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Determination of Classification Characteristics of Bovine Carcasses from Three Different Types of Slaughterhouses in the Mexican Highlands

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A B S T R A C T

In this work, the classification characteristics of bovine carcasses were compared in three different types of slaughterhouses in the state of Queretaro, Mexico, which are slaughterhouses, municipal slaughterhouses, and TIF plants. Carcass classification represents a very useful tool for cattle ranchers to have an objective perspective of the market's perception of their final product. The classification was done following the methodology of NOM-004-SAGARPA-2018 and NMX-FF-078-SCFI-2002, to evaluate the quality of the carcasses through the national classification of three different slaughterhouses. The color of the meat, the color of the fat, and the physiological maturity based on the ossification of the thoracic buttons were evaluated. The results were very inconsistent and difficult to interpret. It was found that the current legislation uses subjective methods that are not very applicable to the reality of municipal slaughterhouses and slaughterhouses, since they do not have the infrastructure to carry out the classification, so that the application of this represents a disadvantage for the users of these plants. It was found that the methodology proposed in the standard is based on subjective methods that make the results unreliable and unreproducible, leaving the decision to the evaluator's discretion, in addition to representing a disadvantage for producers whose target market is not the fine cuts market, since the infrastructure of the slaughterhouses in the country is not appropriate.

Keywords: Quality, Carcasses, and Classification.

1. Introduction

The evaluation of carcass performance and quality traits is relevant to consumers, livestock producers, and meatpackers. Segregating carcasses according to quality attributes around the world has helped meat producers meet consumer demands and, consequently, increase their profits. Consistent, high-quality beef is one of the meat industry's most important requirements for maintaining and expanding markets. However, consumer perceptions of meat quality are complex. This perception is often subjective and varies from market to market and from person to person. Therefore, it is crucial to characterize the quality demanded by each producer's target market.

In Mexico, there is no nationally applicable quality classification system. Currently, there is an Official Mexican Standard that seeks to standardize this classification, but its application is flawed due to the highly heterogeneous nature of the beef market in Mexico. The objective of this work was to apply the method proposed in NOM-004-SAGARPA-2018 to classify bovine carcasses in three types of slaughter plants: TIF Plant, Municipal Slaughterhouse, and Slaughterhouse, to make constructive criticism on the feasibility of its application in the Mexican meat industry.

2. Literature Review

2.1 Meat quality and the benefits of grading it

According to the International Organization for Standardization (ISO), quality is defined as the qualities of a product that supports its ability to meet consumer and regulatory (standards and laws) requirements [1]. Meat quality, in particular, refers to the characteristic features that the consumer associates with the product, such as color, tenderness, and flavor, which are objective and measurable properties [2]. However, another important factor to consider is that quality is defined by the market; that is, quality is determined by the characteristics that the consumer expects from the product. Therefore, quality is not an absolute concept; on the contrary, it evolves and changes along with societal trends and/or the needs it hopes to address.

In Mexico, for beef, two types of markets are considered: supply and fine cuts, with a greater demand for fine cuts in the northern part of the country, where most of the slaughter plants are of the Federal Inspection Type (TIF), compared to the central and southern part of the country, where the greatest demand is for supply meat where the largest number of slaughterhouses and municipal slaughterhouses are concentrated. For example, in meat processing, the most important factors are the water-holding capacity and the consistency of the fat (and the corresponding fatty acid pattern). In contrast, the most important factors for the consumer are the color, tenderness, and typical flavor of the meat [2]. This demonstrates the subjectivity of quality and, therefore, the importance of knowing the market you hope to access.In 2021, Parra-Bracamonte and collaborators carried out an exhaustive bibliographic search to determine the characteristics that the Mexican consumer considers as "quality meat", finding that "in general the Mexican consumer has a generic concept of quality and it is defined by intrinsic characteristics, mainly color and flavor, but also with smell, consistency and juiciness as secondary characteristics" [1]. They also found that the desired parameters for each characteristic vary depending on the region of the country in which the interviews were conducted. In that same study, it was found that approximately two-thirds of consumers preferred low-fat cover and non-marbled meat as their main selection criteria when purchasing meat, and a significant proportion of consumers in Veracruz also displayed these two criteria. However, a significant proportion of consumers in Hermosillo preferred well-marbled meat [1]. Despite regional differences in meat preferences, color is known to be one of the most important intrinsic characteristics for the consumer, as it is traditionally associated with freshness, flavor, and texture, making it the most important characteristic taken into account during the purchasing decision [3].

Understanding market expectations for a product allows producers to modify their production methods and systems to meet consumer needs and desires; therefore, carcass classification is a highly useful tool for livestock producers. Differences in fat cover, color, and muscle mass, among others, should lead to different values for animals depending on the market they are exposed to. This is a basic market principle and is based on the ability to distinguish qualities or characteristics between products that, although similar, have different values [3].

