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Implementation of the Dry Maturation Method and the Sous-Vide Cooking Technique in Bone-in Beef for the Creation of Gastronomic Products

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Abstract: The science behind the curing process and the sous-vide cooking technique has advanced significantly in recent years. Variables such as temperature, time, and microbial growth, among others, have a substantial impact on the preparation and acceptance of culinary creations. This study focused on evaluating the dry aging method and the sous-vide cooking technique applied to various cuts of bone-in beef (Rack, Tomahawk, New York, and Rib Eye) subjected to different aging periods (28, 32, 42, and 45 days) under controlled temperature and storage conditions. The resulting samples underwent microbiological analysis after the curing method and the sous-vide cooking process, and they were also used in different culinary preparations to measure their degree of acceptability.

Keywords: Dry maturation; sous-vide cooking; bone-in beef

1. Introduction

Meat is considered a complete food due to its chemical composition, which is influenced by numerous internal and external factors [1]. According to the food pyramid, meat is an essential component of a healthy diet as it is rich in protein and micronutrients such as iron, zinc, and vitamin B [2]. It is also a source of bioactive compounds such as conjugated linoleic acid (CLA), taurine, creatine, betaine, and carnitine [3]. Meat is efficiently utilized by the body, assimilating almost all of its nutrients. Additionally, meat contains high-quality protein and provides an adequate balance of ten essential amino acids necessary for protein formation, accounting for up to 20% of its weight. It also stimulates the human body's metabolism: 100 grams of red meat provides 20.7 g of protein, while the same amount of white meat provides 21.9 g of protein [4]. The quality of this product is affected by various factors, such as ante-mortem conditions, physicochemical properties, and the slaughter process, which influence the organoleptic quality of the meat and determine optimal aging [5].

The stress generated during this process produces lactic acid in the tissues, which characterizes dark red meat. After the animal's death, the carcasses are cooled, sorted, and incorporated into the distribution and food processing chains; these procedures transform the muscle tissue into meat [1–6]. This process can be influenced by myofibrillar toughness, which undergoes three phases: the pre-rigor phase, the rigor mortis phase, and the softening phase [7]. Rigor mortis usually appears about three hours after slaughter (depending on the species), requiring approximately 48 hours (sometimes 72) in refrigerated environments for this phenomenon to disappear [1]. It is important to mention that rigor mortis, which includes a delayed phase and a fast phase, is one of the most important and

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complex biochemical processes in the conversion of muscle to meat [7]. Adequate meat quality for culinary processing depends largely on the degree of maturation or aging, i.e., the level of development of autolysis, a process where the chemical composition, structure, and properties of the meat change after the animal is slaughtered under the influence of its own enzymes [8].

Maturing conditions, such as time, temperature, humidity, and airflow, also have a significant influence in determining the edible quality of the product [9]. Post-mortem aging of fresh meat is a process recognized to improve its quality, especially in terms of tenderness and flavor, and is essential to enhance the sensory qualities and final flavor of the meat for consumption. To carry out this process, carcasses are subjected to controlled conditions of storage, air circulation, relative humidity, and refrigeration. It usually takes 10 to 20 days to reach the desirable tenderness through proteolysis. Maturation involves the breakdown of large molecules into smaller flavor fragments through proteolysis and lipolysis. This causes changes in various components such as sugars, lipids, organic acids, vitamins, sugar phosphates, and sugars bound to nucleotides. These degraded compounds contribute specific aromas and flavors, driving complex biochemical reactions during cooking, such as the Maillard reaction, oxidation, and their interactions [10]. That is why the meat maturation process is temperature-dependent, as it affects the speed of biochemical reactions. Two types of meat maturation can be considered: the first is dry-aged meat maturation, which involves leaving the meat carcasses in cold chambers at 0°C to 2°C for periods ranging from 7 to 30 days. This system requires large spaces and controlled conditions of humidity and air circulation because any failure in the cooling system can lead to the decomposition of the meat if the temperature rises, or the arrest of the process if the temperature drops excessively [11]. The second type is wet (vacuum) maturation, where the meat is packaged in a sealed barrier film and stored at a temperature above the freezing point of the meat [12,13].

