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Meat Color, Marbling, and the Evaluation of Defects in Beef and Pork at the Point of Purchase

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Abstract: Intentions to purchase meat and repeat purchasing patterns will depend on the consumer's perception of intrinsic and extrinsic quality cues. In order to discover consumers' insights into the quality of pork and beef, the main objective of this study was to investigate meat color, marbling, and types of fresh meat defects. A total of 50 samples of meat were analyzed for three quality characteristics on different levels. This study applied a statistical calculation of a loss function invented by Taguchi. The results showed the values of variations in meat color and marbling that present the limits of consumers' tolerance. Based on the obtained results, it was determined that the tolerable level of color variations of beef is 3.61, while for pork, this limit is 2.00. The most preferred marbling percentages were 21% and 5.74% for beef and pork, respectively. On the other hand, the negative effect of defects was the strongest for "dark cutting" for beef and "blood spotting" for pork loins.

Keywords: beef; pork; meat quality; consumer's tolerance; Taguchi loss

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1. Introduction

Meat is the second largest food category in Serbia, affecting the average annual increase in food prices and accounting for approximately 23.9% of the total increase in these prices [1]. On a per capita basis, pork consumption is expected to increase globally, but to decline in European countries. On the other hand, global per capita beef consumption is projected to drop by up to 5% by 2030 [2]. Furthermore, it has been noticed that the focus in diets has shifted from pork to chicken and turkey meat [3].

Despite a predicted decline in beef and pork consumption, meat producers need to maintain a positive growth in long-term consumption trends and to gain a deeper understanding of consumers' behavior and preferences. By defining consumers' level of tolerance of certain meat characteristics, producers can avoid facing high failure rates and costs. Several authors have highlighted consumer attitudes and preferences towards attributes such as color and marbling [4–7].

Meat color is one of the most critical traits for consumers intending to purchase beef and pork. Many factors, such as slaughter age [8], myoglobin concentration, and the chemical and physical parameters of meat [9], including light scattering and absorbing properties, affect meat color. It is also the result of many other factors, such as pH and the muscle type of the animal. After slaughtering, the pH becomes acidic (pH 5.4–5.7) within 18–24 h. After reaching the lowest point of acidic pH, the pH value will gradually increase to the pH value of fresh meat, which is usually in the range of 5.5–6.2. Furthermore, meat color depends on the breed, age, and diet of the animal; meat from older animals will be darker in color because the myoglobin level increases with age [10]. Many studies provide results on differences in beef color according to different breeds [11].

Marbling is one of the primary carcass attributes used for quality assessment in most beef grading systems. From a technical point of view, marbling represents the content of intramuscular fat (IMF), considered one of the vital factors influencing beef's sensory quality including tenderness, juiciness, flavor, and color [12]. The most popular and used standards for the determination of the level of marbling are the AUS-MEAT Reference Standards [13], MSA (Meat Standards Australia) [14], the USDA Quality Grade and Yield Grade [15], and the Japanese marble score scale (BMS scale) [16]. In Europe, the current beef grading system is the EUROP grid, which is focused on carcass commercial value and carcass classification [9].

Although beef and pork producers are focused on producing meat that is free of quality defects, some classifications of defects have been made. According to previous research [17], the quality defects of beef that can be noted in the retail store are dark-cutting beef, lack of marbling, excess seam fat, too large or too small ribeye, and excessive external fat.

Dark-cutting beef is abnormally dark-colored, lean, and less visually appealing to consumers [18]. The color can range from a dark cherry-red and extremely dark red to almost dark gray [19]. A lack of marbling is commonly linked to a greater variation in tenderness and juiciness. Although marbling is an important characteristic according to beef quality standards, seam fat content may be a more precise predictor of eating quality than visual marbling score evaluated by consumers [20,21].

Dark firm and dry (DFD) meat [22], too much or too little marbling, excess seam fat [23], too much color variation in a single cut, and too much external fat are other examples of common defects. Thus, PSE lean meat not only refers to meat with a less intensive surface color but to meat with all preconditions to become gray or tan to brown.

Meat processors have emphasized the production of consistent high-quality products. Products with quality defects are an economic burden to the industry as a whole and, at the same time, result in discounts of market prices or food waste. Thus, the connection between the economics of production and quality has been one of the main goals in the meat industry. This requires the implementation of various approaches for reducing setup costs (and time) to improve process quality. One of these approaches is the Taguchi method [24–26]. This method is a specific statistical technique for implementing robust processes in product design and improvement in products quality at a relatively low cost [27]. Furthermore, the Taguchi approach, in the form of the Taguchi loss function (TLF), has not been widely used in the food sector. Study [28] gives an overview of how to combine food products or food-related processes with the TLF.

Bearing in mind the limited studies connecting the color, marbling, and defects of beef and pork using the same assessment method, the authors identified this as a research gap. Therefore, the main objective of this paper was to determine the preferred levels of meat color and marbling as decision-making triggers for purchasing meat and implementing the TLF. In this paper, the authors compared three intrinsic characteristics that are found to be the most important in relation to consumer opinions: meat color, marbling, and the presence of defects.

Therefore, two working hypotheses were proposed:

1. The implementation of the TLF for the control of the color and marbling variations of beef and pork is possible.
2. Four typical types of defects of beef and pork will affect consumers' choices.

