Effect of oral glycerol on the carcass and beef quality

R.I. Camargo-Carrasco[1], M.E. Ortega-Cerrilla[1], P. Zetina-Córdoba[2]*, J.R. Kawas-Garza[3], J.G. Herrera-Haro[1].

[1]Campus Montecillo, Recursos Genéticos y Productividad – Ganadería, [1]Colegio de Postgraduados, Km 36.5 Carr. México-Texcoco, Texcoco, C.P. 56230, Estado de México, México; [2]Programa de Ingeniería en Alimentos, Universidad Politécnica de Huatusco, Camino Predio Axol, Reserva Territorial, Huatusco, C.P. 94106, Veracruz, México.[3]Facultad de Agronomía, Universidad Autónoma de Nuevo León, Francisco I. Madero s/n, Ex Hacienda la Cañada, General Escobedo, C.P. 66050, Nuevo León, México.
*Corresponding author email: mtro.pedro.zetina17@uphuatusco.edu.mx

Journal of Livestock Science (ISSN online 2277-6214) 17: 524-529
Received on 4/12/25; Accepted on 20/7/26; Published on 24/7/26
doi. 10.33259/JLivestSci.2026.524-529

Abstract

Glycerol can be used as a gluconeogenic substrate to increase glycogen reserves in steers subjected to stress before slaughter. This study aimed to evaluate the effect of oral glycerol 24 h before slaughtering on the pH of carcass and beef quality. Thirty-eight steers of 450 kg live weight were used. Of these, 19 did not receive glycerol (T_1), and 19 received 600 mL glycerol orally 24 h before slaughter (T_2), under a completely randomized design. During the 24-hour *postmortem*, the pH and temperature of the carcasses were determined. In the last reading, dry matter (DM), crude protein (CP), and ash were determined in the meat samples taken from the rib area, which were also used to determine pH, color, water holding capacity (WHC), texture, CP and ash at 7, 14, 21 and 28 d after slaughter. No differences ($P>0.05$) were found in pH, temperature, or DM and CP contents, in contrast ($P<0.05$) with ash at 24 h post-mortem. Oral administration of glycerol did not affect ($P>0.05$) pH, color, water retention capacity, and texture; however, these were affected ($P<0.05$) during shelf life. The interaction between glycerol and shelf life was not significant ($P>0.05$) for the indicated variables. Concentrations of CP and ash were similar ($P>0.05$) and with a positive interaction ($P<0.05$) for ash in T_2. The administration of 600 mL glycerol 24 h before slaughtering did not cause changes in the pH of carcass and beef quality; however, an effect was observed in color, WHC, and texture in the shelf-life of beef.

Key words: Bovines; Glycerol; Beef quality; pH carcass

Introduction

Transport and slaughter are the most stressful stages for animals because of handling, overcrowding with other animals, changes in temperature, lack of water, food, and noise, causing physiological and behavioral changes (Teke *et al*., 2014,). Stress during transport and before slaughter decreases glycogen reserves in muscles, resulting in low production of post-mortem lactic acid and inadequate carcass pH (>5.8), impairing meat color, tenderness, water holding capacity, and dark meat that affect the appearance, juiciness, and shelf life; these aspects determine consumer acceptance (Liu *et al*., 2022). Feeding different additives during fattening to the steers is gaining importance for its effect on carcass quality (Hamikoeva *et al*., 2021; Kairov *et al*., 2021; Khamikoeva *et al*., 2021; Son et al., 2025). Glycerol is also a suitable substrate for energy, as it can be converted to glucose through gluconeogenesis (Rotondo *et al*., 2017). Studies have shown that administering glycerol in the form of glycerin to ruminants can promote metabolic changes and increase plasma glucose levels for short periods. However, although there are studies on this topic (Eiras *et al*., 2014; Chanjula *et al*., 2014), its effects on carcass and meat characteristics when it is administrated before transport and slaughter are not entirely known (Orrico Junior *et al*., 2015). Therefore, the objective of the study was to evaluate the effects of oral administering glycerol to steers, 24 h before slaughtering, on carcass temperature and pH, chemical composition of the meat at 24 h post-mortem, as well as water retention capacity, texture, crude protein, and ash content during the shelf life meat.