Another important aspect to consider regarding the quality of meat for consumers is the cooking method used. One of these methods is sous-vide cooking, also known as vacuum cooking. This procedure involves packaging the product in a plastic bag with low oxygen permeability and resistance to high temperatures. It is an effective method of long-term low-temperature heating, which contributes to highlighting the characteristics and generating significant benefits, such as preserving juiciness and preventing overcooking. As a result, the food retains a variety of textures, natural liquids, and the main flavor of the product [14,15]. Sous-vide cooking can induce ideal changes in meat characteristics and preserve its condition, moisture content, nutritional value, natural flavor, and microbiological benefits. This method inhibits oxidative changes in the products due to the lack of oxygen in the bags, allows for microbiologically safe food preparation, and prevents cross-contamination after cooking [16].

Vacuum cooking stands out compared to conventional methods, as it allows greater activity of endogenous enzymes, such as cathepsin and calpain, which increase the tenderness of the meat by increasing the solubility of collagen [17]. The cooking time for foods of animal origin must allow the dissolution of collagen to reduce the hardness of the final product. Color is an indicator in the sensory evaluation of foods; in the case of meat, the color change is due to the denaturation of myoglobin [18]. In raw meat, myoglobin, the meat pigment, exists in three forms: oxymyoglobin, deoxymyoglobin, and metmyoglobin, which show bright red, purplish-red, and brown, respectively. As a result of the heat treatment, globin denatures and precipitates with other meat proteins, forming red ferrohaemochrome and brown ferrihaemochrome. Denaturation of myoglobin starts between 55°C and 65°C and is almost complete at 80°C [19–21]. It also contributes to food safety, offering advantages by eliminating the risk of contamination after cooking [22].

Sous-vide cooking is widely used in restaurants due to the advantages it provides [23], and the need for safe heat treatments that guarantee the inactivation of microorganisms, thereby ensuring safety and prolonging shelf life [24]. The selection of dry aging and sous-vide cooking methods impacts the characteristics of the final product as determined by consumer acceptability. Therefore, the objective of the study was to evaluate these two aspects in bone-in beef for the creation of culinary products, considering control variables such as time, temperature, and microbiological conditions, as well as determining the degree of acceptance by an untrained panel.

2. Materials and Methods

This study was carried out in the food laboratory of the Gastronomic Management Technology program at the Corporación Universitaria Comfacauca in the city of Popayán (Cauca - Colombia). Two important aspects for the acceptability of bone-in beef were studied: the first was maturation, and the second was the sous-vide cooking process.

For the dry maturation process of the beef, meat cuts were acquired from cattle herds and/or commercial establishments 24 hours after slaughter. They were transferred to the food laboratory to an exclusive area to begin the maturation process under refrigerated conditions (2°C), where the pieces of meat rested for a determined time. The cleaning of the space was complete and thorough, avoiding any type of contamination that could generate microorganisms. The response variables are shown in Table 1.

Table 1. Experimental Design for Bone-In Beef Maturation.

Factor	Level	Response variables
Dry aging of meat	28 days 32 days 42 days 45 days	Microbiological analysis

Source: Authors, 2021.

For the sous-vide cooking process, a vacuum packer and high-temperature resistant bags were used for the samples that required the application of this technique. Table 2 shows the experimental design and its respective response variables.

Table 2. Experimental design for cooking bone-in beef.

Factor	Level	Response variables
Cooking	Sous vide	Sensory evaluation Microbiological analysis

Source: Authors, 2021.

Treatments subjected to the dry aging and sous-vide cooking processes were microbiologically evaluated in a certified laboratory for pathogenic bacteria.

A standardization of innovative culinary recipes was carried out using the pieces obtained at different maturation times. Possible formulations were defined to be developed in the Corporation's food laboratory, where the necessary equipment was used to conduct preliminary tests on the preparation of dishes using molecular cooking techniques. Some process control variables, such as time, temperature, and the quantity of food additives to be used, were also evaluated.