A model of a standard with seven levels of color and marbling and four types of defects results in an appropriate differentiation among beef and pork chops. Thus, in this study, new color and marbling levels were developed for domestic beef and pork and were then related to samples. Here, it is very important to declare that these color and marbling chips were experimentally provided and were used only for the purposes of this research study. These chips are useful but have the limitation of corresponding to a limited number of beef and pork samples.

Since standards are different in different countries, there is no strictly defined, mandatory number of levels of one characteristic, especially marbling. This is expected, since in different countries, regulations, consumers' demands, breeding systems, and breeds of animals are different. The AUS-MEAT Reference Standards include eleven levels of marbling, where the two starting levels show a "0 score" of marbling [12].

On the other hand, the USDA Quality Grade and Yield Grade contains six levels of marbling categorized into three groups: "USDA Select", for beef chops with a slight and small level of marbling; "USDA Choice", for beef with a modest and moderate level of marbling; and "USDA Prime", for beef with slightly abundant and moderately abundant levels of marbling.

Finally, the Japanese marble score scale (BMS scale) presents ten images with increasing marbling scores, ranging from 3 to 12 [15]. A score of 3 presents the basic minimum of marbling a steak should have, and 12 stands for a steak that is almost white with marbling (because BMS scores of 1 and 2 show almost no marbling, and as such, they are not considered). This Japanese scale is based on Wagyu beef, which is characteristic of Japanese cattle.

Due to the lack of Serbian standards for marbling levels of beef, the authors decided to combine these three most common standards and create seven levels of beef color and marbling for experimental uses. Color and marbling chips were created based on instrumental measurements of experimental samples using a Computer Vision System (CVS) adopted from study [29] with slight modifications. These CVS-generated color measurements better represented the actual color of meat product samples as perceived by trained/experienced panelists. In a study by Tomasevic et al., it was clearly shown that the CVS methodology is not only more accurate and precise for measuring the color of uniformly colored samples, but that it is especially better for bi-colored and non-uniformly colored meat. Thus, using colorimeter for color evaluation of meat products is reliable, but less accurate. Therefore, we used CVS in this study as a more desirable alternative to the traditional method for measuring the color of meat products.

2. Materials and Methods

2.1. Creation of Experimental Color and Marbling Scales

The color chips were built mostly based on the AUS-MEAT Reference Standards but in ranges of real color measurements of meat samples (Tables 1–4). The color measurements were determined using CVS, processed in Adobe Photoshop CC 2019 (Adobe Inc., San Jose, CA, USA), and expressed in a CIE L* a* b* color space according to study [28].

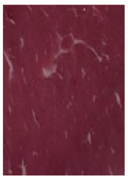
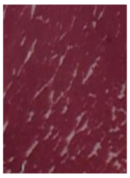
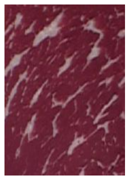
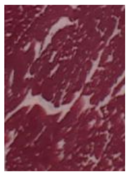
Table 1. Experimental color chips of beef with L* a* b* values for each color level.

L*	65	60	51	49	46	42	40
a*	37	38	39	36	34	31	30
b*	24	24	24	23	24	24	15
	Bright brick-red	Moderately bright brick-red	Slightly bright brick-red	Slightly dark brick-red	Moderately dark red	Dark red	Extremely dark red

Table 2. Experimental color chips of pork with L* a* b* values for each color level.

L* a* b*	83 13 18	80 17 18	70 30 30	66 31 27	57 41 28	52 34 24	48 34 16
							
	Pale grayish-pink	Slightly pale grayish-pink	Moderately light grayish pink	Grayish pink	Slightly grayish-pink	Moderately dark red	Dark red

Table 3. Experimental marbling chips of beef with marbling percentage values for each level.

Marbling percentage (%)	1.0 *	1.5	5.5	10.6	16.0	21.0	26.5 *
							
	Traces	Slight	Small	Modest	Moderate	Slightly Abundant	Moderately Abundant

* Marbling percentage for the first level, "traces", is determined according to the lowest measure of beef samples. The same case is for the highest level of marbling, "moderately abundant", and its value.

Table 4. Experimental marbling chips of pork with marbling percentage values for each level.

Marbling percentage (%)	0.1 *	1.5	5.0	10.0	15.0	19.0	24.5 *
							
	Traces	Slight	Small	Modest	Moderate	Slightly Abundant	Moderately Abundant

* Marbling percentage for the first level, "traces", is determined according to the lowest measure of pork samples. The same case is for the highest level of marbling, "moderately abundant", and its value.

In this study, marbling was assessed by using CVS and calculations were based on a study by Giaretta et al. [30].

The National Pork Producers Council (NPPC) developed a Pork Quality Standard [31], which the authors used in this study as an example of how to create color and marbling chips of pork meat. Instrumentally measured values of the color and marbling of pork samples provided, in total, seven color chips and seven marbling chips.

The marbling measures were obtained by an automatic image analysis using Image J (Microsoft Java) computer software (https://imagej.net/ij/ accessed on 18 August 2023)), an open-source image processing program designed for multidimensional scientific images. The requested output of Image J analysis software in this study were values of marbling percentage derived from the relative white areas (marbling particles) versus red area in total (%). The method of marbling percentage evaluation was used as suggested by Giaretta et al. [30]. The same principle was used for both beef and pork images. As expected, the marbling percentage levels varied between beef and pork.