In Mexico, there is great genotypic and phenotypic variability in cattle for slaughter, in addition to a diversity of production systems and management, resulting in inconsistent carcass and quality production. This variation may be based on yield, quality, or specific characteristics that make the carcass or its meat more desirable in the market. Ideally, this variation should be associated with a system of incentives or penalties that allows producers to align with consumer demands.

Carcass scoring is a tool that the industry can voluntarily use to calculate production characteristics. This is because the analysis of the quantity of meat extracted from a carcass and its quality provides essential data for identifying the most efficient production systems. Ultimately, this method of marketing meat will benefit consumers by allowing them to choose from a wide range of meat cuts of varying qualities and at prices that meet their sensory expectations [3].

2.2 International classification systems

Ideally, a carcass evaluation system seeks to predict carcass quality and yield based on measurements (objective and subjective) of carcass characteristics that are correlated with meat quality and yield [3].

Different channel evaluation programs have been established in each nation, taking into account the following factors:

- The particularities and tastes of the meat-eating population.
- The structure of the national or regional market.
- The type of national or regional livestock farming.
- The type of livestock production in the country or region.

Global carcass valuation systems vary depending on the specificities of each nation, given that not all countries produce the same type of cattle or share the same consumption patterns. According to their methodology, two-channel evaluation systems are distinguished: those that take into account the use of continuous variables and those that incorporate discrete variables. Continuous or grading systems are based on levels or degrees of value or quality, so that one carcass, compared to others, can be organized based on that level, from the lowest to the highest. Grading systems aim to predict the organoleptic quality and yield of meat in the carcass. These systems are based on scientific observations and associations. For example, the fact that meat from older animals is generally tougher than that of younger animals, or the relationship between greater fat coverage on the carcass and better meat quality, has led these systems to eliminate older animals with a low-fat content from the higher grades. Grading systems employ objective criteria such as the thickness of subcutaneous fat, the area or depth of the chop, marbling, and carcass weight, as well as subjective criteria such as the physiological maturity of the animal or excessive kidney fat, among others.

The classification systems are based on describing the carcass using a common language, which must be understood by all members of the production and sales chain, although it does not establish an economic value for the carcass. The essence of classification is that, since it is solely descriptive, there are no better or worse carcasses. For example, if lean meat is not the most desirable for a specific market, that same carcass could be the best for another market, considering it to be of the highest quality. Categorization systems use fundamentally subjective criteria, such as conformation, texture, meat color, thickening, profiles, among others. On a global scale, the carcass properties evaluated to estimate quality and yield vary. Each nation with a specific system has selected the traits that have been proven most effective in estimating the quality and yield of the carcasses they produce [3].

2.3 Mexican standards for channel classification

Currently, two standards are used to classify Mexican carcasses. NMX-FF-078-SCFI-2022 "Livestock Products - Beef Carcass - Classification" establishes as its goal to assist ranchers and other participants in the production, processing, sale, and consumption chain of beef by defining the quality characteristics that carcasses must have for sale [4]. This will allow for fair compensation for their work and support the consumer by ensuring the quality of the product. Since it defines the slaughter plants that operate under the provisions of NOM-008-ZOO-1994 as their field of application. This voluntary standard establishes six basic quality levels: Supreme, Select, Standard, Commercial, and Unclassified. In addition, for a basic classification level, there may be two sublevels, A and B, determined by the degree of marbling [5].

To determine the basic quality grade, physiological maturity is assessed based on ossification, carcass conformation, muscle mass, fat color, and meat color; additionally, the distribution of subcutaneous and perineal fat can be evaluated.

The NOM-004-SAGARPA-2018 Beef - Classification of carcasses according to their physiological maturity and marbling characteristics aims to "establish a classification system for beef carcasses based on the physiological maturity and marbling characteristics for said product" to provide certainty and thereby organize the carcass meat supply sector. Establishing a quality classification allows for reporting on product attributes, avoiding confusion in the domestic and export markets. This mandatory standard establishes the requirements and specifications necessary to establish a series of aspects that allow beef to be classified and, thus, provide relevant information on its quality. Therefore, the objective classification of beef will not only provide consumers with certainty about what they are purchasing, but also allow livestock producers to determine the quality of their products, providing additional added value to this type of product [6]. This standard aims to establish a description of a beef classification system, as well as to determine the physiological maturity and marbling characteristics of said product, with a food-related focus that promotes authenticity, marketability, permitted designations, and conformity assessment procedures for the reference product, including inspection and control mechanisms. This represents an opportunity to add value to beef production in a differentiated segment [6].

The classification is made through the correlation between physiological maturity and the degree of marbling of the carcass.

- Physiological maturity is determined by the bone and muscle maturity of the carcass.
- Bone maturity is measured by the anatomical properties of certain bones, particularly the spine and the ossification of the thoracic knobs. The evaluator must inspect the evidence of ossification in the thoracic knobs; for this purpose, the Average Percentage of Ossification (APO) is used as a reference, thus obtaining three maturity groups: A (9 - 30 months), B (30 - 42 months), and C (+ 42 months).