Finally, a sensory analysis was carried out using an untrained internal panel of 70 people composed of students from the Corporación Universitaria Comfacauca (Popayán, Colombia). Each consumer tasted 4 randomly coded samples, offered at room temperature (25°C) according to a completely randomized block design to avoid the effect of order. The sensory attributes of color, aroma, texture, and flavor were evaluated using a nine-point (9) hedonic scale, with one (1) being equivalent to "I extremely dislike" and nine (9) to "I extremely like".

The statistical analysis of the quantitative data collected was evaluated using an analysis of variance (ANOVA) with 95% confidence ($p < 0.05$) to establish statistically significant differences. The means were then compared using the least significant difference (LSD) test.

3. Results

The research developed stages in which different variables were analyzed to evaluate the effect of maturation and sous-vide cooking on the sensory, nutritional, and microbiological characteristics of bone-in beef for the preparation of value-added culinary recipes.

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3.1. Dry Aging Process for Bone-In Beef

Three bone-in meat cuts extracted from a whole piece (rack) of beef tenderloin (Tomahawk, New York Steak, Ribeye) were used to set up the treatments as fixed variables in the experiment. See Figure 1.

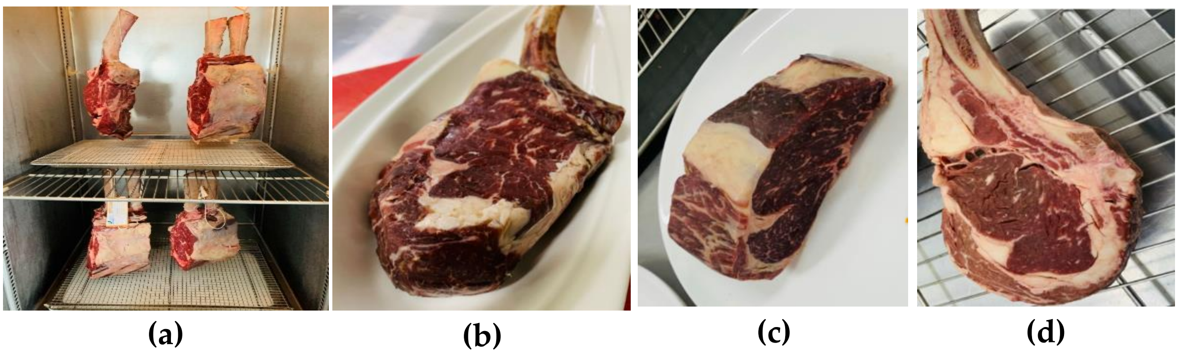

Figure 1. Cuts of bone-in meat removed from a whole loin of beef: (a) Whole rack of beef tenderloin; (b) Tomahawk; (c) New York Steak; (d) Ribeye. Source: Authors, 2022.

Subsequently, an analysis of the behavior of the type of bone-in meat maturation of the cuts was carried out using a completely randomized design, keeping the temperature constant at 2°C. See Figure 2. Each piece was labeled to start the process.