2.2. Meat Selection

This study was carried out on beef steak, sirloin butt, striploin steak from the *M. longissimus thoracis et lumborum* muscle, and neck samples. Striploin steaks were chosen as a typical location for the measurement of beef quality grades for marbling. On the other hand, for pork samples, shoulder, tenderloin, and leg cuts were selected. It is important to note that during the pre-selection of samples, they were chosen to obtain a large variability in terms of color, marbling, and defects. A total of 50 samples were taken: 25 beef cuts and 25 pork chops. More precisely, some of the 25 beef samples were used for measuring color, others for marbling assessment, and others for defect determination. Finally, the same muscles were used for color measurements; another group of muscles was chosen for marbling assessment; only for defect assessment were types of loins mixed.

The samples were taken from the same domestic breed, sex, supplier, and date of slaughter. The authors selected the samples directly from retail. Representative samples were chosen from shelves at a low temperature from 0 to 4 °C in a local butcher's and supermarket. At the point of purchase, the samples were checked for the appropriate color of the meat, the level of marbling, and, on purpose, for the presence of some defects. Each sample was taken in one unit, with a thickness around 2.5 cm and cca. 200 g. Transport to the laboratory of Faculty of Agriculture, University of Belgrade, was achieved using portable mini refrigerators with constant measuring of temperature using a temperature data logger.

2.3. Computer Vision System (CVS)

The CVS used in this study consisted of a Sony Alpha DSLR-A200 digital camera (10.2 Megapixel CCD sensor with the size of 23.7 mm × 15.6 mm and approximate pixel pitch of 6.12 microns) (Sony, Tokyo, Japan). The camera was located vertically at a distance of 30 cm from the sample. The setting was as follows: shutter speed 1/6 s, manual operation mode, aperture Av F/11.0, ISO velocity 100, flash off, focal distance 30 mm, lens: DT-S18-70 mm f 3.5–5.6. Lighting was achieved with four Philips fluorescent lamps (Master Graphic a TLD 965) (Philips, Amsterdam, The Netherlands) with a color temperature of 6500 K [28,31,32].

2.4. Image-Based Survey

Three characteristics were chosen—color, marbling, and presence of defects. The most common meat quality standards were used to determine the levels of these characteristics that were shown to consumers. Specifically, two standards were combined—MSA and USDA [12,13]. A total number of 7 scores were used for color and 7 levels for marbling. As this type of scale was used, our image-based survey can be comparable with a free-choice profiling sensory technique. For this technique, the recommended number of sensory panelists is 8 to 24 participants [30,31]. When it comes to defects, four options (most typical) were presented to consumers, including dark-cutting beef and pale pork, blood splash cuts, excess seam fat, and lack of marbling [16]. Finally, a total of 24 photos of beef samples and 26 of pork chops were taken using CVS and used in the survey. Since image-based surveys are consumer-oriented, using a large number of samples can be comparable with the sorting task sensory technique, which supports from 9 to 20 samples and 20 consumers in a panel [33–37]. Finally, the image-based survey method was used as specified by Ngapo et al. [38].

2.5. Color and Marbling Assessment

Photos of fresh meat cut surfaces were labeled and stored in both RAW and JPEG formats for processing with Adobe Photoshop CC 2019 (Adobe Inc., USA) and Image J software (Microsoft Java), respectively. Adobe Photoshop was used for (a) background removal from each photo, (b) external fat removal in particular photos where the marbling area of the cut was of interest, and (c) measurements of color parameters using the special average color sampler tool (31 × 31 pixels).

The original images were represented in the Lab Color model of the beef steaks and pork loins for color assessment. Fifteen replicate measurements of color on different parts of the images were taken for all fifty photos.

The further use of color measurements in the TLF required the color measurements to be expressed as an ΔE parameter, which includes all L* a* b* color values [29,39]. For this purpose, the following equation was used:

$$\Delta E = [(a^* - a_o^*)^2 + (b^* - b_o^*)^2 + (L^* - L_o^*)^2]^{1/2} \quad (1)$$

where a* indicates the red–green component of color in a sample, and the a_o^* value is associated with the target; b* is the blue–yellow component of color in a sample, and b_o^* is the target b* value. Finally, L* represents lightness from black to white on a scale from 0 to 100 in a sample, while L_o^* represents the target value of lightness.

The percentage of marbling area was calculated as the marbling particle area expressed as a percentage of the selected image area [30]. Images of striploin steaks from the *M. longissimus thoracis et lumborum muscle* of beef and pork tenderloins with different levels of marbling were part of the experiment when marbling was assessed. The process of marbling assessment was performed in Image J software (Microsoft Java) after several steps. In the first step, the image software was used in a way that allowed for pre-processing in the RGB (red, green, and blue) channels. According to [30], color images of T-bone steaks of beef and pork tenderloin were converted into gray-scale 8-bit images, and the threshold was adjusted to highlight the marbling fat over the background, allowing for both the separation of meat from intramuscular fat and the evaluation of marbling area ratio (MA ratio). In the second step, the marbling area (MA) was selected and measured in pixels to justify an appropriate size of 212 × 340 pixels according to [40], before the analysis of particles was performed. The minimum size of fat particles to be considered a marbling fleck was set at 1 mm. The final step was the calculation of the percentage of marbling area.