At muscle maturity, the color and texture of the meat of the long back muscle are evaluated (longissimus dorsi).

For marbling, there are 7 categories: Slightly abundant, moderate, modest, little, light, traces, and practically devoid. Once physiological maturity and marbling have been established, these two elements must be combined to classify beef under the comprehensive classification system, which yields five possible classifications: Premium, Supreme, Select, Standard, and Commercial. It is important to note that neither standard establishes mandatory carcass classification, but instead defines it as an attribute that adds value to cuts obtained from classified carcasses. NMX-FF-078-SCFI-2022 specifies that it applies to all carcasses sold within the country, but NOM-004-SAGARPA-2018 limits it to individuals or legal entities that intend to display such classifications on their products.

2.4 Types of slaughter plants in Mexico and the meat processing

Beef production in Mexico is carried out under different technological levels, management systems, and production purposes, primarily involving the production of steers for slaughter, calf rearing for export, and breeding stock. In Mexico, there are approximately 30 breeds used for beef production, including Hereford, Charolais, Brahman, Nelore, European Brown Swiss, Indobrasil, Gir, Beefmaster, Simmental, Limousin, Brangus, and Angus, among others [7]. Since ancient times, the slaughter of animals for human consumption has been a service provided by the government, and in Mexico, there are three types of slaughter plants: TIF (Federal Inspection Type) plants, municipal slaughterhouses, and slaughterhouses.

The breed, age, and quality of the animals processed at each plant are theoretically homogeneous, as there are no discrimination systems between plants. However, there are very obvious differences in the type of animals slaughtered at each plant, and more importantly, the type of carcasses obtained from them. The Ministry of Health oversees the operation of municipal slaughterhouses and slaughterhouses, which involves monitoring the health of the meat produced. The primary activities carried out at these slaughterhouses include slaughter, carcass management, and the direct sale of beef, pork, sheep, goats, poultry, and other livestock.

TIF plants, on the other hand, are rigorously supervised by the Ministry of Rural Development (SADER) and its certified veterinarians, who guarantee the production of safe food and the enforcement of current legislation. Their main goal is to produce excellent quality meat, with the highest level of safety nationally and internationally. Their periodic inspections reduce the possibility of cross-contamination between products during manufacturing or storage. Therefore, the possibility of products being contaminated by viruses, bacteria, or diseases spread by animals is reduced. Slaughterhouses that have this certification can more easily market meat products, both nationally and internationally, since TIF establishments are the only ones eligible for export [8].

There are clear differences in the working methods at a TIF establishment, as they rely on a mechanized system that municipal slaughterhouses do not. This difference is evident in the handling and treatment of the animal at the time of slaughter and in the processing process [9]. Furthermore, it is important

to mention that TIF establishments are required to keep carcasses at refrigeration temperatures, allowing the conversion of muscle to meat and contributing to food safety at the beginning of the cold chain. However, according to the Commission for the Protection against Sanitary Risks (COFEPRIS), 70% of municipal slaughterhouses and slaughterhouses do not have such facilities, thus releasing hot carcasses onto the market.

Firstly, TIF plants use equipment and methods that comply with health regulations, intending to guarantee the safety of the meat and its presentation [9]. The TIF system guarantees hygiene, reducing the risk of zoonoses and reported animal diseases, thus reducing the impact on public health, animal health, the economy, and national supplies [9]. In Mexico, there are 873 municipal slaughterhouses and slaughterhouses, according to the 2022 list of the National Service of Health, Safety and Agri-Food Quality (SENASICA) and the General Directorate of Phytosanitary Inspection, and 452 TIF plants in the SENASICA Directory.

3. Objectives

3.1 General Objective

To evaluate the quality of carcasses using national classification from three different slaughter plants in the State of Querétaro.

3.2 Particular Objectives

Use the methodology proposed in NOM-004-SAGARPA-2018 to classify processed bovine carcasses in three types of slaughter plants in the state of Querétaro, Mexico, to determine their efficiency.

Provide constructive criticism of the challenges that implementing the methodology proposed in NOM-004-SAGARPA-2018 represents for the diverse livestock species in Mexico.

4. Methodology

4.1 Location of the study area

The study was conducted in the Mexican highlands, sampling three different types of slaughter plants: TIF plants, municipal slaughterhouses, and slaughterhouses. Due to confidentiality issues and agreements with the plants, the location of each will not be disclosed.

4.2 Method

Thirty bovine carcasses were sampled at each slaughterhouse, divided into two visits due to the slaughter volume at each establishment. At the municipal slaughterhouse and slaughterhouse, hot carcasses were sampled approximately 20 minutes after bleeding, before being loaded onto user transport following the normal process, as these plants do not have refrigeration chambers. At the TIF plant, hot carcasses were sampled approximately 30 minutes after bleeding, just before entering the refrigeration chamber.

