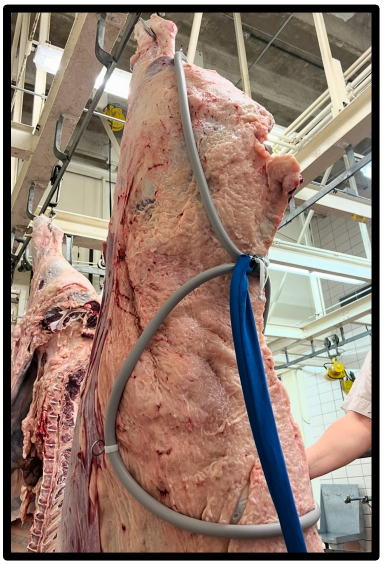
South Dakota State University

Department of Animal Science


FINAL REPORT

EVALUATION OF A NOVEL TECHNOLOGY FOR IMPROVING BEEF TENDERNESS: PULSED ELECTROMAGNETIC FIELD THERAPY

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Executive Summary

Pulsed electromagnetic field (PEMF) therapy is used in human and livestock health to increase muscle metabolism, promote healing, and reduce inflammation. Because muscle tissue continues anaerobic metabolism early postmortem, PEMF application at harvest may alter biochemical processes involved in meat color development and tenderization. We hypothesized that postmortem application of PEMF would accelerate proteolytic enzyme activity, thereby enhancing tenderness development and producing a brighter lean color at 24 h postmortem. While PEMF has been shown to influence muscle metabolism in living animals, limited research has evaluated its potential effects on postmortem muscle metabolism and beef quality. Therefore, the objectives of this study were:

1) Determine the effect of pulsed electromagnetic field (PEMF) application on the aging process (postmortem proteolysis) in beef

2) Evaluate the effect of PEMF on tenderness of two beef muscles.

Beef cattle (n = 20) harvested in northeast Iowa were selected based on similar hot carcass weight (895 ± 12.8 lb) and USDA Choice quality grade. Following carcass splitting and prior to cooler entry, PEMF treatment (PEMF Complete©) was applied to the right loin side of each carcass at 60 Hz and 230 V for 5 minutes, while the left side served as an untreated control. Instrumental color (L*, a*, b*) was measured on the exposed ribeye surface at 24 h postmortem. The strip loin (*m. longissimus lumborum*) and the eye of round (*m. semitendinosus*) from both sides of each carcass were collected and transported to the South Dakota State University Meat Laboratory. Ultimate muscle pH was recorded on the strip loin and eye of round at 3 days postmortem. Muscles were fabricated into steaks and assigned to aging periods for Warner–Bratzler shear force and cook loss evaluation. Postmortem proteolysis was also assessed on strip loin steaks aged for 1, 3, 7, or 14 days using Western blotting techniques to quantify protein degradation and calpain activity.

PEMF treatment did not influence instrumental color measurements, ultimate pH, Warner–Bratzler shear force, percent cook loss, or postmortem proteolysis. Mean L*, a*, and b* values did not differ between PEMF-treated and control sides. Tenderness improved with increasing postmortem aging time, as expected, but no PEMF treatment × aging day interactions were observed. Similarly, neither PEMF treatment nor aging day affected percent cook loss. Measures of postmortem proteolysis followed typical aging responses and were not altered by PEMF application.

In summary, application of PEMF therapy to beef carcasses early postmortem did not elicit measurable changes in muscle metabolism sufficient to impact lean color, tenderness, or other key beef quality attributes under the conditions evaluated. Although PEMF therapy is effective at increasing muscle metabolism in living animals, the frequency, voltage, and duration used in this study were not sufficient to influence postmortem muscle biochemistry. Future research should explore alternative PEMF parameters, as well as antemortem application strategies, to better assess the potential of this technology to enhance postmortem muscle metabolism and beef quality.

Project Background

Meat tenderness is one of the most important, yet variable attributes influencing consumer acceptability and demand for beef. It has been well established that consumers are willing to pay more for a tender beef product. Although dated, Miller et al. (2001) found that 78% of consumers would purchase steaks if the retailer could guarantee them to be tender and identified the potential for beef carcasses classified as "tender" to receive a premium close to $70 per carcass.