2.6. Surveying

In July of 2022, image-based surveys were conducted to examine consumer preferences regarding color, marbling, and level of defect acceptance. Due to four consumers who gave up on assessing all surveys, a total of forty-six consumers were included in this study. The number of participants was based on several studies which analyzed the stability of sample configurations in order to determine how many consumers are necessary. The image-based surveys that were carried out in this study were based on previous studies [38,41].

The experimental setup is provided in Figure 1, starting with photos of beef. Participants were asked to select only one chop they prefer among four chops. The question given to the participants was "Imagine you are in a supermarket and you wish to purchase meat. From the four samples provided, which one do you choose?". This was repeated nine times, every time with four different randomly selected sample images. Further, for the detection of defects, each consumer was asked to select a sample they would buy. In this round, consumers were presented with twelve combinations of four randomly selected images with defects. For this part of the survey, the question that was given to the consumers was: "Imagine you are in a supermarket, and you wish to purchase meat. From the four samples provided, which one do you choose?". Finally, the consumers were asked to fill in a questionnaire on their basic socio-demographic data. Upon the completion of the surveys about beef, the same methodology was applied for pork meat.

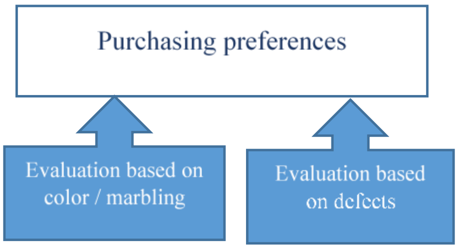


Figure 1. Experimental setup.

2.7. Demographic Characteristics

Demographic analysis was conducted in relation to gender, age, education, and household size (Table 5).

Table 5. Demographic characteristics of participants (N = 46).

Characteristic	Sample N * (%)
Gender	
Female	28 (61%)
Male	18 (39%)
Age	
18–29	1 (2%)
30–39	10 (22%)
40–49	21 (46%)
50–59	10 (22%)
60 and more	4 (8%)
Education	
Primary school	1 (2%)
High school	12 (26%)
Bachelor's degree	7 (15%)
Master's	4 (8%)
PhD degree	22 (48%)
Household (members)	
1	10 (22%)
2	17 (37%)
3	15 (33%)
4 and more	4 (8%)

* N represents the number of interviewed consumers; (%) represents their share in the sample.

2.8. Taguchi Method

The conventional Taguchi method indicates the best combination of variables in order to optimize a production process or the operation of an engine, motor, or device. However, the Taguchi method is usually coupled with other methods for the multi-objective design optimization of processing systems [42]. It includes an experimental design method to identify the effect of factors on the response and to obtain the optimal process conditions. One of the main advantages of this method is providing optimal conditions with the minimum number of experiments, leading to cost reduction [43,44].

When it comes to quality assurance of food, the Taguchi method has been used for the optimization of sampling schemes [45–47], the use of control charts [48], the production of pasta products [49], sous vide-processed fish filet products [50], sales of perishable foods [51], etc.

Taguchi Loss Function (TLF)

The basics of this method lie in prevention, rather than rejection, and in the determination of quality costs as a measure of quality. An important dimension of product quality is the TLF. This function links quality parameters with their costs. These costs can be absolute, such as financial, service costs, cost of staff education, cost of additional production, process controllers, etc. On the other hand, there are indirect costs, such as marketing costs, loss of consumers, etc. [52]. In this study, the TLF presents the connection of color and marbling with costs, defined as the loss of consumers.

The main inputs for the TLF are the measured values of particular quality characteristics, limits, and determined target values. Quality loss for a single product is proportional to the square of the deviation of the quality characteristic from its target value. This loss was characterized by Taguchi as a quadratic function:

$$L(x) = k \cdot (x - m)^2 \quad (2)$$

Total loss refers to loss when the whole sample is obtained with a size of n:

$$L = k \sum (x_i - m)^2 \quad (3)$$

where L(x) is loss per unit, L is total loss, k is the Taguchi loss parameter (a constant that depends on loss type), x is the actual value of the quality characteristic, and m is the target value. While constant k depends on loss value and type, the structure of the TLF depends on the quality characteristic type.

In parallel, constant k depends on two values—the value of cost (A_o) and consumer tolerance (D_o):

$$k = A_o / {D_o}^2 \quad (4)$$

where A_o and D_o depend on the type of cost and characteristic, and these values need to be taken from experimental data, marketing data, scientific data, statistical, financial, or archival data, from experience, etc.

The first type of TLF is the "smaller is better" function, and it is used for characteristics for which smaller values are desirable (Figure 2).

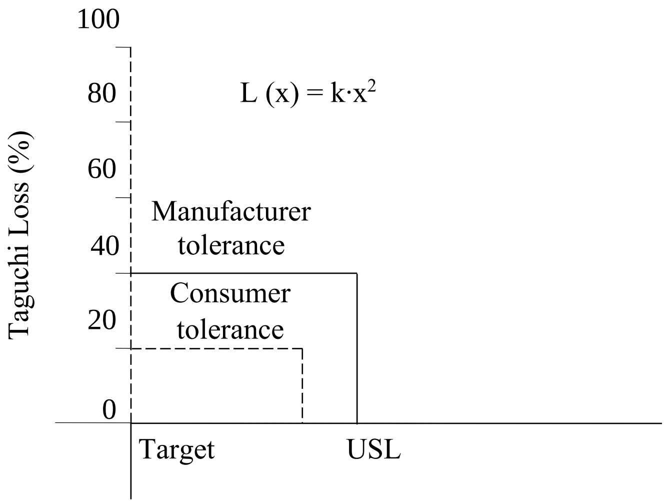


Figure 2. The "smaller is better" Taguchi loss function, adopted from [24]. Note: USL represents the upper specification limit.

