


Research Article

Influence of Vacuum Packaging on Instrumental Surface Color Characteristics of Frozen Beef Steaks

Madison P Wagoner¹, Tristan M Reyes¹, Virginia E Zorn¹, Madison M Coursen¹, Katie E Corbitt¹, Barney S Wilborn¹, Terry D Brandebourg¹, Aerial D Belk¹, Tom Bonner², Jason T Sawyer^{1*}

Abstract

Consumers often consider beef color as a sole indicator of product freshness at the time of purchase. However, disruptions in meat manufacturing may cause manufacturers to create frozen retail meat products, but changes to surface color during frozen storage may be deleterious. Therefore, the objective for the current study was to determine the effect of vacuum packaging on instrumental surface color values of boneless ribeye steaks during frozen storage. Steaks were cut 2.54-cm-thick, assigned to one of three packaging films, allowed to bloom for 30 min and immediately frozen. Throughout the 25 days of frozen storage, instrumental surface color values were collected. Steaks packaged using MDF were lighter ($p < 0.05$) but became darker as storage time increased. However, redness (a^*) values were greater ($p < 0.05$) for steaks packaged using MDF from day 10 to 25, as well as more yellow (b^*) from day 7 to 25 ($p < 0.05$). Furthermore, steaks packaged in MDF were more ($p < 0.05$) vivid (C^*) and possessed redder values for red-to-brown (RTB), oxymyoglobin (OMb), and hue angle from day 7 to 25 of the simulated storage period. These data indicate that choice of vacuum packaging film impacted instrumental surface color of frozen retail cuts with MDF packaging more effectively maintaining optimal color throughout the duration of this study.

Keywords: Beef; Frozen storage; Instrumental color; Vacuum packing

Introduction

The design of packaging materials selected for meat products may alter the chemical state of myoglobin which suggests choice of packaging material could influence product appeal and storage stability. Vacuum packaging provides beef products with an anaerobic environment which protects against spoilage but limits the heme iron in myoglobin availability to bind with oxygen resulting in a meat surface that appears dark purple in color. Given the increasing pressure to produce more food in the face of anticipated population growth, preserving meat quality may be a challenge as overcoming the inefficiencies in the current supply chain due to the deterioration of meat products is hampered by the limited packaging resources which could be deployed to prolong storage life. Presently, storage frozen meat in vacuum packaging is the most common method for high value meat products, particularly for imported or exported meat to aid in storage stability [1]. Therefore, the need for extending cold chain storage or frozen meat logistics is inevitable. To meet this need, it is imperative to develop novel packaging technologies which allow cold storage time to be lengthened

Affiliation:

¹Department of Animal Sciences, Auburn University, Auburn, AL 36849, USA

²Winpak Ltd., 100 Saulteaux Crescent, Winnipeg, MB R3J 3T3, Canada

*Corresponding author:

Jason T Sawyer, Department of Animal Sciences, Auburn University, Auburn, AL 36849, USA

Citation: Madison P Wagoner, Tristan M Reyes, Virginia E Zorn, Madison M Coursen, Katie E Corbitt, Barney S Wilborn, Terry D Brandebourg, Aerial D Belk, Tom Bonner, Jason T Sawyer. Influence of Vacuum Packaging on Instrumental Surface Color Characteristics of Frozen Beef Steaks. *Journal of Food Science and Nutrition Research* 5 (2022): 658-663.