Materials and methods

Experimental site, animals and experimental design

The study was conducted in Tamuín, San Luis Potosí, México, located at 22° 00' 25" North and 98° 47' 19" West. Mean temperature 16°C and 53% relative humidity. This research was approved by the Animal Welfare Committee of the Colegio de Postgraduados. At the end of a 90-d fattening period, 38 Zebu (*Bos indicus*) crosses with Swiss or Simmental (*Bos taurus*) steers, with an average live weight of 450 ± 48 kg, the animals were weighed using a digital livestock scale (TORREY®, Model PG-2000, Monterrey, México) and were selected at random 24 h before slaughter. Steers were subjected to two treatments, in a completely randomized design (n=19); T_1: without oral administration glycerol (GLY), T_2: oral administration of 600 mL GLY (85% pure) per animal, 24 h before slaughter, using a Syrman graduated syringe and were manipulated with the support of a clamp to hold them.

Ante-mortem management

Steers were boarded for transport at 05:30 h (15°C and 90% relative humidity) into 20-steer capacity cages. The estimated time to slaughter in a commercial slaughterhouse with Federal Inspection Service was 20 min. During the entire process and at the reception offices before slaughter, observations were made to detect falls, disembarkation time, animal behavior, and handling. The total waiting time for the 38 steers up to slaughter was 75 min.

pH and temperature of steers carcass

Three h *post-mortem*, initial carcass temperature (T_{3h}) (DELTA TRAK, Model 11050, Waterproof Lollipop, USA) and initial pH (pH_{3h}) (HANNA pH meter Model-HI99163, Woonsocket, RI, USA) were measured, and consecutive readings were performed 6, 9, 12, 15, 18, 21 and 24 h *post-mortem*.

Physicochemical analysis of meat

Quartering and extraction of meat samples (four replications) in the rib area were done at the last reading (24 h). In these samples, immediately, dry matter (DM), crude protein (CP), and ash were determined following the AOAC (2005) methodology (9). Other meat samples were vacuum packed and kept at 5 ºC for analysis at 7, 14, 21, and 28 d *post-mortem*, which correspond to meat shelf life in accord with the commercialization time of perishable products. pH was determined (PELICAN 1400 Case, Model SA 210, CA, USA), and color using Hunter (HUNTER QUEST 45/0, Hunter Associates Laboratory, Reston, VA, USA) values, which include *L** (luminosity), *a** (red to green tones), *b** (yellow to blue tones). These were determined in a colorimeter (KONICA MINOLTA, Model CR400/410, NJ, USA) in meat samples at room temperature. The results are reported as the average of three consecutive measurements. WHC was determined by the methodology proposed by Guerrero *et al*. (2002). Five g of meat were placed in 160 mL tubes and homogenized with 8 mL 0.6 M NaCl. Tubes were then placed in an ice bath for 30 min and centrifuged 15 min at 1500 *g* (CLAY ADAMS, Model 420101, Sparks, USA). The supernatant was decanted and its volume was measured; this represented the non-retained water of the 8 mL NaCl that was added. Three meat segments were extracted with a punch perpendicular to the muscle fibers to determine each sample's texture profile. Then a Warner-Bratzler blade in a texture analyzer TA-XT2 (Texture Technologies Corp, Scarsdale, NY, USA) was used, with forward and backward movement speed of the blade of 5 mm/s (Guerrero *et al*. 2002). Crude protein and ash were also determined (AOAC, 2005).

Statistical analysis

The experimental design was completely randomized, and an analysis of variance was performed with Statistical Analysis System software (SAS, 2004). The chemical composition of the meat at 24 h were analyzed with PROC GLM; pH, temperature of carcass and pH, color, WHC, texture, protein and ash of the meat was

analyzed with measurements repeated through time with PROC MIXED, the model included principal effects and the interaction treatment*time. The means comparation was performed with the Tukey test.