Tenderness is regulated by a myriad of pre- and post-harvest factors that contribute to inconsistency in this trait. After animals are harvested, muscles continue to undergo anaerobic metabolism early postmortem as the body attempts to maintain homeostasis (Aberle et al., 2012). Alterations to this early postmortem muscle metabolism influence processes integral to the development of tenderness. Application of a technology to alter postmortem muscle metabolism, may favor the development of tenderness. A potential method of improving the consistency of tenderness across carcasses and cuts is through the use of a technology that is already available in the livestock industry commonly referred to as "PEMF" or pulsed electromagnetic field therapy. In living tissue, PEMF therapy is a tool used in both animal and human health that has been proven effective in increasing muscle metabolism to promote healing and reduce inflammation (Gaynor et al., 2018). Through the use of alternating magnetic fields, based on the law of electromagnetic induction, the pulsed electromagnetic field promotes electrical currents that depolarize neuromuscular tissue, resulting in supramaximal muscle contraction (Leonardo et al., 2023). This contraction, as a result of PEMF application, occurs through a calcium influx within the cell, which stimulates muscle cell metabolism (Magnawave, 2023). Muscle contraction that occurs early postmortem leads to the onset of rigor and aids in the prevention of cold shortening, a phenomenon known to be detrimental to tenderness. Electrical stimulation is method that has been utilized by beef processing facilities to achieve this early postmortem muscle contraction, thus reducing cold-shortening. However, the strength of the electrical current causes violent contractions in beef carcasses resulting in swinging carcasses that, in combination with the crowded and wet environment of a packing facility, make electrical stimulation a concern for worker safety. Additionally, this contraction can cause carcasses to jolt off of the rail and result in damage such as broken bones that result in profit loss. Because PEMF works through small electrical pulses, this makes it safe to use on humans and animals and results in much less violent contraction. Therefore, it is hypothesized that PEMF may work in a manner to improve tenderness, similar to electrical stimulation, without posing a threat to plant worker safety.

Additionally, the influx of calcium as a result of PEMF can potentially lead to the activation of calcium-dependent enzymes responsible for postmortem proteolysis (meat aging) earlier postmortem, thus resulting in breakdown of muscle structure and a more tender product (Bhat et al., 2018). Of these enzymes, the calpain system supports a major role in the degradation of muscle fibers (Koohmaraie, 1992). Calpains are intracellular, calcium-dependent cysteine proteases that are known to be strong contributors to the proteolysis of structural myofibrillar proteins (Dargelos et al., 2008). If PEMF is able to increase unbound calcium early postmortem, the activity of these calcium-dependent enzymes may potentially be increased, thus resulting in an increase of muscle fiber degradation and a more tender product. Hence, by accelerating calcium release, rate of tenderization also increases, allowing carcasses to require less aging or hanging time in the cooler prior to fabrication. Application of PEMF to beef carcasses has the potential to be a non-invasive option to achieving beef tenderness without extended aging periods. Decreased aging periods could also reduce time carcasses would need to hang in small lockers prior to fabrication. Reducing the storage time of dry-aged carcasses could also reduce product losses caused by dehydration. If successful, this technology could shorten the storage time necessary for wet-aged cuts prior to

retail sale, which would provide additional flexibility for marketing beef. Additionally, cuts traditionally known to be "tougher" cuts, such as the eye of round, are often sold at a discount to cuts from the more tender middle-meats. An improvement in the tenderness of this cut could allow for a higher price point at retail.

While research has been conducted on the use of PEMF and its application in live animals, very little research exists on the potential of this technology to influence the carcasses of livestock used for meat production. Furthermore, the beef industry is still seeking avenues to produce a consistently tender product, making the identification of emerging technologies and novel methods of improving beef tenderness crucial to maintaining and growing consumer satisfaction with beef. If this technology is proven efficacious it would have the potential to be a process intervention that removes tenderness variability, enhances less tender cuts, limits the time needed to age meat prior to sale (thus decreasing cold storage costs), adds value to traditionally tougher cuts of beef, and increases marketing opportunities for value cuts. Further, identification of a novel method to improve tenderness in beef products and shorten aging time would allow beef processors to be more adaptive to rapid increases in beef demand. Therefore, the objectives of this project were:

Objectives

1) Determine the effect of pulsed electromagnetic field (PEMF) application on the aging process (postmortem proteolysis) in beef, and 2) Evaluate the effect of PEMF on tenderness of two beef muscles.

