DISSERTATION

# EFFECTS OF ANABOLIC IMPLANTS, MARBLING, AND TENDERNESS ON CONSUMER ACCEPTABILTY AND PURCHASING DECISIONS FOR BEEF

Submitted by

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In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY WILLIAM JOSEPH PLATTER ENTITLED "EFFECTS OF ANABOLIC IMPLANTS, MARBLING, AND TENDERNESS ON CONSUMER ACCEPTABILITY AND PURCHASING DECISIONS FOR BEEF" BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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## ABSTRACT OF DISSERTATION

# EFFECTS OF ANABOLIC IMPLANTS, MARBLING, AND TENDERNESS ON CONSUMER ACCEPTABILTY AND PURCHASING DECISIONS FOR BEEF


This research was designed to study the effects of repetitive use of anabolic implants on beef carcass quality, tenderness, and consumer ratings for palatability. Data from consumer sensory panels and experimental auctions conducted in this study also were used to examine the effects of marbling score and Warner-Bratzler shear force (WBSF) on consumer acceptability and purchasing decisions for beef.

Crossbred steers (n = 550) were randomly assigned to a non-implanted treatment or to one of ten lifetime implant treatments where cattle were implanted at some or all of five phases of production (branding, weaning, backgrounding, feedlot entry, or re-implant time). Non-implanted steers produced carcasses with higher ($P < 0.05$) marbling scores and steaks with lower ($P < 0.05$) WBSF values and more desirable ($P < 0.05$) consumer tenderness ratings. Implanting steers at branding, weaning, or backgrounding did not affect marbling scores, consumer ratings for like/dislike of steak tenderness, or percentage of consumers rating overall eating quality of steaks as satisfactory. Steaks

from non-implanted steers were rated as more desirable ($P < 0.05$) for overall eating quality than steaks from steers implanted two, three, four, or five times.

The predicted probability for consumer acceptance of steaks increased approximately 10% for each full marbling score increase between Slight to Slightly Abundant. The predicted probability for consumer acceptance of steaks dramatically decreased as steak WBSF value increased from 3.0 to 5.5 kg. Changes in WBSF within the high (> 5.5 kg) or low (< 3.0 kg) portions of the range of WBSF values had little effect on the predicted probability of consumer acceptance of steaks.

On average, premium Choice steaks received a $0.40/kg premium and Prime steaks received a $1.12/kg premium over the mean bid price for Select steaks. Predicted mean bid prices for steaks decreased $1.02/kg for each 1 kg increase in WBSF value.

Collectively, results of these studies suggest that anabolic implant protocols can affect beef palatability traits, such as marbling and tenderness, and differences in marbling and shear force impact the level of overall consumer acceptance and value of beef.

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# DEDICATION

This dissertation is dedicated to my parents Lowell and Lois, the most caring and influential educators in my life.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER I

## INTRODUCTION

For nearly fifty years, anabolic implants have been used by cattle producers to improve rate and efficiency of growth in beef cattle. Historically, the beef cattle industry has been a production-driven business that rewards producers for low-cost, efficient production of a commodity product. The economic benefits of enhancing production characteristics in this type of system have encouraged use of implants by producers in all segments of the beef cattle industry, from cow-calf to feedlot production systems.

During the past two decades, the beef industry has faced weakening demand for its products (Purcell, 1998). A number of factors have been cited as contributing to the decline in demand for beef, including inconsistency in product quality (Lusk et al., 2001). Concern over the steady decline in beef's market share has prompted the beef industry to become increasingly focused on improving the quality, consistency, and tenderness of its products. The National Cattlemen's Beef Association (NCBA) has encouraged the development and implementation of Total Quality Management (TQM) systems to enhance the quality and consistency of beef. This approach requires the identification of "process control steps" throughout the beef production chain, including pre-harvest management practices, that can improve the quality characteristics of beef (Tatum et al., 1999). Since 1991, the beef industry has conducted three national audits (Lorenzen et al., 1993; Boleman et al., 1998; McKenna et al., 2002) that were designed to identify aspects of the beef industry that might be managed to improve the quality, consistency, and competitiveness of beef in the marketplace. Two of these audits identified "reduced quality of beef due to implants" as one of the packing industry's top concerns about the quality of beef. Additionally, the NCBA Beef Palatability Task Force recommended eliminating "aggressive" use of anabolic implants as a means for improving beef palatability (NCBA, 1997).

In response to industry concerns over the negative impact of implants on beef palatability traits, new implant protocols have been proposed that are designed to enhance cattle performance, while limiting reductions in beef carcass quality (Intervet, 2000). However, these recommendations have been limited to implant protocols for cattle in the finishing phase of production because there is a void of information concerning the possible effects of implants administered prior to the finishing phase on beef palatability traits. Because nearly all cattle are implanted during the finishing phase and many are implanted one or more times prior to the finishing phase, there may be important additive effects on beef palatability traits that are associated with repetitive implant use. Therefore, it is important for the beef industry to investigate the effects of implants administered over a beef animal's entire lifetime on tenderness and beef quality so that recommendations for lifetime implant protocols can be formulated and integrated into TQM production systems for beef cattle.

Simply reporting the improvement in beef palatability traits (e.g., marbling and WBSF) associated with implementation of specific management practices may not greatly increase adoption of these practices by producers in the beef industry.

Widespread application of TQM practices to improve of beef palatability will likely be slow unless there is tangible evidence that these practices will increase profitability for producers. Quantifying the economic values that consumers associate with differences in carcass quality and beef palatability is an important step toward building the case for producers to implement TQM beef production systems.

The following research studies were designed to examine 1) effects of lifetime implant protocols on carcass quality, beef tenderness, and consumer ratings of beef palatability, 2) impacts of changes in marbling score, shear force, and consumer ratings for tenderness, juiciness, and flavor on the probability of overall acceptance of beef, and 3) differences in consumer purchasing trends and willingness-to-pay for steaks from a wide range of marbling scores and shear force values.

# CHAPTER II

# REVIEW OF LITERATURE

### *Implant use in the Beef Industry*

The first anabolic steroid approved for use in growing cattle was diethylstilbestrol, approved for use in the U.S. in 1954 (Raun and Preston, 1997). Since that time, a number of anabolic agents for cattle have been approved for use in the United States (Table 2.1).

Currently, compounds that have estrogenic, androgenic, and both estrogenic and androgenic activity are approved for use in growing cattle. The estrogenic compounds approved for use in cattle are 17 β-estradiol, estradiol benzoate, and zeranol (Botts et al., 1997). Testosterone propionate and trenbolone acetate are the two synthetic androgen anabolic agents approved for cattle (Botts et al., 1997). These compounds can be administered to cattle alone or in specific combinations, at various levels, providing several different commercially available implant products (Table 2.2).

Implanting cattle during the finishing phase of production is a common management practice used by producers in the United States. Generally, cattle finished for short periods of time (< 140 d) receive only one implant during the finishing phase, whereas cattle fed for longer periods (> 140 d) are commonly reimplanted (usually at approximately 60 d after the administration of the initial implant). A survey of beef nutrition consultants, who provide their services in major cattle producing states, concluded that most consultants recommend the administration of a combination implant (one containing an estrogenic compound and trenbolone acetate), given 80 to 140 days before slaughter, as the terminal implant for feedlot steers (Galyean, 1997). If two implants are administered to steers during the finishing phase, normally a terminal combination implant is preceded by an implant containing only an estrogenic compound (Galyean, 1997). Table 2.3 lists examples of common implant strategies for steers during the finishing phase of production.

The primary benefits for use of anabolic agents in cattle production are increased growth rates and improved feed efficiency. Data collected over a period of thirty years indicate that improvements in gain and feed conversion of 10 to 20% in feedlot cattle can be obtained with the use of implants (Muir et al., 1985). An increase in growth rate of over 20% during the finishing period has been reported for steers implanted with combination implants compared to non-implanted steers (Trenkle, 1990; Gerken et al., 1995).

Gill and Trapp (1997) estimated that the return for implanting steers with a single implant during the finishing phase was $21 to $43 dollars above the cost of the implant for cattle sold on a live-weight basis. In that study, the estimated return for reimplanting steers in the finishing phase was an additional $4 to $20 per head. These estimates illustrate the economic rewards for implanting cattle during the finishing phase of production in a commodity beef production system.

Producer surveys from various states have indicated that 40 to 65% of stocker cattle operators utilize implants in their grazing programs (Kuhl, 1997). Implanting grazing stocker cattle typically increases cattle weight gains by 8 to 15% (Kuhl, 1997). Lower potency estrogenic implants are used by some cow-calf producers to enhance the growth rate of suckling calves. Selk (1997) reported that an increase in average daily gain of 0.045 kg/d is common for implanted suckling steer and heifer calves compared to non-implanted calves.

***Implant Effects on Beef Carcass Quality and Tenderness***

Research has demonstrated that use of implants tends to decrease marbling scores and USDA quality grades of cattle (Trenkle, 1990; Bartle et al., 1992; Preston et al., 1995; Herscheler et al., 1995; Roeber et al., 2000a). However, other studies have shown that the use of implants has little or no effect on marbling score or USDA quality grade (Gerken et al., 1995, Johnson et al., 1996; Rumsey et al., 1999). In an extensive review of the literature on the effect of implants on carcass traits, Duckett et al. (1997) reported that all implant types administered to steers during the finishing phase, except androgen implants administered alone, reduced marbling scores and the percentage of carcasses grading Choice or higher. In that same review, steers reimplanted during during the finishing phase with an estrogen or a combination implant had lower marbling scores than did steers receiving only a single implant during finishing.

Only a few studies have evaluated the effects of implants administered to steers before finishing beef carcass quality. Researchers have reported no impact of implant treatment on marbling scores for steers implanted during the suckling phase (Mader et al., 1994) or growing phase (Mader, 1994) of production. Simms et al. (1988) reported no difference in mean quality grade for steers receiving an additional zeranol implant during the suckling or growing phase compared to the mean quality grade for steers receiving two zeranol implants during the finishing phase of production. Results of one study suggested that the potency of lifetime implant protocols affected marbling score of steers (Pritchard et al., 2000). In that study, low-potency implant protocols had no effect on marbling scores, but medium to high-potency lifetime implant protocols reduced marbling scores compared to marbling scores of non-implanted steers. Samber et al. (1996) reported that non-implanted steers produced a higher percentage of Choice and Prime carcasses than did steers implanted three times during their lifetime.

Several studies have reported increased shear force values for steaks from carcasses of implanted cattle compared with steaks from carcasses of non-implanted cattle (Foutz et al., 1990; Thonney et al., 1991; Nichols et al., 1996; Samber et al., 1996; Foutz et al., 1997; Rumsey et al., 1999). Conversely, other investigations have reported no difference in shear force values for steaks produced from carcasses of implanted vs. non-implanted cattle (Gerken et al., 1995; Pruneda et al., 1999; Beirman et al., 1999). Morgan (1997) estimated that the average shear force value for top loin steaks from carcasses of implanted cattle was approximately 0.5 kg higher than the average shear force value for top loin steaks from carcasses of non-implanted cattle.

Thonney et al. (1991) and Nichols et al. (1996) reported less desirable trained taste panel ratings for tenderness of steaks from implanted cattle compared to tenderness ratings of steaks from non-implanted cattle. Other investigations evaluating effects of implant use on beef tenderness using trained taste panels have reported no difference in tenderness ratings for steaks from implanted and non-implanted cattle (Crouse et al., 1987; Apple et al., 1991; Perry et al., 1991). Roeber et al. (2000a) reported decreased consumer tenderness ratings for steaks from implanted cattle when compared to consumer tenderness ratings for steaks from non-implanted cattle.

***Relationships between Marbling and Beef Palatability***

The first Official United States Standards for Grades of Carcass Beef (disseminated in 1926 by the United States Secretary of Agriculture) were designed to facilitate the reporting of dressed beef markets (USDA, 1997). In these original standards the word "palatability" does not appear; however, in 1965, the term "quality grade" was defined by the USDA as the factors relating to the "palatability-indicating characteristics of the lean" (Smith et al., 1987). Eventually the phrase "palatability-indicating characteristics of the lean" was defined as those factors relating to the tenderness, juiciness, flavor, and overall palatability of beef (Smith et al., 1987).

Specifications for carcass conformation, maturity, and marbling score were included as factors in the early standards for the assignment of beef quality grades to carcasses. In 1965, the standards for quality grades of steers and heifer carcasses were revised to place less emphasis on differences in maturity during assignment of quality grades for young (A and B maturity) beef carcasses (USDA, 1997). In 1975, the standards for beef carcass grades were revised once again by eliminating the requirement of an evaluation of carcass conformation for assignment of quality grades (USDA, 1997). These revisions in the standards for beef grades have increased the relative influence of marbling score in the assignment of USDA quality grades to young beef carcasses. Consequently, marbling is the primary predictor of beef palatability for young steer and heifer carcasses in the United States beef grading system.

The use of marbling as the primary consideration in assessing the quality of beef has been a source of controversy in the beef industry because of the sometimes ambiguous relationship between marbling and cooked beef palatability. Several studies have reported that all of the organoleptic attributes of beef are related in a positive manner to marbling scores (Campion et al., 1975; Tatum et al., 1982; Smith et al., 1984). In an extensive study examining the relationship between USDA quality grade and cooked beef palatability, Smith et al. (1987) reported that quality grades predicted the flavor, tenderness, juiciness, and overall palatability of loin steaks from youthful beef carcasses with 30 to 38% accuracy. Several investigations have reported only very low or non-existent relationships between marbling scores and beef palatability attributes (Parrish et al., 1973; Crouse et al., 1978; Davis et al., 1977; Smith et al, 1988). A particular concern reported by many researchers is the limitation of marbling scores or quality grades in predicting the tenderness of beef (Jones and Tatum, 1994; Wheeler et al., 1994). Several studies have reported that tenderness of beef is not affected by marbling within a narrow range of marbling scores (Romans et al., 1965; Parrish, 1974; Lawrence et al., 2001; Wulf et al., 2002). Nevertheless, research has suggested that marbling, in general, has a positive impact on consumer ratings of beef palatability (Savell et al., 1987). It is important to note, though, that many studies have demonstrated that the effect of USDA quality grade on consumer ratings for beef palatability can be influenced by cut, degree of doneness, or cooking method (Savell et al., 1999; Lorenzen et al., 1999; Neely et al., 1999).

***Relationships between Shear Force, Beef Tenderness, and Overall Acceptability of Beef***

Researchers have identified tenderness as the most important palatability attribute in determining overall eating satisfaction of beef (Huffman et al., 1996; CCA, 2002). National audits of retail markets, conducted to characterize beef cuts with respect to tenderness, have indicated that a high percentage of beef retail cuts in the United States are unacceptable in tenderness (Morgan et al., 1991; George et al., 1999; Brooks et al., 2000). Consequently, the beef industry has made improving the tenderness of its products a top priority.

Meat scientists have long debated what is the most accurate methodology for assessing beef tenderness. For many decades, Warner-Bratzler shear force (WBSF) has remained the most widely used and accurate instrumental measurement of beef tenderness (Wheeler et al., 1997). Nevertheless, many factors including: rate of freezing, degree of doneness, cooking method, core diameter, orientation of the core, location of steaks within a muscle, and temperature of sample cores have been reported to influence WBSF measurements (Smith et al., 1969). As a result, researchers have recommended standardized procedures for evaluating meat tenderness using WBSF (Wheeler et al., 1996). Universal application of these standard protocols can facilitate a high degree of repeatability and accuracy of WBSF values within and among institutions (Wheeler et al., 1997).

Instrumental devices do not measure tenderness per se, but rather the physical properties which can be related to tenderness attributes sensed organoleptically (Szczesniak, 1972). Several research studies have demonstrated moderately to highly significant relationships between WBSF and trained taste panel evaluations of tenderness attributes (Campion et al., 1975; Shackelford et al., 1995; Otremba et al, 1999; George et al., 1999; Wheeler et al., 2000). Other research has concluded that different methods of preparation by individual consumers make consumer perceptions of tenderness difficult to predict based on objective measurements of tenderness (Lorenzen et al., 2003).

Shackelford et al. (1991) used trained taste panel tenderness data, collected at four institutions, to establish tenderness threshold values for top loin steaks based on WBSF. Results of that study suggested that steaks with a WBSF value of < 4.5 kg would have a 50% chance, and steaks with a WBSF value < 3.9 kg would have a 68% chance of being rated as acceptable in tenderness. Miller et al. (2001) used consumer tenderness evaluations to establish ranges of WBSF values that could be used to sort top loin steaks into four tenderness categories (tender, intermediate, tough, and toughest). Boleman et al. (1997) demonstrated that consumers were able to differentiate between top loin steaks categorized by WBSF, and that consumers generally preferred steaks from the lowest range of WBSF values.

Development of technologies that will identify carcasses yielding "tough" steaks and roasts in the U.S. beef production system is a primary research goal of the NCBA (NCBA, 2002). If carcasses that produce "tough" steaks and roasts could be identified, alternative processing methods known to improve beef tenderness could be selectively applied to such carcasses to improve palatability of resulting retail cuts. Recently, three technologies, two non-invasive methods (Wulf and Page, 2000; Wyle et al., 2003) and one invasive method (Shackelford et al., 1999), were proposed as systems capable of classifying carcasses into tenderness categories. Warner-Bratzler shear force has been used as the primary predictor of tenderness in the development and validation of these beef tenderness classification systems (Wheeler et al., 2002). Tenderness classification methods that use predicted shear force values to segregate carcasses into tenderness categories have proven effective for identifying carcasses that will yield steaks with greater levels of consumer acceptance (Shackelford et al., 2001; Wyle et al., 2003).

***Experimental Economics vs. Stated-Choice Surveys to Determine the Value of Beef***

Consumer preferences for beef products that differ in quality traits have been examined in several beef palatability studies (Savell et al., 1987; Neely et al., 1998; Miller et al., 2001). While information concerning consumer preferences for beef palatability traits such as tenderness and marbling is important, information pertaining to value differences associated with palatability traits that reflect consumers' willingness-to-pay may be more beneficial to the beef industry. Stated-choice surveys and experimental economic methods are the two techniques that can be used by researchers to estimate the difference in value for beef with different levels of quality and tenderness.

Stated-choice (willingness-to-pay) surveys involve directly asking consumers how much they would be willing-to-pay for products (Louviere et al., 2000). The value of products of interest is determined in willingness-to-pay surveys by asking consumers to write down the maximum price or the premium that they would be willing-to-pay, or by circling the maximum price or the premium that they would be willing-to-pay on a response form (Loomis and Walsh, 1997). Variations of stated-choice methods have been used in meat science research to estimate consumer willingness-to-pay values for beef loin steaks classified into tenderness categories based on WBSF (Miller et al., 2001) and slice shear force (Shackelford et al., 2001). Although carefully designed and pretested stated-choice surveys provide reasonably accurate estimates for value improvements to products, the validity of the responses produced from these surveys are often questioned by economists because they are not observations of actual consumer purchasing behavior (Loomis and Walsh, 1997). Studies have indicated that the willingness-to-pay values for products generated by stated-choice surveys can be exaggerated by twice, to as much as five to ten times when compared to willingness-to-pay values for the same products generated using experimental economic methods (Loomis and Walsh, 1997).