Received: August 29, 2022

Accepted: September 05, 2022

Published: September 20, 2022

without negatively impacting product surface color. Current packaging technologies used to store, display, or transport beef products include modified atmosphere packaging (MAP), vacuum skin technology, active packaging systems, and overwrap, however, meat primals are often packaged into vacuum bags for transport to retail venues and for export purposes [2]. There has been extensive research indicating vacuum packaging can extend and aid in stabilization of storage characteristics of beef when compared to other packaging methods [3-7]. Recent efforts comparing beef products in vacuum-packaging to packaging materials such as polyvinyl chloride (PVC) and polyethylene, reported a reduction in oxidation levels and a greater color stability during retail and frozen display periods in products packaged in PVC or polyethylene [5,7]. Consequently, when beef is vacuum packaged, the color quickly changes from a bright red form of oxymyoglobin to a purple form of deoxymyoglobin (DMb) [8]. However, a deoxymyoglobin (purple) pigment is more likely to be rejected by consumers at the point of sale though this behavior can be reversed if consumers are informed that such packaging technology provides for a much longer storage period [2]. Selecting the appropriate vacuum packaging to increase storage duration of beef products requires consideration of the oxygen transmission rate (OTR) which dictates the amount of oxygen that can permeate the packaging film. A minimum OTR is necessary to allow for a sufficient oxygen infiltration necessary to maintain oxymyoglobin pigments at a level which stably promotes the consumer preferred [2]. Additionally, packaging materials used in frozen meat applications contain barrier properties for preventing moisture loss, oxidation, and aid in color stability during a storage period [9]. Freezing meat is primarily used to extend product shelf life, and when compared to the storage of fresh meat products, frozen meats may have twice the storage life of refrigerated meats [10]. Shelf life of fresh red meat is limited by microbial contamination, and extended shelf life of fresh meat products may be achieved by delaying microbial spoilage with frozen storage [11]. Previous research indicates that freezing meat products may reduce microbial growth and cause chemical fluctuations that alter the product quality with a greater impact on surface color [8]. Moreover, it has been reported that vacuum-packages can be used to avoid the negative impact that storing meat frozen has on meat quality [12]. Much research has examined the influence of storage temperature and duration of storage to determine the optimal storage conditions to maintain product quality for frozen meat products this remains a primary limitation to frozen storage [3,6-7,10,14-17]. Importantly, it has been previously reported that packaging materials with reduced oxygen and moisture vapor transmission rates can result in maintaining perceived consumer quality of meat products during frozen storage [13]. Therefore, the objective of this study was to determine the effect of vacuum packaging film on instrumental surface color changes that occur on boneless ribeye steaks during frozen storage.

Materials and Methods

Muscle fabrication

Beef boneless ribeye rolls (IMPS #122A) were purchased from a commercial meat processor and transported under refrigeration (2°C) to the Auburn University Lam-bert Powell Meat Laboratory for processing. Ribeye rolls (N = 18) were cut into 2.54-cm-thick steaks (n = 12 steaks/ribeye roll) using a BIRO bandsaw (Model 334, Biro Manufacturing Company, Marblehead, Ohio, USA). Four steaks from each ribeye roll were randomly selected and allocated to one of three packaging treatments.

Packaging treatments

After cutting, steaks were allowed to bloom for 30 min at 2°C, crust frozen at -23°C for 45 minutes, and then packaged using a rollstock form and fill packaging machine (Model OL0924, Variovac, Zarrentin, Germany). At the time of packaging, steaks were packaged in one of three commercial packaging films (WINPAK, Winnipeg, MB, Canada) consisting of a high barrier (MB) comprised of 150µm of nylon, enhanced ethylene-vinyl alcohol (EVOH), and polyethylene. Steaks packaged in low barrier films were constructed with 150µm polypropylene and polyolefin plastomer (MFS) or a combination of 150µm polyolefin, and polyethylene (MDF). Oxygen transmission rates (OTR) for each packaging treatment consisted of: MB (0.5 cc/sq. m/24h); MFS (1100 cc/sq. m/24h); and MDF (1287 cc/sq. m/24h). In addition, the moisture vapor transmission rates for each packaging treatment accounted for: MB (3.9 g/sq. m/24h); MFS (2.9 g/sq. m/24h); and MDF (3.5 g/sq. m/24h). After packaging, steaks were placed flat onto a plastic tray and stored in a blast freezer (-23°C) for 120 min.

Simulated frozen storage

Packages of frozen steaks were stored in an upright, two-door, reach-in, commercial freezer (Model AF49EX, Arctic Air, Eden Prairie, MN, USA) for 25 days at -13°C. Packaged steaks were stored in the absence of light for the duration of the simulated storage period. Storage temperatures during the frozen stimulated display period were monitored using a data recording device (Model-TD2F, Thermoworks, American Fork, UT, USA) with probes placed within the center of each shelf. Packages of steaks were distributed evenly across all shelves within the freezer and rotated throughout the storage period.