This TLF is given by the following equation:

$$L(x) = k \cdot x^2 \quad (5)$$

The typical type of the TLF is "the nominal value, the best value" and it is represented as a two-sided function (Figure 3).

In Figure 3, LSL is the lower specification limit (e.g., minimal marbling percentage), and USL is the upper specification limit (determined as maximal marbling share), whereas Cs considers the level of customer satisfaction.

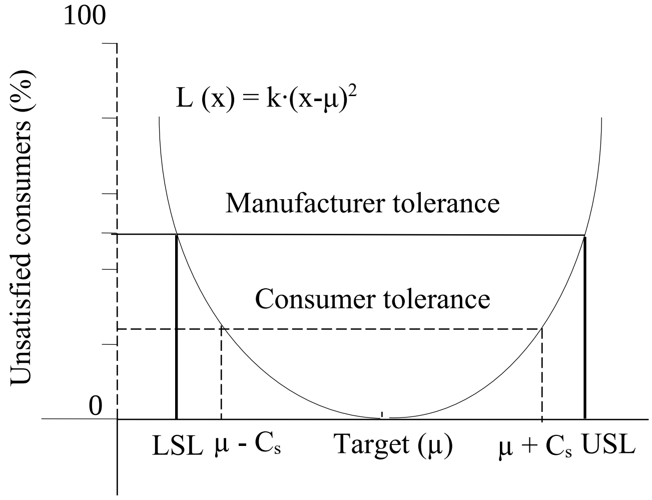


Figure 3. "The nominal value, the best value" TLF adopted from [24]. Note: LSL represents the lower specification limit; USL represents the upper specification limit.

2.9. Statistical Data Analysis

The experimental data were analyzed using SPSS software version 21.0 (IBM SPSS Statistics, Chicago, IL, USA). Statistical data analysis was performed using a one-way between-group ANOVA with a post hoc Tukey's HSD (honest significant difference) multiple comparisons test. Before conducting the ANOVA, the necessary assumptions were met. The normality of data was checked using the Shapiro–Wilk test, while the homogeneity of variance was determined using Levene's test. The ANOVA test was followed by Tukey's HSD (honest significant difference) multiple comparisons test at a 5% level of significance to identify differences between consumers' visual evaluations of meat with external quality defects.

3. Results and Discussion

3.1. Taguchi Loss Function for Color

The TLF can help meat producers to reduce quality losses. For the main inputs, manufacturers use experimental data, marketing data, scientific data, statistical, financial, and archival data, etc. For this purpose, the following survey data were used (Table 6).

Table 6. The main inputs for TLFs for color and marbling of beef and pork.

Characteristic	Parameter	TLF	Target Value m *	Consumers' Tolerance Limit **$D_{oi} = x_o - m$	Cost (A_o % of Unsatisfied Consumers)	Coefficient ($k = A_o/D_o^2$
Color of beef	ΔE	Smaller is better $L(x) = k \cdot x^2$	3.61	$D_{o1} = 6.32 - 3.61 = 2.71$ $D_{o2} = 8.95 - 3.61 = 5.34$	$A_{o1} = 10\%$ $A_{o2} = 20\%$	$k_1 = 10/2.71^2 = 1.36$ $k_2 = 20/5.34^2 = 0.70$
Color of pork	ΔE	Smaller is better $L(x) = k \cdot x^2$	2.00	$D_{o1} = 6.32 - 2.00 = 4.32$ $D_{o2} = 8.94 - 2.00 = 6.94$	$A_{o1} = 10\%$ $A_{o2} = 20\%$	$k_1 = 10/4.32^2 = 0.54$ $k_2 = 20/6.94^2 = 0.42$
Marbling of beef	Marbling score (%) of beef	Smaller is better $L(x) = k \cdot x^2$	/	$D_{o1} = 3.20 - 1.00 = 2.20$ $D_{o2} = 4.50 - 1.00 = 3.50$	$A_o = 10\% A_o = 20\%$	$k_1 = 10/2.2^2 = 2.06$ $k_2 = 20/3.5^2 = 1.63$
	Marbling score (%) of beef	The nominal value, the best value $L(x) = k \cdot (x - m)^2$	Beef 21.00%	$D_{o1} = 27.40 - 21.00 = 6.40$ $D_{o2} = 30.00 - 21.00 = 9.00$	$A_o = 10\% A_o = 20\%$	$k_1 = 10/6.4^2 = 0.24$ $k_2 = 20/9^2 = 0.24$
Marbling of pork	Marbling score (%) of pork	The nominal value, the best value $L(x) = k \cdot (x - m)^2$	Pork 5.74%	$D_{o1} = 11.40 - 5.74 = 5.66$ $D_{o2} = 14.00 - 5.74 = 8.26$	$A_o = 10\% A_o = 20\%$	$k_1 = 10/5.66^2 = 0.31$ $k_2 = 20/8.26^2 = 0.29$

* Determination of targets based on survey responses. ** Values provided by image analysis, where x_o represents measured value for certain percentage of tolerance A_o.

