

EXECUTIVE SUMMARY



# Pre-Harvest Factors Affecting Beef Tenderness in Heifers



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# PRE-HARVEST FACTORS AFFECTING BEEF TENDERNESS IN HEIFERS

## EXECUTIVE SUMMARY



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National Cattlemen's Beef Association*

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## INTRODUCTION

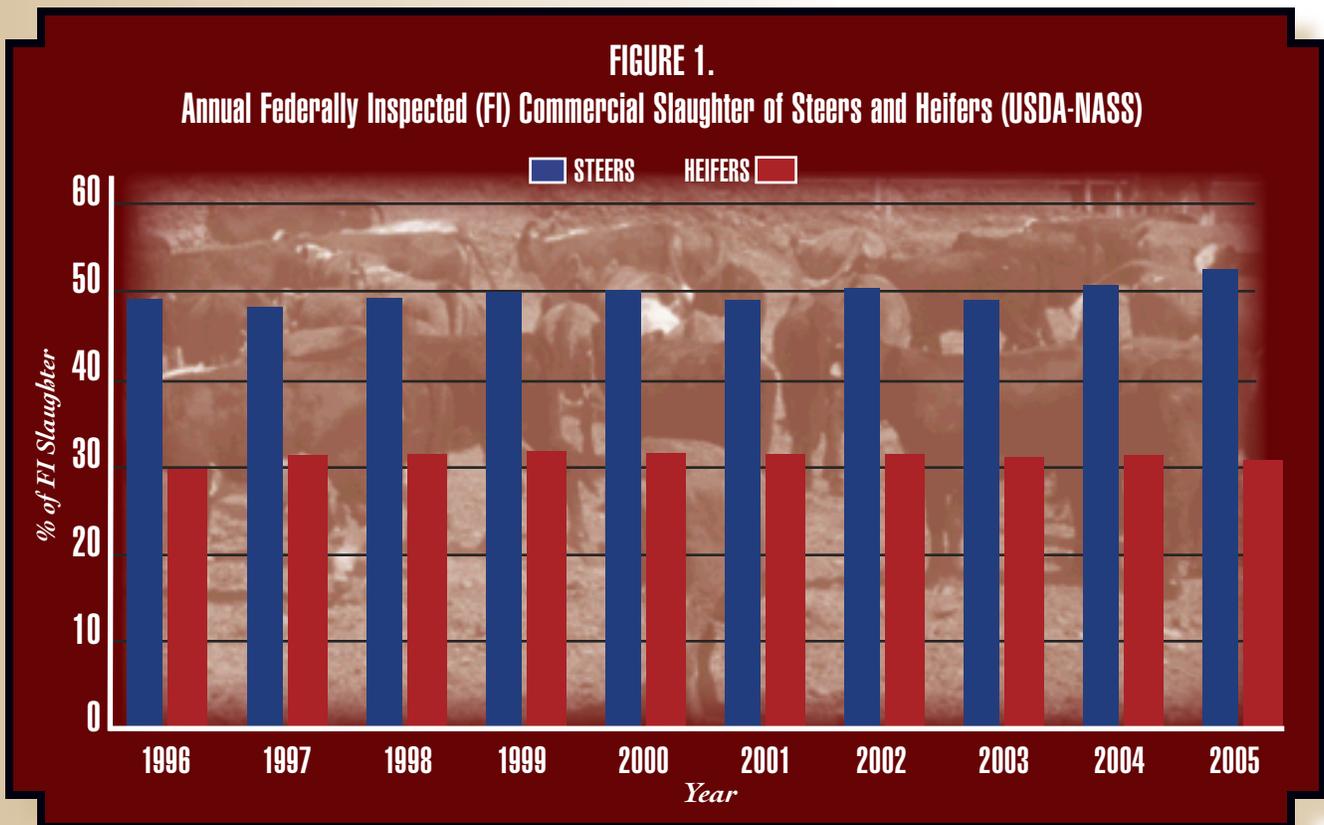
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Although the list of various factors that influence food purchase decisions continues to grow, “taste” remains the primary reason that many consumers make beef their food of choice for a pleasurable dining experience. Experimental market research has shown that beef consumers equate eating quality (tenderness, flavor, juiciness) with value and that superior eating quality not only increases the likelihood that consumers will purchase beef, but also increases the prices they are willing to pay to obtain the level of eating satisfaction they desire.<sup>1-4</sup> Consequently, producing beef that consistently delivers a satisfactory eating experience builds consumer demand and adds value to cattle.



When consumers are asked which beef sensory attribute (tenderness, flavor, or juiciness) is most important in their individual assessments of overall eating satisfaction, most identify tenderness as the primary consideration.<sup>5,6</sup> Beef tenderness is a complex trait that is influenced by a variety of factors, many of which can be managed systematically to reduce the incidence of tenderness problems in the final product.<sup>7,8</sup> Pre-harvest factors that affect beef tenderness include those that are inherent to the animals themselves (e.g., genotype, sex, age, temperament) and those that are associated with cattle production practices (e.g., diet, time-on-feed, use of growth enhancement technologies, handling/stress, health). Effective pre-harvest management of beef tenderness combines strategies to reduce inherent variation in tenderness with application of best management practices to minimize tenderness variation stemming from differences in cattle production methods.<sup>8</sup>

One source of inherent tenderness variation, often overlooked in the design of beef tenderness management systems, is sex classification (heifer vs. steer). Youthful, grain-fed steers and heifers represent approximately 80% of the cattle processed annually in federally inspected (FI) U.S. beef plants. Steers comprise about one-half of total FI slaughter, whereas heifers represent approximately 30% of the annual slaughter mix (Figure 1).<sup>9</sup> Despite the fact that heifers typically produce carcasses with higher marbling scores and more desirable USDA quality grades,<sup>10</sup> product tenderness usually favors steers.<sup>11</sup> This document highlights existing information concerning tenderness differences between youthful, grain-finished heifers and steers and outlines strategies for reducing sex-related effects on product tenderness.



## BEEF TENDERNESS COMPARISONS: HEIFERS VS. STEERS



A surprisingly limited number of studies have compared tenderness of beef produced by heifers vs. steers. Results from ten experiments, conducted between 1985 and 2006, that compared longissimus Warner-Bratzler shear force (WBSF) measurements for heifers (n = 1870) and steers (n = 3054), are summarized in Table 1. A few studies published before 1985 were excluded from this summary, either due to small sample sizes (< 20 animals per sex class) or because measures of variation were not reported, which prevented further analysis. In the ten experiments summarized in Table 1, mean differences in WBSF between heifers and steers (Mean WBSF<sub>heifer</sub> – Mean WBSF<sub>steer</sub>) ranged from -0.50 kg to 0.84 kg. In 8 of the 10 comparisons, WBSF was significantly higher for heifers than for steers (indicating that heifers produced tougher longissimus steaks). In the remaining two comparisons, the difference in

WBSF between the two sexes was not statistically significant (Table 1). The standardized mean sex effect on longissimus WBSF, computed across all ten studies, was 0.25 kg (Table 1).