Results and Discussion

pH and temperature of steers carcass

Administration of GLY to the steers 24 h before slaughter did not affect (P>0.05) carcass temperature (T) or pH at the different monitoring times (Figure 1). A descending trend occurred as the hours lapsed: initial T_{3h} of 33.05 and 32.91ºC, intermediate (15 h *post-mortem*) of 13.4 and 13.8ºC, ending at 27 h with 1.02ºC and 1.31ºC for GLY treatment and without GLY, respectively. Initial pH_{3h} was 6.5 and 6.9, decreasing after 9 h to 5.6 and 5.3, and both treatments stabilized and finalized at a pH_{24h} of 5.6 and 5.7 for GLY treatment and without GLY, respectively. The rate of cooling and the decrease in pH determine the final quality of the meat, so it is essential to know the conversion rates of the energetic substrates linked to changes in the pH and temperature of the muscles (Kufii *et al*., 2017). pH is one of the most important meat quality parameters since it is related to muscle glycogen reserves and is a direct indicator of acid content in the muscle and affects cutting force, drip loss, and meat color (Carrasco-García *et al*., 2020). Francozo *et al*. (2013) included 5 and 10% GLY in the diet of Nellore steers and shipped them 84 km at a density of one animal m^{-2}; they found carcass pH_{24} of 6.35 and 6.11. Lage *et al*. (2014) obtained similar results when they included different GLY levels in the diet. However, Carvalho *et al*. (2014) reported similar values to those found in our study in which pH_{24h} was between 5.5 and 5.8. Chanjula *et al*. (2014) indicated that including 20% GLY in the diet reduces the acetate:propionate ratio because it benefits the population of *Selenomonas*, the primary GLY fermenters in the rumen, metabolizing approximately 80% after 24 h. In our study, pH was not affected by GLY inclusion 24 h before slaughter, possibly because the steers metabolized it rapidly or the amount administered was insufficient. Furthermore, GLY can be absorbed from the rumen in significant amounts, disappear through microbial digestion, and exit from the rumen through the omasal orifice (Werner *et al*., 2015). The short transport time (20 min) and the rapid access to slaughter may not have produced enough stress in the animals to consume all the GLY as the pH values in the carcasses of the two treatments were similar. The pH values in the present study were in a normal pH range (5.4 to 5.7) of non-stressed animals (Piao *et al*., 2021).

Chemical composition of the meat at 24 hours *post-mortem*

Administration of glycerol did not affect (P>0.05) DM or CP content 24 h *post-mortem*. However, it decreased (P≤0.05) the percentage of ash (Table I). Concentrations of CP are found within the 20.7 to 21.8% average in *Longissimus dorsi* of heifers reported by Almeida *et al*. (2021), indicating that administration of GLY (33.3, 66.6 and 99.9 g/kg DM of supplement) did not cause changes. However, Piao *et al*. (2020) report in thoracic *Longissimus thoracis* of Korean cattle steers, 19% CP when they included 3.57% GLY in the diet. The percentage of ash in the meat was high compared with the data of Piao *et al*. (2020), who obtained values of 1.3%. The difference between this study and those cited above can be attributed to the mineral content of the water consumed in the region where the feedlot is located, since the minerals are high (Vieyra-Alberto *et al*. 2013).

Physicochemical characteristics of beef at different days of refrigerated storage

Treatment with GLY did not affect (P>0.05) pH, luminosity (*L**), red tones (*a**), yellow tones (*b**), WHC, or meat texture. However, an effect of time was observed in all the variables (P≤0.05), even though the interaction treatment*time was not significant (P>0.05) (Table 2). Regarding crude protein and ash content, no differences were detected (P>0.05) due to treatment with GLY, and although differences were observed due to the effect of time (P≤ 0.05), the treatment*time interaction was not significant (P>0.05). The quality of meat storage depends on several factors, such as meat pH, growth and type of bacteria, oxidative stability, and enzymatic activity (Bostami *et al*., 2023). The values during the shelf life were different, indicating a change in the use of GLY and the presence of lactic acid, modifying the pH levels over time (Strobel *et al*., 2021), and quality meat is considered to have a final pH in the range of 5.4 – 5.6 (Hughes *et al*., 2014a). The color, WHC, and tenderness are consumers' primary determinants of visual and sensorial attractiveness (Hughes *et al*., 2014b). During meat shelf life, luminosity tended to decrease, which is affected by the quantity of water on the surface, a consequence of its WHC, which in turn affects pH (Francozo *et al*., 2013). These results explain the values obtained of *L** at 28 days of shelf life. Animals under stress before slaughter more frequently produce dark, firm, and dry (DFD) meat (Hughes *et al*., 2014b), however, this type of cut was not observed in this study, where *L** and *b** levels decreased, but *a** values increased, but not significantly. The results obtained from our study can be compared to those reported by Egea *et al*., (2014) for Limousin bulls fed diets with 2 and 4% GLY; their carcasses 7 days *postmortem* had similar **b*, lower *L** and higher *a**. Eiras *et al*. (2014) obtained similar results for *a** and *b**, but higher values in *L** in carcasses of Puruná bulls fed diets with 0, 60, 120, and 178 g GLY/kg DM. Our results were higher than those of San Vito *et al*., (2015) reported in grazed steers supplemented with GLY. Francozo *et al*. (2013) found that color coordinates were lower when 5 and 12% GLY was included in the diets of Nellore steers. However, Carvalho *et*

