΔE^*_{ab}, the easier it is to visually distinguish the color difference between two samples. However, usually, samples with ΔE^*_{ab} values >2 units are considered easily distinguishable[25].

Preliminary validation experiment

In order to validate the visual scale, we evaluated the newly developed visual standards in an industrial setting, under the conditions described below. The visual scale was tested in a slaughterhouse not included in the initial sampling. For validation, a trained sensory panel was formed, with six people familiar with the proposed color pattern. Panelists were selected using the Farnsworth-Munsell test (http://www.color-blindness.com/farnsworth-munsell-100-hue-color-vision-test/#prettyPhoto), which allows dismissing people with color appreciation deficiencies. Selected panelists were required to have a color vision deficiency score of “none” or “mild” (0 to 70 points). The initial group was formed by 20 candidates selected according to the generally accepted guidelines for the planning and selection of trained judges[26].

As a result of the selection process, the sensory panel ended up with six members. Each panelist participated in six evaluation sessions, in which they evaluated six meat samples (2 of normal-colored meat (N), 2 with moderate DC, and 2 with extreme DC), for a total of 36 measurements per judge. For the evaluations, the judges received instructions on how to use a structured 10-cm-long scale, ranging from very light red (L* = 50) to very dark red (L* = 30):



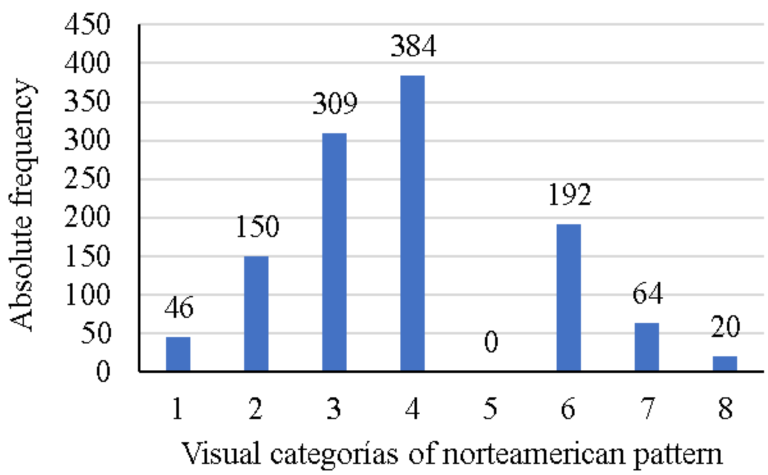
According to the proposed visual scale, extreme DC meat has L* values between 30 and 34; moderate DC between 35-37; and N meat, 38 or more. Judges were asked to mark the scale with a cross to indicate the color that corresponded to the evaluated sample. The position of the cross was measured with a ruler to obtain the estimated L* value. The data were analyzed by a three-factor analysis of variance (judge, sample, session, and their interactions); this corroborated that the only source of significant variation in the evaluations was the sample. Finally, a correlation analysis was performed between the L* values estimated from the color evaluation made by the judges and the real L* values determined with the spectrophotometer. In order to validate the proposed visual scale for beef color evaluation, it was necessary to obtain a significant discriminatory power of the judges, a significant high-magnitude correlation between the real L* values of the samples and the L* values estimated by the judges, as well as a positive hit rate > 80% when assigning a color category to each sample. In previous studies with orange juice and wine, the visual differences of the samples were validated with a much lower hit percentage of the sensory panel (e.g., >50 %)[27,28]. However, the present study looked for a higher hit rate in order to determine if the visual scale worked for most people, which is why color evaluations were also conducted with an untrained panel (n = 6). Consumer panelists were asked to indicate if they observed any difference between N and DC meat samples. The latter meant to corroborate the reliability of the scale when used by people without color evaluation training. Samples were selected and displayed under the same conditions previously described for the trained panel. However, the untrained panel was only presented with pairs of samples, and panelists were asked to choose the sample they preferred based on color.