Furthermore, the "smaller is better" TLF was chosen to determine color variations (ΔE) (Figures 4 and 5).

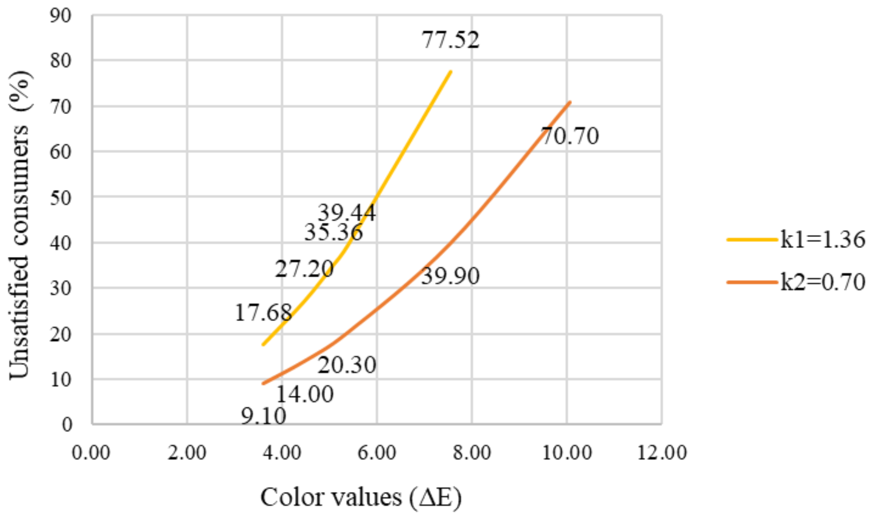


Figure 4. The Taguchi loss function for color variations and costs in beef. Legend: k_1—10% of unsatisfied consumers; k_2—20% of unsatisfied consumers.

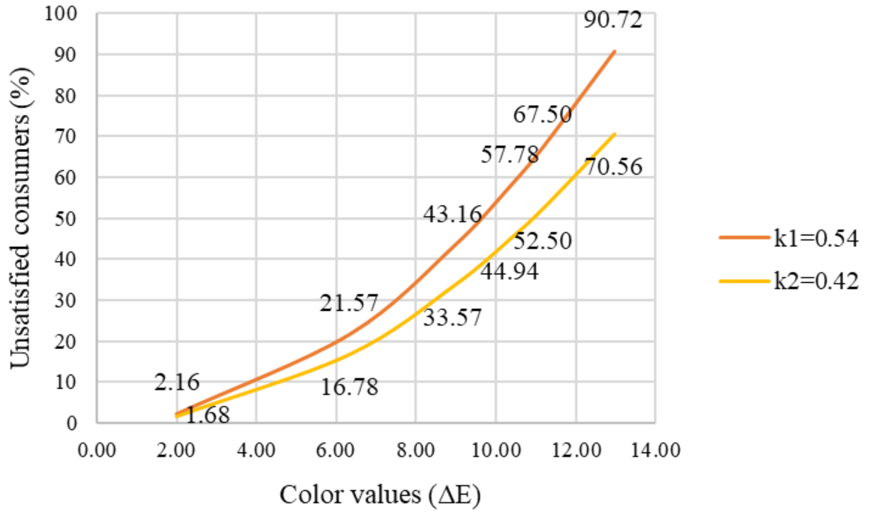


Figure 5. The Taguchi loss function for color variations and costs in pork. Legend: k_1—10% of unsatisfied consumers; k_2—20% of unsatisfied consumers.

To illustrate how TLFs can be used to determine color variations in meat, examples are provided in Table 6 and Figures 4 and 5. Two separate potential functions are presented with two values of consumers' tolerance limits for beef color (Figure 4). The target values of difference in color are presented in Table 6. When it comes to beef, the percentage of unsatisfied consumers for value of color ΔE = 3.61 is 9.10% and 17.68% (Figure 4). The point of the TLF is to make variations smaller and not to increase the limit of consumers' tolerance. Consumer tolerance is a changeable factor that is not under the producer's control, and producers can only visualize consumer tolerance using the TLF. Furthermore, Taguchi's approach is related to measuring costs that reveal quality losses. As such, quality losses are related to a batch rather than a single product [45].

The color variations values used to monitor the number of unsatisfied consumers indicate that pork with color values in a range of 4.00 to 6.00 is within the safety zone. Higher variations induce above 20% of unsatisfied consumers (Figure 5). Since pork color is a crucial quality attribute that significantly influences consumer perception and purchase decisions, producers need to monitor and reduce variations in color. This study focused on how to measure and reduce variations in color using the Taguchi quality loss function. An overview of the factors that affect color variations of fresh pork from farm to fork are provided in a recent study by Gagaoua et al. [53].

3.2. Taguchi Loss Function for Marbling

Although marbling is not a preferred characteristic among Serbian consumers, small levels of marbling are acceptable. According to beef consumers' choices, the most preferred marbling score was 1.00%. These results are in accordance with a study by Benli et al. [54], where a survey based on pictures of marbling illustrations indicated that higher degrees of marbling might be considered too fatty and not purchased by consumers. Every variation from that score will cause a certain cost (A_o) (Table 6).