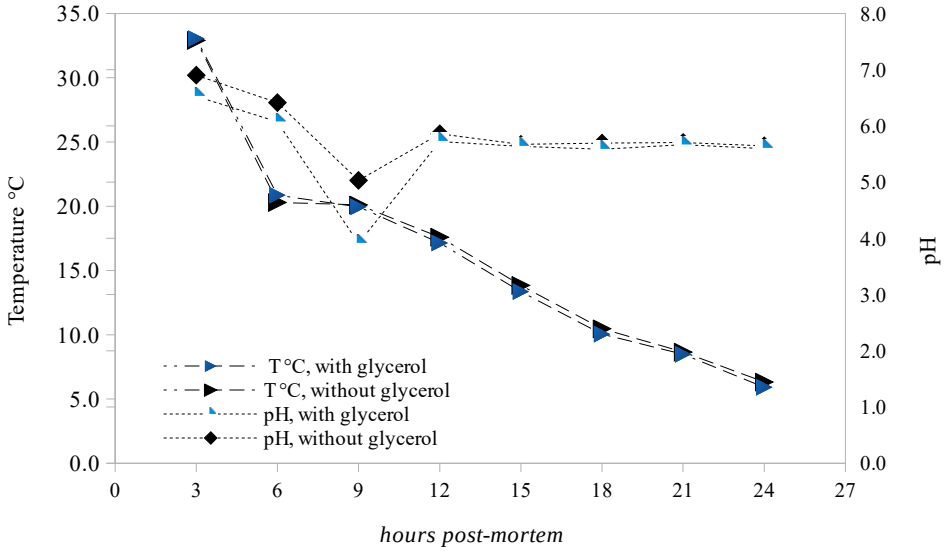

Fig 1. Temperature and pH of the carcass of steers administered with or without glycerol 24 h before slaughter

Table 1. Characteristic of meat of steers administered with and without glycerol 24 h before slaughter

Variable	**T_1**	**T_2**	**SEM**	***p-value***
Dry matter	28.01	26.82	0.18	0.884
As % dry matter				
Crude protein	23.40	23.72	0.15	0.745
Ash	4.00	3.66	0.04	0.032

T_1: Not glycerol administration; T_2: Oral administration of 600 mL glycerol; SEM: Standard error of the mean.

Table 2. Effect of treatments with and without glycerol on the characteristics of steer meat

	Refrigeration days (5°C)												
Ítems	**7**		**14**		**21**		**28**		**SEM**				
	T_1	**T_2**	**T_1**	**T_2**	**T_1**	**T_2**	**T_1**	**T_2**	**T_1**	**T_2**	**Treat**	**Time**	**Treat*Time**
Ph	5.6	5.6	5.5	5.5	5.5	5.5	5.6	5.6	0.30	0.27	0.651	0.005	0.075
*L**	38.91	38.92	36.36	38.17	37.20	37.72	35.20	35.10	0.85	0.77	0.789	0.041	0.955
*a**	14.15	14.36	17.09	17.52	15.21	15.32	16.33	16.77	0.50	0.46	0.058	0.025	0.087
*b**	6.28	6.88	5.21	5.61	5.93	6.03	4.69	4.69	0.33	0.30	0.092	0.001	0.059
WHC	8.3	8.2	8.5	8.3	8.2	8.1	8.1	8.2	0.12	0.11	0.579	0.001	0.195
Texture	1.86	1.89	1.85	1.88	2.06	2.10	1.71	1.96	0.09	0.09	0.478	0.004	0.287
As % DM													
Protein	24.08	23.73	22.94	23.55	23.64	23.86	22.95	23.74	0.31	0.28	0.134	0.032	0.761
Ash	4.12	3.49	3.94	3.69	4.04	3.69	3.89	3.77	0.08	0.07	0.267	0.001	0.039