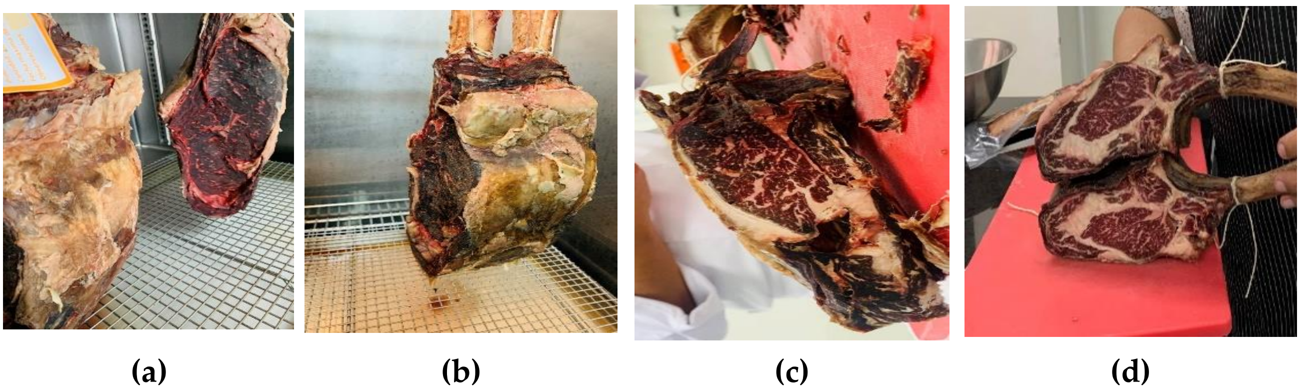

Figure 2. Dry aging process experiment: (a) 28 days - Whole loin rack; (b) 32 days - Tomahawk; (c) 42 days - New York Steak; (d) 45 days – Ribe ye. Source: Authors, 2022.

3.2. Microbiological Tests of the Dry-Aging Process

The microbiological analysis of the dry-aged samples at each of the established times (28, 32, 42, and 45 days) is presented in Table 3.

Table 3. Microbiological Analysis of the Dry-Aging Process.

Treatment	Microbiological analysis *			Result
	Analysis	Method	Specification	
Dry Aging (28 Days)	*NMP fecal coliforms 45	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	120(m) - < 1.100(M)	150
	*Coagulase-Positive Staphylococcus Count (CFU/g-mL)	UNE EN ISO 6888 – 1 2000	100(m) - 1.000(M)	<100 (+/- 1 CFU**)
	Clostridium Sulphite-Reducing Spore Count (CFU/g-mL)	INVIMA:1998. Cap. 2, Num. 10.	100(m) - 1.000(M)	<10

	Detection of Salmonella in 25g	AOAC OMA 2016.01 ED 21: 2019.	Absence	Absence
Dry Aging (32 Days)	*NMP fecal coliforms 45	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	120(m)- < 1.100(M)	180
	*Coagulase-Positive Staphylococcus Count (CFU/g-mL)	UNE EN ISO 6888 – 1 2000	100(m) - 1.000(M)	<100 (+/- 1CFU**)
	Clostridium Sulphite-Reducing Spore Count (CFU/g-mL)	INVIMA:1998. Cap. 2, Num. 10	100(m) - 1.000(M)	<10
	Detection of Salmonella in 25g	AOAC OMA 2016.01 ED 21: 2019.	Absence	Absence
Dry Aging (42 days)	*NMP fecal coliforms 45	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	120(m) - < 1.100(M)	4
	*Coagulase-Positive Staphylococcus Count (CFU/g-mL)	UNE EN ISO 6888 – 1 2000	100(m) - 1.000(M)	<100 (+/- 1CFU**)
	Clostridium Sulphite-Reducing Spore Count (CFU/g-mL)	INVIMA:1998. Cap. 2, Num. 10	100(m) - 1.000(M)	<10
	Detection of Salmonella in 25g	AOAC OMA 2016.01 ED 21: 2019.	Absence	Absence
Dry Aging (45 days)	*NMP fecal coliforms 45	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	120(m) - < 1.100(M)	10
	*Coagulase-Positive Staphylococcus Count (CFU/g-mL)	UNE EN ISO 6888 – 1 2000	100(m) - 1.000(M)	<100 (+/- 1CFU**)
	Clostridium Sulphite-Reducing Spore Count (CFU/g-mL)	INVIMA:1998. Cap. 2, Num. 10	100(m) - 1.000(M)	<10
	Detection of Salmonella in 25g	AOAC OMA 2016.01 ED 21: 2019	Absence	Absence

* ISO 17025 Accredited Analysis. Source: Authors, 2022.

3.3. Cooking Process of Beef on the Bone - Sousvide Method

The bone-in meat maturation treatments were subjected to the sous vide cooking process, as shown in Figure 3.

Figure 3. 300 g boneless piece, vacuum-packed (dry-aged), to be subjected to the sous-vide cooking process. Source: Authors, 2022.

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During this process, the internal temperature of the product is monitored. The set temperature was 60°C, considering the meat doneness levels: rare (50°C), medium (55°C), and medium-well (63°C).