Materials and Methods

Beef cattle (n = 20) harvested at a processing facility in Northeast Iowa (Upper Iowa Beef) were selected based on a common hot carcass weight (895 ± 12.8 lb) and quality grade (USDA Choice).

Treatment & Fabrication*:* After carcass splitting and prior to cooler entry, PEMF treatment (PEMF Complete©) was applied to the loin and round on the right side of each carcass at 60 Hz and 230 V for 5 minutes as shown in Image 1. The left side of each carcass did not receive PEMF treatment and served as the control. At 24 h postmortem a 1-inch steak from the *m. longissimus lumborum* was collected for shear force and western blotting. Eye of round samples were not collected at 1 d postmortem due to the inaccessibility of removing samples from the round on the grade chain. Instrumental color (L* [0 = Black, 100 = White], a* [negative values = green, positive values = red], and b* [negative values = blue, positive values = yellow]) was also recorded at 24 h postmortem at two locations on the *m. longissimus thoracis* using a handheld Minolta colorimeter (Chroma Meter CR-410; Konica Minolta, INC. Osaka, Japan). After color measurements were conducted, the strip loin (*m. longissimus lumborum*) and the eye of round (*m. semitendinosus*) from both sides of each carcass were collected and transported to the South Dakota State University Meat Laboratory. At 3 d postmortem, ultimate pH was recorded using a portable Orion Star A221 pH meter (Thermo Scientific, Beverly, MA) and KNIpHE

Image 1: Application of PEMF treatment to a beef carcass

probe (model 9121 APWP; Orion, Thermo Scientific). The pH probe was inserted in two locations on each subprimal, and the average pH was used for statistical analysis. Strip loins were fabricated into 1-inch steaks. In addition to the steak removed at 1-day postmortem, additional steaks were randomly assigned to 3-, 7-, or 14-day aging periods, with two steaks assigned to each aging period. One strip loin steak from each aging period was assigned for evaluation of Warner-Bratzler shear force and cook loss and one steak was assigned for evaluation of postmortem proteolysis using Western blotting techniques. Eye of round steaks were fabricated into 1-inch steaks and assigned to one of three aging periods (3-, 7-, or 14-days) for evaluation of Warner-Bratzler shear force and cook loss. The steaks from each aging period were vacuum packaged and aged at 32°F the frozen on their respective aging day.

Warner-Bratzler Shear Force & Cook Loss: Warner-Bratzler shear force and cook loss were evaluated on one steak from each subprimal x aging period combination following the procedures outlined by the American Meat Science Association (AMSA, 2015). Percentage of cook loss was determined by weighing steaks before and after cooking. Steaks were thawed for 24 h at 32°F before cooking. Following thawing, steaks were cooked using a flat top grill to an internal temperature of 104°F then flipped and continued cooking until reaching an internal temperature of 160°F. Internal temperature was monitored using thermocouples (model 39658-K; Atkins Technical, Gainesville, FL). Following cooking, steaks were cooled to 39°F and then brought to room temperature for coring. Six cores were collected from each steak and sheared perpendicular to muscle fiber orientation using a texture analyzer (Shimadzu, model EZ SX; Suzhou Instruments Manufacturing, Co., LTD, Jiangsu, China). Peak force was recorded and averaged across all six cores for statistical analysis.

Western Blotting: A strip loin steak from each subprimal x aging period combination was used for Western blotting to evaluate desmin degradation and calpain autolysis. This analysis allowed for comparison of tenderization rates between control and PEMF treated samples. Frozen steaks were powdered in stainless steel blender cups using a commercial blender (model 51BL32; Waring, Torrington, CT) until the sample was uniformly powdered. Protein concentrations were determined using the methods outlined by Melody et al. (2004). Briefly, powdered samples were homogenized in a whole muscle buffer [2% sodium dodecyl sulfate (SDS), 10 mM sodium phosphate; WMB] and centrifuged. Protein samples were diluted to similar concentrations and frozen (14°F) until separation using gel electrophoresis. An 8% and 15% polyacrylamide separating gel was used for determination of calpain autolysis and desmin degradation, respectively. Blots were incubated with primary antibody overnight at 39°F [anti-Mu-Calpain (Thermo Fisher Scientific) for calpain and rabbit anti-desmin (purified in the Lonergan lab, Iowa State University) for desmin, respectively]. Secondary antibody was then applied to each membrane [calpain: goat anti-mouse horseradish peroxidase (Thermo Fisher Scientific) and desmin: goat anti-rabbit horseradish peroxidase (Thermo Fisher Scientific)]. Images were obtained via chemiluminescence using a FluorChem M multifluor imaging system (Protein Simple, San Jose, CA) and analyzed using AlphaView programming (v 3.4.0.0; Protein Simple).