Data summarized in Table 1 suggest that, on-average, heifers produce longissimus steaks that are slightly tougher than those produced by steers. Additionally, heifers have been shown to produce beef that is more variable in tenderness and more likely to be unacceptably tough than beef produced by steers.<sup>12</sup> Voisinet et al. (1997), in a study comparing meat quality characteristics of *Bos indicus* crossbred steers and heifers, reported that heifers produced a significantly higher frequency of tough steaks compared with their steer contemporaries (Figure 2).<sup>13</sup> Similar findings have been reported in experiments involving *Bos taurus* populations.<sup>12, 14</sup>

**TABLE 1.**  
Summary of Research Studies<sup>a</sup> Comparing Mean Values for Warner-Bratzler Shear Force (WBSF) of Longissimus Samples from Heifers vs. Steers

Study	Aging period, d	HEIFERS		STEERS		Mean WBSF difference <sup>b</sup> , kg
		No. of animals	WBSF, kg	No. of animals	WBSF, kg	
Greathouse (1985) <sup>15</sup>	11	42	4.00	42	4.50	-0.50
Jeremiah et al. (1991) <sup>14</sup>	6	978	6.21 <sup>c</sup>	1985	5.68 <sup>c</sup>	0.53*
Huffhines et al. (1993) <sup>16</sup>	18	198	2.95	200	2.74	0.21*
Wulf et al. (1996) <sup>17</sup>	14	170	3.14	222	2.91	0.23*
O'Connor et al. (1997) <sup>18</sup>	14	125	3.00	138	2.78	0.22*
Busby et al. (2001) <sup>19</sup>	14	88	6.95	151	6.63	0.32*
Maher et al. (2004) <sup>12</sup>	14	81	5.38	81	4.54	0.84*
Choat et al. (2006) <sup>11</sup> – Exp I	14	51	3.62	96	3.31	0.31*
Choat et al. (2006) <sup>11</sup> – Exp II	14	60	3.36	60	3.11	0.25*
Gruber et al. (2006) <sup>20</sup>	14	77	3.50	79	3.56	-0.06
<b>STANDARDIZED MEAN SEX EFFECT<sup>d</sup></b>						<b>0.25</b>

<sup>a</sup>Published studies with fewer than 20 animals representing each sex class and those that did not report measures of variation were excluded.

<sup>b</sup>Mean WBSF difference = (Mean WBSF<sub>heifer</sub> – Mean WBSF<sub>steer</sub>).

<sup>c</sup>WBSF measurements obtained using 2.5 cm cores. All other studies used 1.3 cm cores.

<sup>d</sup>Calculated using methodology described by Lipsey and Wilson (2001).<sup>21</sup>

\*Denotes statistical significance (P < 0.05) between heifers and steers.

**FIGURE 2.**  
**Sex Effect on Incidence of Tough Steaks (Source: Voisinet et al., 1997)**

*a,b Means lacking a common superscript letter differ.*



## WHY DOES TENDERNESS DIFFER BETWEEN HEIFERS AND STEERS?



Existing information provides only a partial understanding of the difference in tenderness often observed between heifers and steers. Several different factors have been identified that are believed to be associated with sex effects on tenderness, including: 1) Differences in calpastatin activity and associated effects on early postmortem tenderization, 2) Differences in temperament and reaction to pre-harvest stress, and 3) Hormonal effects, including those associated with endogenous hormone levels, as well as those associated with use of hormonal implants to enhance growth.

### *1. Calpastatin and Early Postmortem Tenderization*

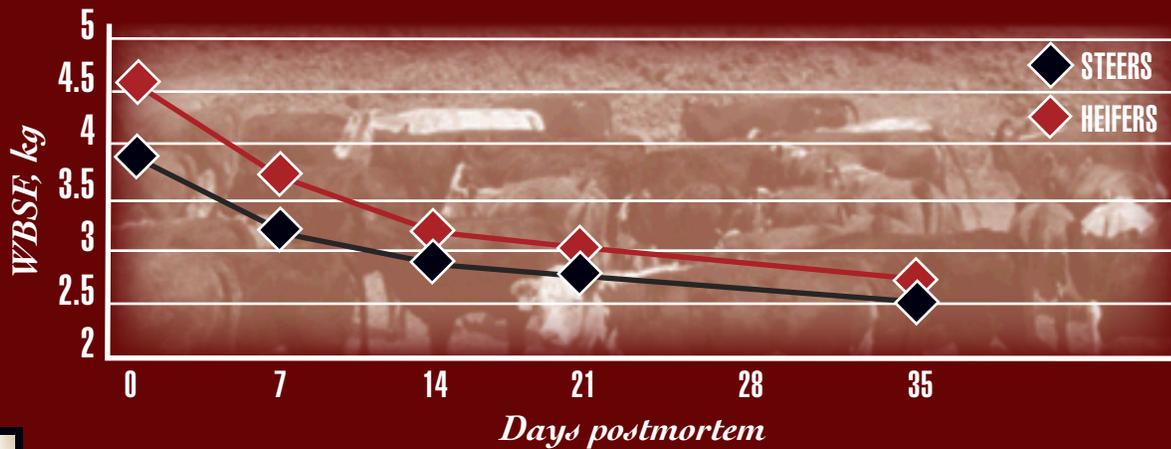
Fresh beef naturally tenderizes during post-mortem storage at refrigerated temperatures. This natural tenderization process, commonly referred to as “aging,” is caused by the degradation of specific structural proteins in muscle fibers by enzymes (proteinases) that reside in skeletal muscle tissue. The specific enzyme responsible for most of the protein degradation

that occurs in bovine muscle during the early postmortem period is  $\mu$ -calpain.<sup>22</sup> Degradation of proteins by  $\mu$ -calpain is regulated by a specific enzyme inhibitor called calpastatin. When calpastatin’s inhibitory activity is low,  $\mu$ -calpain actively degrades key protein structures within the muscle cells, causing the muscle to lose structural integrity and tenderize as it ages. Conversely, when calpastatin activity is high, degradation of structural proteins by  $\mu$ -calpain is limited, which reduces the extent of tenderization that occurs during the early postmortem aging period.

Wulf et al. (1996) and O’Connor et al. (1997) found that longissimus tissue from heifers had a higher 24-hour calpastatin activity than did longissimus muscle tissue from steers.<sup>17</sup> As a result, longissimus steaks from heifers were tougher than steaks from steers, particularly during the early postmortem aging period (Figure 3).<sup>17</sup> Similarly, Choat et al. (2006) reported data showing that differences in longissimus WBSF between heifers and steers, which were statistically significant at 7 and 14

FIGURE 3.

Sex Effect on Postmortem Aging Response of the Longissimus (Source: Wulf et al., 1996)



days postmortem, diminished when the aging period was extended to 21 days.<sup>11</sup> These findings suggest that beef produced by heifers tenderizes more slowly than beef from steers and, therefore, requires a longer postmortem aging period to attain a comparable level of tenderness.

**2. Temperament and Reaction to Pre-Harvest Stress**

Heifers and steers differ in temperament and,

therefore, react differently to pre-slaughter stress.<sup>20</sup> Voisinet et al. (1997) attributed the difference in temperament between heifers and steers to the more excitable behavior of the nulliparous female, which has been documented in various species and is believed to be induced by estrogen secretion.<sup>13, 23</sup> In that study, heifers not only were more temperamental than steers, but also produced a greater number of carcasses with slightly dark lean color compared with steers (Figure 4).<sup>13</sup>

FIGURE 4.

Sex Effect on Incidence of Dark Lean Color (Source: Voisinet et al., 1997)

<sup>a,b</sup>Means lacking a common superscript letter differ.