Experimental economic methods provide reliable estimates of what consumers will pay for goods (Davis and Holt, 1993; Kagel and Roth, 1995). A major advantage of using an experimental economic approach for estimating the value of goods as perceived by consumers is that these methods simulate a non-hypothetical marketplace (Davis and Holt, 1993; Kagel and Roth, 1995). In the case of meat products, participants in an experimental economic study are required to eat real food and purchase meat using real money. An experimental economic design frequently used by researchers to determine willingness-to-pay for products is the Vickrey sealed-bid second-price auction (Vickrey, 1961). In a second-price auction, each consumer submits a bid and the consumer with the highest bid wins, but pays the second highest bid for the product. Using the second highest bid, instead of the highest bid, as the market price for the goods in the auction removes the strategic incentive for consumers to underbid (Roth, 1998). Additionally, using a sealed bid auction allows each consumer in the auction to submit their own perception of the product's value, which is independent of the bidding behavior of other consumers in the auction (Buhr et al., 1993). Consumer values for altering specific food attributes, including improved food safety (Hayes et al., 1995), using growth promotants in food production (Buhr et al., 1993), and changing pork quality attributes (Melton et al., 1996) have been identified using experimental economic methods. Other studies have used experimental economic methods to estimate the premiums consumers would pay for beef loin steaks with a higher degree of marbling (Umberger et al., 2000) and beef loin steaks that were "guaranteed tender" (Lusk et al., 2001).

**Table 2.1. Chronology of approval of cattle anabolic agents in the United States[a]**

| Year | Event |
|---|---|
| 1954 | Oral diethylstilbestrol (DES) approved for cattle |
| 1956 | Estradiol benzoate/progesterone implants approved for steers |
| 1957 | DES implants approved for cattle |
| 1958 | Estradiol benzoate/testosterone propionate implants approved for heifers |
| 1969 | Zeranol implants (36 mg) approved for cattle |
| 1982 | Silastic estradiol implant approved for cattle |
| 1984 | Estradiol benzoate/progesterone implants approved for calves |
| 1987 | Trenbolone acetate (TBA) implants approved for cattle |
| 1991 | Estradiol/TBA implants approved for steers |
| 1994 | Estradiol/TBA implants approved for heifers |
| 1995 | 72 mg zeranol implants approved for cattle |
| 1996 | Estradiol/TBA implants approved for stocker cattle |

[a]Source: Raun and Preston,1997

Table 2.2. List of FDA approved anabolic implants for beef cattle[a]

| Active ingredients | Trade names |
|---|---|
| ***Medium potency estrogenic implants*** | |
| Estradiol benzoate, 20 mg; progesterone, 200 mg | Synovex-S; Component E-S |
| Estradiol benzoate, 20 mg; testosterone, 200 mg | Synovex-H; Component E-H |
| Estradiol, 25.7 mg | Compudose |
| Estradiol, 43.9 mg | Encore |
| Zeranol, 72 mg | Magnum |
| ***Lower potency estrogenic implants*** | |
| Zeranol, 36 mg | Ralgro |
| Estradiol benzoate, 10 mg; progesterone, 100 mg | Synovex-C; Component E-C |
| ***Androgenic implants*** | |
| Trenbolone acetate, 140 mg | Finaplix-S; Component T-S |
| Trenbolone acetate, 200 mg | Finaplix-H; Component T-H |
| ***Medium potency combination implants*** | |
| Estradiol, 24 mg; trenbolone acetate, 120 mg | Revalor-S; Component TE-S |
| Estradiol, 14 mg; trenbolone acetate 140 mg | Revalor-H |
| ***Higher potency combination implants*** | |
| Estradiol benzoate, 28 mg; trenbolone acetate 200 mg | Synovex Plus |
| Estradiol, 20 mg; trenbolone acetate, 200 mg | Revalor-200 |
| ***Lower potency combination implants*** | |
| Estradiol, 8 mg; trenbolone acetate, 40 mg | Revalor-G |
| Estradiol, 16 mg; trenbolone acetate, 80 mg | Revalor-IS |
| Estradiol, 8 mg; trenbolone acetate, 80 mg | Revalor-IH |
| Estradiol benzoate, 14mg; trenbolone acetate, 100 mg | Synovex Choice |

[a]Source: Loy and Miller, 2001.

**Table 2.3. Common implant strategies[a] for steers in the finishing phase of production**

| Days on feed | Initial implant(s)[b,c] administered at feedlot entry | Implant(s)[b,c] administered 80-100d prior to harvest | Anticipated results of implants on cattle performance and carcass quality grade |
|---|---|---|---|
| < 130 | MP estrogenic | - | Good performance, limited reduction in quality grade |
| < 130 | LP combination | - | Good performance, limited reduction in quality grade |
| < 130 | MP estrogenic/androgenic[d] | - | Excellent performance, moderate reduction in quality grade |
| < 130 | MP combination | - | Excellent performance, moderate reduction in quality grade |
| 100-130 | HP combination | - | Superior performance, risk of severe reduction in quality grade |
| 130-170 | - | LP combination | Good performance, limited reduction in quality grade |
| 130-170 | - | MP combination | Good performance, limited reduction in quality grade |
| 130-170 | MP estrogenic | LP combination | Excellent performance, moderate reduction in quality grade |
| 130-170 | MP estrogenic | MP combination | Superior performance, risk of severe reduction in quality grade |
| 130-170 | LP combination | LP combination | Good performance, limited reduction in quality grade |
| 130-230 | LP combination | MP combination | Excellent performance, moderate reduction in quality grade |
| 130-230 | MP combination | MP combination | Excellent performance, moderate reduction in quality grade |
| 130-230 | MP combination | HP combination | Superior performance, risk of severe reduction in quality grade |

[a]Derived from various trade publications.

[b]See Table 2.2 for brand names of implant products.

[c]LP = low potency; MP = medium potency; HP = high potency.

[d]Can be used in substitution for MP combination.

# CHAPTER III

# EFFECTS OF REPETITIVE USE OF HORMONAL IMPLANTS ON BEEF CARCASS QUALITY, TENDERNESS, AND CONSUMER RATINGS OF BEEF PALATABILITY

## ABSTRACT

Effects of repetitive use of anabolic implants on beef carcass quality, tenderness, and consumer ratings for palatability were investigated using crossbred steer calves (n = 550). Steers from each of five ranches were randomly allocated to one of 10 different lifetime implant strategies or to a non-implanted control group. Cattle were implanted at some or all of five phases of production (branding, weaning, backgrounding, feedlot entry, or re-implant time). Carcasses from the control group had higher ($P < 0.05$) marbling scores than did carcasses from steers in all other treatment groups. Implanting steers at branding, weaning, or backgrounding vs. not implanting steers at these production stages did not affect ($P > 0.05$) marbling scores. Steers implanted twice during their lifetime produced carcasses with higher ($P < 0.05$) marbling scores than did steers receiving a total of four or five implants. Steaks obtained from carcasses in the control group had lower ($P < 0.05$) shear force values and were rated by consumers as more desirable ($P < 0.05$) for tenderness like/dislike than steaks obtained from carcasses in all other treatment

groups. Implanting steers at branding or weaning production stages did not affect ($P > 0.05$) steak shear force values, consumer ratings for like/dislike of steak tenderness, or percentage of consumers rating overall eating quality of steaks as satisfactory. Implanting steers at backgrounding vs. not implanting steers at this production stage increased ($P < 0.05$) steak shear force values, but did not influence ($P > 0.05$) consumer ratings for like/dislike of steak tenderness or percentage of consumers rating overall eating quality of steaks as satisfactory. Steaks from non-implanted steers were rated as more desirable ($P < 0.05$) for overall eating quality than steaks from steers implanted two, three, four, or five times. Use of implants increased ($P < 0.05$) average daily gain by 11.8 to 20.5% from weaning to harvest compared to non-implanted controls. Implant strategies increased ($P < 0.05$) hot carcass weight of steers by 8.9 to 13.8% compared to the control group. Use of implants also increased ($P < 0.05$) longissimus muscle area and decreased ($P < 0.05$) estimated percentages of kidney/pelvic/heart fat, but did not affect ($P > 0.05$) dressing percentage or adjusted fat thickness. Our findings suggest that beef quality, palatability, and production characteristics are influenced by lifetime implant protocols.

## INTRODUCTION

Growth promoting implants are used routinely by U.S. beef producers to increase rate and efficiency of growth in cattle. Currently, there are 16 different commercial implant products approved for use in cattle by the Food and Drug Administration (Eng, 2000). Hormonal implants are approved for use in cattle of all ages and may be used to enhance growth during the suckling, growing, and finishing phases of production. Therefore, steers and heifers destined for finishing and harvest may receive as many as four to six (or possibly more) implants throughout their lifetime (Mader, 1997).

The benefits of using implants to improve growth performance of cattle are well documented. However, research suggests that "aggressive" and (or) repetitive use of implants may be detrimental to beef carcass quality and tenderness (Tatum, 1993; Morgan, 1997; Roeber et al., 2000a). The 1991 and 2000 National Beef Quality Audits both identified "reduced quality of beef due to implants" as one of the packing industry's top six concerns about the quality of beef (Smith et al., 1992; Roeber et al., 2000b).

A number of studies have documented the effects of implants administered to steers and heifers during the finishing phase of production on carcass quality and beef tenderness (Samber et al., 1996; Morgan, 1997; Roeber et al., 2000a). However, few studies have examined the possible effects of implants given during the suckling and growing phases of beef production on carcass quality and tenderness. This study was designed to examine the effects of administering growth promoting implants, at sequential stages of production, up to five times during the lifetime of steers, on carcass quality traits, beef tenderness, and consumer ratings of beef palatability.

## MATERIALS AND METHODS

*Animals and experimental treatments.* Five-hundred and fifty crossbred steer calves (representing a variety of biological cattle types) were obtained from five ranches (located in three states) for use in this study (Table 3.1). Calves were allocated either to one of ten different lifetime implant treatment groups or to an untreated, negative control group (50 calves/group; Table 3.2). The steers were implanted, according to their respective treatments, at some or all of five phases of production (branding, weaning, backgrounding, feedlot entry, and re-implant time during the finishing phase). Implant products used at the various phases of production included: Synovex-C® (10 mg estradiol benzoate, 100 mg progesterone) at branding; Ralgro® (36 mg zeranol) at weaning; Ralgro® or Synovex-S® (20 mg estradiol benzoate, 200 mg progesterone) at backgrounding; Synovex-S® or Revalor-S® (24 mg 17-β estradiol, 120 mg trenbolone acetate) during finishing.

Finishing-phase implant protocols for treatment groups two, three, four, six, seven, eight, nine, and ten were standardized (Synovex-S® at feedlot entry followed by Revalor-S® at re-implant time) to permit direct examination of the effects of implants, administered during the suckling and growing phases of production, on carcass quality traits, tenderness, and consumer ratings of palatability. Treatment eleven (Table 3.2) steers received two Revalor-S® implants to represent an "aggressive" feedlot implant protocol and treatment five (Table 3.2) steers did not receive an implant upon feedlot entry to represent a lifetime implant program designed for moderate improvements of production performance for steers destined for marketing on a value-based marketing grid (Rains, 1998).

In addition to the individual treatment comparisons, the experiment was designed to contrast the effects of either receiving implants or not receiving implants at each successive pre-finishing phase of production (branding, weaning, and backgrounding). To examine the effects of the administration of implants at branding, data obtained from steers in treatments three, four, and six (no branding implant; Table 3.2) were pooled and contrasted with pooled data from steers in treatments seven, eight, and ten (implanted at branding). In these contrasts, subsequent implants for treatments seven, eight, and ten were exactly the same as those received by treatments three, four, and six, respectively. To examine the effects of an implant received at weaning, pooled data obtained from steers in treatments four, seven, and eight (no weaning implant; Table 3.2) were contrasted with pooled data from steers in treatments six, nine, and ten (implanted at weaning). Again, implants administered at all other production phases besides weaning were identical for treatments six, nine, and ten as those received by treatments four, seven, and eight, respectively. Effects of a backgrounding implant were determined by contrasting pooled data from steers in treatment two (no implant at backgrounding; Table 3.2) with pooled data from steers in treatments three (Ralgro® implant at backgrounding) and four (Synovex-S® at backgrounding). The design of this study also provided an opportunity to analyze the effects of the number of implants (zero, two, three, four, or five implants) administered throughout the lifetime of steers, without consideration of the timing of implanting (Table 3.2).

*Cattle Management.* Industry recommended protocols for proper implant placement and implant equipment sanitation, designed to minimize implanting defects, were used throughout the course of this study (Zero Defect Implanting, Vetlife, Des Moines, IA). Implants were administered subcutaneously in the middle one-third of the left ear at branding, and implant placement was alternated to the same location in the opposite ear at each subsequent processing phase. Implant needles were disinfected after each use using a sponge soaked in two percent chlorenhexadine solution. At branding, male calves (approximately 60 to 100 d old) at each of the five ranches were castrated and randomly assigned to two groups (implanted and non-implanted). Additional cattle, more than the number specified in the protocol, were identified and included in the study at branding to ensure that an adequate number of steers would be available in each treatment group for analysis at harvest in the event that uncontrolled circumstances caused losses of animals from the study. Because processing conditions on the ranches prevented the measurement of individual calf weights, hoof circumference was measured using a Calf-Scale™ (Ames, IA) measuring tape at the time of branding in an attempt to quantify the size and (or) age of the steer at that time. The tape measurements and the treatments applied at branding (implanted and non-implanted) were used to allocate steers in each contemporary group, in a balanced fashion, to one of the eleven different implant protocols used in the study (Table 3.2). Steers were allowed to remain with their dams until weaning at approximately 240 d of age, at which time the calves were individually weighed and implants were administered to steers according to their respective treatment groups.

Within two wk after weaning, steers from each ranch were transported to the same commercial feedlot in eastern Colorado for growing and finishing. Upon arrival at the feedlot, steers were processed using normal receiving procedures employed by that feedlot, including a seven-way *Clostridial* vaccination, a vaccination for IBR, BVD, BRSV, and treatment for internal and external parasites. After processing, steers from each ranch were placed in large pens (one ranch's cattle per pen) and started on a low-concentrate grower diet, which consisted of 55.7% beet pulp, 17% ground alfalfa hay, 15% dry rolled corn, 10% distiller's grains (wet), and 2.3% liquid supplement. The initiation of the backgrounding period was delayed 45 to 48 d (depending upon ranch) post-weaning. This lag period between weaning and backgrounding represented the acclimation period normally associated with cattle that have been "preconditioned" for the feedlot.

At the initiation of the backgrounding phase, steers (approximately 285 d old) were individually weighed and those scheduled for implanting were implanted according to their respective treatment assignment. After implanting, the pens of steers were allowed to consume the grower diet for an additional period of 64 to 102 d; termination of the backgrouding period for each pen was determined by back-calculating 150 d from a projected average harvest date for all the steers derived from each ranch.

At the initiation of the finishing period, steers were individually weighed and implanted according to their respective implant protocols. During the finishing period, energy levels in the diet were gradually increased (over a 14-d period) from the low-concentrate grower diet to a high concentrate finishing diet via a six level "step-up" program. On d-14 of the "step-up" program, cattle were started on the finishing diet, which consisted of 67% dry rolled corn, 15% distiller's grains (wet), 10% beet pulp, 5% liquid supplement, and 2.5% ground alfalfa hay.

Dates for re-implanting during the finishing phase were determined for the steers from each ranch by back-calculating 80 d from a projected average harvest date for all cattle derived from each ranch. At re-implanting, steers were individually weighed, and all cattle, except those in the non-implanted control group, were administered a Revalor-S® implant.

Steers were harvested when they individually attained 12 to 16 mm of fat thickness over the longissimus muscle at the $12^{th}$ rib (measured using real-time ultrasound). Because of the difference in age and biological type of the steers obtained from each ranch, not all ranches were represented at each harvest date (Table 3.1). However, harvest groups from each ranch consisted of steers from all eleven treatment groups and the average number of d on feed for steers obtained from each ranch was not different across treatments (data not shown). When USDA quality grade is of concern, suppliers of trenbolone acetate (TBA) - containing implants have recommended administration of these products once, 80 to 100 d before harvest (Intervet, 2000). In this study, administration of the terminal TBA combination implant occurred at an average of 82 d ± 10.5 before harvest.

*Carcass Data Collection and Sampling Methods.* On each shipping date, steers in each harvest group were weighed individually, transported approximately 80 km to a commercial beef packing plant, and harvested using conventional procedures. Carcasses were chilled in a cooler with an air temperature of 2°C for 36 h, and sprayed intermittently (2 min on, 8 min off) with a fine mist of 2°C water for the first 8 h of the chill period. Following the carcass-chilling period, a panel of three Colorado State University personnel independently assigned and (or) measured carcass grade data. Each evaluator independently recorded measurements/assessments of fat thickness, longissimus muscle area, percentage of kidney, pelvic and heart fat, lean maturity, skeletal maturity, overall carcass maturity, and marbling score for each carcass. Values for each trait from the three evaluators were averaged, resulting in a single value for each factor for each carcass. The 550 carcasses used in the study were chosen randomly from the steers in the trial that had maintained their appropriate experimental treatment protocols throughout their lifetime.

Strip loins (IMPS 180; USDA, 1988) from the right sides of each of the 550 carcasses were collected after fabrication and transported immediately to the Colorado State University Meat Laboratory. At the Meat Laboratory, the anterior end of each strip loin was "faced" and one 2.54-cm steak was removed, placed in a vacuum-sealed bag, aged at 2°C for 21 d postmortem. The remainder of the strip loin was placed in a vacuum-sealed bag and aged at 2°C for 14 d postmortem. After reaching the appropriate length of aging time, samples were frozen and stored at -20°C for subsequent shear force determination (performed on 14- and 21-d samples) and consumer panel analysis (performed on 14-d samples, only).

Frozen sub-samples of strip loins aged for 14 d were fabricated (in the frozen state) into steaks (2.54 cm) using a band saw (model 5700, Hobart, Troy, OH). The first steak from the anterior end of each strip loin section was identified and placed in an individual vacuum-sealed bag for Warner-Bratzler shear force determination. The next two steaks were identified and vacuum-packaged individually for subsequent untrained, consumer taste panel analysis. Upon completion of fabrication of the 14-d aged sub-samples, the steaks were sorted for intended use and returned to frozen storage (-20°C). Samples used for sensory analysis were stored for approximately 180 d at frozen temperatures.

*Tenderness Measurements.* For shear force determination, frozen steaks were thawed at approximately 2°C for 24 hr and cooked on an electric conveyor grill (model TBG-60, Magikitch'n, Quakertown, PA) to a target internal temperature of 70°C. The steaks were cooked for a constant time of 6 min and 35 sec at a setting of 176°C for the top and bottom heating platens. Peak internal temperature measurements were recorded for each steak using a Type K thermocouple (model 39658-K, Atkins Technical, Gainesville, FL).

After cooking, each steak was allowed to equilibrate to room temperature (22°C) and six to ten cores (1.27 cm in diameter) were removed from each steak parallel to the muscle fiber orientation. Each core was sheared once, perpendicular to the muscle fiber orientation, using a Warner-Bratzler shear machine (G-R Electric Manufacturing Co., Manhattan, KS), and peak shear force measurements were recorded and averaged to obtain a single shear force value for each steak.

*Consumer Sensory Evaluation.* A private marketing and economic research firm (Branson Research Associates, Bryan, TX), with extensive expertise in generating sample populations of consumers, was contracted to generate random phone listings for persons in the Denver, CO metro area. These telephone listings were given to a telemarketing firm (Client Insight, Ft. Collins, CO), with expertise in conducting telephone surveys, to recruit consumers for the untrained consumer panels. Consumers were contacted by telephone and pre-screened to ensure that they were at least 18 years of age and consumers of beef products. Sampling methods employed by the market and economic research firm targeted a sample population of consumers that was representative of the age, income, and ethnic background of the United States population. Consumers, selected according to criteria specified above and who were willing to participate in the study, were assigned to one of four testing locations utilized to conduct untrained consumer evaluation panels in the Denver Metro area (Denver, Lakewood, Arvada, or Littleton). A total of 25 consumer panel evaluation sessions were conducted that included a total of 489 consumers.