In Figure 4, two aged pieces subjected to sous-vide cooking are illustrated. An internal temperature of 55°C was achieved in a boneless aged piece cooked sous-vide (70°C for 20 minutes) and an internal temperature of 60°C with the same temperature for 25 minutes.

(a) **(b)**

Figure 4. Matured, sous-vide cooked piece cut in half: (a) Internal temperature 55°C y (b) Internal temperature 60°C. Source: Authors, 2022.

On the other hand, microbiological monitoring was carried out on each of the aged and cooked samples. See Table 4.

Table 4. Microbiological Analysis of the Dry Aging and Sous-Vide Cooking Process.

Treatment	Microbiological analysis *			Result
	Analysis	Method	Specification	
Dry Aging (28 Days)	Total Mesophilic Aerobic Count (CFU/g-mL)	AOAC 966.23 ED 21:2019	<10.000	(l) 85.000
	*NMP total coliform /g-mL	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	<3	(l) 9
	*NMP fecal coliforms 45/g-mL	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	<3	(l) 9
	*Coagulase-Positive Staphylococcus Count (CFU/g-mL)	UNE EN ISO 6888 – 1:2000	<100	<100 (+/- 1CFU**)
	*Bacillus aereus count CFU/g-mL L	UNE EN ISO 7932:2005	<100	<100 (+/- 1CFU**)
	* Detection of Salmonella in 25g	ISO 6579 – 1:2017	Absence	Absence
Dry Aging (32 Days)	Total Mesophilic Aerobic Count (CFU/g-mL)	AOAC 966.23 ED 21:2019	<10.000	(l) 80.000
	*NMP total coliform /g-mL	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	<3	(l) 10
	*NMP fecal coliforms 45/g-mL	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	<3	(l) 10
	*Coagulase-Positive Staphylococcus Count (CFU/g-mL)	UNE EN ISO 6888 – 1:2000	<100	<100 (+/- 1CFU**)
	*Bacillus aereus count CFU/g-mL L	UNE EN ISO 7932:2005	<100	<100 (+/- 1CFU**)

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	* Detection of Salmonella in 25g	ISO 6579 – 1:2017	Absence	Absence
Dry Aging (42 days)	Total Mesophilic Aerobic Count (CFU/g-mL)	AOAC 966.23 ED 21:2019	<10.000	(l) 90.000
	*NMP total coliform /g-mL	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	<3	(l) 23
	*NMP fecal coliforms 45/g-mL	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	<3	(l) 23
	*Coagulase-Positive Staphylococcus Count (CFU/g-mL)	UNE EN ISO 6888 – 1:2000	<100	<100 (+/-1CFU**)
	*Bacillus aereus count CFU/g-mL L	UNE EN ISO 7932:2005	<100	<100 (+/-1CFU**)
	* Detection of Salmonella in 25g	ISO 6579 – 1:2017	Absence	Absence
Dry Aging (45 days)	Total Mesophilic Aerobic Count (CFU/g-mL)	AOAC 966.23 ED 21:2019	<10.000	(l) 90.000
	*NMP total coliform /g-mL	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	<3	(l) 23
	*NMP fecal coliforms 45/g-mL	ICMSF:2000 Method 1, Volume 1, Ed. 2:2000	<3	(l) 23
	*Coagulase-Positive Staphylococcus Count (CFU/g-mL)	UNE EN ISO 6888 – 1:2000	<100	<100 (+/-1CFU**)
	*Bacillus aereus count CFU/g-mL L	UNE EN ISO 7932:2005	<100	<100 (+/-1CFU**)
	* Detection of Salmonella in 25g	ISO 6579 – 1:2017	Absence	Absence

*ISO 17025 Accredited Analysis. Source: Authors, 2022.

3.4. Standardization of Matured Sous Vide Beef Recipes

The recipes were standardized using the raw material obtained in the previous phases. After finalizing each recipe, the information was consolidated in standardized files. Subsequently, the level of acceptability of the developed culinary recipes was determined through sensory analysis. Four standard recipes were evaluated, representing the different maturation times (28, 32, 42, and 45 days), the meat cuts, and the sous-vide cooking technique. See Figure 5.