Instrumental color

Instrumental color readings were measured on day 0, 5, 10, 15, 20 and 25 by scanning the surface of each steak (N= 216) through the packaging according to guidelines [18] previously described. Surface color values were collected using a HunterLab MiniScan XE Plus Colorimeter (Model 45/0-L, Hunter Associates Laboratory Inc., Reston, VA,

USA) calibrated against a standard black and white glass tile each day immediately before data collection. The L* (lightness), a* (redness), b* (yellowness) values of each steak were determined from the average of three readings using Illuminant A10, with a 10° observer and a 25-mm diameter aperture and the Commission Internationale de l'Eclairage (CIE L*a*b*) color scale [19]. Chroma (C*) was calculated using the following equation $\sqrt{a^{*2} + b^{*2}}$ with a larger value indicative of a more vivid color. Hue angle was calculated as: $\tan^{-1}(b^*/a^*)$ with a greater value indicative of the surface color shifting from red to yellow. Reflectance values within the spectral range 400 to 700 nm were used to calculate the surface color changes from red to brown by with the reflectance ratio of 630 nm:580 nm, and the relative percentages of deoxymyoglobin (DMb = $\{[1.395 - \{(A572 - A700) / \{(A525 - A700)\}]\} \times 100$), metmyoglobin (MMb = $\{2.375 \times [1 - \{(A473 - A700) / \{(A525 - A700)\}]\} \times 100$), and oxymyoglobin (OMb = DMb - MMb) according to American Meat Science Association [18].

Statistical analysis

The current study was conducted and analyzed as a completely randomized design with packaged steak serving as the experimental unit and 72 replications of each treatment. Data were analyzed using the GLIMMIX model procedure of SAS (version, 9.2; SAS Inst. Inc. Cary, NC, USA). Packaging treatment served as the lone fixed effect and replication serving as the random effect for instrumental color. Day of simulated frozen storage served as a repeated measure, with packaging, day, and packing × day interaction as the fixed effects. Least squares means were generated, and, when significant ($p \leq 0.05$) F-values were observed, least squares means were separated using the pair-wise t-test (PDIF option).

Results and Discussion

Instrumental color

Currently fresh, never-frozen product represents a large portion of meat sold to consumers in the United States. However, with a growing focus on extending cold chain storage or frozen meat logistics, it is imperative to investigate color changes that may occur during cold storage in the face of the paucity of published studies addressing surface color variations that are known to occur in frozen beef steaks. To address this, we measured instrumental color values of beef ribeye steaks were measured during a simulated frozen storage period. There was an interaction ($p < 0.05$) for packaging treatment × day of simulated frozen display that occurred for surface lightness values (Table 1). Frozen steak surface color was lighter ($p < 0.05$) for steaks packaged using MDF initially (day 0), but steaks packaged in MFS and MDF were darkest ($p < 0.05$) as the duration of frozen storage time increased beyond day 20 (Table 1). Frozen steaks were redder and more yellow ($p < 0.05$) when packaged using MDF film. It is plausible the surface color changes reported on frozen steaks may be attributed to oxygen transmission rate for each packaging film. The OTR for MDF film was greater than MDF or MB which presumably allowed for greater myoglobin binding with oxygen resulting in greater percentages of oxymyoglobin throughout frozen storage. Higher redness values are often indicative of a redder fresher surface color in fresh meat and have a pro-found positive influence on the consumer at the time of purchase. These data therefore support the hypothesis that MDF film promotes a superior surface color in frozen steaks. Given the surface color of beef during frozen storage has not been extensively

Table 1: The interactive impact of packaging treatment × day on instrumental color values of vacuum-packaged, frozen, beef ribeye steaks during simulated storage.

	Day						SEM
	0	7	10	15	20	25	
MB¹							
L* ²	43.70 ^{bcd}	44.03 ^{bc}	42.57 ^{defgh}	42.99 ^{cdef}	43.00 ^{cdef}	42.88 ^{cdefg}	0.4323
a* ²	27.81 ^a	23.77 ^d	22.38 ^f	19.06 ^g	16.86 ^h	15.38 ⁱ	0.3684
b* ²	21.66 ^{bc}	19.56 ^{gh}	20.04 ^{efg}	17.37 ^j	16.42 ^k	15.58 ^l	0.2984
MFS¹							
L* ²	44.37 ^b	42.03 ^{fgh}	41.78 ^{gh}	42.15 ^{fgh}	41.55 ^h	41.43 ^h	0.4323
a* ²	24.83 ^c	24.35 ^{cd}	24.57 ^{cd}	23.59 ^{de}	22.59 ^{ef}	21.84 ^f	0.3684
b* ²	19.07 ^{hi}	19.27 ^{ghi}	20.02 ^{fg}	19.34 ^{gh}	18.79 ^{hi}	18.49 ⁱ	0.2984
MDF¹							
L* ²	47.06 ^a	43.52 ^{bode}	42.48 ^{efgh}	43.22 ^{bcddef}	42.13 ^{fgh}	41.49 ^h	0.4323
a* ²	27.79 ^a	26.68 ^b	28.26 ^a	26.67 ^b	25.30 ^c	24.51 ^{cd}	0.3684
b* ²	21.11 ^{bcd}	20.66 ^{def}	22.88 ^a	21.75 ^b	20.86 ^{cde}	20.59 ^{def}	0.2984