Statistical Analyses: Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc, Cary, NC). Carcass characteristics, pH, and instrumental color were analyzed using fixed effects of treatment. Western blot analysis, shear force, and cook loss data were analyzed as repeated measures using the compound symmetry covariance structure of SAS with aging day, treatment, and their interactions as fixed effects. Peak internal temperature was used as a covariate for shear force and cook loss analyses. Gel was considered a random effect for western blot analyses.

Significance was declared at $p < 0.05$. The treatment × aging day interaction was evaluated where appropriate and was reported when significant.

Results

Color and Ultimate pH: There was no effect ($P > 0.05$) of PEMF treatment on instrumental color (*L*, a*, b**) on carcass sides at 1 d postmortem. Mean values for *L*, a*,* and *b** for the treatment and control sides are presented in Figure 1. Previous research in electrical stimulation of beef carcasses has reported that steaks from electrically stimulated beef carcass are lighter, more red, and more yellow in color than steaks from control sides due to increased oxygen permeability of the meat as a result of the weakened muscle structure caused by intense contractions that occurred during stimulation (Bakker et al., 2021). The muscle contraction that is caused by PEMF treatment occurs in pulses and is not as violent as the contractions observed in electrical stimulation. Therefore, the pulsatile actions of PEMF may not have been intense enough to elicit such a response in the PEMF treated sides. Additionally, there was no effect of PEMF treatment on ultimate pH of beef strip loins or eye or rounds ($P > 0.05$), and pH of both cuts was within the expected range for normal meat pH (Aberle et al., 2012). The mean pH was 5.55 and 5.53 (SEM = 0.016) for the treatment and control strip loins, respectively, and the mean pH for both the treatment and control eye of rounds was 5.48 (SEM = 0.012).

Shear Force & Cook Loss: There was no interaction ($P > 0.05$) between PEMF treatment and postmortem aging day. There was also no treatment effect ($P > 0.05$) for objective tenderness values for strip loin or eye or round steaks. The mean WBSF value for treatment and control strip loin steaks were 6.90 lbs vs 7.14 lbs, respectively, which both fall under the threshold to be classified as "tender," according to the 2022 National Beef Tenderness Survey (Gonzalez et al., 2024). The mean WBSF values for both the treatment and control eye of round steaks was 9.44 lbs, classifying both cuts to fall under the "intermediate" classification of tenderness (Gonzalez et al, 2024). Postmortem aging influenced ($P < 0.001$) tenderness for both the strip loin and the eye of round steaks (Figure 2). Strip loin steaks aged 1 d were less tender than steaks aged for 3 d (8.56 lbs vs. 7.14 lbs for strip loins, respectively). Additionally, steaks aged for 3 d were less tender than steaks aged for 7 d (7.14 lbs vs. 6.20 lbs for strip loins and 10.76 lbs vs 9.31 lbs for eye of rounds, respectively). Strip loin steaks aged for 14 d did not differ from steaks aged for 7 d (6.13 lbs vs 6.20 lbs, respectively). However, eye of round steaks aged for 14 d were more tender than steaks aged for 7 d (8.25 lbs vs 9.33 lbs, respectively). This data indicates that eye of round steaks may benefit from being aged for longer periods of time, whereas strip loin steaks gained no additional benefit after 7 days of aging.