Paired steaks from each of the 50 carcasses per experimental treatment group were randomly assigned to one of the 25 consumer panel evaluation sessions. Within a session, paired steaks from 22 different carcasses were selected for sensory evaluation. In the randomization scheme, treatments were balanced within session (two carcass identification numbers representing each treatment). However, steaks from different ranches were assigned randomly to sessions. Steak identification numbers, as well as order of service to consumer panelists, were assigned randomly to be fed to each of the 20 consumers per session. Each consumer evaluated steak samples from each of the 11 treatment groups during each 60 min session.

Frozen steaks prepared for consumer panel evaluation were thawed at 2°C for 24 h and cooked for approximately 15 min on electric grills (model GGR64, Salton, Inc., Mt. Prospect, IL) that heated steaks from both sides, simultaneously, to a final internal temperature of 70°C. A Type K thermocouple (Omega Engineering Inc., Stamford, CT) was placed in the geometric center of each steak and the internal temperature of each steak was monitored during cooking using a microprocessor thermometer (model HH21, Omega Engineering Inc., Stamford, CT). Steaks were cut into 1.3 × 1.3 × 2.5 cm portions, covered, and placed in a warming oven (49°C) until served to consumers. One steak of each pair of steak samples from each carcass identification number was prepared for serving during the first half of the session, whereas the other matched steak from each carcass was prepared for serving in the last half of the session to minimize any changes in sensory attributes associated with holding samples for longer periods of time in a warming oven.

Consumer panel evaluation procedures used for this study were approved by the Colorado State University Use of Humans in Research Committee. At each location, consumers were randomly seated at tables arranged in a circular order in a room containing standard fluorescent lighting. Instructions regarding the structure of the ballot and sampling procedures for the steak samples were provided verbally to the consumers in each session. Panelists were provided double-distilled, deionized water and saltless saltine crackers, and were instructed to take a bite of cracker and a drink of water before evaluating each sample to cleanse their palate and to minimize sensory fatigue between samples.

Consumers rated each steak sample for like/dislike of tenderness, flavor, and juiciness using nine-point, end-anchored hedonic scales where 1 = like extremely and 9 = dislike extremely. Additionally, consumers were asked if they were satisfied (yes or no) with the overall eating quality of each sample.

*Statistical Methods.* Analyses of growth traits and carcass data were conducted using the least squares, mixed model procedure of SAS (SAS Inst. Inc., Cary, NC). In all analyses, individual animals were used as the experimental units. The statistical model for the steer growth traits included treatment as the independent fixed effect, ranch (a block effect), and ranch × treatment as random effects. For analysis of carcass traits, harvest date (date), date within ranch and treatment × date within ranch were added to the analysis of variance model as random effects because not all of the cattle were harvested on the same date. Because the design of this experiment specified feeding the steers to a common fat thickness (measured over the $12^{th}$ rib), adjusted fat thickness was used as a covariate in the analyses of all carcass traits. All of the fixed and random variables included in the analysis of variance model used to analyze carcass data also were included in the analysis of variance model used to analyze shear force data. Additionally, aging period (14 and 21 d) was included as a fixed effect (repeated measure), aging period × date within ranch and aging period × ranch × treatment were included as random effects and peak internal steak temperature served as a covariate for analysis of shear force data.

Treatment and location of the panel (location) were included as fixed effects in the model used to analyze the data generated from consumer panels. Date within ranch, treatment × ranch, treatment × date within ranch, steer identification number within treatment × date × ranch, panel session within location, and consumer within panel session × location were included as random effects in the analysis of variance model used to analyze consumer panel sensory ratings.

Additional analyses for all traits were performed substituting number of implants administered during the lifetime of each steer (zero, two, three, four, or five) for the fixed treatment class variable to ascertain the effects of the number of implants administered on the respective traits analyzed in each model.

When *F*-tests were significant ($P < 0.05$), multiple comparisons of treatment means were performed using paired comparison t-tests. Frequency distributions of USDA quality grades (Choice and Prime plus upper two-thirds Choice and Prime) and shear force values (above and below 4.5 kg) among control and treatment groups were compared using the Chi-square test of SAS (1998). If the overall Chi-square analysis was significant, Fisher's exact test of SAS was used to separate the percentages. Contrasts were partitioned in analysis of variance models to compare effects of implanting at branding, weaning, and backgrounding in mixed model analysis of variance (SAS Inst. Inc., Cary, NC).

## RESULTS AND DISCUSSION

*Carcass Quality Traits.* Comparisons of mean marbling scores and USDA quality grade distributions for each treatment group are presented in Table 3.3. Carcasses of steers in the control group (Treatment 1) had higher ($P < 0.05$) marbling scores than did carcasses of steers in all other treatment groups. Steers in treatment two, which were not implanted before the finishing phase, produced carcasses that had higher ($P < 0.05$) marbling scores when compared to steers in treatments six, seven, and eleven (e.g., those that received some of the more aggressive lifetime implant strategies). Implanting steers at branding, weaning, or backgrounding prior to the finishing phase, vs. not implanting at these production stages, did not affect ($P > 0.05$) marbling scores (Table 3.4). Steers receiving only two implants produced carcasses with higher ($P < 0.05$) marbling scores than did steers receiving four or five implants (Table 3.5).

The percentage of carcasses grading Choice and Prime (range, 56 to 82%) did not differ ($P = 0.15$) among treatments (Table 3.3). However, the frequency distribution of USDA quality grades within the Choice and Prime grades was shifted slightly as a result of the administration of some implant strategies. Within the control group, 54% of the steers produced carcasses that graded upper two-thirds Choice and Prime, which was higher ($P < 0.05$) than the percentage of carcasses with the same grade classifications in treatments three, seven, nine, and eleven (Table 3.3). Steers in treatment two produced a higher ($P < 0.05$) percentage of carcasses grading upper two-thirds Choice and Prime than did steers subjected to treatment eleven (36 vs. 14%; Table 3.3). Implanting steers at branding, weaning, or backgrounding prior to the finishing phase, vs. not implanting at these production stages, did not affect ($P > 0.05$) the percentage of carcasses grading

Choice and Prime (Table 3.4). The percentage of carcasses grading Choice and Prime was higher ($P < 0.05$) for non-implanted steers than for steers implanted four or five times (Table 3.5). Similarly, the percentage of carcasses grading upper two-thirds Choice and Prime was higher ($P < 0.05$) for non-implanted steers than for steers implanted three, four, or fives times (Table 3.5). Implanting steers five times decreased ($P < 0.05$) the percentage of carcasses grading upper two-thirds Choice and Prime compared to implanting steers twice (Table 3.5).

In agreement with the results of the present study, several other studies have shown that the use of implants tends to decrease marbling scores and USDA quality grades (Bartle et al., 1992; Preston et al., 1995; Herscheler et al., 1995). Conversely, some studies have shown that the use of implants has little or no effect on marbling score or USDA quality grade (Gerken et al., 1995, Johnson et al., 1996; Rumsey et al., 1999).

Most previous studies documenting the effects of implant strategy on beef carcass quality have been limited to evaluations of a single implant or two successive implants administered during the finishing period. Only a few studies have compared the effects of implants administered in the suckling and growing phases of production on beef carcass quality. Mader et al. (1994) reported that marbling scores did not differ for steers that received a pre-weaning implant (Synovex-C®) compared with steers that were not implanted prior to weaning. In another study, Mader (1994) compared steers receiving a Synovex-S® implant in the growing phase with steers that were not implanted in the growing phase and observed no effect of implant treatment on marbling score. Pritchard et al. (2000) reported similar marbling scores for non-implanted steers and steers receiving a low potency lifetime implant strategy; whereas, marbling scores were higher for non-implanted steers than for steers receiving intermediate or high potency lifetime implant treatments. Samber et al. (1996) reported that steers in a treatment group administered three implants in their lifetime produced carcasses with lower marbling scores and a lower percentage of Choice and Prime carcasses than did steers in a non-implanted control group. In that study, similar marbling scores and percentages of carcasses grading USDA Choice or Prime were observed for steers in the non-implanted treatment and steers in a treatment group administered two implants in their lifetime (Samber et al., 1996).

*Shear Force.* Least squares means for the repeated measurement of shear force obtained after 14 and 21 d of aging are reported in Table 3.3. Steaks obtained from steers in the control group had lower ($P < 0.05$) mean shear force values than steaks obtained from steers in all other treatment groups (Table 3.3). Steers assigned to treatment two (the most conservative lifetime implant protocol, other than the non-implanted control) produced steaks with lower ($P < 0.05$) mean shear force values than steaks obtained from steers in treatments three and eleven. Implanting at branding or weaning production phases did not affect ($P > 0.05$) shear force values; however, implanting at the backgrounding production phase increased ($P < 0.05$) mean shear force values (Table 3.4).

A Warner-Bratzler shear force value of 4.5 kg is commonly used as a maximum "threshold" level of consumer desirability for tenderness of beef top loin steaks (NCA, 1994). Using this threshold level, the percentage of steaks, after a 14- or 21-d aging period, with shear force values < 4.5 kg produced from steers receiving three, four, or five implants was lower ($P < 0.05$) than the percentage of steaks produced from steers in the control group (Table 3.5). Postmortem aging time improved ($P < 0.05$) shear force values, with a 15.3% reduction in shear force values for steaks aged for 21 d compared to steaks aged only 14 d. The interaction of postmortem aging period and implant treatment group was not significant ($P = 0.99$), indicating that the tenderness response to aging for 14 and 21 d was similar for all treatment groups.

In a review, Morgan (1997) reported that the average shear force value of top loin steaks obtained from implanted cattle was approximately 0.5 kg greater than for steaks from carcasses of non-implanted cattle and, regardless of aging time, steaks from carcasses of "aggressively" implanted cattle were tougher than steaks from non-implanted or "conservatively" implanted cattle. Results of our study were consistent with other studies that have reported increased shear force values for steaks obtained from carcasses of implanted cattle (Samber et al., 1996; Foutz et al., 1997; Rumsey et al., 1999). In contrast, Gerken et al. (1995) and Pruneda et al. (1999) reported no difference in shear force values for steaks produced from implanted and non-implanted cattle. Pritchard et al. (2000) reported higher shear force values for steaks obtained from steers administered a "high potency" lifetime implant strategy (e.g., Synovex-C®; Revalor-G®, Synovex-S®, and Revalor-S®) compared with steaks obtained from steers treated with a "low potency" lifetime implant protocol (e.g., 4 consecutive Ralgo® implants). Other evidence suggests that shear force values are not affected by the aggressiveness of the lifetime implant regimen for calf-fed steers (Schoonmaker et al., 2001).

*Consumer Sensory Panels.* Frequency distributions for consumer demographic attributes are reported by category as a percentage of the total sample population (Table 3.6). The majority of the consumer panelists were female (56%) and were the primary shopper within the household (75%). The average age of consumers was 46 yr, with a total range in age within the sample population of 18 to 84 yr. Of the incomes reported, the highest percentage of consumers had a total household income of between $40,000 and $49,000 per yr, but incomes ranged from less than $10,000 to greater than $90,000 per year across panelists. A high percentage of consumers reported their ethnic background as Caucasian (76%), followed by African-American (11%) and Hispanic (8%). A very low percentage of the sample population reported an ethnicity of American Indian and Asian or Pacific Islander. Taste panel participants said they consumed beef as part of an evening meal two to three times per week. Because this sample population represented consumers from diverse age levels, income levels, and ethnic backgrounds, and included consumers categorized as "beef-eaters," the consumer demographic profile was deemed to be an acceptable population to test whether or not the repetitive use of implants influenced consumer perception of beef palatability attributes.

Consumer ratings for like/dislike of tenderness, flavor, and juiciness were influenced ($P < 0.05$) by treatment group (Table 3.7). Steaks from non-implanted steers received more desirable ($P < 0.05$) ratings for tenderness like/dislike and juiciness like/dislike than did steaks from steers in all other treatment groups. Among treatment groups that received implants, steaks produced by steers in treatment eleven were rated less desirable ($P < 0.05$) for like/dislike of tenderness compared to steaks produced by steers in treatments two, seven, and nine, and less desirable ($P < 0.05$) for like/dislike of juiciness and like/dislike of flavor compared to steaks produced by steers in treatment group two. Steers in the control group produced steaks with more desirable ($P < 0.05$) consumer sensory ratings for like/dislike of flavor than did steers in all other treatment groups;

except for treatment group two. For steers receiving implants, the number of implants administered had no effect ($P > 0.05$) on consumer ratings for like/dislike of tenderness, flavor, or juiciness (Table 3.8). Moreover, administering implants at branding, weaning, or backgrounding did not affect ($P > 0.05$) consumer ratings of like/dislike of tenderness, flavor, or juiciness (data not shown).

On average, 60 to 74% of consumers were satisfied with the overall eating quality of steaks from the various experimental treatment groups (Table 3.7). The percentage of consumers satisfied with overall eating quality of steaks was not influenced ($P = 0.22$) by treatment when all 11 treatment groups were compared. However, when grouped by number of implants, implant protocol affected ($P < 0.05$) the percentage of satisfied consumers with respect to overall steak eating quality. Administering implants two, three, four, or five times decreased ($P < 0.05$) the percentage of satisfied consumers compared with a lifetime implant protocol that used no implants (Table 3.8). Implanting steers at branding, weaning, and backgrounding production phases had no effect ($P > 0.05$) on the percentage of satisfied consumers with respect to overall eating quality of the resulting steaks (data not shown).

Only a limited amount of information is available concerning the effects of implant strategies on consumer sensory evaluations of beef palatability traits. Roeber et al. (2000a) reported decreased consumer tenderness ratings for beef strip loin steaks derived from implanted steers (in six out of seven finishing implant protocols) when compared to steaks of non-implanted cattle. The 1995 Beef Consumer Satisfaction Report (NLSMB, 1995) indicated that there was a tendency for consumer ratings of overall beef desirability to be reduced for beef from cattle administered two successive androgen-containing implants when compared to beef from cattle administered a single implant, two consecutive estrogenic implants, or an estrogenic implant followed by a estrogenic + androgenic implant. Conversely, Roeber et al. (2000a) reported that consumer ratings of like/dislike of flavor and juiciness and overall like/dislike were not influenced by a combination estrogenic + androgenic implant.

Research has shown that consumer sensory responses for overall tenderness and overall like for strip loin steaks may be influenced by USDA quality grade (NLSMB, 1995). In this study, when all steak consumer panel ratings were adjusted to reflect a common carcass marbling score, no differences ($P > 0.05$) in consumer ratings (between treatment or classification by number of implants) for like/dislike of tenderness, flavor, or juiciness, or for the percentage of consumers satisfied with overall eating quality of steaks were observed (data not shown).

*Growth and Carcass Traits.* Contrasts comparing the effects of implanting at different phases of production on growth and carcass traits are presented in Table 3.4. Pre-finishing implants generally increase the growth rate of steers during the production phase immediately following administration of these implants (Selk, 1997; Kuhl, 1997; Duckett et al., 1997). The net effect on the overall lifetime growth rate of steers for each implant administered throughout a steer's lifetime can be dependent on various factors such as the animal's age, weight, production rate, and previous and subsequent implant treatment (Mader, 1994; Kuhl, 1997; Mader et al., 1997). In this study, implanting steers at branding did not affect ($P = 0.16$) weaning weight. Steers administered implants at branding and (or) weaning were heavier ($P < 0.05$) at the initiation of the backgrounding phase compared with steers not implanted at these production phases. Implants administered at branding or weaning did not influence ($P > 0.05$) feedlot entry weights. Implants administered at backgrounding increased ($P < 0.05$) feedlot entry weights and the increase in weight was maintained throughout the remainder of the feeding period, resulting in increased ($P < 0.05$) final live weights for steers that received implants at backgrounding compared with those that did not.

Final live weights of implanted steers were between 7.7 to 12.5% heavier ($P < 0.05$), and ADGs (weaning to harvest) were 11.8 to 20.5% higher ($P < 0.05$), than those for control steers (Table 3.9). Implants administered at branding did not influence ($P = 0.37$) final live weights, and were actually associated with decreased ($P < 0.05$) post-weaning weight gains. These results were consistent with those of Mader et al. (1985, 1994) and Simms et al. (1988) who reported no influence, in lifetime weight gains, of implanting steers with estrogenic compounds during the suckling phase, provided that two or three additional implants were administered at regular intervals during the subsequent growing and finishing phases of production.

Implants administered at weaning did not influence ($P = 0.22$) post-weaning ADG, but tended ($P = 0.056$) to increase final live weights of steers (Table 3.4). Backgrounding implants increased ($P < 0.05$) post-weaning ADG and final live weights of steers (Table 3.4). The most distinct improvement in growth rate for implanted steers was observed during the finishing period (feedlot entry to harvest) where ADG was increased ($P < 0.05$) 20.2 to 34% compared with ADG for control steers (Table 3.9). Post-weaning rates of gain were higher ($P < 0.05$) and final live weights were heavier ($P < 0.05$) for steers implanted three, four, or five times compared to steers implanted twice (Table 3.5). No differences ($P > 0.05$) in final live weights or post-weaning ADG were observed for treatments that received three, four, or five implants (Table 3.5).

Comparisons of treatment least squares means for harvest and carcass traits (adjusted to the mean external fat thickness for all steers) are presented in Table 3.9. Implant treatment had no effect ($P = 0.15$) on dressing percentage. Mean hot carcass weights for implanted steers were between 8.9 to 13.8% heavier ($P < 0.05$) than those for control steers. Branding implants had no effect ($P = 0.30$) on hot carcass weight; however, weaning implants increased ($P < 0.05$), and backgrounding implants tended ($P = 0.078$) to increase, hot carcass weights (Table 3.4). Administering five implants throughout a steer's lifetime increased ($P < 0.05$) hot carcass weight compared to the use of only two implants (Table 3.5).

Implanting steers increased the mean ($P < 0.05$) longissimus muscle area, measured at the 12$^{th}$ rib (LMA), of steers in all treatment groups compared to the mean for steers in the control group. Numerous studies have reported that the use of implants, administered in the finishing phase, increases LMA (Anderson et al., 1991; Samber et al., 1996; Roeber et al., 2000a). In this study, implanting steers at any production phase prior to feedlot entry did not affect ($P > 0.05$) LMA (Table 3.4).

In agreement with results of the present study (Table 3.9), several previous studies have shown little effect of implant treatment on external fat thickness (Samber et al., 1996; Foutz et al., 1997; Roeber et al., 2000a). Implant treatment affected the estimated percentage of kidney, pelvic, and heart fat, as steer carcasses in the control group had a lower ($P < 0.05$) mean value for this trait than did steer carcasses in all other treatment groups.

Carcasses of steers in the non-implanted control group had higher ($P < 0.05$) mean values for calculated USDA yield grade than did carcasses of steers in nine out of the ten implanted treatment groups. Additionally, the numerical percentage of carcasses assigned yield grades of 1or 2 was lowest for the control group (16%) and highest for treatment six (40%), but these values did not differ statistically ($P > 0.05$) when tested via the chi-square procedure. Implanting steers at branding, weaning, and backgrounding production phases had no effect ($P > 0.05$) on calculated USDA yield grades of carcasses (Table 3.4).

Steers in treatment eleven produced carcasses exhibiting advanced overall maturity scores, differing ($P < 0.05$) from all other treatments except groups eight and ten (data not shown). Implanting at branding, vs. not implanting at this production phase, increased ($P < 0.05$) overall maturity scores (Table 3.4). Steers implanted four or five times produced carcasses exhibiting more advanced ($P < 0.05$) overall maturity scores than did steers implanted zero, two, or three times (Table 3.5). However, 98.9% of the carcasses in this study were classified as A-maturity, so the practical significance of observed differences in maturity scores was considered to be minor.

Previous research has linked the use of combination (androgen and estrogen) implants in steers at the time of reimplantation in the feedlot with an increased incidence of carcasses exhibiting "dark-cutting" beef characteristics (Scanga et al., 1998). In the present study, only 0.7% of the carcasses exhibited the "dark-cutting" condition, and there were no apparent differences among treatments in the incidence of "dark-cutting carcasses (data not shown).