Results

Definition of visual categories and their relation with instrumental measurements

Visual evaluation allowed to identify, in the studied sample, seven of the eight categories represented in the North American visual standards because none of the samples had an appearance similar to category 5 (slightly dark red). Figure 3 shows the distribution of samples in each of the seven identified classes

Figure 3: Distribution of samples (n = 1,165) in each of the visual categories identified using the North American pattern for beef color evaluation (the description of each category is the same as in Figure 2).



The meat proportion associated with quality defects (categories 7 and 8 represent different degrees of DC appearance) was relatively low (7 %). In contrast, more than 70 % of the samples corresponded to the categories 2-4, an appearance generally associated with normal quality meat.

Moreover, the ANOVA was significant (*P*<0.0001) for all the instrumental color variables (Table 1). However, L* was the only variable with significant differences between the means across all the categories. Furthermore, the ANOVA of L* was the only one with a high coefficient of determination (R^2=0.9171), while in the other variables, it ranged from 0.2744 to 0.4284.

Table 1: Least square means of the instrumental color variables in meat of each of the visual categories identified in the sample

	Visual categories								
Variable	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**SE±[1]**	R^2
n	30	62	283	264	314	144	68		
L*	48.8[a]	46.7[b]	44.4[c]	42.1[d]	40.1[e]	37.7[f]	34.8[g]	0.94***	0.9171
a*	27.4[a]	27.8[a]	27.5[a]	27.1[ab]	26.3[b]	25.1[c]	22.6[d]	2.04***	0.2744
b*	20.1[a]	20.2[a]	19.1[b]	18.3[c]	17.3[d]	16.0[e]	13.5[f]	2.12***	0.3522
C*	34.1[a]	34.3[a]	33.4[ab]	32.7[b]	31.5[c]	29.8[d]	26.3[e]	2.21***	0.3082
h*	36.3[a]	35.9[a]	34.7[b]	33.9[c]	33.2[d]	32.4[e]	30.7[f]	1.41***	0.4284

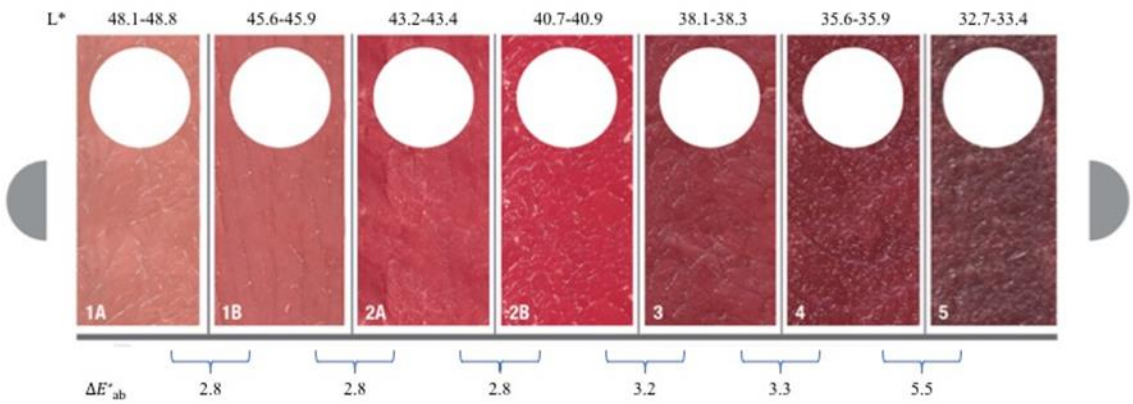
[1]Standard error of the estimator.

[a,b,c,d,e,f,g] Means with different letters in a same row indicate statistical difference (P<0.05).