(a) **(b)**

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(c) (d)

Figure 5. Culinary recipes: (a) New York Steak on a bed of vegetables with demi-glace sauce and sweet wine, (b) Grilled dry-aged New York Steak, (c) Ribe ye in beetroot reduction, and (d) Grilled Toma hawk. Source: Authors, 2022.

3.5. Sensorial Analysis of Culinary Recipes

Table 5 shows the results of the comparative evaluation of the sensory attributes of the four samples of the standardized preparations:

New York Steak on a bed of vegetables with demi-glace sauce and sweet wine
Grilled dry-aged New York Steak
Ribe ye in beetroot reduction
Grilled Toma hawk.

Table 5. Evaluation of Sensory Attributes of Standardized Culinary Recipes.

Culinary recipes	Sensory Attributes				General acceptability
	Aroma	Colour	Flavour	Texture	
New York Steak on a bed of vegetables and demiglace sauce with sweet wine	7,94 ± 1,05	8,29 ± 1,01	8,37 ± 0,85	8,26 ± 1,05	8,215 ± 0,99
Grilled dry-aged New York Steak	6,50± 1,57	6,47 ± 1,59	6,6 ± 1,97	6,86 ± 2,09	6,61 ± 1,805
Ribe ye in beetroot reduction	7,21 ± 1,48	7,60 ± 1,16	7,77 ± 1,41	7,87 ± 1,05	7,612 ± 1,275
Grilled Toma hawk	7,29 ± 1,46	7,21 ± 1,40	7,21 ± 1,48	8,29 ± 1,01	7.5 ± 1,34

Source: Authors, 2022.

The samples were coded separately for each evaluation with three-digit codes and submitted for assessment. Figure 6 shows the degree of acceptability for each of the preparations.

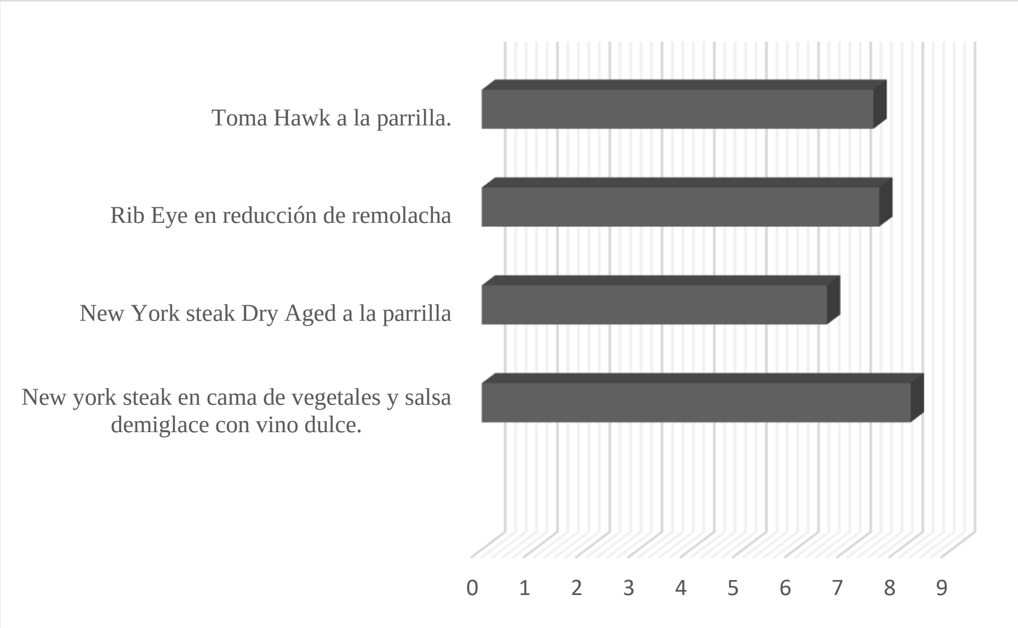

Figure 6. General Degree of Acceptability of Culinary Recipes. Source: Authors, 2022.