## IMPLICATIONS

Results of this study suggest that lifetime implant protocols affected both the eating quality and tenderness of beef, and emphasize the importance of choosing implant programs based on specific marketing targets for cattle. Producers retaining ownership of steer calves, destined for marketing on a "quality" oriented value-based grid, may choose not to implant cattle until backgrounding or feedlot entry in order to minimize the risk of detrimental effects on beef quality associated with "aggressive" lifetime implant strategies. The effects of lifetime implant protocols on beef acceptability may be of particular interest to vertically coordinated branded beef programs interested in maximizing quality, consistency, and tenderness of their beef products.

**Table 3.1. Description of sample population and simple means for carcass and production traits of steers stratified by ranch**

| | Ranch | | | | | |
|---|---|---|---|---|---|---|
| Item/Trait | 1 | 2 | 3 | 4 | 5 | Pooled SD |
| Ranch location | Wyoming | Texas | Idaho | Wyoming | Wyoming | |
| Cattle breed type | English (75%) × Continental (25%) | Santa Gertrudis | English | English ( ≥ 75%) × Continental ( ≤ 25%) | English ( ≥ 75%) × Continental ( ≤ 25%) | |
| Number of steers | 113 | 116 | 107 | 144 | 70 | - |
| Weaning weight, kg | 228 | 219 | 168 | 174 | 168 | 40.0 |
| Final live weight, kg | 585 | 578 | 569 | 572 | 564 | 49.0 |
| Carcass weight, kg | 369 | 364 | 359 | 358 | 351 | 32.3 |
| Fat thickness, cm | 1.55 | 1.40 | 1.47 | 1.50 | 1.52 | 0.41 |
| Ribeye area, $cm^2$ | 84.8 | 83.5 | 80.3 | 84.8 | 82.2 | 7.96 |
| Calculated yield grade | 3.3 | 3.2 | 3.4 | 3.2 | 3.3 | 0.66 |
| Marbling[a] | 475 | 380 | 465 | 474 | 515 | 104.0 |
| % Choice and Prime | 74.3 | 31.0 | 72.0 | 76.9 | 88.0 | - |
| Number of harvest dates | 2 | 3 | 2 | 3 | 3 | - |
| Days between first and last harvest dates | 27 | 43 | 28 | 48 | 48 | - |

[a]300 = slight, 400 = small, and 500 = modest.

**Table 3.2. Experimental design outlining implant strategy, number of implants administered, and number of steers for each treatment group**

| | Experimental treatment group[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Implant at branding | NO | NO | NO | NO | C | NO | C | C | C | C | C |
| Implant at weaning | NO | NO | NO | NO | NO | RA | NO | NO | RA | RA | RA |
| Implant at backgrounding | NO | NO | RA | S | S | S | RA | S | RA | S | S |
| Implant at feedlot entry | NO | S | S | S | NO | S | S | S | S | S | REV |
| Re-implant in feedlot | NO | REV | REV | REV | REV | REV | REV | REV | REV | REV | REV |
| Total number of implants administered | 0 | 2 | 3 | 3 | 3 | 4 | 4 | 4 | 5 | 5 | 5 |
| Treatments used for branding phase contrast[b] | - | - | O | O | - | O | X | X | - | X | - |
| Treatments used for weaning phase contrast[b] | - | - | - | O | - | X | O | O | X | X | - |
| Treatments used for backgrounding phase contrast[b] | - | O | X | X | - | - | - | - | - | - | - |
| No. of steers ranch 1 | 9 | 10 | 10 | 10 | 11 | 10 | 10 | 10 | 11 | 11 | 11 |
| No. of steers ranch 2 | 11 | 11 | 11 | 11 | 10 | 11 | 11 | 11 | 10 | 9 | 10 |
| No. of steers ranch 3 | 10 | 10 | 10 | 10 | 9 | 10 | 10 | 10 | 10 | 9 | 9 |
| No. of steers ranch 4 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 14 | 13 |
| No. of steers ranch 5 | 7 | 6 | 6 | 6 | 7 | 6 | 6 | 6 | 6 | 7 | 7 |
| Total number of steers (n) | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |

[a]Abbreviations used: NO = no implant; C = Synovex-C®; RA = Ralgro®; S = Synovex-S®; REV = Revalor-S®.

[b]Within each row, data from treatments coded with an X were pooled and contrasted with pooled data from treatments coded with an O.

**Table 3.3. Least squares means of marbling scores of carcasses, USDA quality grade distribution of carcasses, and Warner-Bratzler shear force values[a] (WBSF) for 2.54-cm striploin steak samples cooked to 70$^{O}$ C stratified by lifetime implant strategy**

| | Implant strategy[b] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trait | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | SEM |
| Marbling score[c] | 538$^{w}$ | 485$^{x}$ | 465$^{xy}$ | 454$^{xyz}$ | 464$^{xyz}$ | 439$^{yz}$ | 442$^{yz}$ | 457$^{xyz}$ | 460$^{xyz}$ | 453$^{xyz}$ | 430$^{z}$ | 25.4 |
| Choice and Prime, % | 82$^{w}$ | 70$^{w}$ | 74$^{w}$ | 64$^{w}$ | 68$^{w}$ | 56$^{w}$ | 60$^{w}$ | 62$^{w}$ | 72$^{w}$ | 64$^{w}$ | 60$^{w}$ | - |
| Upper two-thirds Choice and Prime, % | 54$^{w}$ | 36$^{wx}$ | 24$^{xy}$ | 26$^{wxy}$ | 26$^{wxy}$ | 26$^{wxy}$ | 22$^{xy}$ | 26$^{wxy}$ | 22$^{xy}$ | 28$^{wxy}$ | 14$^{y}$ | - |
| Overall mean WBS, kg | 3.54$^{z}$ | 3.95$^{y}$ | 4.46$^{w}$ | 4.19$^{wxy}$ | 4.19$^{wxy}$ | 4.15$^{wxy}$ | 4.12$^{wxy}$ | 4.05$^{xy}$ | 4.05$^{xy}$ | 4.14$^{wxy}$ | 4.38$^{wx}$ | 0.18 |
| Steaks ≤ 4.5 kg (14-d), % | 82$^{w}$ | 66$^{wx}$ | 44$^{wx}$ | 56$^{wx}$ | 54$^{wx}$ | 58$^{wx}$ | 50$^{wx}$ | 70$^{wx}$ | 62$^{wx}$ | 58$^{wx}$ | 38$^{x}$ | - |
| Steaks ≤ 4.5 kg (21-d), % | 94$^{w}$ | 88$^{w}$ | 76$^{w}$ | 74$^{w}$ | 76$^{w}$ | 80$^{w}$ | 78$^{w}$ | 84$^{w}$ | 82$^{w}$ | 80$^{w}$ | 64$^{w}$ | - |

[a]Repetitive measurements of peak shear force values, performed on adjacent steaks of strip loin samples, after respective 14- and 21-d aging periods.

[b]Implant strategy with respect to products administered: 1 = no/no/no/no/no (control); 2 = no/no/no/Synovex-S®/Revalor-S®; 3 = no/no/Ralgro®/Synovex-S®/Revalor-S®; 4 = no/no/Synovex-S®/ Synovex-S®/ Revalor-S®; 5 = Synovex-C®/no/ Synovex-S®/no/ Revalor-S®; 6 = no/ Ralgro®/Synovex-S®/ Synovex-S®/Revalor-S®; 7 = Synovex-C®/no/ Ralgro®/Synovex-S®/Revalor-S®; 8 = Synovex-C®/no/ Synovex-S®/ Synovex-S®/Revalor-S®; 9 = Synovex-C®/ Ralgro®/ Ralgro®/ Synovex-S®/ Revalor-S®; 10 = Synovex-C®/ Ralgro®/ Synovex-S®/ Synovex-S®/Revalor-S®; 11 = Synovex-C®/ Ralgro®/ Synovex-S®/ Revalor-S®/ Revalor-S®.

[c]Adjusted to a common fat thickness

[d]300 = slight, 400 = small, and 500 = modest.

[w,x,y,z]Means in the same row lacking a common superscript letter differ ($P < 0.05$).

**Table 3.4. Probabilities of significance of contrasts for means of implant strategies differing by phase of production**

| | Least squares means | | | | | | *P* of contrasts | | |
|---|---|---|---|---|---|---|---|---|---|
| | Branding | | Weaning | | Backgrounding | | Branding | Weaning | Backgrounding |
| Implanted at production phase[a] Trait[b] | No | Yes | No | Yes | No | Yes | No/Yes | No/Yes | No/Yes |
| Marbling[cd] | 453 | 451 | 451 | 451 | 485 | 460 | 0.825 | 0.936 | 0.087 |
| Choice and Prime, % | 64.7 | 62.0 | 62.0 | 64.0 | 70.0 | 69.0 | 0.406 | 0.661 | 0.9241 |
| Shear force, kg | 4.26 | 4.10 | 4.12 | 4.11 | 3.95 | 4.33 | 0.104 | 0.958 | 0.016 |
| WW, kg | 189 | 194 | - | - | - | - | 0.164 | - | - |
| BKW, kg | 239 | 246 | 239 | 250 | - | - | 0.046 | 0.009 | - |
| FLEW, kg | 360 | 364 | 360 | 367 | 339 | 357 | 0.301 | 0.109 | 0.009 |
| FW | 583 | 578 | 576 | 586 | 563 | 581 | 0.366 | 0.056 | 0.027 |
| ADG, WW to BKW | 1.09 | 1.14 | 1.09 | 1.21 | - | - | 0.222 | 0.006 | - |
| ADG, BKW to FLEW | 1.39 | 1.37 | 1.37 | 1.37 | 1.21 | 1.39 | 0.289 | 0.723 | 0.001 |
| ADG, FLEW to FW | 1.48 | 1.42 | 1.44 | 1.43 | 1.42 | 1.49 | 0.001 | 0.533 | 0.297 |
| ADG,WW to FW | 1.43 | 1.39 | 1.40 | 1.42 | 1.33 | 1.43 | 0.020 | 0.216 | 0.001 |
| HCW[c], kg | 367 | 364 | 361 | 369 | 356 | 365 | 0.302 | 0.022 | 0.078 |
| LMA[c], cm$^2$ | 84.8 | 83.5 | 83.5 | 84.8 | 82.8 | 84.1 | 0.196 | 0.179 | 0.241 |
| YG[c] | 3.24 | 3.25 | 3.25 | 3.26 | 3.27 | 3.25 | 0.973 | 0.984 | 0.814 |
| Overall maturity[c] | $A^{59}$ | $A^{63}$ | $A^{61}$ | $A^{62}$ | $A^{57}$ | $A^{58}$ | 0.014 | 0.303 | 0.375 |

[a]Lifetime implant strategies were identical for the two groups used in each contrast, except for implant administered at the specific production phase. See Table 3.2 for details on the contrasts.

[b]Abbreviations used: WW = weaning weight; BKW = backgrounding weight; FLEW = feedlot entry weight; FW = final live weight; ADG = average daily gain (kg$^{-1}$/d$^{-1}$); HCW = hot carcass weight; LMA = longissimus muscle area; YG = calculated USDA yield grade.

[c]Adjusted to a common fat thickness.

[d]300 = slight, 400 = small, and 500 = modest.

**Table 3.5. Least squares means of implant strategies differing by number of implants administered**

| | Means by number of implants administered | | | | | |
|---|---|---|---|---|---|---|
| Trait[a] | 0 | 2 | 3 | 4 | 5 | SEM |
| Marbling[bc] | $538^{x}$ | $485^{y}$ | $461^{yz}$ | $447^{z}$ | $447^{z}$ | 24.1 |
| Choice and Prime, % | $82.0^{x}$ | $70.0^{xy}$ | $68.7^{xy}$ | $59.3^{y}$ | $65.3^{y}$ | - |
| Upper two-thirds Choice and Prime, % | $54.0^{x}$ | $36.0^{xy}$ | $25.3^{yz}$ | $24.7^{yz}$ | $21.4^{z}$ | |
| Shear force, kg | $3.54^{z}$ | $3.97^{y}$ | $4.27^{x}$ | $4.12^{xy}$ | $4.19^{xy}$ | 0.15 |
| Steaks ≤ 4.5 kg (14-d), % | $82.0^{x}$ | $66.0^{xy}$ | $51.3^{y}$ | $59.3^{y}$ | $52.7^{y}$ | - |
| Steaks ≤ 4.5 kg (21-d), % | $94.0^{x}$ | $88.0^{xy}$ | $75.3^{y}$ | $80.7^{y}$ | $75.3^{y}$ | - |
| FW, kg | $523^{z}$ | $564^{y}$ | $580^{xy}$ | $579^{xy}$ | $582^{x}$ | 5.93 |
| HCW[b], kg | $326^{z}$ | $355^{y}$ | $363^{xy}$ | $364^{xy}$ | $367^{x}$ | 4.01 |
| ADG, kg WW to FW | $1.20^{z}$ | $1.35^{y}$ | $1.43^{x}$ | $1.41^{x}$ | $1.41^{x}$ | 0.048 |
| LMA[b], $cm^2$ | $74.8^{y}$ | $83.2^{x}$ | $83.2^{x}$ | $84.5^{x}$ | $84.5^{x}$ | 1.01 |
| Overall maturity[b] | $A^{57y}$ | $A^{55y}$ | $A^{58y}$ | $A^{62x}$ | $A^{64x}$ | 1.88 |

[a]Abbreviations used: FW = final live weight; HCW = hot carcass weight; WW = weaning weight; LMA = longissimus muscle area; ADG = average daily gain ($kg^{-1}/d^{-1}$).

[b]Adjusted to a common fat thickness.

[c]300 = slight, 400 = small, and 500 = modest.

[x,y,z]Means in the same row lacking a common superscript letter differ ($P < 0.05$).

**Table 3.6. Frequency distribution of consumer demographic information**

| Category | % |
|---|---|
| Gender | |
| Male | 44.2 |
| Female | 55.8 |
| Annual household income level | |
| < $10,000 | 4.6 |
| $10-20,000 | 7.8 |
| $20-30,000 | 10.3 |
| $30-40,000 | 13.7 |
| $40-50,000 | 14.1 |
| $50-60,000 | 12.7 |
| $60-70,000 | 7.0 |
| $70-80,000 | 9.3 |
| $80-90,000 | 5.9 |
| >$90,000 | 14.6 |
| Ethnic background | |
| African-American | 10.8 |
| American Indian | 0.8 |
| Asian or Pacific Islander | 1.7 |
| Hispanic | 8.9 |
| White | 75.7 |
| Other | 2.1 |
| Primary shopper of the household | |
| Yes | 74.6 |
| No | 25.4 |
| Number of times per week beef is consumed as a portion of an evening meal | |
| Never | 0.2 |
| 1 | 10.3 |
| 2 | 31.4 |
| 3 | 33.5 |
| 4 or more times | 24.6 |

**Table 3.7. Least squares means for consumer sensory responses by experimental treatment group**

| Consumer sensory response | Model P > F | SEM | Implant strategy[a] 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tenderness[b] | 0.009 | 0.21 | $3.15^{z}$ | $3.79^{y}$ | $4.05^{xy}$ | $4.00^{xy}$ | $3.87^{xy}$ | $3.91^{xy}$ | $3.78^{y}$ | $3.96^{xy}$ | $3.71^{y}$ | $3.80^{xy}$ | $4.25^{x}$ |
| Flavor[b] | 0.037 | 0.12 | $3.34^{z}$ | $3.62^{yz}$ | $3.81^{xy}$ | $3.76^{xy}$ | $3.71^{xy}$ | $3.73^{xy}$ | $3.74^{xy}$ | $3.83^{xy}$ | $3.70^{xy}$ | $3.82^{xy}$ | $3.92^{x}$ |
| Juiciness[b] | 0.030 | 0.17 | $3.54^{z}$ | $3.91^{y}$ | $4.17^{xy}$ | $4.11^{xy}$ | $4.00^{xy}$ | $4.12^{xy}$ | $4.02^{xy}$ | $4.17^{xy}$ | $4.06^{xy}$ | $4.02^{xy}$ | $4.30^{x}$ |
| Satisfaction with overall eating quality, % | 0.222 | 3.90 | 73.6 | 65.0 | 61.1 | 63.7 | 65.1 | 61.4 | 66.9 | 62.1 | 67.3 | 62.5 | 60.4 |

[a]Implant strategy with respect to products administered: 1 = no/no/no/no/no (control); 2 = no/no/no/Synovex-S®/Revalor-S®; 3 = no/no/Ralgro®/Synovex-S®/Revalor-S®; 4 = no/no/Synovex-S®/ Synovex-S®/ Revalor-S®; 5 = Synovex-C®/no/ Synovex-S®/no/ Revalor-S®; 6 = no/ Ralgro®/Synovex-S®/ Synovex-S®/Revalor-S®; 7 = Synovex-C®/no/ Ralgro®/Synovex-S®/Revalor-S®; 8 = Synovex-C®/no/ Synovex-S®/ Synovex-S®/Revalor-S®; 9 = Synovex-C®/ Ralgro®/ Ralgro®/ Synovex-S®/ Revalor-S®; 10 = Synovex-C®/ Ralgro®/ Synovex-S®/ Synovex-S®/Revalor-S®; 11 = Synovex-C®/ Ralgro®/ Synovex-S®/ Revalor-S®/ Revalor-S®.

[b]Tenderness, flavor, and juiciness like to dislike rating by consumers where: 1 = liked extremely and 9 = disliked extremely.

[x,y,z]Means in the same row lacking a common superscript letter differ ($P < 0.05$).

**Table 3.8. Least squares means for consumer sensory ratings of steaks from implant strategies differing by number of implants administered**

| | Means by number of implants administered | | | | | |
|---|---|---|---|---|---|---|
| Consumer sensory response | 0 | 2 | 3 | 4 | 5 | SEM |
| Tenderness[a] | $3.15^{z}$ | $3.79^{y}$ | $3.97^{y}$ | $3.88^{y}$ | $3.93^{y}$ | 0.157 |
| Flavor[a] | $3.34^{z}$ | $3.62^{y}$ | $3.76^{y}$ | $3.77^{y}$ | $3.82^{y}$ | 0.088 |
| Juiciness[a] | $3.54^{z}$ | $3.91^{y}$ | $4.10^{y}$ | $4.10^{y}$ | $4.13^{y}$ | 0.116 |
| Satisfaction with overall eating quality, % | $73.6^{y}$ | $65.0^{z}$ | $63.2^{z}$ | $63.5^{z}$ | $63.5^{z}$ | 3.075 |

[a]Tenderness, flavor, and juiciness like to dislike rating by consumers where: 1 = liked extremely and 9 = disliked extremely.

[y,z]Means in the same row lacking a common superscript letter differ ($P < 0.05$).