***P<0.0001.

Although other prediction models were tested (see Table S1 in supplementary information), none of them were better than the one obtained with L* as the only explicative variable and, hence, were discarded. Therefore, 95 % confidence intervals of the mean value of L* were used as a criterion to select the representative photos from each of the visual categories that form the developed color scale (Figure 4). An important feature of the latter is that meat appearance in some adjacent categories is very similar. For example, categories 1 and 2 represent light meat. Similarly, categories 3 and 4 are representative of the bright cherry-red hue, which is usually the most attractive to consumers at retail. Therefore, at first, we considered merging both pairs of categories into one. However, the ΔE^*_{ab} between these pairs was of almost three CIELAB units, which means that they are clearly differentiable from each other with the naked eye. Therefore, instead of merging them, it was used a denomination that would allow the user to identify that both categories are associated with similar hue meat. Hence, categories 1 and 2 were renamed as 1A and 1B, respectively, while 3 and 4 were denominated 2A and 2B. These adjustments forced the name modification of the remaining categories (5, 6, and 7) into 3, 4, and 5; their appearance is clearly differentiable from each other, with a much higher ΔE^*_{ab} between them (3.3 to 5.5 CIELAB units).

Figure 4: Visual scale for evaluating beef meat color in Mexico



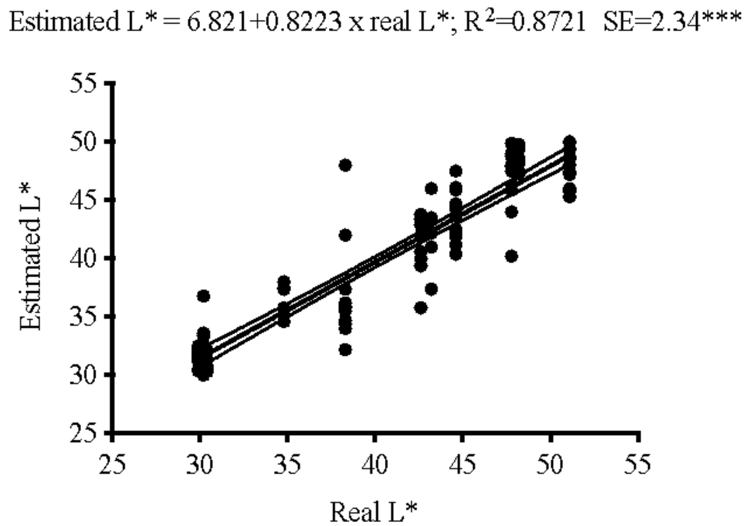
L* values correspond to the 95% confidence interval of the mean for each category. The numbers at the bottom indicate the total color differences (ΔE^*_{ab}) between adjacent categories.

Preliminary validation of the descriptive scale under industrial conditions

The first validation criterion for the color scale was for the sensory panel to detect the differences between the samples. Judges, both individually and as a group, showed sufficient discriminatory power (significant ANOVA, P<0.0001); therefore, results were satisfactory. Furthermore, the sample was the only factor that significantly influenced (P=0.0002) the score of the judges (see Tables S2 to S4 in supplementary information).

The correlation between the real L* values of the samples and the values assigned by the judges (Figure 5), which was the second validation criterion, was significant and of high magnitude (r=0.9338, P<0.0001). These results correspond to the percentage of correct answers by the judges, third and last validation criterion of the scale; judges, on average, correctly assigned the samples to the visual category of the pattern in 92.6 % of the evaluations. The scale showed even better performance in the detection of DC; the judges correctly assigned samples with this condition in 100 % of the evaluations. Furthermore, the scale also allowed to distinguish the different degrees of the DC defect; trained judges confused moderate DC with extreme DC in only 5 % of the evaluations. Finally, the evaluation performed by the untrained panel corroborated the relevance of the categories that describe the DC defect, since in 85.3 % of the evaluations performed by untrained panelists, the color of N meat was preferred over the color of DC meat. Overall, the results of the sensory tests demonstrate the technical viability of the proposed color scale since both trained personnel and consumers were able to use it to dictate the appearance of meat correctly.

Figure 5: Regression analysis between the L* estimated by the trained sensory panel and the real L* of the samples measured using the spectrophotometer (n=108)



The model includes the bilateral prediction limits. ****P*<0.0001.

Discussion

This research presents the first visual pattern for evaluating beef meat color in Mexico, scientifically supported by data obtained from domestic cattle. The developed scale contains categories that describe light, cherry-red, deep red, dark red, and very dark red-looking beef. These hues are visually differentiable and, also, show a high correlation with instrumental color variables, particularly with L*. The latter coincides with results from previous studies, in which L* was the variable best related to the visual appearance of the meat(29,30).