4.3 Channel quality classification:

Carcass classification was carried out following the procedure established in NOM-004-SAGARPA-2018, excluding the evaluation of marbling, since users did not allow the carcass to be cut at the 12th and 13th ribs. Carcasses were classified as Premium, Supreme, Select, Standard, or Commercial, as established by the standard.

4.4 Bone maturity

Bone maturity was determined by assessing the level of ossification of the sacral vertebrae, ribs, and the thoracic buttons of the 10th, 11th, and 12th thoracic vertebrae. Both halves of the carcass were inspected, and an Average Percentage of Ossification (APO) was assigned. The APO is a mathematical estimate using the following formula:

$$ppo = \frac{(\%T10 + \%T11 + \%T12)}{3} \quad (1)$$

Where %T10, %T11, and %T12 correspond to the visual estimate of the percentage of bone tissue relative to cartilage for each of the buttons corresponding to the 10th, 11th, and 12th thoracic vertebrae, respectively. Figures for the visual estimate of the percentage of bone tissue are shown in Appendix 2 of the standard.

Depending on the PPO results, carcasses are classified into three maturity groups: Group A: APO less than 10%, corresponding to young animals between 9 and 30 months of age. Group B: APO between 10% and 35%, corresponding to animals between 30 and 42 months of age. Group C: APO greater than 35%, corresponding to animals 42 months of age or older.

Table 1- Parameters to determine bone maturity in a bovine carcass (NOM-004- SAGARPA-2018).

Description	Maturity group A (9-30 MONTHS)		B (30-42 MONTHS)		C (+42 MONTHS AGE)
	PREMIUM	**SUPREME**	**SELECT**	**STANDARD**	**COMMERCIAL**
Vertebrae Sacred	There is a distinguished separation between vertebrae	Separation is barely visible by the presence of cartilage	Vertebrae completely merged	Ossified vertebral bodies are completely merged	Ossified vertebral bodies are completely merged
Vertebrae Lumbar	Cartilage of the vertebral process without ossification	Almost completely ossified	The cartilage of the vertebral processus presents complete ossification	The cartilage of the vertebral processus presents complete ossification	The cartilage of the vertebral processus presents complete ossification
Vertebrae Thoracic	The cartilage of the vertebral process doesn´t present ossification	The cartilage of the vertebral process doesn´t present ossification	Cartilage of the vertebral process sample, total ossification or partial	Cartilage of the vertebral process with complete ossification	Cartilage of the vertebral process with complete ossification
Appearance of the ribs	Narrow an oval	Slightly wide and flat, cream color	Slightly flat and wide, white color	Wide, flat, white color	Wide, flat, white color
Characteristics of the Vertebral Bodies	Red, porous, and soft	Red, porous, and soft	Slightly hard, from slightly red to white	Hard, colored red to white	Hard, colored white

For this purpose, as described in the standard, and to facilitate data analysis, the number 1 was assigned to carcasses whose bones were consistent with what was described for Group A of maturity, which corresponds to the Premium and Supreme classification; the number 2 was used for the Maturity group B, Select and Standard quality, while number 3 was used for Maturity group C, Commercial quality. Once classified as 1, 2, or 3 for the 4 criteria (sacral vertebrae, lumbar vertebrae, appearance of ribs, and APO) according to the degree of ossification of each channel, the average of each sample was obtained to obtain the final result of the degree of maturity.

4.5 Organoleptic characteristics

The color of the meat was determined using the color scale established in NOM-004-SAGARPA-2018, and was classified according to the criteria of the same standard (Fig. 1 and Table 2).

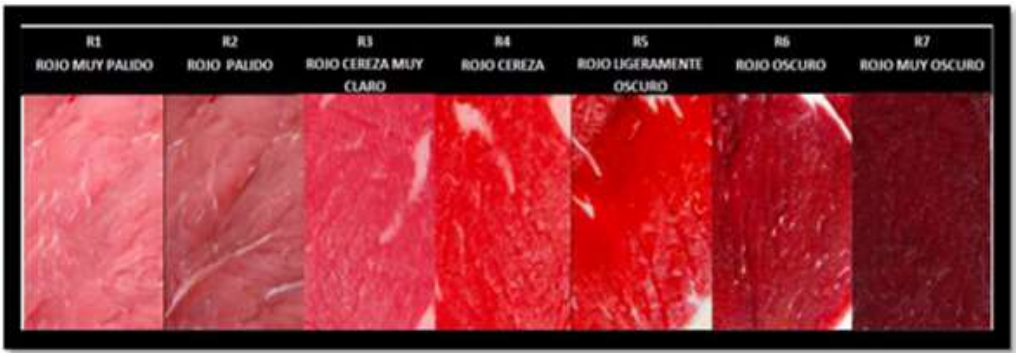

Fig. 1 - Color scale for determining the quality of beef [6].