Wulf et al. (1997) also found that heifers were more temperamental than steers and presented data showing that cattle temperament score was significantly correlated with several longissimus muscle characteristics including muscle color, calpastatin activity, WBSF, and sensory panel ratings for tenderness and flavor.<sup>24</sup> In that study, cattle with more excitable temperaments had higher final muscle pH measurements, darker muscle color, higher calpastatin activities, higher shear force values, and lower sensory panel ratings for tenderness and flavor compared with cattle having calmer temperaments.<sup>24</sup>

Cattle subjected to pre-harvest stress often produce carcasses with higher-than-normal muscle pH and darker-than-normal lean color (commonly referred to as “dark cutters”). The degree of the dark cutting condition is dependent upon final pH of the carcass

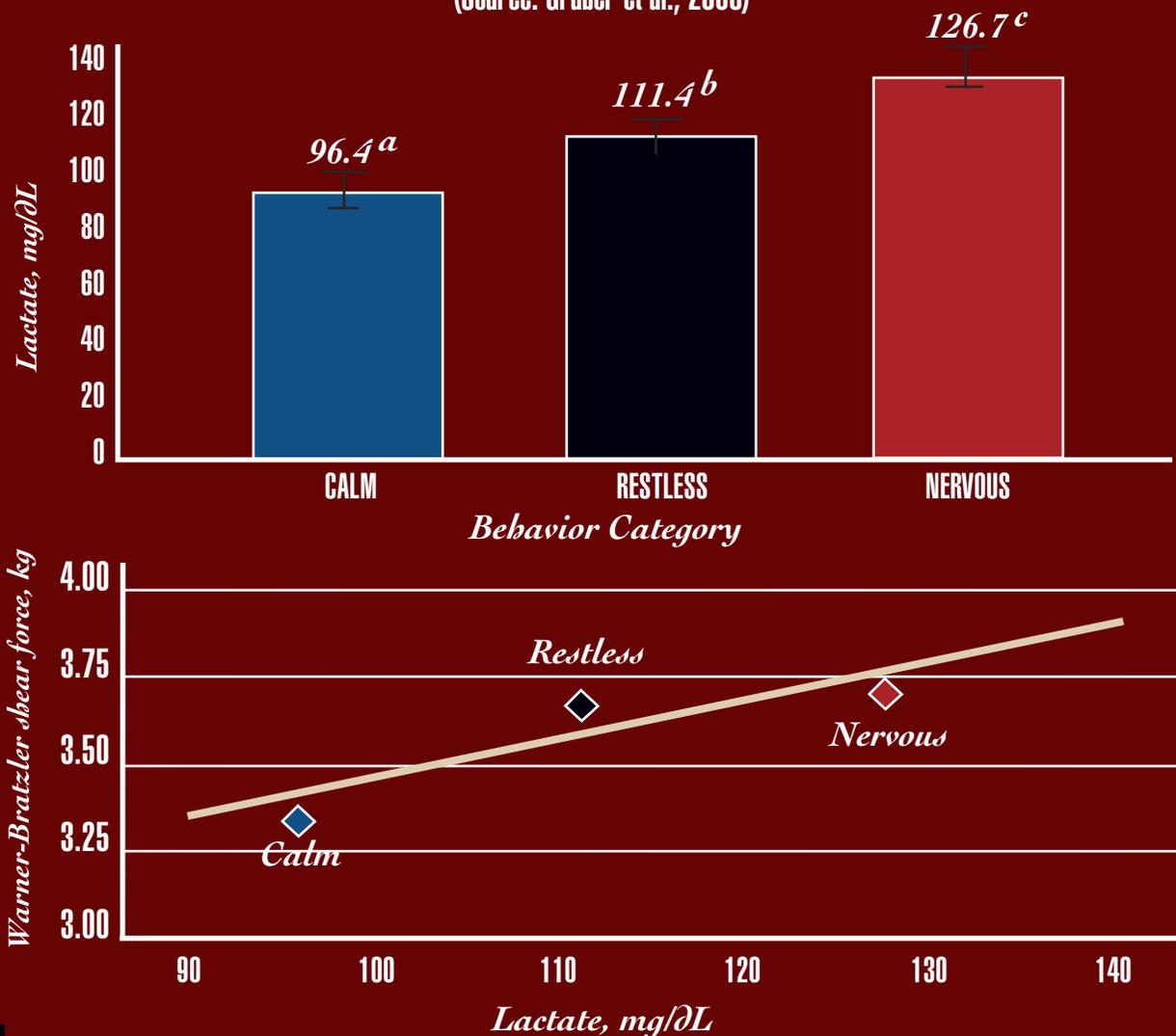
musculature. Final muscle pH within a range of 5.4 to 5.7 is considered normal for beef. As muscle pH increases above 5.7, lean color becomes progressively darker. Beef carcasses with slightly higher-than-normal final muscle pH values, ranging from 5.8 to 6.2, exhibit a lean color that is only slightly dark; however, research has shown that muscle pH values within this range are associated with a comparatively high frequency of meat toughness problems.<sup>24-26</sup> Watanabe et al. (1996) documented a relationship between final muscle pH and the rate of postmortem meat tenderization and determined that the slowest aging rate occurred in muscle with a final pH of approximately 6.0.<sup>25</sup>

Recent research suggests that avoiding stress immediately prior to harvest is important for assuring acceptable beef tenderness, even if muscle pH remains unaffected.<sup>20</sup>

Gruber et al. (2006) monitored groups of cattle for behavior and several physiological stress indicators as each group was transported to a commercial beef packing facility for harvest. In that study, differences in post-transportation behavior of cattle were associated with pronounced differences in blood lactate concentration (measured at harvest). Moreover, these differences in post-transportation behavior and blood lactate levels (reflecting differences in reaction to acute transport stress) were associated with differences in longissimus WBSF, even though final longissimus pH values were less than 5.8.<sup>20</sup> Cattle exhibiting calm behavior

immediately following transport had the lowest blood lactate levels, and also produced the most tender beef, whereas animals exhibiting more agitated behavior (nervous or restless), immediately following transport, had higher blood lactate levels and produced less tender beef (Figure 5). These findings underscore the importance of gentle handling of slaughter cattle during transport and immediately before harvest for assurance of final product quality. Because of their excitability, it is especially important to exercise careful handling practices when transporting heifers.

**FIGURE 5.**  
Relationships Among Post-Transportation Behavior, Plasma Lactate Concentration at Harvest, and Longissimus Shear Force  
(Source: Gruber et al., 2006)



### 3. Hormonal Effects

#### ENDOGENOUS HORMONES

Information concerning hormonal effects on beef tenderness is limited; however, existing evidence suggests that higher circulating estrogen levels of heifers may contribute to their tendency to produce beef that is tougher than beef produced by steers. Choat et al. (2006), using non-implanted cattle, compared longissimus WBSF values (measured after 7 days of postmortem aging) for steers, intact heifers, and spayed heifers (Figure 6). Compared with steers, intact heifers had significantly higher longissimus WBSF values; however, spaying, which reduces serum estrogen concentrations,<sup>27</sup> produced heifers whose longissimus WBSF values were similar to those for steers (Figure 6).<sup>11</sup>

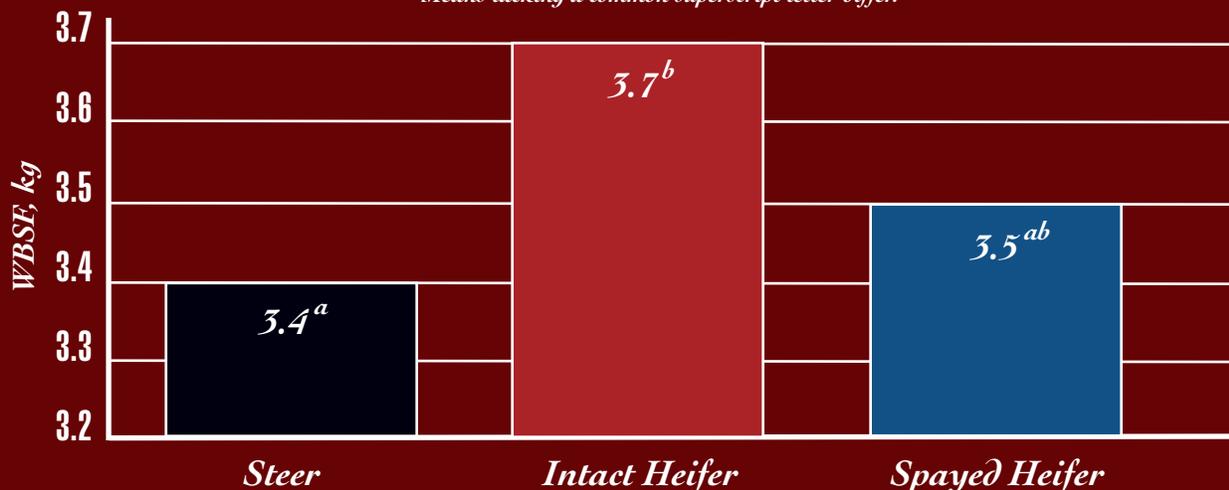
Jeffery et al. (1997) compared intact heifers with surgically spayed heifers and reported significantly lower longissimus WBSF values for spayed heifers.<sup>28</sup> Other reports, however, suggest that spaying has little effect on beef tenderness.<sup>27, 29</sup> While spaying prevents estrus and pregnancy and mitigates estrogen-induced behavioral issues, it is not always cost-effective.<sup>30</sup>