Some studies performed in Mexico have used Chroma (C*<30) as one of the criteria to identify DC meat(3). Although the instrument and measurement conditions in this study were different, C* values of less than 30 were also observed in meat with dark-cutting appearance. However, C* only explained about 30 % of the differences between the different levels of the scale, while for L*, the coefficient of determination was greater than 90 %. The high correlation between L* and visual appearance observed in this study suggests that instrumental measurements can either guide evaluators who use the visual scale or substitute the use of the latter in companies with instrumental technology to measure color.

Moreover, the categories included in the scale can be associated with specific commercial advantages or quality defects. For example, the meat represented in categories 1A and 1B has an appearance similar to that described in pale, soft, and exudative (PSE) meat[31]. This defect is associated with impaired functional properties, especially with a reduced water holding capacity. However, the PSE phenomenon occurs very rarely in cattle, and it usually only occurs when the carcasses are subjected to very slow chilling[32]. Nonetheless, 46 units (3.9 %) of the analyzed sample had an extremely pale appearance, and another 150 (12.9 %) were classified as moderately pale; probably due to slow chilling of carcasses or excessive muscularity that limits or delays heat loss and promotes a faster drop in muscle pH, conditions that could be common in many TIF slaughterhouses in Mexico. However, recent studies suggest that Mexican consumers perceive the light red color as a quality indicator in beef[33], which implies that fresh meat with this appearance must not suffer price penalties.

The following two categories (2A and 2B) represent the typical appearance (bright cherry-red) that consumers look for in fresh beef[4]. Apparently, a good part of the beef produced in the country meets this demand, since 60 % of the samples analyzed presented these hues. Therefore, the identification of this type of meat helps to exploit to the maximum the competitive advantages offered by its favorable appearance for retail sales.

Moreover, category 3 describes the meat that is in the limit of acceptable quality. Its appearance is slightly darker, determined by the lowest L* values, which puts it at a disadvantage concerning cherry-red, which is associated with younger animals. As animals grow old, the lightness of meat decreases, which results in a darker appearance[34]. However, category 3 keeps a relatively safe total color difference (3-5 CIELAB units) regarding the categories that describe the DC defect (4 and 5).

Finally, categories 4 and 5 represent the DC defect, which leads to millionaire losses to the industry and is, by far, on a global scale, the most important quality defect in beef[7]. Although different degrees of the DC condition have been described (e.g., classic, light, and atypical), recent studies have shown that all share an undesirable dark appearance and deteriorated quality attributes[5,35], for which they deserve economic penalization. In Mexico, according to estimations, the value of DC carcasses decreases by approximately 85 USD[3]. Although the proportion of units with DC appearance in the analyzed sample is low (7 %), the economic impact of this rate, if it occurred at a national scale, can represent millions of dollars, considering that the annual slaughter is 4 million heads, only on TIF slaughterhouses[36]. Therefore, the description of DC meat on the proposed scales is highly relevant, since it provides the basis for the early detection of this defect, offering the possibility of segregating the defective meat and, also, managing the slaughter-associated processes to reduce its incidence.

The calculation of ΔE^*_{ab} showed that the categories represented on the scale can be easily differentiated visually. Some studies have suggested that the human eye can perceive color differences from values of $\Delta E^*_{ab} \geq 1$[25], a much lower figure than those observed in this work among the visual categories proposed (2.8-5.5).

Moreover, validation proved the relevance of the followed scale developing strategy, with a high correlation between the trained sensory panel and the predictive variable used (L*); this undoubtedly contributed to more than 90 % of the trained judges correctly assigning the visual category to the evaluated samples. Similarly, the categories associated with DC, which is the primary quality defect in beef, are easily identified by both trained people and consumers. The latter opens the possibility of using the visual scale routinely in the industrial environment, as an alternative to instrumental measurements, which requires economic investments that are beyond the reach of most of the industry.