Importantly, according to consumers' responses in this study, beef marbling needs to be observed from two aspects. It was noticed that the majority of consumers demanded meat with less intramuscular fat, while a significant percentage of consumers wanted to buy and consume meat with a target level of marbling (21.00%) (Table 6). Thus, the authors employed two different TLFs to monitor two different types of consumers (Figure 6). In some studies, more than two groups of consumers can be distinguished according to their perceptions of meat color and marbling and based on their socio-demographic characteristics [7].

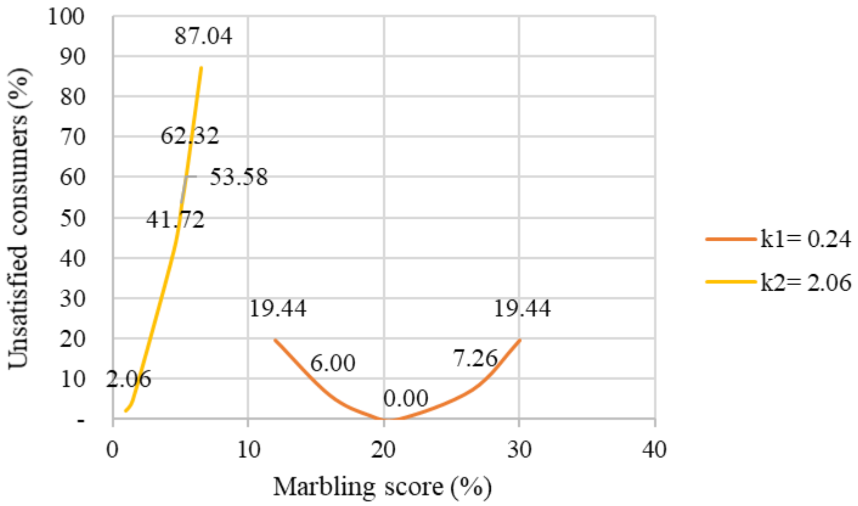


Figure 6. Two Taguchi loss functions for beef marbling: "the nominal value, the best value" (k_1 = 0.24) and "smaller is better" (k_2 = 2.06).

As for pork standards, there are not as many defined marbling levels as in beef standards. However, the most preferable marbling score for pork was 5.74%. Thus, the type of TLF that was applied was "the nominal value, the best value" (Figure 7).

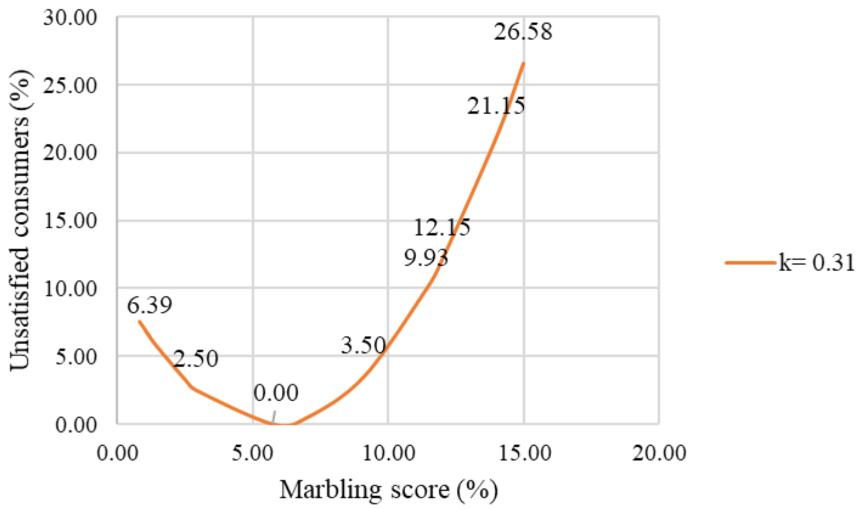


Figure 7. The Taguchi loss function for pork marbling. **Legend**: k—10% of unsatisfied consumers.

3.3. Beef and Pork Defects

When consumers were asked questions about the point of purchase, defects easily attracted consumers' attention. Statistical analysis showed that the result of Levene's test for the homogeneity of variances was 0.488, which means that it was not significant ($p > 0.05$), and the population variances for each group were approximately equal; thus, the groups were independent. Between-group significance was determined by the F-ratio of degrees of freedom (dfs) (3.96). The F-ratio was 3.802 and the significance was 0.015 ($p < 0.05$), which means the selections of defects of beef and pork cuts were significantly different. Using Tukey's HSD test, it was shown between which types of defects there was significant difference (Table 7). It can be noticed according to the results of the Tukey test in Table 7 that significantly different mean values exist between the following types of defects: "dark cutting beef", "excess seam fat", and "lack of marbling". The same case is seen between the defects "blood splash cuts", "excess seam fat", and "lack of marbling". Beef consumers recognized "dark cutting beef" and "blood splash cuts" as major defects, as samples with these defects obtained the smallest number of consumer selections. This means that these two defects, especially "dark cutting beef", are the most undesirable among consumers. However, a significant difference between these two types of defects was not seen ($p > 0.05$). The small number of selections of "blood splash cuts" may have emerged from consumers' opinion that these beef cuts have unpleasant flavors, precisely more livery, bloody, metallic, rancid, salty, and bitter flavor notes [55]. Moreover, "blood splash cuts" are not visually appealing. On the other side, consumers usually perceive "dark cutting beef" as a characteristic related to contaminated meat. Dark, firm, and dry (DFD) beef cuts with high pH can prompt the development of undesirable microorganisms. However, "excess seam fat" and "lack of marbling" meat defects were chosen significantly more often by consumers. That means these defects are more acceptable to consumers in comparison with "dark cutting beef" and "blood splash cuts".