4. Discussion

Dry aging process for bone-in beef: The maturation process applied to bone-in beef presents significant changes in its organoleptic characteristics, driven by enzymatic action on the proteins. After the animal is slaughtered, enzymes initiate the breakdown of large molecules into smaller fragments, breaking protein bonds into amino acids and fats, as well as converting fat-like membrane molecules into aromatic fatty acids [25], making the pieces more attractive to consumers. This process triggers constant enzymatic activity, breaking down the proteins inside the muscle after the rigor mortis phase. As a result, a product with optimal appearance, flavor, and texture for consumption is obtained [26].

In addition, evidence from various studies reveals the influence of specific variables in the maturation process. Temperature management is an important factor; as high temperatures facilitate bacterial growth. According to Meat technology update [27] meat initiates the freezing process at -1.5°C, with the optimum temperature for prolonged maturation being -0.5°C ± 1°C.

Time is another control variable since endogenous proteolytic enzymes remain active after 21 days, improving meat tenderness over time and generating changes such as evaporative loss, which contributes to flavor development due to the concentration and oxidation of aromatic compounds in the meat [28]. The suggested minimum dry aging time is 14 days to improve the flavor profile and achieve the desired tenderness. For the present investigation, four time periods (28, 32, 42, and 45 days) were used, as shown in Figure 2. Among these, the best dry-aged meat, which achieved the highest degree of acceptance, was New York Steak at 42 days. Thus, it can be affirmed that the dry aging process presents superior characteristics, resulting in beef with added value and unique flavor, according to Dashdorj et al. [29] and Lee et al. [30].

The protein degradation process, which occurs over approximately two weeks, involves enzymes known as calpains that promote proteolysis. These enzymes act during this period and then disintegrate, resulting in meat tenderization [31]. Studies on dry aging at different times (7, 16, 35, and 60 days) show an increase in dry matter content [32]. It can be stated that dry aging can achieve customized flavor profiles and consistent quality by manipulating several variables in favor of the final consumer [33]. Although dry-aged beef is gaining popularity in the culinary community, there is limited understanding of the impacts of environmental aging on final product quality [34].

Microbiological Tests of the Dry Aging Process (Dry-Aged): Recent studies indicate that the dry aging process involves the growth of several microorganisms on the meat surface. During a maturation period of 12, 30, 70, and 160 days, it was observed that bacterial growth was lowest on

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day 12 and increased as the maturation process progressed. However, the fungal profile did not show a significant trend with aging time [35]. In the study by Ryu et al. [36], the abundance of lactic acid bacteria increased to log 6 CFU on the surface of longissimus thoracis and biceps femoris dry-aged beef samples during 60-day aging. No Clostridium spores or Salmonella were detected, and fecal coliform and Staphylococcus counts were within acceptable ranges, suggesting that the samples were of adequate sanitary-hygienic quality for further processing.

Surface dehydration of meat pieces under dry aging may be responsible for the low presence of microorganisms. Ribeiro et al. [37] verified that meat aged by this method for 30 days showed significantly lower counts of total coliforms, aerobic mesophiles, psychrotrophs, and molds and yeasts. In a study by Gowda et al. [38] on beef aged for 21 days, large numbers of total aerobic psychrotrophic bacteria, Enterobacteria, and Pseudomonas spp., among others, were detected on the surface of beef tenderloins during aging. The variability in these counts could be due to a variety of factors, including differences in production parameters and meat-related factors such as pH and pre-process storage.

During the conversion of muscle to meat, the pH drops as hydrogen accumulates until the isoelectric point is reached. Meat pH can be important during the dry aging process, as it affects the muscle's ability to retain water. Some studies have reported a pH similar to that of fresh meat, while others have found a positive correlation between pH and lactic acid bacteria growth in dark-cut samples. Throughout the drying process, a dynamic microbiome is created on the meat surface, composed primarily of various Lactobacillus spp., including L. sakei and L. plantarum, which limit bacterial growth and promote the emergence of beneficial molds. The continuous activity of bacteria, yeasts, and molds that metabolize and produce metabolites in meat affects its quality and safety.