¹ Packaging treatments are defined as: (MB) nylon + enhanced ethylene-vinyl alcohol + polyethylene; (MFS) polypropylene + polyolefin plastomer; and (MDF) polyolefin + polyethylene.

² L* values are a measure of darkness to lightness (larger value indicates a lighter color); a* values are a measure of redness (larger value indicates a redder color); and b* values are a measure of yellowness (larger value indicates a more yellow color).

^{a-l} Mean values within day of display and packaging method lacking common superscripts differ ($p < 0.05$).

Table 2: The interactive impact of packaging treatment × day on instrumental surface color values of vacuum packaged beef ribeye steaks during a frozen storage.

	Day						SEM
	0	7	10	15	20	25	
MB¹							
C* ²	35.28 ^{ab}	30.83 ^{gh}	30.09 ^{hi}	25.84 ^k	23.58 ^l	21.94 ^m	0.459
Hue (°) ³	37.71 ^{ij}	39.71 ^{def}	42.20 ^c	42.68 ^c	44.49 ^b	45.56 ^a	0.2461
RTB ⁴	5.04 ^a	3.54 ^{fg}	3.19 ^h	2.44 ⁱ	1.99 ^j	1.81 ^j	0.0971
MMb ⁵	25.89 ^l	33.81 ^{ef}	37.71 ^d	40.10 ^c	45.14 ^b	47.22 ^a	0.5545
DMb ⁵	6.51 ^b	3.74 ^{cd}	4.44 ^c	4.83 ^c	6.46 ^b	8.52 ^a	0.4171
OMb ⁵	70.45 ^{ab}	61.65 ^h	56.93 ⁱ	53.95 ^j	47.07 ^k	42.76 ^l	0.7287
MFS¹							
C* ²	31.34 ^{gh}	31.07 ^{gh}	31.71 ^{efg}	30.52 ^{ghi}	29.39 ^{ij}	28.64 ^j	0.459
Hue (°) ³	37.34 ^{jk}	38.35 ^{hi}	39.18 ^{fg}	39.33 ^{fg}	39.74 ^{def}	40.25 ^d	0.2461
RTB ⁴	4.26 ^{bc}	3.96 ^d	3.97 ^d	3.66 ^{ef}	3.43 ^{gh}	3.27 ^{gh}	0.0971
MMb ⁵	25.68 ^l	29.67 ^{ij}	30.75 ^{hi}	30.46 ^{hij}	32.98 ^{ef}	33.94 ^e	0.5545
DMb ⁵	4.04 ^{cd}	2.33 ^{ef}	2.14 ^{ef}	2.06 ^{ef}	1.94 ^{ef}	2.29 ^{ef}	0.4171
OMb ⁵	70.18 ^{ab}	67.52 ^{cde}	66.59 ^{def}	66.96 ^{cde}	64.61 ^{fg}	63.08 ^{gh}	0.7287
MDF¹							
C* ²	34.93 ^{bc}	33.76 ^{cd}	36.37 ^a	34.43 ^{bc}	32.81 ^{de}	32.02 ^{ef}	0.459
Hue (°) ³	37.01 ^k	37.66 ^k	38.93 ^{gh}	39.16 ^{fg}	39.48 ^{efg}	40.04 ^{de}	0.2461
RTB ⁴	4.79 ^a	4.49 ^b	4.92 ^a	4.33 ^b	4.01 ^{cd}	3.86 ^{de}	0.0971
MMb ⁵	26.15 ^l	28.06 ^k	28.95 ^k	29.40 ^{jk}	31.39 ^{gh}	32.37 ^{fg}	0.5545
DMb ⁵	3.02 ^{de}	1.99 ^{ef}	2.07 ^{ef}	1.78 ^f	1.48 ^f	1.44 ^f	0.4171
OMb ⁵	70.83 ^a	69.78 ^{ab}	68.78 ^{bc}	68.58 ^{bcd}	66.83 ^{cde}	65.83 ^{ef}	0.7287