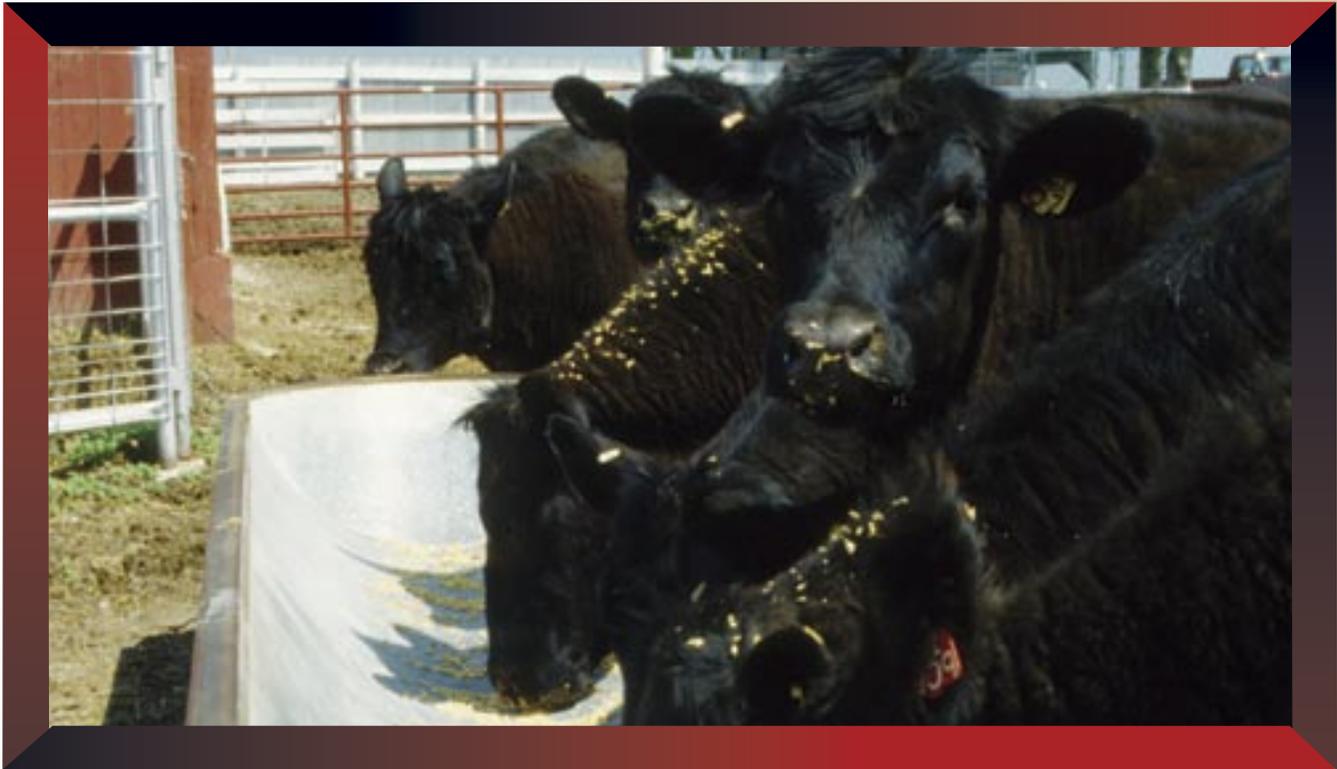
#### INCLUDING MGA IN FINISHING DIETS FOR HEIFERS

A widely used approach for suppressing estrus and reducing estrogen-induced behavioral problems among finishing heifers is dietary supplementation with melengestrol acetate. Melengestrol acetate (MGA) is an orally active progestin that, when included in the diets of heifers: prevents cycling;<sup>30</sup> counteracts estrogen-induced hyperactivity, resulting in calmer behavior;<sup>25</sup> and improves growth performance.<sup>19</sup> Research suggests that feeding MGA is not detrimental to beef tenderness. Nichols et al. (1996) found that inclusion of MGA in diets of feedlot heifers had no effect on longissimus tenderness,<sup>31</sup> whereas Busby et al. (2001) reported that feeding MGA resulted in a slight improvement in tenderness.<sup>19</sup> In the U.S., MGA has no withdrawal requirement. To avoid beef quality problems, heifers should not be removed from MGA-supplemented diets for periods longer than 24 hours prior to harvest. Heifers receiving diets that include MGA normally show signs of estrus within 2 to 7 days of MGA withdrawal. The stress associated with behavioral estrus, following withdrawal from MGA-supplemented diets, can result in

**FIGURE 6.**  
Comparison of 7-d Longissimus WBSF Values for Steers, Intact Heifers, and Spayed Heifers (Source: Choat et al., 2006)

*a,b Means lacking a common superscript letter differ.*





an abnormally high frequency of dark cutting carcasses and decreased product tenderness.

#### HORMONAL IMPLANTS

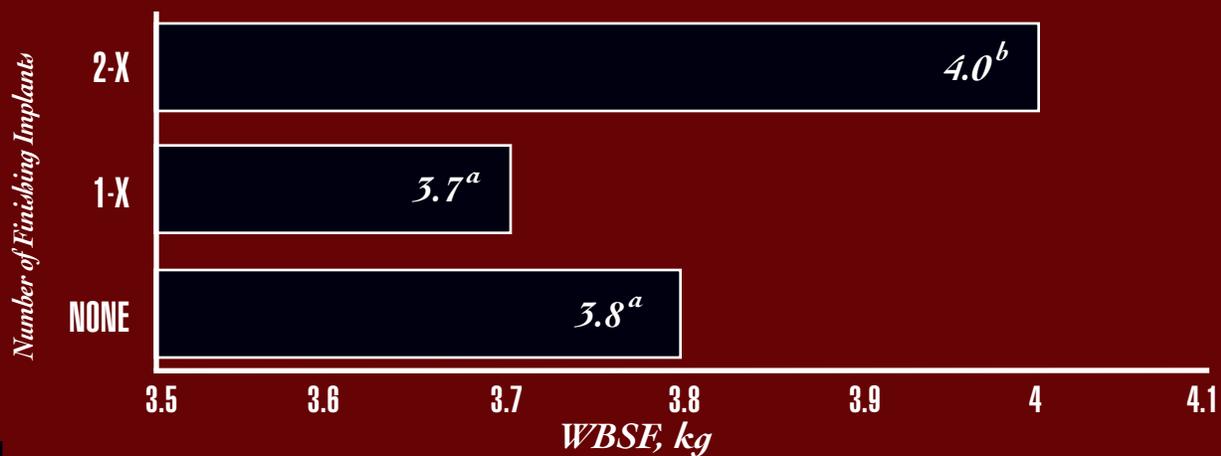
Very few studies have investigated the effects of heifer finishing implants on beef tenderness. However, recent research suggests that both number and potency of hormonal implants