Table 7. Number of beef defect selections at the point of purchase (N = 552).

Defects	(Mean ± Std. Deviation)	Defects	Mean ± Std. Deviation	Mean Difference	Sig.
(I)		(J)		(I–J)	
Dark cutting beef	182 ± 56.628	Blood splash cuts	208 ± 56.529	−26	0.783
		Excess seam fat	347 ± 63.927	−165 *	0.006
		Lack of marbling	469 ± 72.578	−287 *	0.008
Blood splash cuts	208 ± 56.529	Dark cutting beef	182 ± 56.628	26	0.783
		Excess seam fat	347 ± 63.927	−139 *	0.013
		Lack of marbling	469 ± 72.578	−261 *	0.007
Excess seam fat	347 ± 63.927	Dark cutting beef	182 ± 56.628	165 *	0.006
		Blood splash cuts	208 ± 56.529	139 *	0.013
		Lack of marbling	469 ± 72.578	−122 *	0.024
Lack of marbling	469 ± 72.578	Dark cutting beef	182 ± 56.628	287 *	0.008
		Blood splash cuts	208 ± 56.529	261 *	0.007
		Excess seam fat	347 ± 63.927	122 *	0.024

* The mean difference is significant at the 0.05 level.

When it comes to pork defects (Table 8), the defects "excess seam fat" and "lack of marbling" were more acceptable according to consumers' choices in comparison to two other types of defects, "pale pork" and "blood spotting". According to our results, "lack of marbling" is the most acceptable defect of pork cuts, which is not surprising, as many studies showed that consumers preferred less marbled pork [56,57]. In study [57], highly marbled pork chops were less likely to be purchased than leaner chops. However, the multiple comparisons and Tukey's HSD test results showed that there is a significant difference between "pale pork" and "excess seam fat" and "lack of marbling" pork cuts ($p < 0.05$). On the other hand, "blood spotting" was significantly different when compared to “excess seam fat” and “lack of marbling” defects. According to our results, the most undesirable defect in pork is “blood spotting”. The reason can lie in easily noticing blood stains or blood spots against brighter fresh meat such as pork. In second place among the most undesirable defects was “pale pork”. However, a significant difference between these two types of defects was not seen ($p > 0.05$).

Table 8. Number of pork defect selections at the point of purchase (N = 552).

Defects	(Mean ± Std. Deviation)	Defects	Mean ± Std. Deviation	Mean Difference	Sig.
(I)		(J)		(I–J)	
Pale pork	212 ± 48.526	Blood spotting	149 ± 57.529	63	0.128
		Excess seam fat	407 ± 55.127	−195 *	0.007
		Lack of marbling	503 ± 47.812	−291 *	0.003
Blood spotting	149 ± 57.529	Pale pork	212 ± 48.526	−63	0.128
		Excess seam fat	407 ± 55.127	−258 *	0.002
		Lack of marbling	503 ± 47.812	−354 *	0.001
Excess seam fat	407 ± 55.127	Pale pork	212 ± 48.526	195 *	0.007
		Blood spotting	149 ± 57.529	258 *	0.002
		Lack of marbling	503 ± 47.812	−96	0.253
Lack of marbling	503 ± 47.812	Pale pork	212 ± 48.526	291 *	0.003
		Blood spotting	149 ± 57.529	354 *	0.001
		Excess seam fat	407 ± 55.127	96	0.253

* The mean difference is significant at the 0.05 level.

4. Conclusions

Using consumer preferences and an image-based survey, it was observed that consumers in Serbia had similar strategies for choosing beef and pork. Participants strictly avoided blood splash cuts of both beef and pork. After pieces of beef with blood defects, consumers gave “dark-cutting beef” chops the highest score of unacceptance. Likewise, pale pork was not acceptable to consumers. When it comes to fat cover, consumers had the same opinions and decisions about beef and pork. They did not consider seam fat and a lack of marbling to be serious defects, especially for pork chops.

The Taguchi method determines color and marbling as limits of quality variation in fresh meat using loss functions. The method is fast, low-cost, robust, portable, and very interesting for the purposes of cost reduction analysis. It is also manageable and easily adaptable to other meat types and consumers from different regions or countries. The final functions obtained from the color values and marbling scores justify to a certain extent the effectiveness of this technique in visualizing consumer tolerance. The results suggest that certain values of quality parameters could become a clear sign for potential consumer rejection. Consequently, the application of the TLF could enable the development of a relatively simple method to predict beef and pork quality loss in relation to unsatisfied consumers.

It would be interesting to expand the area of investigation considering other quality attributes of meat and meat products, including health, nutritional, environmental, cultural, etc., aspects of cost.

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