However, foodborne pathogenic bacteria, such as Listeria monocytogenes, enterohemorrhagic Escherichia coli, and Salmonella spp., may be present and can proliferate during the dry aging process, as they are active at low temperatures [19–21]. Dry-aged samples showed a decrease in total bacterial counts, and only molds and yeasts presented significant growth during aging [40,41].

Another important characteristic is water retention, which translates into greater juiciness. Several studies have shown that dry-aged beef is characterized by better flavor, odor, and taste. It is also often considered to have more favorable palatability, with stronger notes of meaty, roast meat, and brown roast meat, as well as scoring higher for umami, buttery, caramelized, sweet, and nutty flavors [42].

Bone-in beef cooking process - Sousvide method: taking into account research [43], to ensure a six-decimal-place reduction in spore counts of non-proteolytic Clostridium botulinum and vegetative pathogens such as Listeria, Salmonella, and Escherichia coli, heat treatment at 90°C for 10 minutes is recommended, achieving an internal temperature of 65°C in the center of the product. However, these conditions can result in the loss of thermolabile vitamins and affect the nutritional and sensory quality of the meat. Therefore, treatments at lower temperatures and shorter times have been defined.

The 70/2 heat treatment, which involves reaching 70°C in the thickest part for 2 minutes, reduces 99.9999% of Listeria monocytogenes in sous-vide products. This treatment is recommended for the food service industry to guarantee the shelf life of products. Additionally, there is a category of sous-vide products cooked to a minimum temperature of 63°C, which ensures acceptance of taste, texture, and appearance in both restaurant and home-prepared dishes [44].

The sous-vide method improves the cooking yield of meat by approximately 7% in red meat and reduces water evaporation compared to conventional heat treatment methods. However, authors such as Cho et al. [45] and Xiong [46] suggest combining the sous-vide method with other thermal processing methods, such as frying or grilling, to improve the sensory quality of the products.

These treatments offer good hygienic and sanitary quality, which is essential for advancing recipe standardization. Recent studies on sous-vide cooking confirm its application in the home, in restaurants, in molecular gastronomy, and in the food industry. This technique, based on low temperature management and extended cooking times, has been used by renowned chefs for decades, generating increased demand for high-quality processed foods. Sous-vide has been shown to improve flavor and aroma, increase tenderness and desirable texture, reduce lipid oxidation and flavor losses, and enhance the color and visual appearance of foods [14]. Additionally, it reduces thermal damage to proteins and lipids, minimizing the loss of thermolabile liquids and nutrients, and improves texture compared to conventional cooking methods [47].

It is important to bear in mind that the type of meat, size, and intramuscular connective tissue influence the sous-vide cooking method. Tougher meats with more collagen require longer heat treatments for the collagen to transform into gelatin. Conversely, tender meats with less collagen and more myofibrillar protein require less cooking time to avoid loss of juiciness [48]. Rinaldi et al. [49] and Latoch et al. [50] found a higher content of aromatic compounds in beef cooked for 2 hours at 100°C compared to sous-vide samples. However, the sous-vide method retains aromas better during storage and reduces unpleasant aftertastes, such as hexanal and 3-octanone [34–51].

Sensory Analysis of Culinary Recipes: the sensory analysis of the preparations revealed statistically significant differences ($p < 0.05$) in the attributes of aroma, color, flavor, and texture, indicating that the panelists' responses varied according to each attribute. In general, the preparation "New York steak on a bed of vegetables with demi-glace sauce and sweet wine" was the most accepted, standing out in the attributes of color, flavor, and texture.

This preparation was highly accepted by the seventy panelists, with an overall rating of 7.94 on the scale used, classified as "I like it very much." It underwent a 28-day maturation process at 2°C, followed by a sous-vide cooking method with an internal temperature of 60°C. The microbiological analysis performed after the ripening and sous-vide cooking process showed no presence of pathogenic microorganisms, guaranteeing a balanced product in terms of safety, sensory, and nutritional quality [52].

The panelists' comments particularly highlighted the tenderness and flavor of the dish, confirming the excellence of this preparation both in terms of food safety and sensory experience.

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