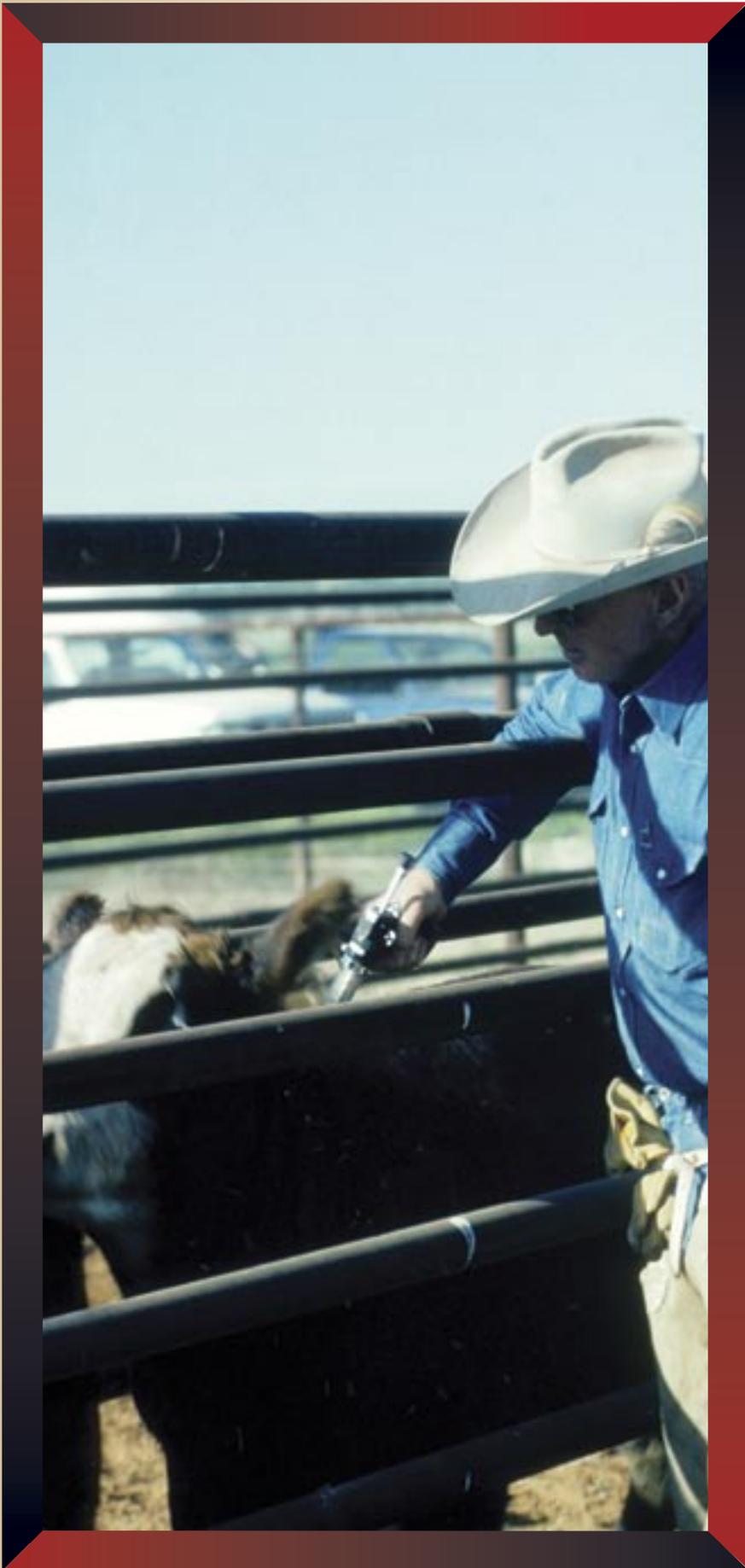
administered to heifers during the finishing period can influence tenderness of the final product.<sup>32</sup> Use of a single finishing implant for heifers seems to have little effect on tenderness; however, use of two successive finishing implants has been shown to significantly increase longissimus WBSF (Figure 7).<sup>32</sup>

**FIGURE 7.**

**Heifer Finishing Implants and 14-d Longissimus WBSF: Effect of Number of Implants (Source: Schneider et al., 2006)**

*a,b Means lacking a common superscript letter differ.*



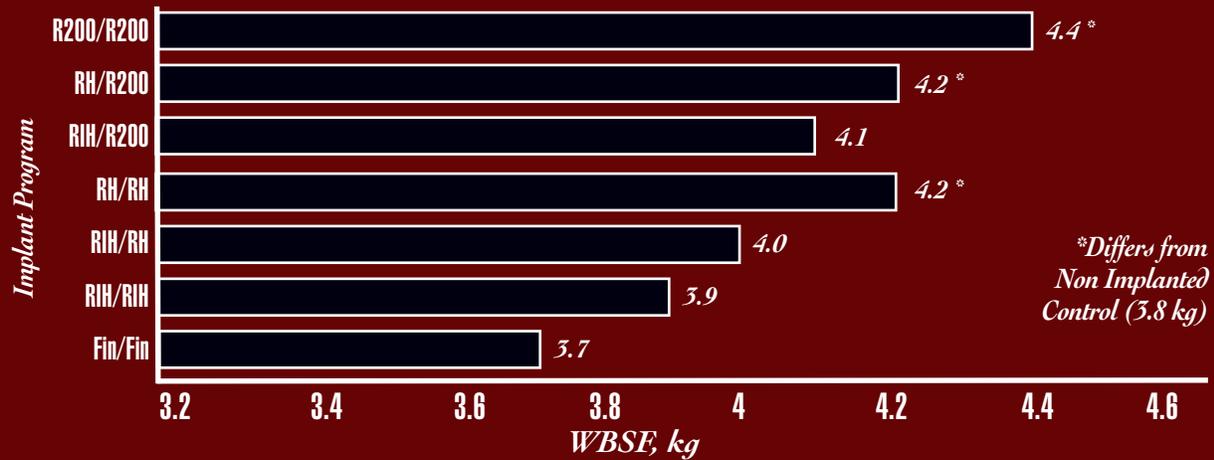


Moreover, existing evidence suggests that not all two-implant programs for finishing heifers have detrimental effects on tenderness.<sup>32</sup> Implant/re-implant programs that involve some of the more potent combination implants are the only ones that have been found to elicit negative effects on tenderness in heifers (Figure 8).