¹Packaging treatments are defined as: (MB) nylon + enhanced ethylene-vinyl alcohol + polyethylene; (MFS) polypropylene + polyolefin plastomer; and (MDF) polyolefin + polyethylene.

²Chroma is a measure of total color (larger number indicates a more vivid color).

³Hue angle represents the change from the true red axis (larger number indicates a greater shift from red to yellow).

⁴RTB calculated as 630 nm reflectance/580 nm reflectance, which represents a change in color of red to brown (larger value indicates a redder color).

⁵Calculated percentages of oxymyoglobin (OMb), deoxymyoglobin (DMb), and metmyoglobin (MMb) using relative spectral values.

^{a-m}Mean values within day of display and packaging method lacking common superscripts differ (p < 0.05).

investigated, these data represent an important addition to the literature and indicate that further research into the use of MDF is warranted.

Limited previous research noted similar trends that the effect of freezing on beef color stability will result in a decrease of instrumental color parameters of lightness, redness, and yellowness [20]. These surface color changes have been attributed to the lack of myoglobin oxidation as the duration of frozen storage time increases, surface color changes occur due to the lack of myoglobin oxidation [20]. However, chilled then frozen storage lamb longissimus muscle was reported to have more stable redness (a*), chroma and hue angle values when compared to never frozen chilled lamb meat [21]. Additionally, it has been reported that when beef is frozen in vacuum packaging detrimental effects like protein denaturation and a declining in myoglobin activity, can result in darker redness (a*) and yellowness (b*) values as storage time increases [22]. Our observation in the current study that redness and yellowness values declined as storage time increased in frozen ribeye steaks is consistent with the

limited results focusing on color changes in other meat cuts that appear in the literature. Interestingly, it has been reported that surface color deterioration is less likely to occur when beef steaks reach rigor at higher temperatures prior to frozen storage at temperatures around 35°C [23-24]. Nevertheless, surface color values for redness and yellowness are correlated to color deterioration and as these values decrease, the formation of metmyoglobin will ultimately change the color from red to a brownish-red [13]. The lack of published studies focusing on frozen surface color of beef steaks suggest additional research efforts are necessary to identify the mechanisms of underlying color changes in frozen beef steaks and the potential for packaging films such as MDF to disrupt them to stabilize surface color. A packaging method × day of frozen display (p < 0.05) interaction for surface color or chroma (C*), hue angles, red to brown (630:580nm) and calculated forms of myo-globin (Table 2). Frozen steak surface color was more vivid (p < 0.05) for steaks packaged in MDF throughout the entire storage period. Furthermore, steaks packaged with MB had the greatest (p < 0.05) shift

from red to yellow (Hue°) and red to brown (RTB) as the duration of frozen storage time increased beyond day 7. Calculated values were greater for oxymyoglobin ($p < 0.05$) when packaged using MDF film from day 7 to 25 of frozen storage. Whereas the calculated value of deoxymyoglobin and metmyoglobin increased ($p < 0.05$) for steaks packaged using MB and MFS films throughout the entire display period. It is plausible that because of the oxygen transmission rate of films MDF and MFS that a greater shift calculated color values occurred. These results support the hypothesis that packaging films can influence surface color in frozen steaks and that MDF promotes a more optimal surface color over time in storage.