**Table 3.9. Least squares means for growth and carcass traits**

| | Implant strategy[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trait[b] | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | SEM |
| WW, kg | 193$^{v}$ | 190$^{v}$ | 190$^{v}$ | 187$^{v}$ | 188$^{v}$ | 190$^{v}$ | 189$^{v}$ | 194$^{v}$ | 194$^{v}$ | 198$^{v}$ | 190$^{v}$ | 13.8 |
| FEW, kg | 346$^{xy}$ | 339$^{y}$ | 357$^{vwx}$ | 357$^{vwx}$ | 355$^{wx}$ | 365$^{vw}$ | 358$^{vwx}$ | 364$^{vx}$ | 366$^{vw}$ | 371$^{v}$ | 362$^{vw}$ | 11.4 |
| FW, kg | 523$^{x}$ | 564$^{w}$ | 584$^{v}$ | | 578$^{vw}$ | 588$^{v}$ | 575$^{vw}$ | 573$^{vw}$ | 581$^{vw}$ | 588$^{v}$ | 580$^{vw}$ | 6.99 |
| ADG, kg FEW to FW | 1.12$^{x}$ | 1.42$^{vw}$ | 1.50$^{vw}$ | 1.48$^{vw}$ | 1.50$^{v}$ | 1.47$^{vw}$ | 1.42$^{vw}$ | 1.42$^{vw}$ | 1.43$^{vw}$ | 1.41$^{vw}$ | 1.35$^{w}$ | 0.043 |
| DOF, finishing phase | 146$^{v}$ | 147$^{v}$ | 144$^{v}$ | 143$^{v}$ | 148$^{v}$ | 145$^{v}$ | 147$^{v}$ | 144$^{v}$ | 144$^{v}$ | 146$^{v}$ | 148$^{v}$ | 10.7 |
| ADG, kg WW to FW | 1.20$^{y}$ | 1.35$^{x}$ | 1.43$^{vw}$ | 1.43$^{vw}$ | 1.40$^{vwx}$ | 1.44$^{v}$ | 1.39$^{vwx}$ | 1.38$^{wx}$ | 1.41$^{vw}$ | 1.41$^{vw}$ | 1.39$^{vwx}$ | 0.052 |
| HCW[c], | 326$^{z}$ | 355$^{y}$ | 367$^{vwx}$ | 363$^{vwxy}$ | 359$^{wxy}$ | 371$^{v}$ | 361$^{vwxy}$ | 358$^{xy}$ | 364$^{vwxy}$ | 370$^{vw}$ | 366$^{vwxy}$ | 4.86 |
| Dressing[c] % | 62.4$^{v}$ | 63.0$^{v}$ | 62.8$^{v}$ | 62.9$^{v}$ | 62.2$^{v}$ | 63.1$^{v}$ | 62.8$^{v}$ | 62.5$^{v}$ | 62.8$^{v}$ | 63.0$^{v}$ | 63.2$^{v}$ | 0.270 |
| FT, cm | 1.63$^{v}$ | 1.50$^{v}$ | 1.52$^{v}$ | 1.52$^{v}$ | 1.47$^{v}$ | 1.47$^{v}$ | 1.52$^{v}$ | 1.47$^{v}$ | 1.55$^{v}$ | 1.50$^{v}$ | 1.55$^{v}$ | 0.079 |
| LMA[c], $cm^2$ | 75.6$^{z}$ | 83.0$^{xy}$ | 85.1$^{vwx}$ | 84.1$^{vwxy}$ | 81.3$^{y}$ | 86.4$^{v}$ | 84.9$^{vwx}$ | 82.5$^{xy}$ | 83.5$^{wxy}$ | 84.8$^{vwx}$ | 85.9$^{vw}$ | 1.21 |
| KPH[c] % | 2.52$^{v}$ | 2.29$^{w}$ | 2.16$^{wxy}$ | 2.13$^{xy}$ | 2.26$^{wx}$ | 2.18$^{wxy}$ | 2.15$^{wxy}$ | 2.17$^{wxy}$ | 2.14$^{xy}$ | 2.07$^{y}$ | 2.15$^{wxy}$ | 0.058 |
| YG[c] | 3.43$^{v}$ | 3.27$^{wv}$ | 3.24$^{x}$ | 3.25$^{x}$ | 3.38$^{vw}$ | 3.22$^{x}$ | 3.19$^{x}$ | 3.30$^{wx}$ | 3.28$^{wx}$ | 3.27$^{wx}$ | 3.19$^{x}$ | 0.058 |

[a]Implant strategy with respect to products administered: 1 = no/no/no/no/no (control); 2 = no/no/no/Synovex-S®/Revalor-S®; 3 = no/no/Ralgro®/Synovex-S®/Revalor-S®; 4 = no/no/Synovex-S®/ Synovex-S®/ Revalor-S®; 5 = Synovex-C®/no/ Synovex-S®/no/ Revalor-S®; 6 = no/ Ralgro®/Synovex-S®/ Synovex-S®/Revalor-S®; 7 = Synovex-C®/no/ Ralgro®/Synovex-S®/Revalor-S®; 8 = Synovex-C®/no/ Synovex-S®/ Synovex-S®/Revalor-S®; 9 = Synovex-C®/ Ralgro®/ Ralgro®/ Synovex-S®/ Revalor-S®; 10 = Synovex-C®/ Ralgro®/ Synovex-S®/ Synovex-S®/Revalor-S®; 11 = Synovex-C®/ Ralgro®/ Synovex-S®/ Revalor-S®/ Revalor-S®.

[b]Abbreviations used: WW = weaning weight; FEW = feedlot entry weight; FW = final live weight; ADG = average daily gain ($kg^{-1}/d^{-1}$); DOF = d on feed; HCW, hot carcass weight; FT = adjusted fat thickness; LMA = longissimus muscle area; KPH = estimated kidney, pelvic and heart fat; YG = calculated USDA yield grade.

[c]Adjusted to a common fat thickness.

[v,w,x,y,z]Means in the same row lacking a common superscript letter differ ($P < 0.05$).

# CHAPTER IV

# RELATIONSHIPS OF CONSUMER SENSORY RATINGS, MARBLING SCORE, AND SHEAR FORCE VALUE TO CONSUMER ACCEPTANCE OF BEEF STRIP LOIN STEAKS

## ABSTRACT

Logistic regression was used to quantify and characterize the effects of changes in marbling score, Warner-Bratzler shear force (WBSF), and consumer panel sensory ratings for tenderness, juiciness, or flavor on the probability of overall consumer acceptance of strip loin steaks from beef carcasses (n = 550). Consumers (n = 489) evaluated steaks for tenderness, juiciness, and flavor using nine-point hedonic scales (1 = like extremely and 9 = dislike extremely) and for overall steak acceptance (satisfied or not satisfied). Predicted acceptance of steaks by consumers was high (> 85%) if the mean consumer sensory rating for tenderness, juiciness, or flavor for a steak was three or lower on the hedonic scale. Conversely, predicted consumer acceptance of steaks was low (≤ 10%) when the mean consumer rating for tenderness, juiciness, or flavor for a steak was five or higher on the hedonic scale. As mean consumer sensory ratings for tenderness, juiciness, or flavor decreased from three to five, the probability of acceptance of steaks by consumers diminished rapidly in a linear fashion. These results suggest that

small changes in consumer sensory ratings for these sensory traits have dramatic effects on the probability of acceptance of steaks by consumers. Marbling score displayed a weak ($R^2$ *adj* = 0.053), yet significant ($P < 0.01$), relationship to acceptance of steaks by consumers; and, the shape of the predicted probability curve for steak acceptance was approximately linear over the entire range of marbling scores (Traces$^{67}$ to Slightly Abundant$^{97}$), suggesting that the likelihood of consumer acceptance of steaks increases approximately 10% for each full marbling score increase between Slight to Slightly Abundant. The predicted probability curve for consumer acceptance of steaks was sigmoidal for the WBSF model, with a steep decline in predicted probability of acceptance as WBSF values increased from 3.0 to 5.5 kg. Changes in WBSF within the high (> 5.5 kg) or low (< 3.0 kg) portions of the range of WBSF values had little effect on the probability of consumer acceptance of steaks.

## INTRODUCTION

According to the 2001 to 2004 Beef Industry Long Range Plan, improving consumer satisfaction with the palatability and consistency of beef products is one of the U. S. beef industry's key strategies for attaining the goal of increasing consumer beef demand by six percent by the year 2004 (NCBA, 2001). Beef palatability research studies often use traits such as marbling score, Warner-Bratzler shear force (WBSF) value, and consumer or trained taste panel evaluations of tenderness, juiciness, and flavor as indicators of beef palatability. However, only a few large consumer studies (Savell et al., 1987; Miller et al., 2001; Lorenzen et al., 2003) have examined the impact of relative differences in these traits on overall consumer acceptance of steaks, because of the difficulty and costs associated with conducting large-scale consumer taste panels. Development of reliable statistical models representing relationships between the most commonly measured beef palatability traits and overall consumer acceptance of steaks would be useful to the beef industry, especially when interpreting results of beef palatability studies that have not directly measured overall consumer acceptability ratings in consumer taste panels. Consequently, the current analyses were undertaken to quantify and document the impacts of changes in several commonly measured beef traits (marbling score, WBSF, and consumer panel sensory ratings for tenderness, juiciness, or flavor) on the probability of overall consumer acceptance of beef strip loin steaks.

## MATERIALS AND METHODS

*Sample.* Data presented in this report were from the same source as data reported by Platter et al. (2003). Detailed descriptions of the cattle management history, experimental procedures through harvest, and strip loin sample collection were provided in the preceding report (Platter et al., 2003). Briefly, strip loins (Institutional Meat Purchase Specification 180; USDA, 1988) were collected from the right sides of 550 carcasses originating from crossbred steers of various biological types. Strip loins were transported to the Colorado State University Meat Laboratory, where a single steak 2.54-cm thick steak was removed from the anterior end of each strip loin. The remaining portion of the strip loin was placed in a vacuum-sealed bag and aged at 2°C for 14 d. After the aging period, the strip loin sections were frozen and stored at -20°C. Strip loin sections were fabricated (in the frozen state) into 2.54-cm thick steaks using a band saw (model 5700, Hobart, Troy, OH). The first steak from the anterior end of each strip loin was identified and placed in an individual vacuum-sealed bag for subsequent WBSF determination. The next two steaks were identified, individually vacuum-packaged, and stored for subsequent untrained, consumer taste panel analysis. Upon completion of the fabrication process, steaks were sorted for intended use and returned to frozen storage (-20°C). Samples used for sensory analysis were stored frozen for approximately 180 d.

*Shear Force Determination.* The 14-d aged steak from each strip loin section was removed from freezer storage and allowed to thaw for 24 h at 2°C. Steaks were cooked on an electric conveyor grill (model TGB-60, Magikitch'n, Quakertown, PA) for 6 min and 35 sec at a setting of 176°C to a target internal temperature of 70°C. After cooking, each steak was allowed to equilibrate to room temperature (22°C), and six to ten 1.27-cm diameter cores were removed from each steak parallel to the muscle fiber orientation. Each core was sheared once, perpendicular to the muscle fiber orientation, using a Warner-Bratzler shear machine (G-R Electric Manufacturing Co., Manhattan, KS), and peak shear force measurements were recorded and averaged to obtain a single WBSF value for each steak.

*Consumer Sensory Panels.* Branson Research Associates, Bryan, TX performed extensive demographic analyses of the Denver, CO metropolitan area to select a test population representative of the age, income, and ethnic background of the U.S. population. Consumers were contacted by telephone and pre-screened to ensure that they were at least 18 yr of age and consumers of beef products. Four testing sites, located in the Denver metropolitan area (Denver, Lakewood, Arvada, and Littleton), were used to conduct a total of 25 consumer panel sessions that included a total of 489 consumers. Because this sample population represented consumers from diverse age levels, income levels, and ethnic backgrounds, and included consumers categorized as "beef-eaters," the consumer demographic profile was considered an acceptable population to model relationships of consumer sensory ratings, WBSF, and marbling scores to overall acceptance of steaks by consumers.

Within a session, paired steaks from 22 different carcasses were selected for sensory evaluation. Steak identification numbers, as well as order of service to consumer panelists, were assigned randomly to each of the 20 consumers per session. Frozen steaks prepared for consumer panel evaluation were thawed at 2°C for 24 h and cooked for approximately 15 min on electric grills (model GGR64, Salton, Inc., Mt. Prospect, IL) designed to heat steaks from both sides, simultaneously, to a final internal temperature of 70°C. A Type K thermocouple (Omega Engineering Inc., Stamford, CT) was placed in the geometric center of each steak, and internal temperature was monitored during cooking using a microprocessor thermometer (model HH21, Omega Engineering Inc., Stamford, CT). Steaks were cut into 1.3 × 1.3 × 2.5-cm portions, covered, and placed in a warming oven (49°C) until consumers were served. One steak from each pair of steak samples from each carcass identification number was prepared for serving during the first half of the session, whereas the other matched steak was prepared for serving in the last half of the session to minimize any changes in sensory attributes associated with holding samples for longer periods of time in a warming oven.

Consumer panel evaluation procedures used for this study were approved by the Colorado State University, Use of Humans in Research Committee. At each location, consumers were randomly seated at tables arranged in a circular order in a room containing standard fluorescent lighting. Instructions regarding the structure of the ballot and sampling procedures for the steak samples were provided verbally to the consumers in each session. Panelists were provided double-distilled, deionized water and saltless saltine crackers, and were instructed to take a bite of cracker and a drink of water before evaluating each sample to cleanse their palate and to minimize sensory fatigue between samples.

Consumers rated each steak sample for like/dislike of tenderness, flavor, and juiciness using nine-point, end-anchored hedonic scales (1 = like extremely and 9 = dislike extremely). Additionally, consumers were asked if they were satisfied ("yes" or "no") with the overall eating quality of each sample.

*Statistical Approach and Rational.* The statistical technique chosen to model the relationship between consumer sensory ratings, marbling, or WBSF and overall acceptability of steaks by consumers was logistic regression analysis. Logistic regression analysis models the relationship between a binary or ordinal response variable (e.g., "yes" or "no" response) and one or more explanatory variables (Ott and Longnecker, 2001). Logistic regression transforms the dependent variable into a logit variable (the natural log odds of the response variable occurring or not). After transformation of the dependent variable, logistic regression applies maximum likelihood estimation, and, in this way, can estimate the probability that a certain event will occur. Maximum likelihood estimation seeks to maximize the log likelihood that the observed values of the dependent variable will be predicted from the observed values of the independent variables. Unlike ordinary least squares regression, logistic regression does not require normally distributed variables, does not assume linearity of relationship between the independent variables and the dependent variable, and does not assume homoscedasticity

(Hosmer and Lemeshow, 2000). The binomial response variable in this case was the overall consumer acceptance ("yes" or "no") of a steak. Explanatory variables included WBSF value, marbling score, or mean consumer sensory rating for tenderness, juiciness, or flavor.

Numerous studies have documented the existence of a tenderness gradient across longissimus muscle steaks that may impact WBSF and sensory tenderness ratings of longissimus muscle (Smith et al., 1969; Wheeler et al., 1996; Kerth et al., 2002). Additionally, the ASTM (1968) Manual on Sensory Testing Methods, Special Technical Bulletin 434 stated that, although the variability of consumer preference testing is high, the use of larger numbers of panelists will improve the discrimination of the test. These reports suggest that both location of the sample within a steak and panelist bias may influence individual consumer sensory ratings. Averaging consumer sensory ratings by steak reduces the variance of consumer panel data (Polkinghorne et al., 1999). Nevertheless, outlier sensory rating responses made by individual consumers can greatly influence average steak sensory ratings. Recently, researchers employed by Meat and Livestock Australia developed standards for a new grading system (Meat Standards Australia) to describe palatability of beef based solely on the use of sensory results from consumer testing (Thompson, 2002). Outliers among consumer sensory ratings were prevalent in the dataset used for the development of Meat Standards Australia, requiring researchers to devise a method to minimize the impact of these observations on the palatability prediction equation (Polkinghorne et al., 1999). In that analysis, average consumer sensory ratings were calculated after four responses (the two highest and the two lowest sensory ratings) out of a total of 10 individual consumer responses for each steak were removed from the dataset (Polkinghorne et al., 1999). In our study, seven to ten consumers were asked if they were satisfied (yes or no) with the overall eating quality of each steak. Effects of individual consumer bias were minimized in our analyses by using an average consumer satisfaction rating, by steak (without removal of outliers), to designate whether or not the overall palatability of a steak was designated as acceptable by consumers. Steaks were designated as acceptable, in our analyses, if two-thirds or more (an average of 66% or more) of the consumers sampling each steak indicated that they were satisfied with its overall eating quality.

*Data Analysis.* Analyses were conducted to examine the correlation structure of the data using the PROC CORR procedure, and logistic regression equations were developed using the PROC LOGISTIC procedure of SAS (SAS Inst. Inc., Cary, NC). Generalized adjusted coefficients of determination were calculated for each model using the RSQ option of the LOGISTIC procedure. Predicted probability values were obtained from each logistic regression model, and the accuracy of these predictions was tested against actual observations in the original dataset via a classification table using a procedure that approximates an unbiased "jackknifing" method (SAS, 1999). The predictive accuracy of each model also was tested on a separate population (Wheeler et al., 2002) by computing the predicted probability values of overall acceptance of steaks by consumers and comparing these predictions with actual observations via a classification table.

## RESULTS AND DISCUSSION

*Consumer Panel Participants.* Frequency distributions for consumer demographic attributes are reported by category as a percentage of the total sample population (Table

4.1). Approximately 56% of the consumer panelists were female, whereas about 44% were male. A high percentage (80%) of panelists had some form of post-secondary education, and about 52% were married. The age of consumers in the sample population ranged from 18 to 84 yr, and the mean age of consumers was 46 yr. Of the incomes reported, the highest percentage of consumers had a total household income of between $40,000 and $49,000/yr, but incomes ranged from less than $10,000 to greater than $90,000/yr among panelists. A high percentage of consumers reported their ethnicity as Caucasian (76%), followed by African-American (11%), and Hispanic (8%). A very low percentage of the sample population reported an ethnicity of American Indian and Asian or Pacific Islander.

Survey responses of panelist's consumption and eating preferences are presented in Table 4.2. Seventy-five percent of the consumers in the sample population were the primary shopper of the household. Fifty-eight percent of panelists reported consuming beef as a portion of an evening meal three or more meals/wk. Fewer consumers reported consuming pork (5%) and poultry (31%) as a portion of an evening meal three or more times each wk. A small percentage (9%) of consumers reported consuming a vegetarian evening meal three or more times each wk. A majority (93%) of panelists reported eating an evening meal outside of the home at least once a wk. Fifty-two percent of the consumers in the sample population listed tenderness as the most important sensory attribute when purchasing beef, whereas 38% of consumers considered flavor, and 11% of consumers considered juiciness, as most important. These results are remarkably similar to consumer survey responses reported by Huffman et al. (1996), where 51% of consumers listed tenderness, 39% of consumers listed flavor, and 10% of consumers listed juiciness as the most important beef sensory attribute when determining their eating satisfaction in a home or restaurant environment.

*Marbling and Shear Force Characteristics of Sample.* Distribution of marbling scores of steaks in the experimental sample is provided in Figure 4.1. According to data from the 2000 National Beef Quality Audit, only 0.43% of carcasses from fed steers and heifers had Moderately Abundant or Abundant marbling scores and only 0.02% of carcasses had marbling scores of Practically Devoid (McKenna et al., 2002). The mean marbling score of steaks used in this analysis was 458 ± 105 (Small$^{58}$) with a range in marbling score from Traces$^{67}$ to Slightly Abundant$^{97}$, resulting in a sample that closely resembled the range in marbling scores of the majority of U.S. fed steer and heifer carcasses.

The distribution of WBSF values is presented in Figure 4.2. The range for WBSF values was from 2.33 to 7.51 kg, with a mean WBSF value of 4.35 ± 0.93 kg. Other studies (Morgan et al., 1991; George et al., 1999; Brooks et al., 2000) have reported slightly lower means, but similar ranges, for WBSF values for retail strip loin steaks.

*Correlation analysis.* Results of the analysis of the correlation structure of the data revealed moderate to high correlations ($P < 0.05$) among mean marbling scores, WBSF values, and mean consumer palatability ratings (Table 4.3). The correlation between consumer tenderness ratings and WBSF values was moderately high (r = 0.63). Marbling scores were moderately correlated with WBSF, consumer tenderness ratings, consumer juiciness ratings, and consumer flavor ratings (r = -0.31, -0.27, -0.34, -0.22, respectively). High, positive correlations (r = 0.80 to 0.84) were observed among all consumer sensory ratings.