Table 2- Meat quality classification by color [6].

Muscular maturity	Color scale key	Quality Grade
PINK	R1	STANDARD
VERY PALE RED	R2	
VERY LIGHT CHERRY RED	R3	SUPREME, SELECT
CHERRY RED	R4	PREMIUM
		SUPREME
		SELECT
SLIGHTLY DARK RED	R5	SELECT, STANDARD
DARK RED	R6	STANDARD
VERY DARK RED	R7	COMMERCIAL

Fat color was determined using the provisions of NMX-FF-078-SCFI-2002, Livestock Products - Beef Carcass - Classification (Fig. 2 and Table 3)

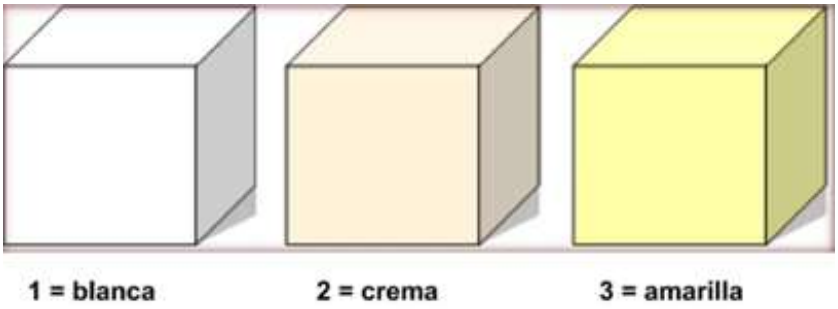

Fig. 2 - Color scale for determining the color of fat in raw meat [3].

Table 3- Classification of meat quality according to fat color [4].

Concept	Quality grades of the carcasses:			
	Supreme	**Select**	**Standard**	**Commercial**
Fat color	White (Equivalent to PowerPoint 255-255-255 key)	White to cream (Equivalent to PowerPoint 255-255 key of 255 to 210)	Creamy to slightly yellow (Equivalent to PowerPoint 255-255 key of 210 to 200)	It can be yellow (Equivalent to PowerPoint 255-255 key less than 200)

Minimum criteria and/or maximum limits of general application throughout the country to establish the different basic quality grades.

5. Results and discussion

5.1 Quality classification based on bone maturity

The APO is the most relevant indicator for establishing bone maturity, given that the vertebral column of animals ossifies from the caudal or posterior end towards the center of the back and the head also towards the center of the back, therefore, the first bones to ossify are the sacrum, then the lumbar vertebrae and finally the thoracic vertebrae [3]. The results for the bovine carcass maturity group based on the 4 ossification criteria described in NOM-004-SAGARPA-2018 are presented in Table 4.

Table 4- Classification of meat quality according to fat color [4].

Plant of the Slaughter / Group of Maturity	Classification according to the NOM	Slaughterhouse		Municipal Slaughterhouse		TIF		TOTAL	
		%	#	%	#	%	#	%	#
TO	Premium/ Supreme	23.3	7/30	26.7	8/30	50	15/30	33.3	30/90
B	Select / Standard	13.3	4/30	60	18/30	30	9/30	34.4	31/90
C	Commercial	63.3	19/30	13.3	4/30	20	6/30	32.2	29/90

The application of the methodology proposed in NOM-004-SAGARPA-2018 to establish a quality grade based on bone maturity presented difficulties, since the determination of the PPO and the characteristics observed in the other vertebrae and ribs did not always present a logical pattern. An example of this is seen in Table 5.

Table 5- EXAMPLE: Bone characteristics of a bovine carcass

Sacral vertebrae	Lumbar vertebrae	Ribs appearance	PPO (%)	PPO	Average Of The 4 Criteria	Group of Maturity
3	1	2	0%	1	2	B

According to Table 5, the carcass had “fully fused” sacral vertebral bodies, classifying it as maturity group C (3 in our system). The cartilage in the lumbar vertebrae was observed to be “almost completely ossified,” so it was assigned number 1 (Maturity Group A); while the ribs were observed to be “slightly flat and wide, white,” so it was assigned number 2. The average percentage of ossification of the thoracic buttons was classified as 1, since they presented 0% ossification.

The average score across the four criteria is 2, so the carcass is classified as maturity group B; however, having a carcass with such an advanced degree of ossification in the sacral vertebrae suggests that it is an old animal, while a 0% degree of ossification in the thoracic buttons is consistent with a very young animal. Having both classification groups in a single carcass for the different criteria exemplifies how the method proposed by the standard leaves the final classification to the evaluator's discretion. The scores for each criterion of each sampled carcass were evaluated one by one, and the final maturity level was determined. As can be seen in Table 4, the same percentage of cattle with all three maturity levels were slaughtered in the three types of slaughter plants (33.3% in group A, 34.4% in group B, and 32.2% in group C).