Studies have reported that vacuum packaging for frozen beef storage provides the product with a more stable color than alternative oxygen permeable packaging [24-27]. However, very limited previous research has been conducted examining vacuum-packaging film materials and their impact on frozen beef color. Due to MB film limiting the exposure of packaged meat to oxygen because of the low OTR of MB, the observed increase in deoxymyoglobin observed in the present study for MB packaged steaks was unexpected. However, a decrease in myoglobin oxygenation overtime has been reported to disrupt the mitochondrial respiration in skeletal muscle which can result in myoglobin remaining in the DMb state, and a correspondingly darker pigmented surface color [23]. Differences in oxygen penetration between packaging films has been reported with higher rates allowing for more oxygen to penetrate the surface of the meat during freezing and frozen storage, resulting in greater oxymyoglobin values [17]. Our observation that oxymyoglobin values increased with increasing frozen storage time in steaks packaged using higher oxygen permeable vacuum-packaging films is consistent with the few previously published studies in the literature. However, it has been reported that vividness (C*) and a reduced shift from red to yellow (Hue°) was associated with reduced oxygen exposure packaging as storage time increased for beef steaks which is not consistent with the results of this current study [5]. Moreover, it has also been reported that an increase in hue angle can be influenced by the gradual oxidation of myoglobin resulting in a greater accumulation of metmyoglobin over time [25]. This observation is consistent with results in this study when comparing the hue angle and MMb increase shown in the steaks packaged in MB. Generally, the few published studies to date indicate that vacuum-packaging film materials can influence frozen surface color of beef steaks and the present study extends this literature. Contradictions that do exist amongst available studies point to the continued need for supplementary research aimed at identifying mechanisms by which packaging film materials alter the oxidative state of myoglobin in order to better understand the interaction between these films and surface color changes during cold storage.

Conclusions

The results presented here suggest that oxygen transmission rates of thermoforming vacuum packaging film used for frozen storage of beef steaks should be considered to minimize surface color changes throughout a frozen storage period. Our data indicates that steaks packaged in MDF film possessing a greater oxygen transmission rate experienced a more stable surface color throughout storage compared to films with lower oxygen transmission rates. These findings support the use of MDF film for preserving optimal surface color when using vacuum packaging for frozen storage or transportation purposes. However, additional research should be conducted to evaluate the sensory taste profile, surface color after frozen storage, and cookery of frozen, vacuum packaged steaks.

Author contributions

Conceptualization, M.P.W, T.M.R. and J.T.S.; methodology, M.P.W.; validation, T.M.R., V.E.Z., M.M.C, and K.E.C.; formal analysis, J.T.S.; investigation, T.M.R., V.E.Z., M.M.C., and K.E.C.; data curation, M.P.W.; writing-original draft preparation, M.P.W.; writing-review and editing, M.P.W., T.M.R., C.W.S., A.D.B., T.D.B., and J.T.S.; supervision, J.T.S.; C.W.S; T.D.B., A.D.B., and B.S.W.; project administration, J.T.S; B.S.W.; funding acquisition, J.T.S. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Acknowledgments

Appreciation is extended to the Lambert-Powell Meats Laboratory at Auburn University with procurement of raw materials and processing technology. Additionally, the authors are grateful for the support provided by WINPAK for providing the Variovac thermoforming machine and supplying thermoforming films to complete this study. Authors are grateful for partial funding support through the Agricultural Research Service, U.S. Department of Agriculture, under Agreement No. 58-6010-1-005

Conflicts of interest

The authors declare no conflict of interest.