Color: *L** = Luminosity; *a**= red index; *b**= yellow index. WHC= Water holding capacity of raw beef (mL 100^{-1} g). Texture = resistance to cutting with a Warner-Bratzler blade (kg cm^{-2}). DM: Dry matter. T_1: without glycerol administration T_2: Oral administration of 600 mL glycerol.

al. (2014) reported that the inclusion of 6, 12, and 18 % GLY in the diet affected steer carcass color, with higher values of *a** but lower values of *L** and *b**. Water retention may not be altered when GLY is administered in the diet, as has been demonstrated in studies by Francozo *et al*. (2013) and Egea *et al*. (2014). A similar situation occurs when administered directly, considering that GLY increases cell osmotic pressure, increasing intracellular water that can increase WHC (Egea *et al*., 2014). The results obtained in this study indicate that GLY did not affect WHC or texture (P>0.05). The differences in WHC over time can be attributed to protein deterioration and pH levels, which are affected by glycogen transformed to lactic acid, and reduced ATP (Abril *et al*., 2023), however, in this study, the WHC levels in the beef were normal. These results are significant because they affect product quality, which is closely related to texture, color, and pH. According to Eiras *et al*. (2014), adding GLY does not

affect meat tenderness. In our study, the final pH values, as well as those of texture, were similar in the two treatments. According to Warner Bratzler's classification, this study's results are in the range of tender meat.

Conclusion

Oral administration of 600 ml of glycerol 24 h to steers before slaughter did not affect the pH of the carcass during the first 24 h post-mortem. Likewise, the dry matter and crude protein content (except ash) was not affected at 24 h post-mortem. The administration of glycerol before slaughter did not cause changes in the characteristics of the meat, however, it affected the pH, color, water retention capacity and texture on the different days of storage.

Acknowledgments

The authors thank the Colegio de Postgraduados, Campus Montecillo, for the facilities to do this research, also the line of research “Knowledge Generation: Efficient Livestock with the Use of Biotechnology, and Animal Welfare Considering Climate Change".

Conflict of interest:

The authors declare no potential conflicts of interest.

References

1) Abril, B., Bou, R., García-Pérez, J.V. and Benedito, J.B. 2023. Role of enzymatic reactions in meat processing and use of emerging technologies for process intensification. Foods 12(10): 1940. https://doi.org/10.3390/foods12101940

2) Almeida, V.V.S., Oliveira, A.C., Silva, R.R., Ribeiro, J.S., Oliveira, H.C., Santos, L.S. and Lima Jr, D.M. 2021. Crude glycerin in the supplementation of crossbred heifers in tropical pastures. Animal 15(2): 100088. https://doi.org/10.1016/j.animal.2020.100088.

3) AOAC. 2005. Official Methods of Analysis of Association of Analytical Chemist. 18th edition. Association of Official Analytical Chemists, Washington, DC, USA.

4) Bostami, A.B.M.R., Mun, H-S. and Yang, C-J. 2023. Longissimus dorsi Muscle’s Chemical Composition, Fatty Acid Pattern, and Oxidative Stability in Korean Hanwoo Finishing Cattle Following Slaughtering and Stunning with or without Brain Disruption and State of Consciousness. Foods 12: 928. https://doi.org/10.3390/foods12050928

5) Carrasco-García, A.A., Pardío-Sedas, V.T., León-Banda, G.G., Ahuja-Aguirre, C., Paredes-Ramos. P., Hernández-Cruz, B.C. and Vega-Murillo, V. 2020. Effect of stress during slaughter on carcass characteristics and meat quality in tropical beef cattle. Asian-Australasian Journal of Animal Sciences 33(10): 1656-1665. https://doi.org/10.5713/ajas.19.0804