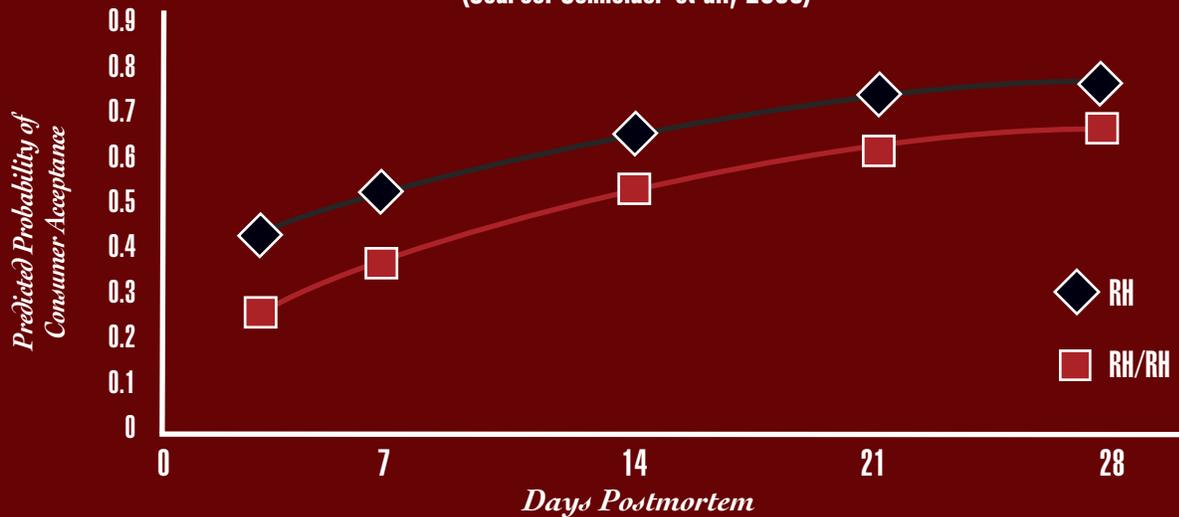
Implant effects on tenderness tend to be most pronounced for the first few days postmortem and, then, gradually diminish as length of the postmortem aging period is extended. Correspondingly, increased toughness observed among re-implanted heifers receiving relatively potent implants (Figure 8) seems to be largely mitigated by aging for 21 days or longer (Figure 9).<sup>32</sup> Implant effects on the aging response have not been fully explained; however, Gerken et al. (1995) found that steers administered implants containing either estradiol benzoate or the combination of  $E_2$  and TBA had higher longissimus calpastatin activities than did non-implanted steers or steers implanted with TBA alone.<sup>33</sup> Similarly, Schneider et al. (2006) found that longissimus samples from heifers implanted with  $E_2$  plus TBA tenderized more slowly during aging than did samples from heifers implanted with TBA alone.<sup>32</sup>

Re-implanting of heifers also has been shown to reduce marbling score,<sup>34, 35</sup> which can be detrimental to both tenderness and flavor. Heifers receiving two comparatively potent finishing implants often produce reduced numbers of carcasses grading Choice & Prime, whereas less aggressive implant programs tend to have minimal effects on quality grade performance (Figure 10).

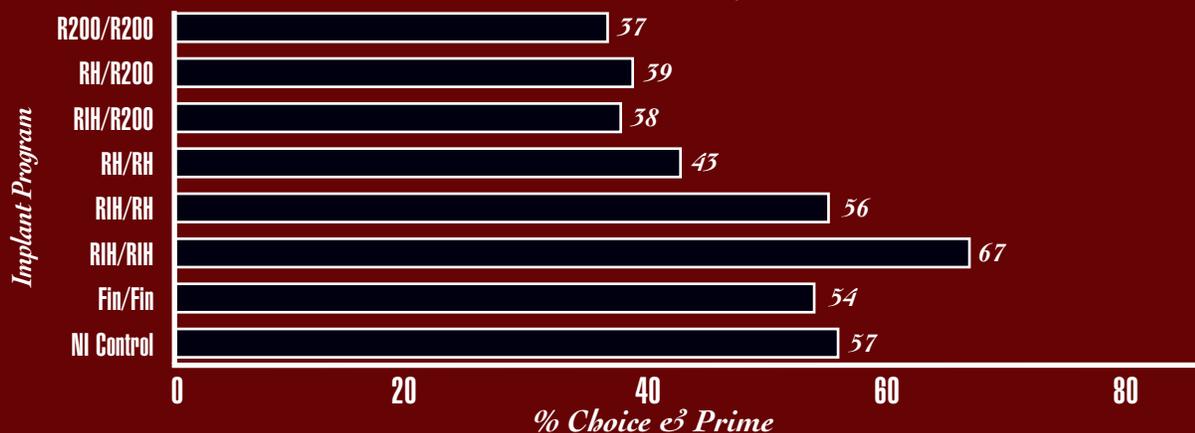
**FIGURE 8. Heifer Finishing Implants and 14-d Longissimus WBSF: Comparison of Two-Implant Programs**  
(Source: Schneider et al., 2006)



**FIGURE 9. Implants and Aging Effects On Consumer Acceptability of Strip Loin Steaks**  
(Source: Schneider et al., 2006)



**FIGURE 10. Heifer Finishing Implants and Quality Grade Performance: Comparison of Two-Implant Programs**  
(Source: Schneider et al., 2006)



Legend for Figures 8, 9, and 10: Fin – Finaplix-H (200 mg TBA), RIH – Revalor-IH (8 mg E<sub>2</sub>, 80 mg TBA), RH – Revalor-H (14 mg E<sub>2</sub>, 140 mg TBA), R200 – Revalor-200 (20 mg E<sub>2</sub>, 200 mg TBA).