In the slaughterhouse, a greater number of carcasses with bone maturity characteristics consistent with maturity group C were found (63.3%), while the majority of the carcasses sampled in the municipal slaughterhouse were classified as B (60%) and in the TIF plant, carcasses from maturity group A were found with a higher prevalence (50%).Traditionally, both slaughterhouses and municipal slaughterhouses receive cattle from small producers and even improvised fatteners or one-time customers (due to a social event) since these types of establishments have no restrictions on the type of animals they process, whether these are backyard or culled animals, etc.

The results regarding the degree of maturity found at the slaughterhouse may be because the lack of regulation in slaughterhouses and the low cost of their service make them more attractive to extensive livestock producers who cannot invest in other types of slaughterhouses. It is expected that extensive livestock producers will bring older animals to slaughter, since their more limited access to concentrated feed means that the time to reach the expected slaughter weight takes longer.

The results of the municipal slaughterhouse may be because a wider variety of producers use this service, such as cattle ranchers with more technically advanced productions, who are not interested in accessing an export market, but rather a local market where hot carcasses are accepted and where the degree of quality classification is not very important since the sale is equally to all consumers. The results obtained at the TIF plant present a pattern that reflects the type of cattle producers who use its services. Fifty percent of the samples were classified as maturity group A, meaning young animals whose genetic characteristics combined with environmental conditions (such as a balanced diet, concentrated feed, and more technologically advanced facilities) allowed them to reach slaughter weight in less time, resulting in a higher-quality carcass. Only 20% of the carcasses sampled at the TIF plant were classified as group C, which may belong to culled animals slaughtered by dairy farmers at the end of their productive lives, or may represent the genetic variability of having early-maturing and late-maturing breeds in the same pen within the state's meat production facilities, since there is no rigorous selection of the different breeds and maturity types that are fattened.

5.2 Meat Color

Regarding meat color, it was found that very dark red (R7) predominated in the three slaughter plants (Table 7); this being the color of 93.3% (28/30) of the samples in the Slaughterhouse, 80% (24/30) in the Municipal Slaughterhouse and 90% (27/30) in the TIF Plant. The remaining 6.67% (2/30) of the samples from the Slaughterhouse were classified as very light cherry red (R3); the remaining 20% in the Municipal Slaughterhouse (6/30) were classified as dark red (R6), as was the remaining 10% of the samples from the TIF Plant (3/30) (Table 6).

Table 6- Quality grade of bovine carcasses based on the color of the meat according to the NOM-004-SAGARPA-2018

Plant / Color	Quality grade according to the NOM	Slaughterhouse		Municipal Slaughterhouse		TIF		TOTAL	
		%	#	%	#	%	#	%	#
R7 (Very dark red)	Standard / Commercial	93.3	28/30	80	24/30	90	27/30	87.7	79/90
R6 (Dark red)		0	0/30	20	6/30	10	3/30	10	9/90
R5 (Slightly dark red)	Select / Standard	0	0/30	0	0/30	0	0/30	0	0/90
R4 (Cherry red)	Premium / Supreme / Select	0	0/30	0	0/30	0	0/30	0	0/90
R3 (Very light cherry red)	Supreme / Select	6.67	2/30	0	0/30	0	0/30	2.2	2/90
R2 (Very pale red)	Standard	0	0/30	0	0/30	0	0/30	0	0/90
R1 (Pink)		0	0/30	0	0/30	0	0/30	0	0/90

According to the guidelines of NOM-004-SAGARPA-2018 based on meat color, 97.7% (88/90) of the carcasses sampled for meat color were classified as “Standard” or “Commercial” quality; while only 2.2% (2/90) of the carcasses were classified as “Supreme” or “Select” (Table 6). The standard directly links a dark meat color with an “old” animal: “The color of the meat intensifies to a darker tone and the texture becomes more irregular with the corresponding advances in age,” which is correct, however, there are other factors that can alter the color of the meat such as chronic stress and pre-slaughter and/or feeding. Considering the results found in this study for bone maturity, which describes animals from the three maturity groups, it is important to consider all the factors that can alter meat color when performing a quality classification on Queretaro cattle.

Animals subjected to chronic heat stress have been reported to have reduced muscle glycogen stores, leading to lower lactic acid production, resulting in dark, firm, dry (DFD) meat characterized by a high final pH and increased water holding capacity, commonly observed in ruminants [10]. Heat stress reduces feed intake and, because liver glycogen does not normally maintain energy homeostasis because ruminants rely primarily on volatile fatty acids (VFAs) as glucose precursors, therefore, during heat stress, animals must use muscle glycogen as a source of glucose [10]

According to the Manuals of Good Livestock Practices of the Regional International Organization for Agricultural Health (OIRSA) and the Government of Mexico, it is established that pens for confined beef cattle must have "Sufficient shade for all animals" [11]; the Ministry of Agriculture and Rural Development (SADER) establishes that in regions where the average annual temperature does not exceed 35ºC, the shade must cover 30% of the pen surface, giving 2.30 m2per animal and be 4 to 5 m tall; however, it has been observed that fattening ranches in the state of Querétaro do not have facilities that meet this shade requirement for cattle, leaving them exposed to the weather throughout the fattening period. Therefore, it can be inferred that the animals are under chronic heat stress, which could affect the color of the final meat.