6) Carvalho, J.J.R., Chizzotti. M.L., Ramos, E.M., Machado, O.R.N., Lanna, D.P.D., Lopes, L.S., Teixeira, P.D. and Ladeira, M.M. 2014. Qualitative characteristics of meat from young bulls fed different levels of crude glycerin. Meat Science 96(2): 977-983. https://doi.org/10.1016/j.meatsci.2013.10.020

7) Chanjula, P., Pakdeechanuan, P. and Wattasanit, S. 2014. Effects of dietary crude glycerine supplementation on nutrient digestibility, ruminal fermentation, blood metabolites, and nitrogen balance of goats. Asian-Australasian Journal of Animal Sciences 27(3): 365-374. https://doi.org/10.5713/ajas.2013.13494

8) Egea, M., Linares, M.B., Garrido, M.D., Vollodre, C., Madrid, J., Orengo, J., Martínez, S. and Hernández, F. 2014. Crude glycerine inclusion in Limousin bull diets: Animal performance, carcass characteristics and meat quality. Meat Science 98: 673-678. https://doi.org/10.1016/j.meatsci.2014.06.034

9) Eiras, C.E., Barbosa, L.P., Marques, J.A., Araújo, F.L., Lima, B.S., Zawadzki, F., Perotto, D. and Prado, I.N. 2014. Glycerine levels in the diets of crossbred bulls finished in feedlot: Apparent digestibility, feed intake and animal performance. Animal Feed Science and Technology 197: 222-226. https://doi.org/10.1016/j.anifeedsci.2014.07.004

10) Francozo, M.C., Nunes, I.P., Cecato, U., Velandia, M.V., Zawadzki, F., Lolato, O.R., do Prado, R.M. and Visentainer, J.V. 2013. Growth performance, carcass characteristics and meat quality of finishing bulls fed crude glycerin supplemented diets. Brazilian Archives of Biology and Technology 56(2): 327-336. https://doi.org/10.1590/S1516-89132013000200019

11) Guerrero, L.I., Ponce, A.E. and Pérez, M.L. 2002. Curso práctico de tecnología de carnes y pescado. Universidad Metropolitana Unidad Iztapalapa, D. F. México, 171 p.

12) Hamikoeva, S.R., Temiraev, R.B., Chabaev, M.G., Tsis, E.Yu., Gappoeva, V.S., Khabaeva, Z.G., Gagloeva, A.R. 2021. Effect of adsorbent and enzyme preparations on productivity of fattening steers with diets containing heavy metals. Journal of Livestock Science 12: 60-64. doi. 10.33259/JLivestSci.2021.60-64

13) Hughes, J.H., Kearney, G. and Warner, R.D. 2014a. Improving beef meat colour scores at carcass grading. Animal Production Science 54: 422-429. https://doi.org/10.1071/AN13454