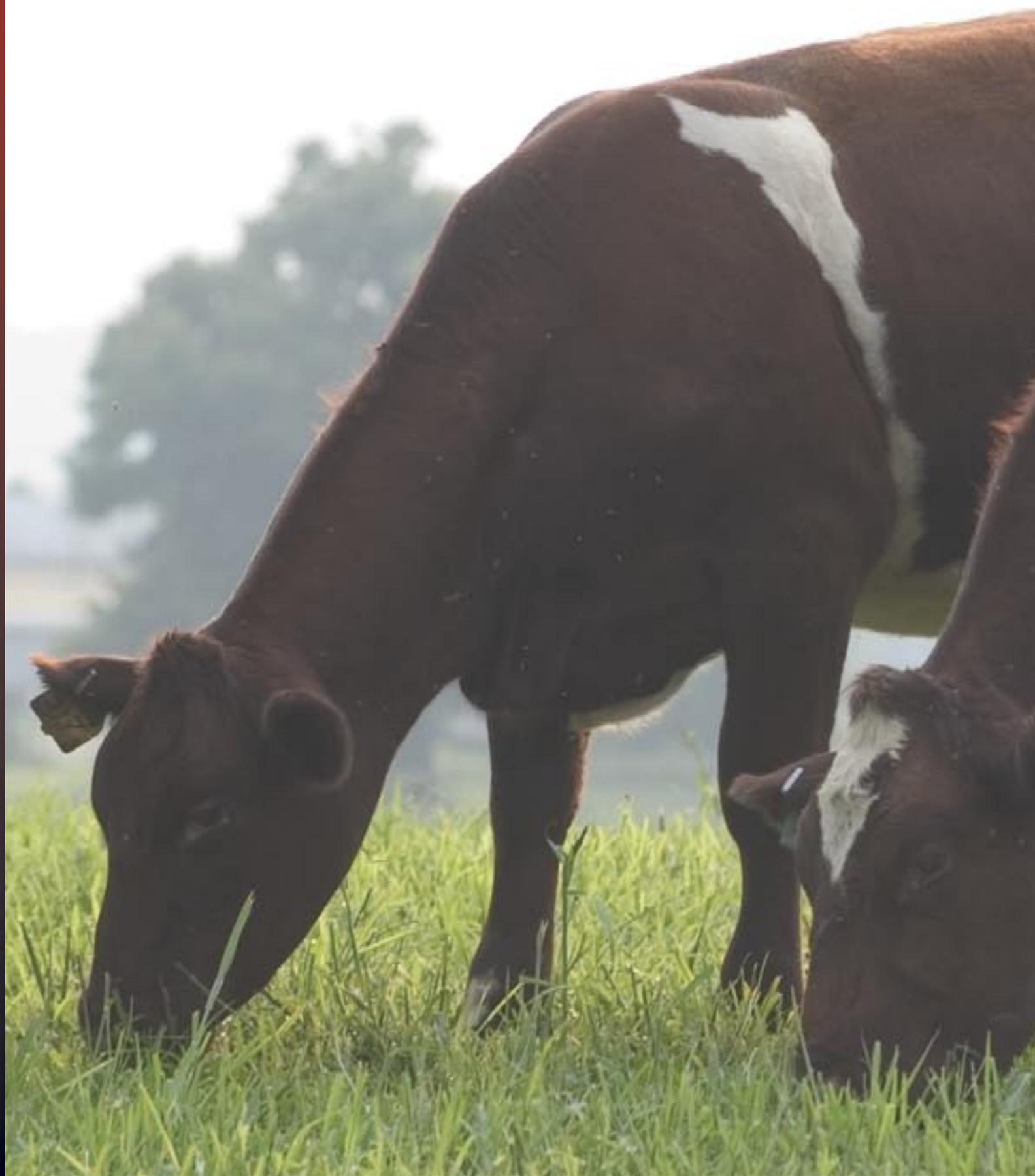
## KEY POINTS: MANAGING HEIFERS TO MINIMIZE BEEF TENDERNESS PROBLEMS



- Existing research information suggests that beef produced by heifers is more likely to be tough than beef from steers.
- Compared to steers, heifers are more excitable and, therefore are more likely to exhibit stress-related meat quality problems (dark lean color and reduced tenderness). When shipping heifers, extra precautions should be taken to avoid aggressive handling, excitement, or physical exertion before, during, or following transport to the processing plant.
- Finishing diets that include MGA can be used to suppress estrus and improve growth performance of heifers, without negatively affecting beef tenderness. However, to avoid beef quality problems, heifers should not be removed from MGA-supplemented diets for periods longer than 24 hours prior to harvest.
- The number and potency of finishing implants can influence beef tenderness and carcass quality grade. For heifers requiring two finishing implants, use of two successive high-potency implants should be avoided.
- Beef produced by heifers tenderizes more slowly during storage and requires a longer postmortem aging period than beef from steers to attain a comparable level of tenderness. Based on existing research information, postmortem aging periods of at least 21 days are recommended for heifer beef.







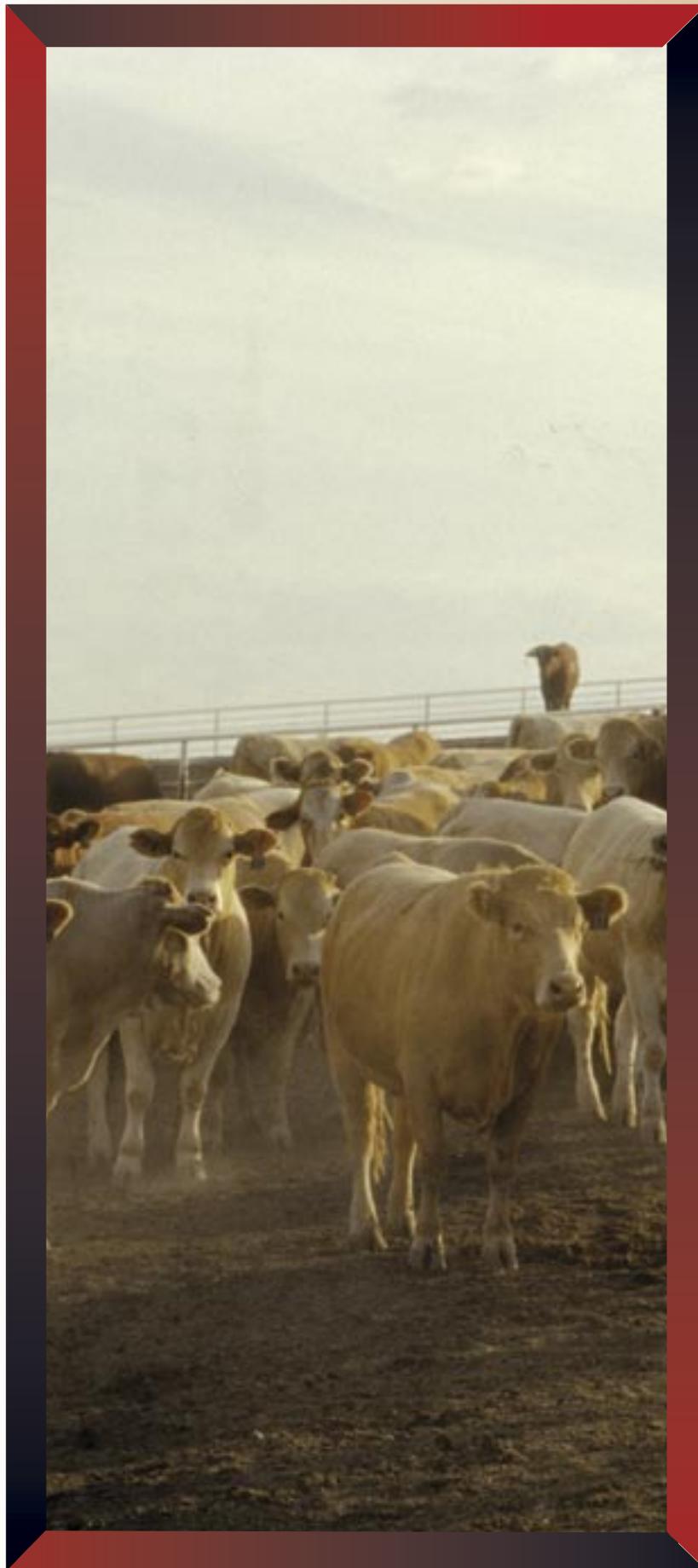
## REFERENCES



- 1 Boleman, S.J., S.L. Boleman, R.K. Miller, J.F. Taylor, H.R. Cross, T.L. Wheeler, M. Koohmaraie, S.D. Shackelford, M.F. Miller, R.L. West, D.D. Johnson, and J.W. Savell. 1997. Consumer evaluation of beef of known categories of tenderness. *J. Anim. Sci.* 75:1521-1524.
- 2 Lusk, J., J. Fox, T. Schroeder, J. Mintert, and M. Koohmaraie. 1999. Will consumers pay for guaranteed tender steak? Research Bulletin 3-99. Research Institute on Livestock Pricing. Available at: [www.aaec.vt.edu/rilp](http://www.aaec.vt.edu/rilp).
- 3 Platter, W.J., J.D. Tatum, K.E. Belk, S.R. Koontz, P.L. Chapman, and G.C. Smith. 2005. Effects of marbling and shear force on consumers' willingness-to-pay for beef strip loin steaks. *J. Anim. Sci.* 83:890-899.
- 4 Sitz, B.M., C.R. Calkins, D.M. Feuz, W.J. Umberger, and K.M. Eskridge. 2005. Consumer sensory acceptance and value of domestic, Canadian, and Australian grass-fed beef steaks. *J. Anim. Sci.* 83:2863-2868.
- 5 Huffman, K.L., M.F. Miller, L.C. Hoover, C.K. Wu, H.C. Brittin, and C.B. Ramsey. 1996. Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. *J. Anim. Sci.* 74:91-97.
- 6 Platter, W.J., J.D. Tatum, K.E. Belk, P.L. Chapman, J.A. Scanga, and G.C. Smith. 2003. Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. *J. Anim. Sci.* 81:2741-2750.
- 7 Tatum, J.D., K.E. Belk, M.H. George, and G.C. Smith. 1999. Identification of quality management practices to reduce the incidence of retail beef tenderness problems: Development and evaluation of a prototype quality system to produce tender beef. *J. Anim. Sci.* 77:2112-2118.
- 8 Tatum, J.D. 2006. Pre-harvest cattle management practices for enhancing beef tenderness, Executive Summary, pp. 1-24. National Cattlemen's Beef Association, Centennial, CO. Available at: <http://www.beefresearch.org/ExecutiveSummaries.htm>.
- 9 USDA-NASS. 2006. Livestock Slaughter. Available at: <http://www.nass.usda.gov/>.
- 10 Corah, L. and M. McCully. 2006. Declining quality grades: A review of factors reducing marbling deposition in beef cattle. White Paper distributed by Certified Angus Beef, LLC, Wooster, OH. Available at: [http://www.cabfeedlots.com/news/research/declining\\_quality\\_grades.pdf](http://www.cabfeedlots.com/news/research/declining_quality_grades.pdf).