Despite what has been analyzed so far, it should be noted that the present study does not propose the use of the visual pattern as the only criterion to determine meat quality. Although it is widely documented that color is a key factor affecting consumer choices, it is known that it does not correlate well with tenderness or palatability of meat[4]. Hence, to evaluate the quality of carcasses, it will be necessary to complement the color evaluation with that of other quality attributes (e.g., final pH, physiological maturity of the animals, marbling, among others)[7]. Furthermore, the scale herein is based on measurements made at 24 h *postmortem*. Therefore, its application across segments of the distribution chain could not be entirely consistent, since storage temperature, type of packaging, muscle biochemistry, among other factors, can modify the color of meat and its stability[11,37].

Moreover, although it is possible to opt for the exclusive use of instrumental measurement for color evaluation, certain precautions must be taken. First, the typical L* values reported for each category were measured with a spectrophotometer whose configuration (port size opening, geometry, illuminant, among others) may be different from that of other equipment. Therefore, the use of different instruments or configurations may vary the results.

Despite the latter, the developed scale can be very useful to estimate, from the slaughterhouses, whether the appearance of the meat could have a positive or negative impact on the consumer buying decision. Furthermore, its use can facilitate more efficient communication through the use of an objective technical descriptor, when marketing meat. In particular, the scale proved to work very well for the identification of meat with a dark-cutting appearance, the early detection of which, on the slaughterhouses, is of great economic importance.

Conclusions and implications

The descriptive scale developed in this study provides representative illustrations of beef appearance in Mexico, as well as the L* intervals associated with each one of them. The concurrence of visual and instrumental criteria in the tool allows its versatile implementation, either with sensory panels, with instrumental measurements, or by combining both. The scale is conceived as a tool for color evaluation on the slaughterhouse at 24 h postmortem and has shown excellent performance for the detection of meat with a dark-cutting appearance in validation tests performed under industrial conditions. In companies that perform carcass evaluation, this tool could be included as an additional criterion to define their quality.

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(Supplementary information)

Table S1: Visual category prediction models, tested in a step-by-step selection strategy, using the visual category as a dependent variable, and the instrumental color variables and their interactions as explicative variables (n= 1,165) in the Generalized Linear Model procedure of Statgraphics XV Centurion

Explicative variables included in the model	**SE±[1]**	**P**	**R^2**
L*	0.40	<0.0001	0.9145
a*	1.22	<0.0001	0.2134
b*	1.13	<0.0001	0.3269
C*	1.18	<0.0001	0.2651
h*	1.05	<0.0001	0.4172
L*, a*, b*, C*, h*	0.40	<0.0001	0.9168
L*, a*, b*, C*	0.40	<0.0001	0.9153
L, a*, b* (L* x a* x b*)	0.40	<0.0001	0.9163
L*, a*, (L* x a*)	0.40	<0.0001	0.9165
L*, b*, (L* x b*)	0.40	<0.0001	0.9159
L*, C*, (L* x C*)	0.40	<0.0001	0.9160
L*, h*, (L* x h*)	0.40	<0.0001	0.9156

[1]Standard error of the estimator.

Table S2: F value and statistical significance level (*P*) of the ANOVA performed with the color grading data emitted by each trained judge (n= 36) in meat samples with light red, normal, moderate DC, and extreme DC appearances

Judge	**F_{ANOVA}**	***P***
1	193.3	<0.0001
2	139.1	<0.0001
3	138.3	<0.0001
4	116.5	<0.0001
5	103.9	<0.0001
6	91.9	<0.0001

Table S3: ANOVA performed with the color grading data emitted by trained sensory panel in meat samples with light red, normal, moderate DC, and extreme DC appearances

Source	Sum of squares	DF[1]	Mean square	F ratio	*P* value
Between groups	141.022	3	47.0074	639.52	0.0000
Intra-groups	7.64444	104	0.0735043		
Total (Cor.)	148.667	107			

[1]Degrees of freedom.

Table S4: Multifactorial ANOVA[1] for color grading

Effect	F ratio	*P* value
Judge	0.95	0.4491
Sample	7.04	0.0002
Session	0.89	0.4919
Judge x sample	0.86	0.6126
Judge x session	0.68	0.8701
Sample x session	1.03	0.4254
Judge x sample x session	0.92	0.9860