*Interpretation of logistic regression diagnostic statistics.* Statistics describing the strength of the relationship between the independent variables and the dependent variable, the discriminatory power, and the success of a regression equation are different for logistic regression than for ordinary linear regression (Hosmer and Lemeshow, 2000). There is no direct analog to the coefficient of determination ($R^2$) in logistic regression; however, a generalized $R^2$ ($R^2$ *adj*) that attempts to measure the strength of association of a logistic regression model has been proposed (Nagelkerke, 1991). The area under the receiver operating characteristic curve (c-statistic) is a measure of the discriminatory power of the logistic equation (Hosmer and Lemeshow, 2000). The value of the c-statistic can range from 0.50 (the model's predictions are no better than chance) to 1.0 (the model can perfectly discriminate the observed responses in the sample). Classification tables are often used to tally correct and incorrect estimates of the logistic regression model and measure the predictive accuracy of the model (SAS, 1995). A $2 \times 2$ classification table for binary response variables can be created by comparing the predicted outcomes of the model with the actual observations in the dataset. When the value of the estimated probability of an observation is greater than, or equal to, 0.50, the observation is classified as a predicted event (i.e., an acceptable steak). When the estimated probability is less than 0.50, the observation is classified as a predicted nonevent (i.e., an unacceptable steak). From the classification table, the probability that the model correctly classifies the sample data (percent correct) can be calculated. Additionally, the ratio of the number of correctly classified acceptable steaks to the total number of acceptable steaks (sensitivity) and the ratio of the number of correctly classified non-acceptable steaks to the total number of non-acceptable steaks (specificity) can be derived from a classification table.

*Sensory rating models.* Figure 4.3 displays plots of the predicted probability curves for overall acceptance of steaks by consumers as derived from the cumulative logit response functions of average steak consumer ratings for tenderness, juiciness, or flavor. The $R^2$ *adj* values for predicting overall acceptance of steaks by consumers were 0.574, 0.516, and 0.520 for models using average steak consumer ratings for tenderness, juiciness, and flavor, respectively. The discriminatory power of the sensory rating models were high (c-statistic = 0.869 to 0.891), and the models correctly classified a large percent of the observations (percent correct = 77.7 to 79.3%). Sensitivity percentages were higher than specificity percentages for consumer tenderness (83.2 vs. 75.2%), juiciness (78.6 vs. 76.7%), and flavor (82.1 vs. 75.6) rating models predicting overall acceptance of steaks by consumers (data not shown). Ordinary least squares regression analysis performed by Huffman et al. (1996) indicated that consumer tenderness ratings accounted for the most variation ($R^2$ = 0.56) in overall consumer palatability ratings for steaks prepared in a restaurant setting, whereas consumer flavor ratings accounted for the most variation ($R^2$ = 0.67) in overall consumer palatability ratings for steaks prepared in the home. In that study, a three-variable ordinary, least squares regression model that included tenderness, juiciness, and flavor ratings accounted for 79% of the variation in consumer overall palatability ratings (Huffman et al., 1996). Similarly, in the current study, a three-variable logistic regression equation including average steak consumer ratings for tenderness, juiciness, and flavor had a stronger relationship ($R^2$ *adj* = 0.62) to overall steak acceptance and more discriminatory power (c-statistic = 0.908) than single consumer sensory rating models (data not shown).

Predicted probability curves for overall acceptance of steaks by consumers were similar for all sensory rating models. This was expected, given the high correlations among consumer sensory ratings for tenderness, juiciness, and flavor (Table 4.3). Predicted overall acceptance of steaks by consumers was high (> 85%) if the average consumer sensory rating for tenderness, juiciness, or flavor for a steak was three, or lower, on a nine-point hedonic scale. Conversely, predicted consumer acceptance of steaks was low ($\leq$ 10%) when the average consumer rating for tenderness, juiciness, or flavor for a steak was five or higher. As mean consumer sensory ratings for tenderness, juiciness, or flavor decreased from three to five, the probability of overall acceptance of steaks by consumers diminished rapidly in a linear fashion. These results suggest that small changes in consumer sensory ratings for these sensory traits have dramatic effects on the probability of overall consumer acceptance of steaks. Additionally, these results suggest a mean consumer sensory rating for tenderness, juiciness, or flavor which is at, or beyond, the mid-point of a nine-point scale would result in a low probability of overall steak acceptance by consumers.

*Marbling score model.* The probability curve for overall acceptance of steaks by consumers, as predicted by the cumulative logit response functions of marbling scores, is presented in Figure 4.4. The $R^2$ *adj* value for predicting overall steak acceptance for the marbling score model was 0.053, suggesting a relatively weak relationship between marbling score and overall consumer acceptability. The marbling score model had a c-statistic of 0.574, and correctly classified 54.5% of the observations, indicating low discriminatory power of the model. These results are consistent with research that has shown marbling scores to have a low to moderate relationship with overall beef palatability ratings (Crouse and Smith, 1978; Tatum et al., 1982; Smith et al., 1984).

Marbling score is used as the primary predictor of beef palatability among carcasses of similar maturity characteristics in the USDA beef grading system (USDA, 1997). Based on results of a large consumer retail beef study, Savell et al. (1987) concluded that increasing the amount of marbling in top loin steaks had a positive impact on the eating quality of beef. Trained sensory panel results from other studies have indicated that overall palatability ratings of beef steaks generally increased as marbling score increased, but the differences in palatability ratings for each successive increase in marbling score were not always statistically significant (Tatum et al., 1980; Smith et al., 1984). Interestingly, the shape of the predicted probability curve for overall acceptance of steaks by consumers in this analysis was nearly linear over the entire range of marbling scores (Traces$^{67}$ to Slightly Abundant$^{97}$), and suggests that the likelihood of consumer acceptance of steaks increases approximately 10% for each full marbling score increase from Slight to Slightly Abundant (Figure 4.4).

*Shear force model.* A majority of consumers in this study (Table 4.2), and other studies (Huffman et al., 1996; CCA, 2002), indicated that tenderness is the single most important palatability trait for determining overall steak acceptance. Warner-Bratzler shear force is routinely used by scientists as an objective measurement of meat tenderness and, despite criticism, has remained the most popular and accurate instrumental measurement of meat tenderness (Wheeler et al., 1997). Otremba et al. (1999) and Wheeler et al. (1996) reported WBSF value correlations (r) of -0.68 and -0.85, respectively, with trained panelist overall tenderness ratings for longissimus steaks. Shackelford et al. (1995) reported that a single variable regression equation using WBSF values explained 73% of the variation in trained panelist overall tenderness ratings for longissimus muscle steaks. Because tenderness is an important driver of overall steak acceptability and WBSF is used as an objective measure of tenderness, it is reasonable to assume that WBSF values could be used in a logistic regression model to predict overall acceptability of steaks by consumers.

Figure 4.5 represents a plot of the predicted probability curve for overall consumer acceptance of steaks resulting from the cumulative logit response functions of WBSF value. The strength of the relationship between consumer acceptance of steaks and WBSF values was moderate ($R^2$ *adj* = 0.225). The WBSF model had moderate discriminatory power (c-statistic = 0.738) and correctly classified 66.7% of the observations. Boleman et al. (1997) demonstrated that consumer perceptions of tenderness and overall satisfaction of beef top loin steaks were affected when steaks were segmented into categories based on WBSF value. Lorenzen et al. (2003) reported low correlations of WBSF values with "in-home" consumer panelist ratings of tenderness (r = -0.26) and consumer overall likeness ratings (r = -0.18) for top loin steaks, but attributed the lack of relationship of these traits, in part, to the variation in steak preparation encountered during "in-home" consumer studies.

Shackelford et al. (1991) used trained taste panel responses to determine WBSF "threshold" values for predicting acceptable consumer steak tenderness ratings ("slightly tender" or higher). Results of that analysis indicated that a WBSF value of 4.6 kg would have a 50% chance, and a WBSF value of 3.9 kg would have a 68% chance, of being rated as acceptable in tenderness by consumers. Results of our analysis produced results similar to those of Shackelford et al. (1991), with predicted probabilities of consumer steak acceptance of 50% and 68% at approximate WBSF values of 4.4 kg and 3.7 kg, respectively. Many researchers have employed various WBSF values for describing consumer tenderness acceptability "thresholds" in beef palatability studies (Shackelford et al., 1995; Miller et al., 2001; Vote et al., 2003). In a review, Meilgaard et al. (1999) stated that some experts question the validity of sensory "thresholds" because they are ill-defined in theory, may not reproduce results well, and may not even exist.

An advantage of the current form of analysis describing the relationship of WBSF values to overall acceptance of steaks by consumers is that the relationship can be compared over a wide range of WBSF values. The predicted probability curve for overall acceptance of steaks by consumers was sigmoidal-shaped for the WBSF model, with a steep decline in predicted probability of acceptance as WBSF values increased from 3.0 to 5.5 kg. Changes in WBSF within the high (> 5.5 kg) or low (< 3.0 kg) portions of the range of WBSF values had little effect on the probability of consumer acceptance of steaks.

*Validation of Logistic Regression Models.* Consumer sensory ratings, marbling score, and WBSF value models developed in our analysis were tested against the population described by Wheeler et al. (2002). Predicted probabilities for observations in the validation dataset were calculated from the logistic regression equations developed from the original population, and compared to actual consumer acceptance ratings via a classification table. Of the three sensory ratings models, the tenderness rating model was the most accurate (78.7%), whereas the juiciness and flavor rating models were less accurate (63.7 and 68.7%, respectively) for determining whether or not two-thirds of consumers would have rated steaks as acceptable. The equations from the marbling score and WBSF models were 57.3 and 70.7% accurate, respectively, for determining whether, or not, two-thirds of consumers would have rated steaks as acceptable. Applying the logistic regression equations to a separate dataset for validation purposes produced results similar to those observed in the original analyses.

## IMPLICATIONS

The relationship between common measurements of beef palatability traits and overall consumer steak acceptance levels is extremely important when interpreting the results of beef palatability research. Marketing implications of small, but significant, differences in consumer sensory ratings, marbling scores, or shear force values can be difficult to interpret in some beef palatability studies. Results of our study may assist researchers in describing the potential effects of results from research studies of beef palatability on overall steak acceptability as perceived by consumers.

**Table 4.1. Consumer panelist demographic information**

| Item | Category | Percentage of respondents |
|---|---|---|
| Gender | Male | 44.2 |
| | Female | 55.8 |
| Age, yr | < 30 | 19.7 |
| | 30 to 49 | 36.8 |
| | 50 to 69 | 35.6 |
| | ≥ 70 | 7.9 |
| Number of people within household | 1 | 23.3 |
| | 2 | 33.9 |
| | 3 | 16.0 |
| | 4 or more | 26.8 |
| Marital status | Single | 25.4 |
| | Married | 51.9 |
| | Divorced | 13.0 |
| | Widowed | 6.4 |
| | Separated | 1.2 |
| | Domestic partnership | 2.1 |
| Education, last grade of school completed | Elementary school | 1.2 |
| | Some high school | 4.1 |
| | Completed high school | 14.7 |
| | Some college | 24.0 |
| | Completed college | 29.1 |
| | Graduate school | 15.1 |
| | Trade school | 11.6 |
| Total household income, $/yr | < 20,000 | 12.5 |
| | 20,000 to 39,999 | 24.0 |
| | 40,000 to 59,999 | 26.8 |
| | 60,000 to 79,999 | 16.3 |
| | ≥ 80,000 | 20.4 |
| Ethnic background | Caucasian | 75.7 |
| | African-American | 10.8 |
| | Hispanic | 8.9 |
| | American Indian | 0.8 |
| | Asian or Pacific Islander | 1.7 |
| | Other | 2.1 |

**Table 4.2. Survey responses of panelist's consumption and eating preferences**

| Item | Category | Percentage of respondents |
|---|---|---|
| Panelist was primary shopper of household | Yes | 74.7 |
| | No | 25.3 |
| Average number of times per week **beef** is consumed as a portion of evening meal | Never | 0.2 |
| | 1 time | 10.3 |
| | 2 times | 31.4 |
| | 3 or more times | 58.1 |
| Average number of times per week **pork** is consumed as a portion of evening meal | Never | 20.4 |
| | 1 time | 58.9 |
| | 2 times | 16.0 |
| | 3 or more times | 4.8 |
| Average number of times per week **poultry** is consumed as a portion of evening meal | Never | 2.7 |
| | 1 time | 24.3 |
| | 2 times | 42.1 |
| | 3 or more times | 30.9 |
| Average number of times per week an evening meal does not include meat | Never | 44.2 |
| | 1 time | 35.3 |
| | 2 times | 12.0 |
| | 3 or more times | 8.5 |
| Average number of times per week an evening meal is consumed outside the home | Never | 7.0 |
| | 1 time | 52.8 |
| | 2 times | 24.4 |
| | 3 or more times | 15.8 |
| Beef quality attribute considered most important to the panelist | Tenderness | 51.6 |
| | Flavor | 37.6 |
| | Juiciness | 10.8 |

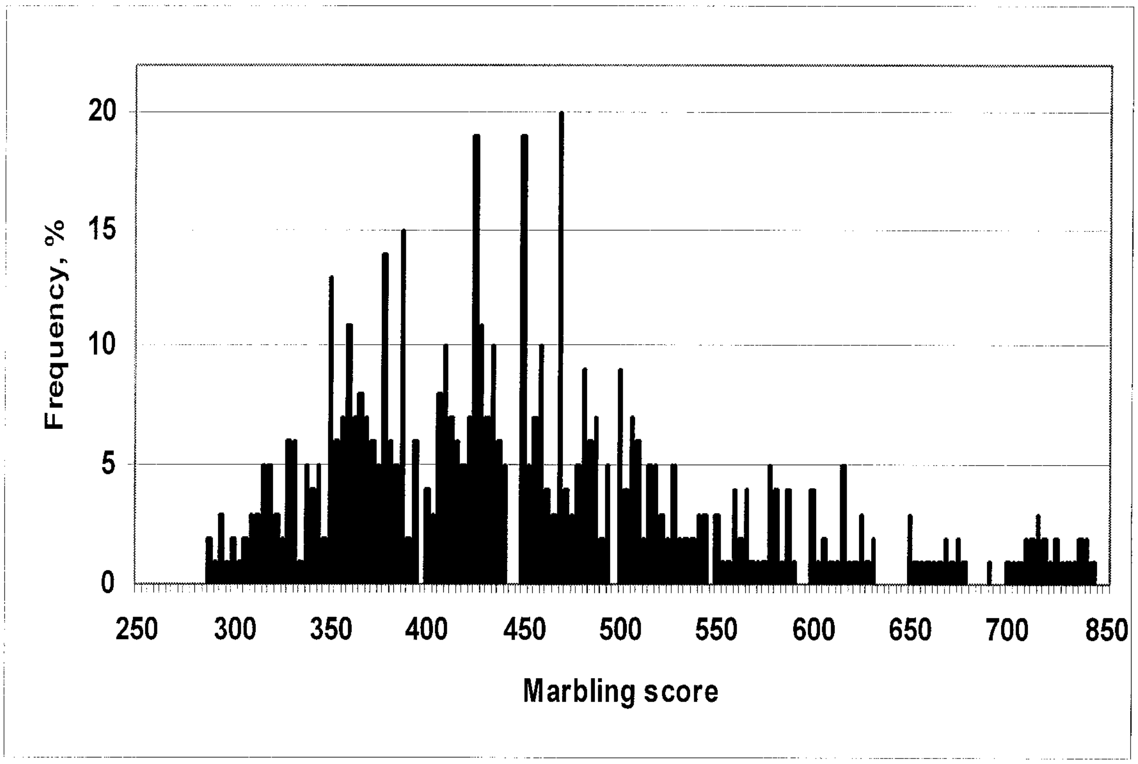


**Figure 4.1. Frequency distribution of marbling scores of steaks in the test population (n = 550). Marbling score: 200 = Traces, 300 = Slight, 400 = Small, 500 = Modest, 600 = Moderate, and 700 = Slightly Abundant.**

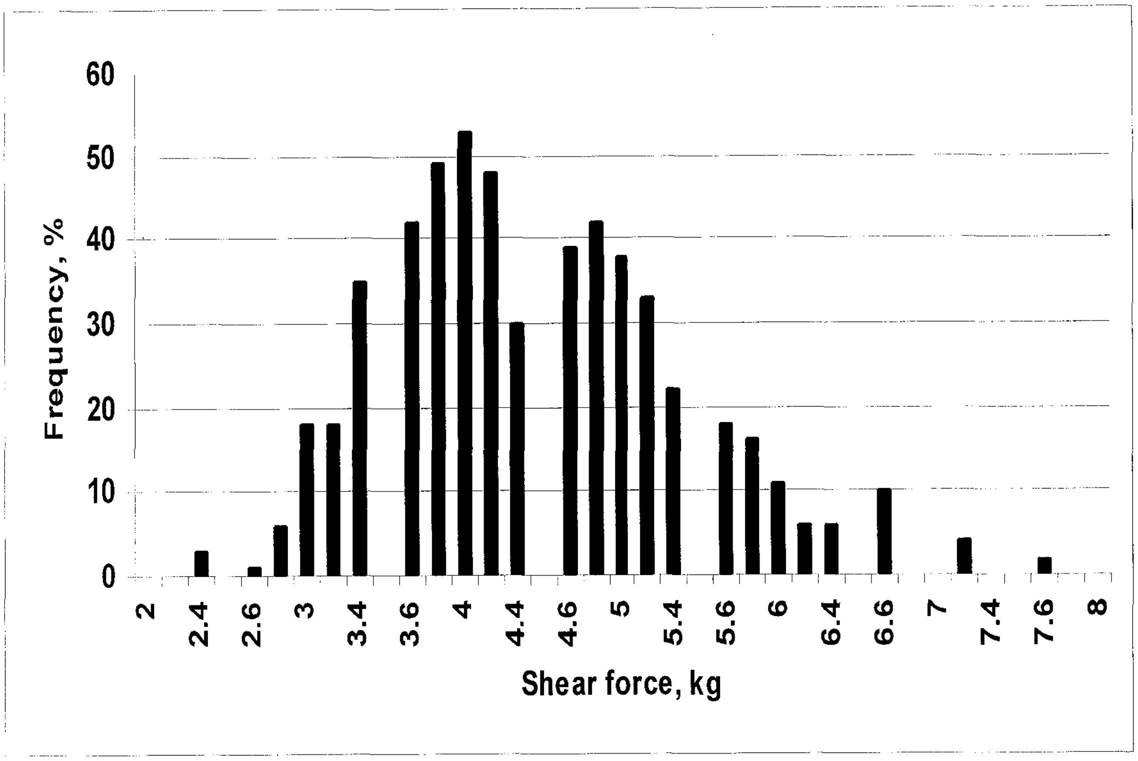


**Figure 4.2. Frequency distribution of Warner-Brazler shear force values of steaks in the test population (n = 550).**

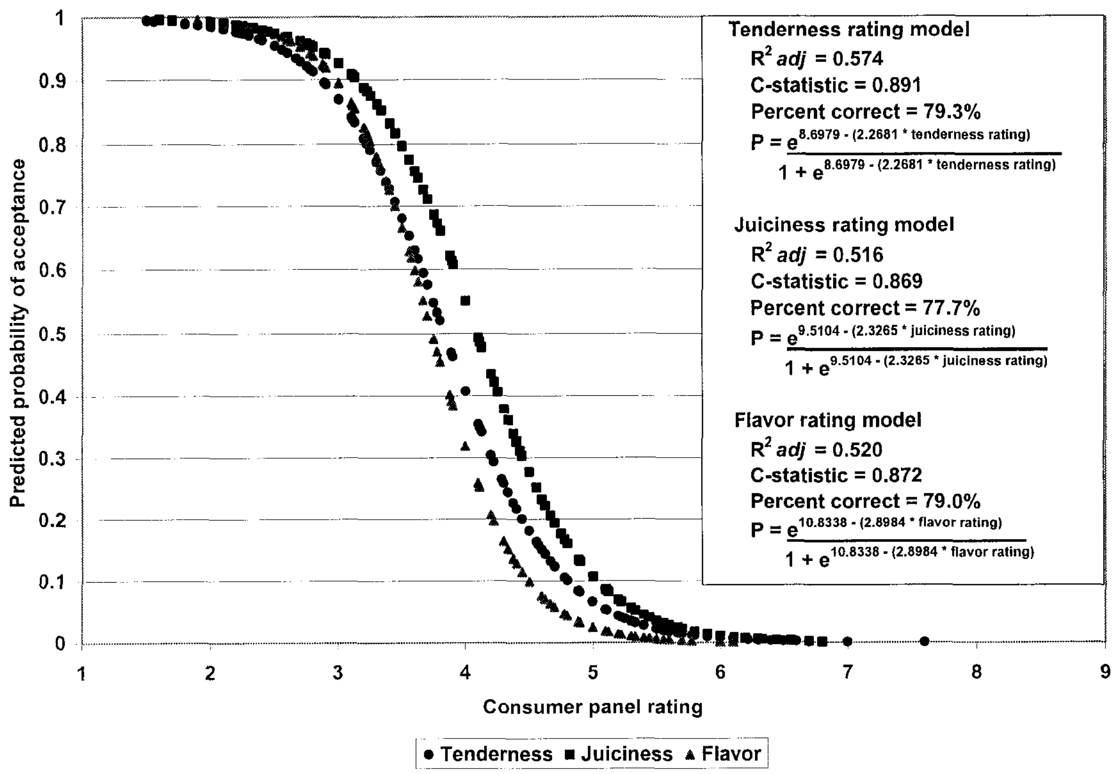


**Figure 4.3. Predicted probability of overall consumer acceptance of steaks by mean consumer rating for tenderness, juiciness and flavor. Consumer like to dislike rating, for tenderness, flavor, and juiciness (1 = like extremely and 9 = dislike extremely). The $R^2$ *adj* is a generalized coefficient of determination. The c-statistic is the area under the receiver operating characteristic curve. Percent correct is the percentage of observations in the dataset correctly classified by the logistic regression equation. The symbol "P" represents the predicted probability for a steak being rated as acceptable by consumers. The constant "e" equals the base of the natural logarithm (2.718282).**