14) Hughes, J.M., Oiseth, S.K., Purslow, P.P. and Warner, R.D. 2014b. A structural approach to understanding the interactions between colour, water-holding capacity and tenderness, Meat Science, 98(3): 520-532, 2014b. https://doi.org/10.1016/j.meatsci.2014.05.022
15) Kairov, V.R., Gadzhiev, A.M., Baeva, Z.T., Nikkolova, B.S., Kozhokov, M.K., Tsagaraeva, E.F., Tsalieva, L.V. 2021. Effect of feeding adsorbent additives for heavy metal detoxification in steers. Journal of Livestock Science 12: 351-355 doi. 10.33259/JLivestSci.2021.351-355
16) Khamikoeva, S.R., Bosieva, O.I., Temiraev, V.Kh., Temiraev, R.B., Pshikova, O.V., Bobyleva, L.A., Cis, E.Yu., 2021. Effect of feeding sorbent and enzymes on heavy metal toxicity in young steers. Journal of Livestock Science 12: 341-345 doi. 10.33259/JLivestSci.2021.341-345
17) Kuffi, K.D., Lescouhier, S., Nicolai, B.M., De Smet, S., Geeraerd, A. and Verboven, P. 2018. Modelling postmortem evolution of pH in beef M. biceps femoris under two different cooling regimes. Journal of Food Science and Technology 55(1): 233-243. https://doi.org/10.1007/s13197-017-2925-9
18) Lage, J.F., Berchielli, T.T., San Vito, E., Silva, R.A., Ribeiro, A.F., Reis, R.A., Dallantonia, E.E., Simonetti, L.R., Delevatti, L.M. and Machado, M. 2014. Fatty acid profile, carcass and meat quality traits of young Nellore bulls fed crude glycerin replacing energy sources in the concentrate. Meat Science 96(3): 1158-1164. https://doi.org/10.1016/j.meatsci.2013.10.027
19) Liu, J., Ellies-Oury, M.P., Stoyanchev, T. and Hocquette, J.F. 2022. Consumer Perception of Beef Quality and How to Control, Improve and Predict It? Focus on Eating Quality. Foods 11(12): 1732. https://doi.org/10.3390/foods11121732
20) Orrico Junior, P.M.A., Bottini Filho, F.D.E., Vargas Junior, F.M., Orrico, A.C.A. and da Silva, J.C.S. 2015. Crude glycerin in diets of confined lambs: performance, carcass traits and economic feasibility. Bioscience Journal 31(4): 1152-1158. https://doi.org/10.14393/BJ-v31n4a2015-26226
21) Piao, M., Jung, D.J.S., Kang, H.J., Park, S.J., Lee, L.O., Kim, M., Jin, K.H., Hyun, K.D., Kyeom, S.J., Jo, C., Najmul, H.M. and Baik, M. 2020. Effects of dietary glycerol inclusion on growth performance, carcass and meat quality characteristics, glycogen content, and meat volatile compounds in Korean cattle steers. Animal Bioscience 34(4): 603-612. https://doi.org/10.5713/ajas.20.0186
22) Rotondo, F., Ho-Palma, A.C., Remesar, X., Fernández-López, J.A., Romero, M.M. and Alemany, M. 2017. Glycerol is synthesized and secreted by adipocytes to dispose of excess glucose, via glycerogenesis and increased acyl-glycerol turnover. Scientific Reports 7: 8983. https://doi.org/10.1038/s41598-017-09450-4
23) SAS Institute. 2004. SAS/STAT® 9.1 User's Guide. SAS Institute Inc. Cary. North Carolina USA
24) San Vito. E., Lage, J.F., Ribeiro, A.F., Silva, R.A. and Berchielli, T.T. 2015. Fatty acid profile, carcass and quality traits of meat from Nellore young bulls on pasture supplemented with crude glycerin. Meat Science 100: 17-23. https://doi.org/10.1016/j.meatsci.2014.09.008
25) Son, G.H., Shim, J.Y., Shin, S.U., Choi, C.S., Ahn, J.S., Kim, M.J., Kim, Y.L., Lee, S.H., Shin, J.S., Park, B.K. 2025. Effect of crude protein content on growth performance and carcass characteristics of late fattening Hanwoo steers. Journal of Livestock Science 16: 61-71 doi. 10.33259/JLivestSci.2024.61-71
26) Strobel, P., Galaz, A., Villaroel-Espíndola, F., Apaoblaza, A., Slebe, J.C., Jerez-Timaure, N., Gallo, M. and Ramírez-Reveco, A. 2021. Temperature, but not excess of glycogen, regulates "in vitro" AMPK activity in muscle samples of steer carcasses. PLoS One 16(1): e0229480. https://doi.org/10.1371/journal.pone.0229480
27) Teke, B., Akdag, F., Ekiz, B. and Ugurlu, M. 2014. Effect of different lairage times after long distance transportation on carcass and meat quality characteristics of Hungarian Simmental bulls. Meat Science 96(1): 224-229. https://doi.org/10.1016/j.meatsci.2013.07.009
28) Vieyra-Alberto, R., Domínguez-Vara, I.A., Olmos-Oropeza, G., Martínez-Montoya, J.F., Borquez-Gastelum, J.L., Palacio-Nuñez, J., Lugo de la Fuente. J.A. and Morales-Almaráz, E. 2013. Mineral profile and interrelationship in water, forage and blood serum of beef cattle during two seasons in the Huasteca Potosina, México. Agrociencia, 47 (2): 121-133.
29) Werner, O.A., Kronqvist, C., Zhongyan, L., Martens, H. and Holtenius, K. 2015. The fate of glycerol entering the rumen of dairy cows and sheep. Journal of Animal Physiology and Animal Nutrition (Berl). 99(2):258–64. https://doi.org/10.1111/jpn.12245