References

1. Wang HH, Chen J, Bai J, et al. Meat Packaging, Preservation, and Marketing Implications: Consumer Preferences in an Emerging Economy. *Meat Sci* 145 (2018): 300-307.
2. McMillin, K.W. Advancements in Meat Packaging. *Meat Sci* 132 (2017): 153-162.
3. Daszkiewicz T, Kubiak D, Panfil A. The Effect of Long-Term Frozen Storage on the Quality of Meat (*Longissimus Thoracis et Lumborum*) from Female Roe Deer (*Capreolus Capreolus L.*). *J. Food Qual* 12 (2018): 19-31.
4. Fernández-López J, Sayas-Barberá E, Muñoz T, et al. Effect of Packaging Conditions on Shelf-Life of Ostrich Steaks. *Meat Sci* 78 (2008): 143-152.
5. Reyes TM, Wagoner MP, Zorn VE, et al. Vacuum Packaging Can Extend Fresh Color Characteristics of Beef Steaks during Simulated Display Conditions. *Foods* 11 (2022): 520.
6. Kenawi MA. Evaluation of Some Packaging Materials and Treatments on Some Properties of Beef during Frozen Storage. *Food Chem* 51 (1994): 69-74.
7. Lanari MC, Zaritzky NE. Effect of Packaging and Frozen Storage Temperature on Beef Pigments. *Int. J. Food Sci. Technol.* 26 (1991): 629-640.
8. Lagerstedt A, Ahnström ML, Lundström K. Vacuum Skin Pack of Beef- A Consumer Friendly Alternative. *Meat Sci* 88 (2011): 391-396.
9. Aberle E, Forrest J, Gerrard D, et al. *Principles of Meat Science*, (5th edtn), Kendall Hunt (1989).
10. Lentz CP. Effect of Light Intensity and Other Factors on the Color of Frozen Prepackaged Beef. *Can. Inst. Food Technol. J.* 12 (1979): 47-50.
11. Vieira C, Diaz MT, Martínez B, et al. Effect of Frozen Storage Conditions (Temperature and Length of Storage) on Microbiological and Sensory Quality of Rustic Crossbred Beef at Different States of Ageing. *Meat Sci* 83 (2009): 398-404.
12. Dainty RH, Mackey BM. The Relationship between the Phenotypic Properties of Bacteria from Chill-Stored Meat and Spoilage Processes. *Soc Appl Bacteriol Symp Ser* 21 (1979): 103-114.
13. Esmer OK, Irkin R, Degirmencioglu N, et al. The Effects of Modified Atmosphere Gas Composition on Microbiological Criteria, Color and Oxidation Values of Minced Beef Meat. *Meat Sci* 88 (2011): 221-226.
14. Richardson WD, Scherubel EF. The Deterioration and Commercial Preservation of Flesh Foods. Second Paper-The Storage of Beef at Temperatures above the Freezing Point. *J. Ind. Eng. Chem.* 1 (1909): 95-102.
15. Qian S, Li X, Wang H, et al. Effect of Sub-Freezing Storage (-6, -9 and -12 °C) on Quality and Shelf Life of Beef. *Int. J. Food Sci. Technol.* 53 (2018): 2129-2140.
16. Lee Y, Saha A, Xiong R, et al. Changes in Broiler Breast Fillet Tenderness, Water-Holding Capacity, and Color Attributes during Long-Term Frozen Storage. *J. Food Sci.e* 73 (2008): E162-E168.
17. Wang F, Liang R, Zhang Y, et al. Effects of Packaging Methods Combined with Frozen Temperature on the Color of Frozen Beef Rolls. *Meat Sci* 171 (2021): 108292.
18. American Meat Science Association. *Meat Color Measurement Guidelines*, American Meat Science Association: Champaign, IL, USA (2012).
19. Commission Internationale de l' Eclairage. *Recommendations on Uniform Color Spaces-Color Differences Equations, Psychometric Color Terms*; C.I.E. Publication No. 15 (1978): 197245.
20. Coombs CEO, Holman BWB, Friend MA, et al. Long-Term Red Meat Preservation Using Chilled and Frozen Storage Combinations: A Review. *Meat Sci* 125 (2017): 84-94.
21. Kim YHB, Frandsen M, Rosenvold K. Effect of Ageing Prior to Freezing on Colour Stability of Ovine *Longissimus Musc*. *Meat Sci* 88 (2011): 332-337.
22. Farouk MM, Swan JE. Effect of Muscle Condition Before Freezing and Simulated Chemical Changes During Frozen Storage on the PH and Colour of Beef. *Meat Sci* 50 (1998): 245-256.
23. Mancini RA, Ramanathan R. Effects of Postmortem Storage Time on Color and Mitochondria in Beef. *Meat Sci* 98 (2014): 65-70.
24. Bhattacharya M, Hanna MA. Kinetics of Drip Loss, Cooking Loss and Color Degradation in Frozen Ground Beef during Storage. *J. Food Process Eng.* 9 (1989): 83-96.
25. Lanari MC, Bevilacqua AE, Zaritzky NE. Pigments Modifications During Freezing and Frozen Storage of Packaged Beef. *J. Food Process Eng.* 12 (1990): 49-66.
26. Brewer M, Wu S. Display, Packaging, and Meat Block Location Effects on Color and Lipid Oxidation of Frozen Lean Ground Beef. *J. Food Sci.* 58 (1993): 1219-1236.
27. Limbo S, Torri L, Sinelli N, et al. Evaluation and Predictive Modeling of Shelf Life of Minced Beef Stored in High-Oxygen Modified Atmosphere Packaging at Different Temperatures. *Meat Sci* 84 (2010): 129-136.