**Table 4.3. Simple correlation coefficients of mean marbling scores, mean shear force values, and mean consumer palatability ratings**

| Trait[a] | Shear force | Marbling score | Tenderness | Juiciness | Flavor |
|---|---|---|---|---|---|
| Shear force | | -0.31* | 0.63* | 0.46* | 0.41* |
| Marbling score | | | -0.27* | -0.34* | -0.22* |
| Tenderness | | | | 0.84* | 0.80* |
| Juiciness | | | | | 0.81* |
| Flavor | | | | | |

[a]Shear force = 14-d shear force value; Marbling score = expert marbling score; Tenderness, Juiciness, and Flavor ratings (1 = like extremely to 9 = dislike extremely).

*$P < 0.05$.

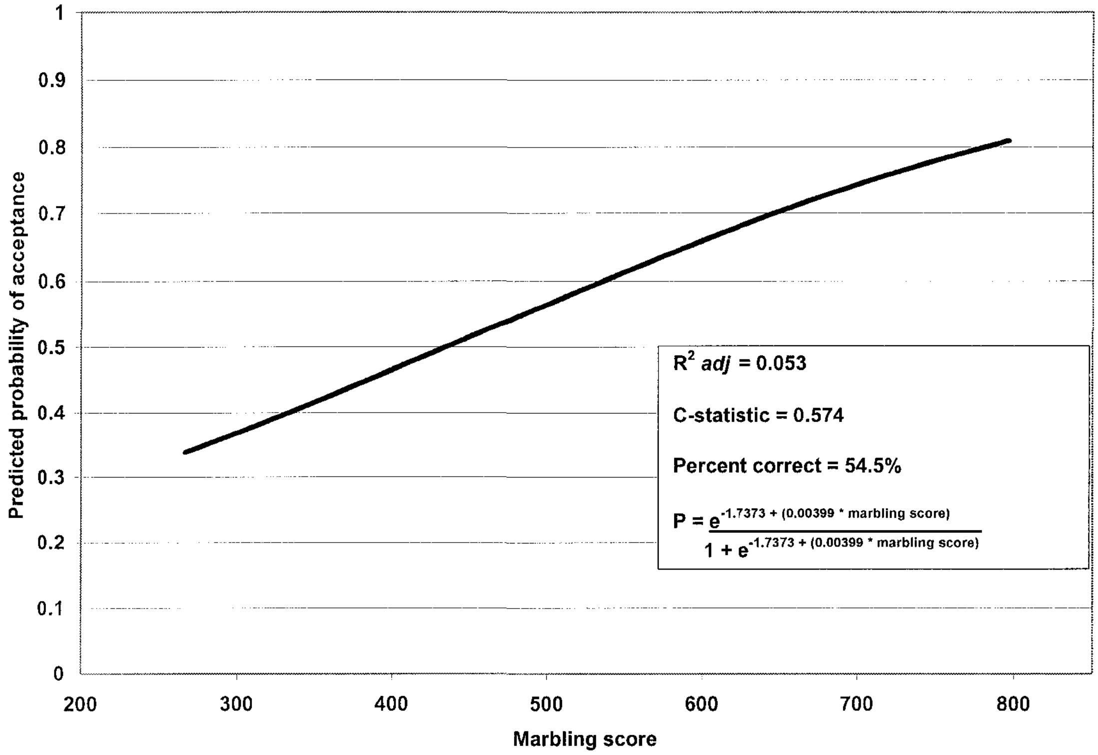


**Figure 4.4. Predicted probability of overall consumer acceptance of steaks by mean marbling score. Marbling score: 200 = Traces, 300 = Slight, 400 = Small, 500 = Modest, 600 = Moderate, and 700 = Slightly Abundant. The $R^2$ *adj* is a generalized coefficient of determination. The c-statistic is the area under the receiver operating characteristic curve. Percent correct is the percentage of observations in the dataset correctly classified by the logistic regression equation. The symbol "P" represents the predicted probability for a steak being rated as acceptable by consumers. The constant "e" equals the base of the natural logarithm (2.718282).**

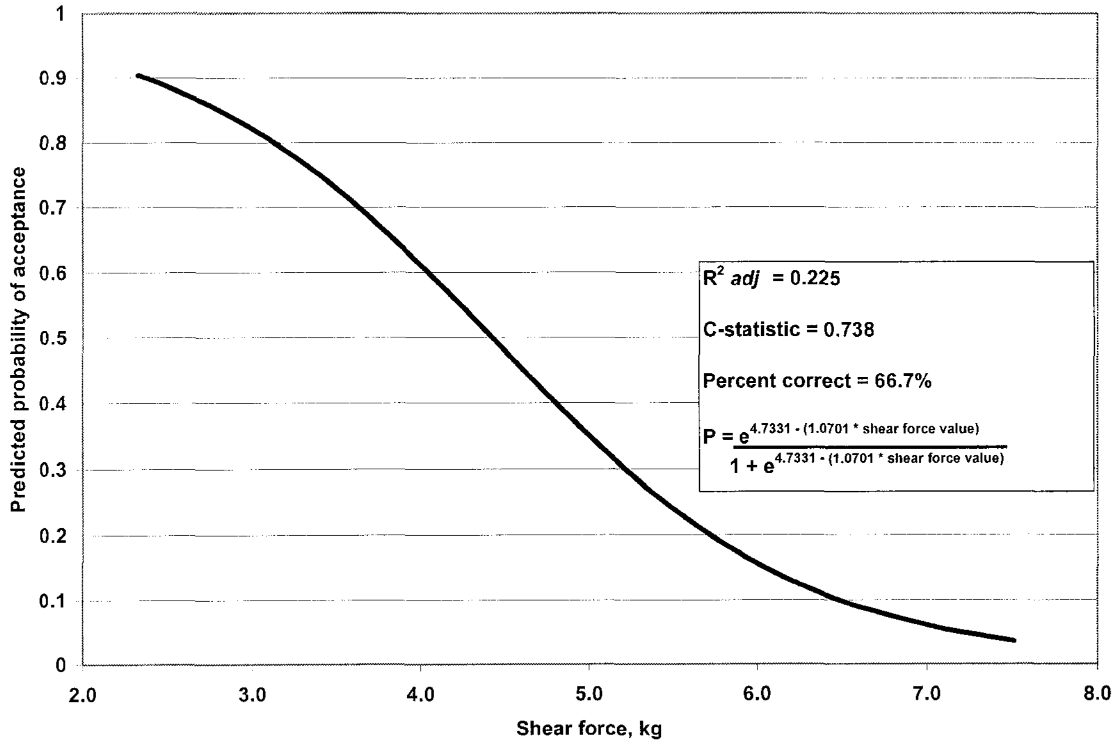


**Figure 4.5. Predicted probability of overall consumer acceptance of steaks by mean Warner-Bratzler shear force value. The $R^2$ *adj* is a generalized coefficient of determination. The c-statistic is the area under the receiver operating characteristic curve. Percent correct is the percentage of observations in the dataset correctly classified by the logistic regression equation. The symbol "P" represents the predicted probability for a steak being rated as acceptable by consumers. The constant "e" equals the base of the natural logarithm (2.718282).**

## CHAPTER V

# EFFECTS OF MARBLING AND SHEAR FORCE ON CONSUMERS' WILLINGNESS-TO-PAY FOR BEEF STRIP LOIN STEAKS

## ABSTRACT

Experimental economic procedures were used to measure the effects of changes in marbling score and Warner-Bratzler shear force (WBSF) on consumer purchasing behavior and willingness-to-pay for strip loin steaks from beef carcasses (n = 541). Consumers were more likely to bid on a steak during the experimental auction if the steak had a high marbling score or low WBSF value. Averaging across all consumers in the study (n = 489), the predicted odds that consumers would submit a bid were favorable for steaks with a marbling score > Modest$^{50}$ or a WBSF value < 3.9 kg. Bid prices for steaks were analyzed with respect to changes in steak marbling score, WBSF value, quality grade marketing category classification (Select, low Choice, premium Choice, and Prime), and WBSF marketing category classification (very tender, $\leq$ 3.4 kg; slightly tender, 3.41 - 4.40 kg; slightly tough, 4.41 – 5.40 kg; or very tough, > 5.40 kg). The frequency of zero bids submitted for steaks by consumers identified as "buyers" during the auction is a direct measurement of refusals to purchase steaks by beef customers. The percentage of bids that were zero was highest ($P < 0.05$) for Select steaks, intermediate

($P < 0.05$) for low Choice steaks, and lowest ($P < 0.05$) for premium Choice or Prime steaks. Steaks in the very tender category had the lowest ($P < 0.05$) percentage of zero bids and steaks in the slightly tough and very tough categories had the highest ($P < 0.05$) percentage of zero bids submitted from "buyers" in the auction. Premium Choice and Prime steaks were valued higher ($P <0.05$) than Select steaks by consumers. On average, premium Choice steaks received a $0.40/kg premium and Prime steaks received a $1.12/kg premium over the mean bid price for Select steaks. Predicted mean bid prices for steaks decreased by $1.02/kg for each 1 kg increase in WBSF value. On average, steaks in the very tender marketing category received a higher ($P < 0.05$) bid price compared to the bid price for steaks in the slightly tender, slightly tough, and very tough categories (+ $0.83/kg, + $2.09/kg, + $2.55/kg, respectively). Mean bid prices for steaks from the slightly tough and very tough categories were not different ($P = 0.184$). Compared to the mean bid price for steaks in the slightly tender category, steaks from the slightly tough and very tough categories were discounted ($P < 0.05$) by $1.26/kg and $1.72/kg, respectively. Our results suggest that marbling score and WBSF influence both the probability that consumers will purchase, and the price that they are willing to pay for, strip loin steaks.

## INTRODUCTION

According to Purcell (1999), higher prices for live cattle are directly associated with increased demand for beef and higher retail beef prices. A principle beef demand driver is consumer satisfaction, and it is clear that consumers are not always satisfied with beef's quality, consistency, or tenderness (Moller and Courington, 1998). In an effort to improve the quality of beef products offered to consumers, the National Cattlemen's Beef

Association (NCBA) has encouraged the implementation of Total Quality Management (TQM) beef production systems and development of technologies that can classify beef carcasses based on tenderness (NCBA, 2002). However, these changes have not been widely adopted by the beef industry, in part, because of the financial costs and the uncertainty of rewards associated with their implementation. Reliable estimates of the willingness of consumers to pay for differences in palatability traits of beef, as reflected by differences in marbling score and Warner-Bratzler shear force (WBSF), would provide useful information for estimating the economic incentives for improving the quality and tenderness of beef.

Auction bidding in experimental valuation methods is designed to reveal consumers' "true preferences" and provides a more reliable estimate of consumers' willingness-to-pay than hypothetical willingness-to-pay survey methods (Davis and Holt, 1993; Kagel and Roth, 1995). Willingness-to-pay surveys (stated-choice surveys) tend to overestimate consumers' actual willingness-to-pay for differences in products (Loomis and Walsh, 1997). Experimental auctions create a non-hypothetical market where participants use real money and actually place bids on real products. Previous studies using experimental market procedures have estimated consumer willingness-to-pay values for steaks classified into two categories based on marbling scores (Umberger et al., 2000) and WBSF (Lusk et al., 2001). This study was conducted to evaluate the differences in consumer purchasing trends and willingness-to-pay values for steaks from a wide range of marbling scores and WBSF values.

## MATERIALS AND METHODS

*Sample.* Detailed descriptions of the cattle management history, experimental procedures through harvest, and strip loin sample collection were provided in a preceding report (Platter et al., 2003a). Because of the low frequency of strip loins from the USDA Standard grade, all data from these samples were removed from the dataset, prior to analysis, resulting in a total of 541 strip loins used for these analyses. Briefly, strip loins (Institutional Meat Purchase Specification 180; USDA, 1988) aged for 14 d at 2°C and then frozen at -20°C, were fabricated (in the frozen state) into 2.54-cm thick steaks using a band saw (model 5700, Hobart, Troy, OH). The first steak from the anterior end of each strip loin was identified for WBSF determination, while the next two steaks cut from each strip loin were identified for untrained, consumer sensory analysis. The remaining steaks from each strip loin were identified and labeled for retail sale during the experimental auction. Upon completion of the fabrication process, steaks were individually packaged in vacuum-sealed bags, sorted for intended use, and returned to frozen storage (-20°C). Samples used for sensory analysis were stored frozen for approximately 180 d.

*Shear Force Determination.* Steaks designated for WBSF determination were removed from freezer storage and allowed to thaw for 24 h at 2°C. Steaks were cooked on an electric conveyor grill (model TGB-60, Magikitch'n, Quakertown, PA) for 6 min and 35 sec at a setting of 176°C to a target internal temperature of 70°C. After cooking, each steak was allowed to equilibrate to room temperature (22°C), and six to ten 1.27-cm cores were removed from each steak parallel to the muscle fiber orientation. Each core was sheared once, perpendicular to the muscle fiber orientation, using a Warner-Bratzler shear machine (G-R Electric Manufacturing Co., Manhattan, KS), and peak shear force measurements were recorded and averaged to obtain a single WBSF value for each steak.

*Consumer Sensory Panel Methods.* Consumer panel evaluation procedures used for this study were approved by the Colorado State University, Use of Humans in Research Committee. Branson Research Associates, Bryan, TX performed extensive demographic analyses of the Denver, CO metropolitan area to select a test population representative of the age, income, and ethnic background of the U.S. population. Consumers were contacted by telephone and pre-screened to ensure that they were at least 18 yr old and consumers of beef products. Four testing sites, located in the Denver metropolitan area (Denver, Lakewood, Arvada, and Littleton), were used to conduct a total of 25 consumer panel sessions that included a total of 489 consumers.

Within a session, paired steaks from 22 different carcasses were selected for sensory evaluation. Steak identification numbers, as well as order of service to consumer panelists, were assigned randomly to each of the 20 consumers per session, with each consumer sampling a total of 11 different steaks. Frozen steaks prepared for consumer panel evaluation were thawed at 2°C for 24 h, and cooked for approximately 15 min on electric grills (model GGR64, Salton, Inc., Mt. Prospect, IL) designed to heat steaks from both sides, simultaneously, to a final internal temperature of 70°C. A Type K thermocouple (Omega Engineering Inc., Stamford, CT) was placed in the geometric center of each steak, and internal temperature was monitored during cooking using a microprocessor thermometer (model HH21, Omega Engineering Inc., Stamford, CT). Steaks were cut into 1.3 × 1.3 × 2.5 cm portions, covered, and placed in a warming oven (49°C) until consumers were served. One steak from each pair was prepared for serving during the first half of the session, whereas the other matched steak was prepared for serving in the last half of the session to minimize any changes in sensory attributes associated with holding samples for longer periods of time in a warming oven.

At each location, consumers were seated randomly at tables arranged in a circular order in a room containing standard fluorescent lighting. Instructions regarding the structure of the auction ballot and sampling procedures for the steak samples were provided verbally to the consumers in each session. Panelists were provided double-distilled, deionized water and saltless saltine crackers, and were instructed to take a bite of cracker and a drink of water before evaluating each sample to cleanse their palates and to minimize sensory fatigue between samples.

*Experimental Economics Procedures.* An experimental auction market procedure was used to obtain consumer willingness-to-pay values for differences in marbling score and WBSF of strip loin steaks. Participants were compensated $40 for their participation in the consumer sensory panel. Panelists were instructed that their compensation was only for the evaluation of the organoleptic properties (tenderness, juiciness, flavor, and overall acceptability) of the steak samples. However, during the consumer sensory panels consumers were asked, without obligation, to participate in a variation of a sealed-bid Vickrey auction for the purchase of steaks, identical to the samples they evaluated (Vickrey, 1961). Participants in the auction were asked to submit a bid for an identical 0.454 kg (1 pound) package of frozen steaks (2 steaks per package) for each sample they evaluated during the consumer sensory panel. Consumers who chose to participate in the auction were allowed to submit a non-bid (submit a zero bid) for steaks they perceived to be unacceptable in overall palatability. An average retail price of $14.32/kg was given to the consumers as a reference price for the auction. Moreover, panelists were instructed that there was a minimum acceptable bid price for all steaks ($7.71/kg); however, this price was not disclosed to the participants until after the completion of the auction. The actual market price for packages of steaks was established by actively bidding participants in the auction.

Before each sensory panel session, consumers were informed that there were two 0.454 kg packages of steaks representing each sample evaluated during the session that would be available for purchase during the auction. Therefore, two possible winning auction participants, of the seven to ten participants that evaluated each sample, could purchase steaks representing each sample evaluated during each session. The market price for each sample was established at the third highest bid price submitted for each sample. The auction participants that submitted the two highest bids for each sample were *required* to purchase a package of steaks at the third highest bid price (as long as the price exceeded $7.71/kg). Participants were asked to write their bids on a ballot after evaluating each sample. At the completion of the taste panel session, all panelists were asked to submit their ballots to the taste panel moderator. At any time prior to submission of the bid ballot to the moderator, panelists could modify their bids on any of the 11 samples they evaluated. After the bid ballots were submitted, auction winners were informed of their purchases, payments were reconciled, and steaks were distributed to consumers.