There was no interaction ($P > 0.05$) between treatment and aging day for cook loss of steaks for either muscle. There was no effect of PEMF treatment on percent cook loss of strip loin or eye of round steaks ($P > 0.05$). Mean cook loss for strip loin steaks that received PEMF treatment and control steaks were 19.77% and 19.88%, respectively (SEM = 0.496). Mean cook loss for eye of round steaks that received PEMF treatment and control steaks were 32.59% and 32.89%, respectively (SEM = 0.494). There was no effect ($P > 0.05$) of aging day on cook loss of strip loin or eye of round steaks.

Postmortem Proteolysis: There was no interaction ($P > 0.05$) between PEMF treatment and postmortem aging day for desmin degradation or calpain autolysis of strip loin samples. The ratio of intact desmin and percent calpain are presented in Table 1. A lower ratio indicates more degradation of intact desmin has occurred and there was no difference ($P > 0.05$) in the ratio of

intact desmin between the PEMF treatment and control strip loin steaks. Postmortem aging influenced ($P < 0.001$) desmin degradation and calpain autolysis (Table 2). Treatment of PEMF application did not influence ($P > 0.05$) calpain autolysis.

Implications

The application of PEMF to beef carcasses early postmortem did not influence lean color, ultimate pH, tenderness, percent cook loss, or proteolysis of strip loin or eye of round steaks. The level of PEMF therapy applied in the present study did not elicit changes in muscle metabolism to an extent great enough to impact beef quality. However, this technology has been proven effective at increasing muscle metabolism of animals when applied antemortem. Therefore, future research could evaluate the efficacy of antemortem application of PEMF therapy on postmortem muscle metabolism or the application of higher levels of PEMF therapy to pre-rigor muscle.

Project Deliverables

This project served as an undergraduate research experience for two undergraduate students (Haley Mouser and Charlee Peterson). It also served as a graduate project for Sydni Borders who was the Ph.D. student that mentored the undergraduates and managed the project. The project outcomes were presented in a scientific abstract and poster at the 2025 Reciprocal Meats Conference in Columbus, OH. One manuscript is in preparation for submission to a scientific journal and will be submitted within one year of the completion of the project. The manuscript will be shared with the Iowa Beef Industry Council no less than 20 days prior to submission and the Iowa Beef Council will be credited for providing funding. Outcomes will also be reported through an Extension article and through the 2026 SDSU Animal Science Research and Extension Report.

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Figures & Tables:

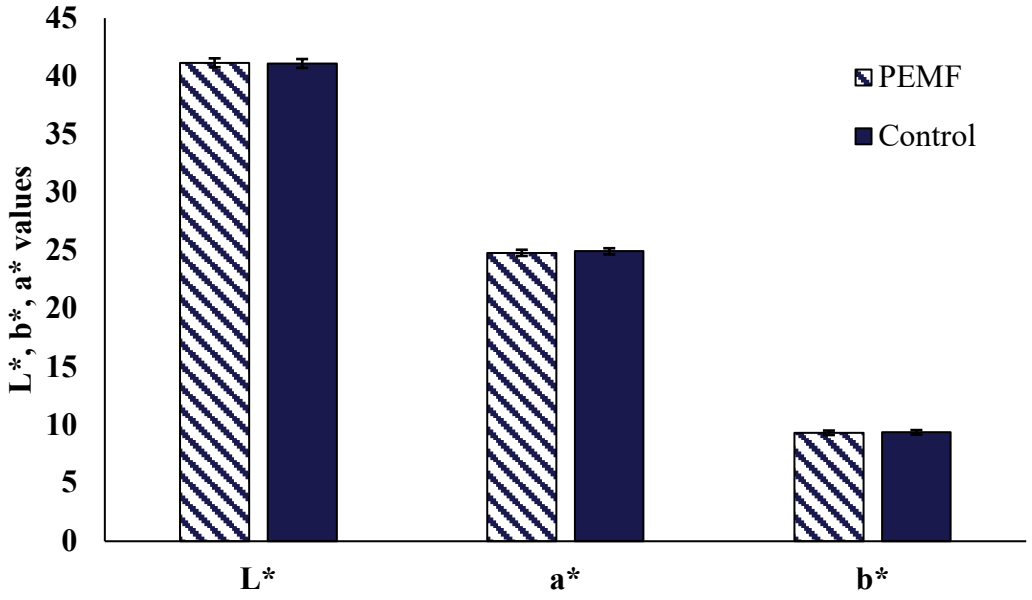

Figure 1: Least square means for the effect of PEMF treatment on *L**, *a**, and *b** values of beef *m. longissimus thoracis*.