In a study conducted in Texas, the incidence of firm, dark, dry meat or DFD was compared in animals housed in shaded pens during the summer and in unshaded animals. A lower incidence of DFD was found in the shaded animals, although there were no differences in hot carcass weight, marbling, or muscle area longissimus. The authors also reported less aggressive behavior in shaded cattle, consistent with previous reports indicating that heat stress can increase bullying behavior by depleting glycogen stores. These studies demonstrated that providing shade to cattle is a suitable solution to minimize the negative effects of heat stress on performance and improve meat quality [10]. There are conflicting theories regarding the effects of diet on meat color; however, it is known that forage-restricted diets promote oxidative, rather than anaerobic, muscle metabolism. This would limit glycogen storage and result in a darker color compared to concentrated diets.ad libitum [12].

Meat color is one of the crucial attributes of meat quality that influences consumers' purchasing decisions [12]. Meat purchasing decisions are influenced by color more than any other quality factor because consumers use discoloration as an indicator of freshness and healthiness. As a result, nearly 15% of retail beef is marked down due to surface discoloration, corresponding to $1 billion in annual revenue losses [13]. This is why the environmental and feeding conditions under which cattle are raised in Mexico must be taken into account before establishing a classification system that harms a significant proportion of cattle farmers due to the quality grade results.

5.3 Fat Color

Regarding the color of the fat, it was found that the most common color in the 90 sampled carcasses was “White to creamy” (43/90), which is equivalent to a Select Quality classification as established in NMX-FF-078-SCFI-2002.

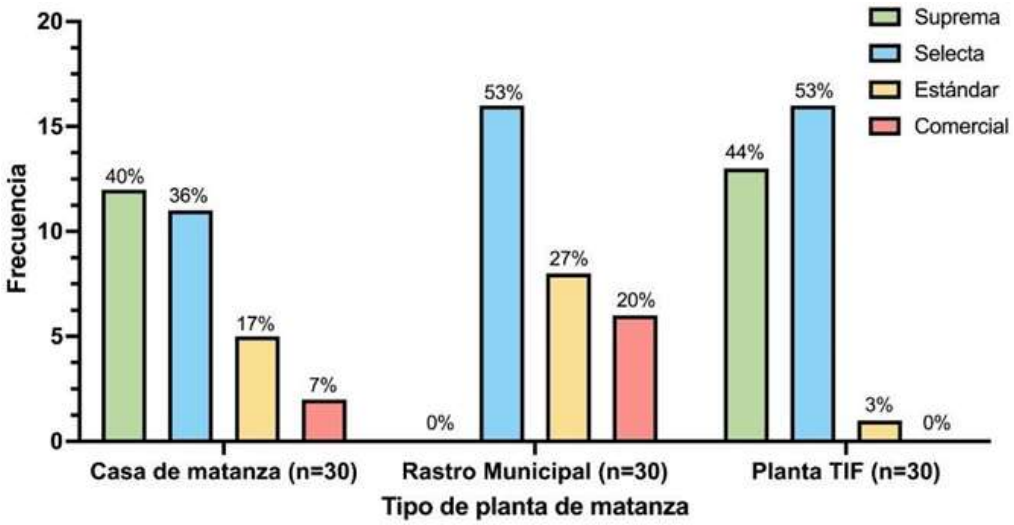

Fig. 3 - Quality grade of beef carcasses based on fat color according to NMX-FF-078-SCFI-2002 in three types of slaughter plants

At the slaughterhouse, it was reported that 40% (12/30) of the carcasses had white fat, equivalent to the Supreme classification; 36% (11/30) had white to creamy fat, Select quality; 17% (5/30) had creamy to slightly yellow fat, Standard quality, while only 7% (2/30) of the carcasses had yellow fat, Commercial quality (Figure 3). Similarly, at the TIF Plant, 44% (13/30) of the samples had a Supreme classification in terms of fat color; the most prevalent fat color was White to creamy, corresponding to 53% (16/30) of the carcasses; while the remaining 3% (1/30) had creamy to slightly yellow fat, equivalent to Standard quality (Figure 3). Finally, at the municipal slaughterhouse, the most predominant fat color was white to creamy, with 53% (16/30) of the carcasses being Select grade; 27% (8/30) had only creamy to slightly yellow fat, of Standard quality; and the remaining 20% (6/30) had yellow fat, of Commercial quality (Figure 3).