- 11 Choat, W.T., J.A. Paterson, R.M. Rainey, M.C. King, G.C. Smith, K.E. Belk, and R.J. Lipsey. 2006. The effects of cattle sex on carcass characteristics and longissimus muscle characteristics. *J. Anim. Sci.* 84:1820-1826.
- 12 Maher, S.C., A.M. Mullen, A.P. Moloney, D.J. Buckley, and J.P. Kerry. 2004. Quantifying the extent of variation in the eating quality traits of the *M. longissimus dorsi* of conventionally processed Irish beef. *Meat Sci.* 66:351-360.
- 13 Voisinnet, B.D., T. Grandin, S.F. O'Connor, J.D. Tatum, and M.J. Deesing. 1997. *Bos indicus*-cross feedlot cattle with excitable temperaments have tougher meat and a higher incidence of borderline dark cutters. *Meat Sci.* 46:367-377.
- 14 Jeremiah, L.E., A.K.W. Tong, and L.L. Gibson. 1991. The usefulness of muscle color and pH for segregating beef carcasses into tenderness groups. *Meat Sci.* 30:97-114.
- 15 Greathouse, J.R. 1985. Effects of feeder cattle frame size, sex, and age class on performance, carcass and palatability characteristics. Ph.D. Diss. Colorado State University, Fort Collins.
- 16 Huffhines, C.P., G.C. Ledall, J.E. Cannon, J.D. Tatum, T.G. Field, M.A. Head, J.B. Morgan, and G.C. Smith. 1993. Carcass characteristics and cooked-steak palatability of straightbred Hereford steers and heifers and Hereford crossbred steers. 1993 CSU Beef Program Report, pp. 145-152. Department of Animal Sciences, Colorado State University, Fort Collins, CO.
- 17 Wulf, D.M., J.D. Tatum, R.D. Green, J.B. Morgan, B.L. Golden, and G.C. Smith. 1996. Genetic influences on beef longissimus palatability in Charolais- and Limousin-sired steers and heifers. *J. Anim. Sci.* 74:2394-2405.
- 18 O'Connor, S.F., J.D. Tatum, D.M. Wulf, R.D. Green, and G.C. Smith. 1997. Genetic effects on beef tenderness in *Bos indicus* and *Bos taurus* cattle. *J. Anim. Sci.* 75:1822-1830.
- 19 Busby, D., D. Loy, and G. Rouse. 2001. Effect of MGA on performance, sexual behavior, carcass quality, and tenderness in mixed-sex pens of cattle. A.S. Leaflet R1743, 2001 Beef Research Report, pp. 25-28, Department of Animal Science, Iowa State University, Ames, IA.
- 20 Gruber, S.L., J.D. Tatum, T. Grandin, J.A. Scanga, K.E. Belk, and G.C. Smith. 2006. Is the difference in tenderness commonly observed between heifers and steers attributable to differences in temperament and reaction to pre-harvest stress? Final Report, submitted to the National Cattlemen's Beef Association, pp. 1-38, Department of Animal Sciences, Colorado State University, Fort Collins, CO.
- 21 Lipsey, M.W. and D. Wilson. 2001. Practical meta-analysis. *Applied Social Research Methods*, Vol. 49, Sage Publications, Thousand Oaks, CA.
- 22 Koochmaraie, M. and G.H. Geesink. 2006. Contribution of postmortem muscle biochemistry to the delivery of consistent meat quality with particular focus on the calpain system. *Meat Sci.* 74:34-43.
- 23 Hossner, K.L. 2005. Hormonal regulation of farm animal growth. CABI Publishing, Cambridge, MA.
- 24 Wulf, D.M., S.F. O'Connor, J.D. Tatum, and G.C. Smith. 1997. Using objective measures of muscle color to predict beef longissimus tenderness. *J. Anim. Sci.* 75:684-692.
- 25 Watanabe, A., C.C. Daly, and C.E. Devine. 1996. The effects of ultimate pH of meat on tenderness changes during aging. *Meat Sci.* 42:67-78.
- 26 Wulf, D.M., R.S. Emmett, J.M. Leheska, and S.J. Moeller. 2002. Relationships among glycolytic potential, dark cutting (dark, firm, and dry) beef, and cooked beef palatability. *J. Anim. Sci.* 80: 1895-1903.
- 27 Vestergaard, M., S. Purup, P. Henckel, E. Tonner, D.J. Flint, L.R. Jensen, and K. Sejrsen. 1995. Effects of growth hormone and ovariectomy on performance, serum hormones, insulin-like growth factor-binding proteins, and muscle fiber properties of prepubertal Friesian heifers. *J. Anim. Sci.* 73:3574-3584.
- 28 Jeffery, M., I. Loxton, S. Van der Mark, T. James, R. Shorthose, K. Bell, and M. D'Occhio. 1997. Liveweight gains and carcass and meat characteristics of entire, surgically spayed or immunologically spayed beef heifers. *Austr. J. of Exp. Agric.* 37:719-726.
- 29 Bouton, P. E., P. V. Harris, and W. R. Shorthose. 1982. A comparison of the meat properties of pasture-fed steers, heifers, pregnant heifers and spayed heifers. *Meat Sci.* 6:301-308.

- 30 Anderson, P.T. 1991. Implant programs for finishing heifers. Beef Cattle Extension Publication, Issue 21, Univ. of Minnesota, pp 1-15.
- 31 Nichols, W.T., M.I. Wray, T.H. Montgomery, B. Schutte, J.B. Morgan, H.G. Dolezal, and D.P. Hutcheson. 1996. The effects of anabolic agents alone and in combination on feedyard performance, carcass characteristics, and meat quality of finishing heifers fed for 108, 131, or 143 days. Tech. Bull. 3. Hoechst-Roussel Agri-Vet, Co., Somerville, NJ.
- 32 Schneider, B.A., J.D. Tatum, T.E. Engle, T.C. Bryant, J.A. Scanga, K.E. Belk, and G.C. Smith. 2006. Do heifer finishing implants affect beef tenderness? Final Report, submitted to the National Cattlemen's Beef Association, pp. 1-31, Department of Animal Sciences, Colorado State University, Fort Collins, CO.
- 33 Gerken, C.L., J.D. Tatum, J.B. Morgan, and G.C. Smith. 1995. Use of genetically identical (clone) steers to determine the effects of estrogenic and androgenic implants on beef quality and palatability characteristics. J. Anim. Sci. 73:3317-3324.
- 34 Berger, L.L. and M.L. Galyean. 2000. Evaluation of various implant programs on performance and carcass merit of finishing heifers. Revalor-IH Tech. Reference 1. Intervet, Inc., Millsboro, DE.
- 35 Brandt, R.T., W.K. Rowland, E.G. Johnson, J. Johnson, G.E. Sides, J.P. Hutcheson, W.T. Nichols, and C.D. Reinhardt. 2000. Evaluation of implants containing reduced-dose combinations of trenbolone acetate and estradiol on performance and carcass merit of finishing heifers (Idaho). Revalor-IH Tech. Bull. 1. Intervet, Inc., Millsboro, DE.





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