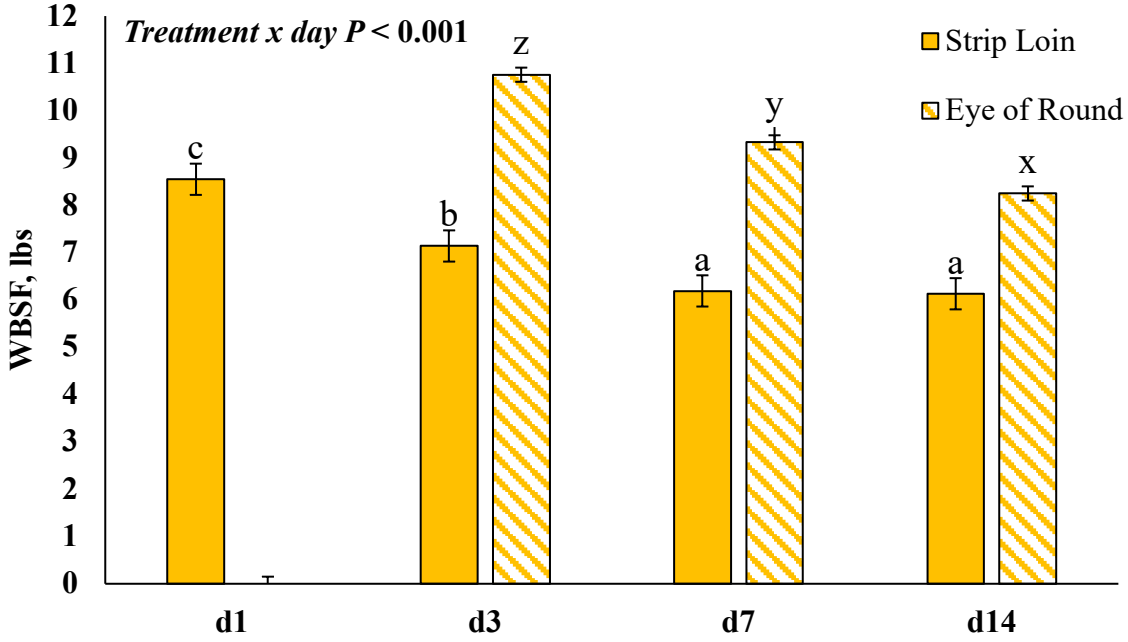

Figure 2: Least square means for the effect of aging day on Warner-Bratzler shear force (WBSF) values for strip loin and eye of round steaks.
[a,b,c,x,y,z]Means lacking common superscripts differ within muscle ($P < 0.05$)

Table 1. Mean values of the ratio[1] of intact desmin and percent calpain autolysis in strip loin steaks

	PEMF	Control	SEM[2]	*P*-Value
Desmin	1.06	1.04	0.029	0.459
Calpain[3], %				
80 kDa	15.16	14.47	0.866	0.351
78 kDa	33.11	33.40	0.838	0.711
76 kDa	51.84	52.14	1.534	0.808

[1]A lower ratio indicates more proteolysis of intact desmin
[2]Standard error of the mean
[3]Percent calpain autolysis; 80kDa = not active, 78kDa = active, 76 kDa = previously active

Table 2. Ratio[1] of intact desmin and percent calpain autolysis in strip loin steaks

	Aging Day					
	1	3	7	14	SEM[2]	*P*-Value
Desmin	1.18[d]	1.08[c]	1.02[b]	0.94[a]	0.038	<0.0001
Calpain[3], %						
80 kDa	19.78[c]	13.91[b]	10.76[a]	nd[4]	0.953	<0.0001
78 kDa	37.78[c]	33.19[b]	28.79[a]	nd	0.933	<0.0001
76 kDa	42.57[a]	52.85[b]	60.54[c]	nd	1.963	<0.0001

[1]A lower ratio indicates more proteolysis of intact desmin
[2]Standard error of the mean
[3]Percent calpain autolysis; 80kDa = not active, 78kDa = active, 76 kDa = previously active
[4]nd = not determined
[a,b]Values within a row with different superscripts differ ($P < 0.05$)