Although the color of carcass fat is not a reflection of its organoleptic quality, socially, consumers prefer to buy meat with white fat rather than yellow. The yellowish hue of fat is usually attributed to the presence of carotenoid compounds originating in flora. Ruminants store these compounds because they are precursors of vitamin A and also have antioxidant activity [3]. Feeding grains for 36 days before slaughter allows for white fat in the carcasses, thus increasing the quality of the cuts. This is intended to avoid harming ranchers due to a characteristic that doesn't affect the quality of the product.

In NOM-004-SAGARPA-2018, fat color is not described as a criterion to evaluate the quality level of carcasses; however, in NMX-FF-078-SCFI-2002, as well as other evaluation systems, fat color is considered an important criterion to determine carcass quality. This is unfair to extensive productions that do not have the resources or infrastructure to administer a pre-slaughter diet with grains that decrease the yellow pigment of the fat, condemning them to always have low quality levels. Market preferences regarding the color of fat that they consider to be of "better quality" must also be taken into account.

5.4 Comprehensive quality level

A comprehensive quality assessment of the carcasses sampled in this study was performed, taking into account maturity, meat color, and fat color. The results are shown in Table 7.

Table 7- Comprehensive determination of the quality of bovine carcasses in three types of slaughterhouses in the state of Queretaro.

Classification according to the NOM	Slaughterhouse		Municipal Slaughterhouse		TIF		TOTAL	
	%	#	%	#	%	#	%	#
Premium	0	0/30	0	0/30	0	0/30	0	0/90
Supreme	16.7	5/30	0	0/30	30	9/30	15.6	14/90
Select	13.3	4/30	23.3	7/30	13.3	4/30	16.7	15/90
Standard	26.7	8/30	63.3	19/30	36.7	11/30	42.2	38/90
Commercial	43.3	13/30	13.3	4/30	20	6/30	25.6	23/90

The Standard classification was the most prevalent among the 90 samples, and also within the municipal slaughterhouse group (63.3%) and the TIF plant (36.7%). At the slaughterhouse, the Commercial classification was the most prevalent (43.3%), followed by the Standard (26.7%), then the Supreme (16.7%), and finally the Select (13.3%). At the municipal slaughterhouse, after Standard classification, the most prevalent classification was Select (23.3%), followed by Commercial (13.3%). At the TIF plant, in descending order, they were classified as Supreme (30%), then Commercial (20%), and finally Select (13.3%).

Of the 90 channels sampled, none were classified as Premium. Meat color is the most important factor for consumers when purchasing meat, while the degree of maturity is the most important for determining the quality characteristics of the carcass. Therefore, both factors are of great importance in determining the final quality grade.

The results found in this work for maturity show a homogeneous pattern between the three types of slaughter plant, while the results for meat color are Polarized toward a Standard or Commercial classification. Having characteristics that match a young carcass, Premium or Supreme classification for bone maturity, but with a very dark red meat color that classifies it as Standard or Commercial, and a creamy white fat color that classifies it as Select, means that the final determination of carcass quality is based on the evaluator's judgment. It is known that the color of meat can be affected by different factors, making it an unreliable measure, while bone maturity is not affected by anything other than the age of the animal. However, the determination of the degree of maturity is based on the observation and judgment of the evaluator and not on an arithmetic measure that allows the age to be accurately determined in order to predict the organoleptic characteristics of the meat.

The methodology described in the standard determines the overall quality grade based on the degree of maturity and the degree of marbling. The grade is determined by the evaluator based on their experience and the amount of intramuscular fat observed in the carcass. The level of marbling was not determined in this work because the farmers did not consent to this cut being made to the carcasses; however, taking into account the challenges that determining the degree of maturity presented, it can be inferred that determining the level of marbling becomes equally dependent on the evaluator's criteria, so that determining the final quality degree would represent the same challenges even measuring these parameters.

The application of this standard requires extensive experience and training to ensure that a standardized criterion is in place in all slaughter plants where this activity is carried out, thereby guaranteeing producers that the quality level determined is reliable and accurate. However, the application of a method with these characteristics presents disadvantages for the meat industry, since the human factor involved allows for the questioning and challenging of the results presented. The use of quantitative methods such as photoluminescence will help reduce human involvement and the possibility of results being questioned based on doubts about the evaluator's judgment.

6. Conclusion

The implementation of the methodology proposed in the NOM presents significant limitations related to the infrastructure and working methods of municipal slaughterhouses and slaughterhouses, as they lack the space required to perform the analysis of these characteristics. Furthermore, when marketing hot carcasses, the results obtained are biased because they are not carcasses that have already gone through the process of converting muscle to meat.

Therefore, if such a NOM is to be made mandatory, it should be considered that it be used only in TIF plants, and a comprehensive training and instruction system should be created that allows for a uniform criterion in all plants where such a determination is made, or a commitment should be made to the implementation of technology that reduces the subjectivity of the results and the participation of the evaluator's judgment.

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