There are a number of advantages for using experimental auction methods to obtain consumer willingness-to-pay values (Menkhaus et al., 1992; Davis and Holt, 1993; Kagel and Roth, 1995). An experimental auction market simulates a non-hypothetical marketplace because consumers are informed that if they participate in the auction their bids are considered binding and they are required to purchase a package of steaks if they are successful bidders. Another benefit of using the Vickery sealed-bid auction is that each consumer submits his/her own perception of value, independent of the bidding behavior of others (Buhr et al., 1993). Additionally, each bid submitted by consumers in the auction is a true estimate of a consumer's willingness-to-pay for a product, because the structure of the auction does not reward consumers for under, over, or other forms of strategic bidding. For example, suppose a consumer was willing-to-pay $8.00/kg for a package of steaks and was one of the two highest bidders in the auction. The consumer would be required to purchase a package of steaks, but the price he/she would have to pay for the package would be less than $8.00/kg because the market price for each package of steaks in the auction is established at the third highest bid. In this case, the consumer is satisfied with the market price for the package of steaks, because it is below his/her actual willingness-to-pay value. It is not beneficial for a consumer to bid more than his/her actual willingness-to-pay because he/she may be a successful bidder and be forced to pay an amount above his/her actual willingness-to-pay value ($8.00/kg). Moreover, submitting a bid lower than their actual willingness-to-pay value is not advantageous to a consumer because the market price could be above his/her bid, but lower than their "true" willingness-to-pay. In this case, the consumer would not be able to purchase the package of steaks at what he/she perceives as a "good value".

*Statistical Methods.* Stepwise logistic regression procedures were used to develop equations for the prediction of the probability that consumers would bid on steaks during the auction (SAS Inst. Inc., Cary, NC). Separate analyses were conducted to develop equations including either WBSF or marbling score as explanatory variables in the prediction equations. Initial analyses were conducted to gain preliminary insight into associations between consumer demographic information and the likelihood that consumers would bid on steaks in the auction. Consumer demographic information was condensed into fewer categories based on these preliminary analyses. Specifically, information on consumer consumption habits for beef, poultry, pork, fish, and vegetarian meals were reduced to two categories (light or heavy consumers) and yearly household income for consumers was reduced to four categories (< \$20,000; \$20-39,999; \$40-59,999; or ≥ \$60,000). A consumer demographic variable was included in the equations if the significance of the Wald statistic for that variable was $P < 0.05$. The accuracy of the model prediction was tested against actual observations in the dataset by construction of a two-way classification table using a procedure that approximates an unbiased "jackknifing" method (SAS, 1999).

Of primary interest in this study were the relationships of marbling score or WBSF to the bid prices submitted by consumers in the experimental auction. Marbling score has been a major influence in beef marketing in the U.S. because it is a primary component of the USDA quality grading system. For analyses of the effect of marbling score on bid prices in this study, steaks were classified into four quality grade marketing (QGMKT) categories typically encountered in U.S. beef trade – Prime, premium Choice (upper two-thirds Choice), low Choice, and Select. Boleman et al. (1997), Lusk et al. (2001), and Miller et al. (2001) have used various ranges of WBSF values to classify steaks by tenderness categories and subsequently examine consumer willingness-to-pay for steaks in these categories. Previous analysis of these data used WBSF value to predict the likelihood of overall acceptance of steaks by consumers (Platter et al., 2003b). Based on the equation reported by Platter et al. (2003b), the probability of overall consumer acceptance of steaks would be 75, 50, and 25% for steaks with mean WBSF values of 3.4, 4.4, and 5.4 kg, respectively. For the current analyses, the effect of WBSF on consumer bid prices for steaks in the experimental auction were evaluated with WBSF values for steaks as a continuous variable and when steaks were classified into WBSF marketing categories (WBSFMKT) as follows: very tender, ≤ 3.4 kg; slightly tender, 3.41 - 4.40 kg; slightly tough, 4.41 – 5.40 kg; or very tough, > 5.40 kg.

Differences in the frequency of zero bids submitted by consumers for steaks in QGMKT and WBSFMKT categories were tested for significance using chi-square analyses (SAS Inst. Inc., Cary, NC). An equation that estimated the probability that consumers would submit a zero bid for a steak using WBSF value as an independent explanatory variable was developed using logistic regression analyses. Linear regression models predicting the average bid prices for steaks were developed using steak marbling score or WBSF value as explanatory variables in separate analyses. Least squares analyses of variance for the mean bid prices for steaks were conducted using models that included either QGMKT or WBSMKT as main effects. When F-tests for these marketing classes were significant ($P < 0.05$), differences in mean bid prices for steaks were determined using protected LSD tests. For all analyses of bid prices, regression models were developed using the PROC REG procedure and the analyses of variance were conducted using the PROC GLM procedure of SAS (SAS Inst. Inc., Cary, NC).

## RESULTS AND DISCUSSION

*Consumer demographics.* A detailed summary of the demographic profile of the participants in the consumer sensory panels in this study was reported in a preceding report (Platter et al., 2003a). A summary of socio-economic characteristics of the consumer sample population that may have influenced whether or not consumers would bid on steaks in the experimental auction are listed in Table 5.1.

*Probability of Consumers Bidding.* Previous analyses of the consumer panel data in this study documented the relationship of marbling score and WBSF to the overall acceptance of steaks by consumers (Platter et al., 2003b). Intuitively, increasing consumer acceptance of steaks would have a positive effect on beef demand, but, quantifying the influence of differences in marbling score and WBSF on consumer purchasing decisions is essential for positioning beef products in the marketplace. Logistic regression equations predicting the probability that consumers would submit a bid (be willing to purchase steaks) during the auction were developed using marbling score, WBSF value, and consumer demographic information (Tables 5.2 and 5.3). The logistic regression or effect coefficients for the explanatory variables in these equations predicted a change in the log odds that consumers would bid on a 0.454 kg package of steaks, based on either a unit change (e.g., 1 kg of WBSF) or a categorical shift (e.g., male vs. female) for their respective explanatory variable. Effect coefficients for explanatory variables in the logistic regression equations were converted to an odds ratio (Tables 5.2 and 5.3), or a percentage change in probability (Figures 5.1 and 5.2) of the predicted event (i.e., consumers submitting a bid) for a unit change or categorical shift in their explanatory variables.

Effect coefficients for the consumer socio-economic attributes of age, gender, income class, household size, steak degree of doneness preference, and average consumption levels for beef, poultry, pork, fish, and vegetarian meals were significant ($P \leq 0.05$) for predicting the probability that consumers would submit a bid during the auction, in the equation that included marbling score as an explanatory variable (Table 5.2). These same socio-economic variables (except level of pork consumption) were significant ($P \leq 0.05$) for predicting the probability consumers would submit a bid during the auction in the equation that included WBSF as an explanatory variable (Table 5.3). In both equations, the estimated probability that a consumer would be willing to purchase a steak during the auction increased if the consumer was older, male, or preferred steaks cooked to a rare to medium degree of doneness. Also, the estimated probability that a consumer would attempt to purchase steaks during the auction was lower for consumers from a household size of three and for consumers who lived in a household with an annual income of $20,000 to $39,000. Panelists who tended to consume heavy amounts of beef or fish were predicted to be more likely to bid on steaks during the auction than consumers who rarely consumed these products. Conversely, consumers that often consume poultry or vegetarian meals were predicted to be less likely to attempt to purchase steaks during the auction. In the marbling score equation, panelists that consumed heavy amounts of pork were predicted to be more likely to bid on steaks during the auction. Including the socio-economic characteristics of the consumer panelists improved the accuracy of the equations predicting the likelihood that consumers would attempt to purchase a steak by 6.8% and 5.8% for the marbling score and WBSF equations, respectively (data not shown). Interestingly, the effect coefficients for marbling score were similar for a single variable (with marbling score as the only explanatory variable) and the multiple variable regression equation (0.00104 and 0.00109, respectively). Moreover, the effect coefficient for WBSF value for predicting the probability that consumers would bid on steaks during the auction was similar for the single and multiple variable equations (-0.2145 vs. -0.2106, respectively). Therefore, the impact of marbling score and WBSF on the predicted probability that consumers would attempt to purchase steaks during the auction was not greatly influenced by including consumer socio-economic variables in the prediction equations.

Marbling score influenced ($P = 0.0002$) the probability that consumers would be willing to purchase steaks during the experimental auction. Using the prediction from the single variable marbling score equation (averaging across all consumers) the probability that consumers would be willing to purchase steaks was 0.50 at an approximate marbling score of Modest$^{50}$ (Figure 5.1). Therefore, the predicted odds of consumers bidding were 1 (1 to 1) for steaks with a marbling score of Modest$^{50}$. The predicted odds of consumers bidding were reduced to 0.905 (estimated probability of 0.475) for steaks with a marbling score of Small$^{50}$ and increased to 1.105 (estimated probability of 0.527) for steaks with a marbling score of Moderate$^{50}$, when adjusted by the odds ratio for marbling score from the single variable regression equation. These predictions suggest that a marbling score of Modest$^{50}$ or higher is required to produce favorable odds that consumers would be willing to purchase steaks in the experimental auction, and that the probability of consumers purchasing steaks increases as marbling score increases.

Warner-Bratzler shear force value of steaks influenced ($P < 0.0001$) the predicted probability that consumers would submit a bid on steaks during the auction. Based on the single variable regression equation (averaging across all consumers), the predicted probability that consumers would bid on steaks during the auction was 0.50 when the WBSF value of a steak was 3.9 kg (Figure 5.2). The predicted odds of consumers bidding were reduced to 0.807 (estimated probability of 0.450) for steaks with a WBSF value of 4.9 kg and were increased to 1.239 (estimated probability of 0.556) for steaks with a WBSF value of 2.9 kg.

Boleman et al. (1997) evaluated how consumer buying trends for top loin steaks were influenced when steaks were sorted into three categories based on their WBSF value (2.27 to 3.58 kg; 4.08 to 5.40 kg; and 5.90 to 7.21 kg). In that study, consumers evaluated steaks from each of the three categories and, then, were allowed to purchase steaks based on their evaluations. Consumers had two opportunities to purchase steaks during that experiment, and in each case, consumers purchased a considerably higher percentage of steaks from the category of steaks with the lowest range of WBSF values (Boleman et al., 1997). Our results suggest that WBSF is a valuable indicator for the probability that consumers will attempt to purchase steaks. Furthermore, in our study, a WBSF value of $\leq 3.9$ kg was required to attain favorable odds that consumers would be willing to purchase steaks.

*Refusal to purchase steaks.* A total of 141 (28.8%) of the 489 consumers in this study chose not to submit a bid on any of the steaks they evaluated during the consumer taste panel. These consumers were classified as "non-buyers" and were removed from the dataset prior to analysis of bid prices for steaks. Removing these consumers allowed for analyses of bidding behavior for a segment of consumers that were considered "buyers", because they attempted to purchase steaks on the day of the auction. The "trimmed" dataset represented consumers that submitted at least one bid during the auction.

The frequency of zero bids submitted for steaks by consumers identified as "buyers" during the auction is a direct measurement of refusals to purchase steaks by beef customers. The percentage of zero bids was the highest ($P < 0.05$) for steaks in the Select grade, intermediate ($P < 0.05$) for low Choice steaks, and lowest ($P < 0.05$) for premium Choice and Prime steaks (Table 5.4). These results suggested that consumers who were interested in buying steaks during the auction were able to perceive differences in value between steaks from different QGMKT categories and were more likely to refuse to purchase low Choice and Select steaks than premium Choice and Prime steaks.

A logistic regression equation that included WBSF value as the only explanatory variable for predicting the probability that a consumer would submit a zero bid during the auction is presented in Figure 5.3. This equation indicated that, as WBSF increased, the estimated probability that a consumer would submit a zero bid for a steak increased. Moreover, the percentage of zero bids was influenced ($P < 0.05$) by WBSFMKT category. Steaks in the very tender category had the lowest ($P < 0.05$) percentage of zero bids and steaks in the slightly tough and very tough categories had the highest ($P < 0.05$) percentage of zero bids (Figure 5.3). These results indicated that consumers in the auction perceived differences in value between steaks of different WBSFMKT categories and that steak "buyers" were generally more likely to refuse to buy steaks as the WBSF value of steaks increased.

*Consumer bid prices for steaks.* Marbling score alone accounted for only 3% of the observed variation in average bid price for steaks (data not shown). However, when steaks were pooled and classified into QGMKT categories, based on their marbling and overall maturity scores, significant ($P < 0.05$) among-category differences in mean bid prices for steaks were observed (Table 5.4). Mean bid price for steaks in the low Choice category tended ($P = 0.056$) to be higher than the mean bid price for steaks in the Select category. Premium Choice and Prime steaks were valued higher ($P < 0.05$) than Select steaks. On average, premium Choice steaks received a premium of $0.40/kg and Prime steaks received a premium of $1.12/kg over the mean bid price received for Select steaks. Umberger et al. (2001) recently conducted an experimental market study that examined consumers' relative willingness-to-pay values for steaks that differed in quality grade (premium Choice vs. Select), but were comparable in WBSF value. In that study, there were consumers that preferred the Select steaks (13.7%), consumers that preferred the premium Choice steaks (28.8%), and consumers that were indifferent between Choice and Select steaks (57.5%). Interestingly, both the group that preferred the Select steaks and the group that preferred the premium Choice steaks were willing-to-pay a significantly higher price for steaks of their preference category; however, on average, consumers were willing-to-pay $0.31/kg more for premium Choice steaks than for Select steaks. Results of the present study also reflected a tendency for consumers to place a higher value on steaks from higher QGMKT categories.

Boleman et al. (1997) demonstrated that consumers could discriminate between steaks of different tenderness classes and were willing-to-pay a premium for tenderness. In our study, WBSF values were negatively related to mean bid prices for steaks submitted by consumers in the auction. Predicted mean bid prices for steaks decreased by $1.02/kg for each 1 kg increase in WBSF value (Figure 5.4). The mean bid price for steaks in the very tender WBSFMKT category was higher ($P < 0.05$) than the mean bid price for steaks in the slightly tender, slightly tough, or very tough categories (+ \$0.83/kg, + \$2.09/kg, + \$2.55/kg, respectively). However, mean bid prices for steaks from the slightly tough and very tough categories were not different (P = 0.184).

Miller et al. (2002) used stated-choice survey methods to estimate differences in consumer willingness-to-pay for strip loin steaks classified into four categories based on WBSF value. In their study, estimated premiums for steaks in the tender category were \$0.59/kg, \$1.08/kg, and \$1.23/kg over the mean value of steaks from the intermediate, tough, and toughest categories, respectively (Miller et al., 2001). In our study, steaks from the slightly tough and very tough categories were discounted ($P < 0.05$) by \$1.26/kg and \$1.72/kg, respectively, compared to the mean bid price for steaks in the slightly tender category. Results of another study that used an experimental auction method to obtain consumer willingness-to-pay (Lusk et al., 2001) indicated that consumers, on average, would pay \$2.71/kg to upgrade from a "tough" to a "tender" steak. Our results support the concept that consumers can discriminate between steaks that differ in WBSF value or WBSFMKT category and would likely be willing to pay more for steaks with lower WBSF values.

## IMPLICATIONS

Consumers in this study attached "value" to perceived differences in beef palatability associated with quality grade or Warner-Bratzler shear force. These results suggested that improving product quality and tenderness will increase both consumers' willingness-to-purchase and the price they will pay for beef. Results of this study suggest that if the beef industry wants to command higher prices and create demand for its products, it must focus on improving product performance with respect to eating quality.

**Table 5.1. Responses of panelist demographic information and consumption habits[a]**

| Item | Category | Percentage of respondents |
|---|---|---|
| Gender | Male | 44.2 |
| | Female | 55.8 |
| Total household income, $/yr | < 20,000 | 12.5 |
| | 20,000-39,999 | 24.0 |
| | 40,000-59,999 | 26.8 |
| | ≥ 60,000 | 36.7 |
| Household size | 1 | 23.2 |
| | 2 | 34.0 |
| | 3 | 16.0 |
| | 4 or more | 26.8 |
| Panelist's degree of doneness preference for steaks | 60 to 71.1 °C[a] | 68.4 |
| | 73.9 to 76.7 °C[a] | 31.6 |
| Panelist's beef consumption[b] | Light | 10.5 |
| | Heavy | 89.5 |
| Panelist's poultry consumption[b] | Light | 27.0 |
| | Heavy | 73.0 |
| Panelist's pork consumption[b] | Light | 79.2 |
| | Heavy | 20.8 |
| Panelist's fish consumption[b] | Light | 82.9 |
| | Heavy | 17.1 |
| Panelist's vegetarian meal consumption[b] | Light | 79.6 |
| | Heavy | 20.4 |

[a]60 to 71.1°C = steaks cooked to a rare, medium rare, or medium degree of doneness; 73.9 to 76.7 °C = steaks cooked to a medium well or well done degree of doneness.

[b]Light consumption = never consumed or consumed once per week as a part of an evening meal; heavy consumption = consumed two or more times per week as part of an evening meal.

**Table 5.2. Logistic regression equation[a] for the probability of consumers bidding on steaks in the experimental auction based on marbling score and consumer demographic information**

| Variable | Effect coefficient[b] | SE estimate[c] | Wald p-value | Odds ratio[d] |
|---|---|---|---|---|
| Intercept | -1.2737 | 0.1798 | <0.0001 | - |
| Marbling score[e] | 0.00109 | 0.0029 | 0.0002 | 1.001 |
| Age, yr | 0.0126 | 0.0021 | <0.0001 | 1.013 |
| Male | 0.2163 | 0.0308 | <0.0001 | 1.541 |
| Female | - | - | - | - |
| Income class 1[f] | 0.1624 | 0.0747 | 0.0297 | 1.129 |
| Income class 2[f] | -0.2096 | 0.0558 | 0.0002 | 0.779 |
| Income class 3[f] | 0.0658 | 0.0530 | 0.9013 | 0.967 |
| Income class 4[f] | - | - | - | - |
| Household size, n = 1 | 0.0805 | 0.0596 | 0.1768 | 1.194 |
| Household size, n = 2 | 0.2025 | 0.0493 | <0.0001 | 1.348 |
| Household size, n = 3 | -0.1867 | 0.0625 | 0.0028 | 0.914 |
| Household size, n = $\geq$ 4 | - | - | - | - |
| Prefer steaks cooked to 60 to 71.1°C[g] | 0.1176 | 0.0329 | 0.0003 | 1.265 |
| Prefer steaks cooked to 73.9 to 76.7 °C[g] | - | - | - | - |
| Beef consumption light[h] | -0.2651 | 0.0517 | <0.0001 | 0.588 |
| Beef consumption heavy[h] | - | - | - | - |
| Poultry consumption light[h] | 0.0698 | 0.0347 | 0.0441 | 1.150 |
| Poultry consumption heavy[h] | - | - | - | - |
| Pork consumption light[h] | -0.0763 | 0.0385 | 0.0472 | 0.858 |
| Pork consumption heavy[h] | - | - | - | - |
| Fish consumption light[h] | -0.1638 | 0.0432 | 0.0001 | 0.721 |
| Fish consumption heavy[h] | - | - | - | - |
| Vegetarian meal consumption light[h] | 0.1257 | 0.0378 | 0.0009 | 1.286 |
| Vegetarian meal consumption heavy[h] | - | - | - | - |

[a]Equation classified 60.0% of the observations correctly.

[b]Change associated in the log odds of consumers bidding on steaks.

[c]Standard error of the estimate for the effect coefficient.

[d]The coeffiecient for the change in the original odds of consumers bidding on steaks.

[e] Marbling score: 300 = slight, 400 = small, 500 = modest, 600 = moderate, and 700 = slightly abundant.

[f]Income classification (annual total household income): 1 = < \$20,000; 2 = \$20,000 to 39,999; 3 = \$40,000 to 59,999; 4 = $\geq$ \$60,000.

[g]60 to 71.1°C = steaks cooked to a rare, medium rare, or medium degree of doneness; 73.9 to 76.7 °C = steaks cooked to a medium well or well done degree of doneness.

[h]Light consumption = consume product one time or less per week as part of an evening meal; heavy consumption = consume product two or more times per week as part of an evening meal.

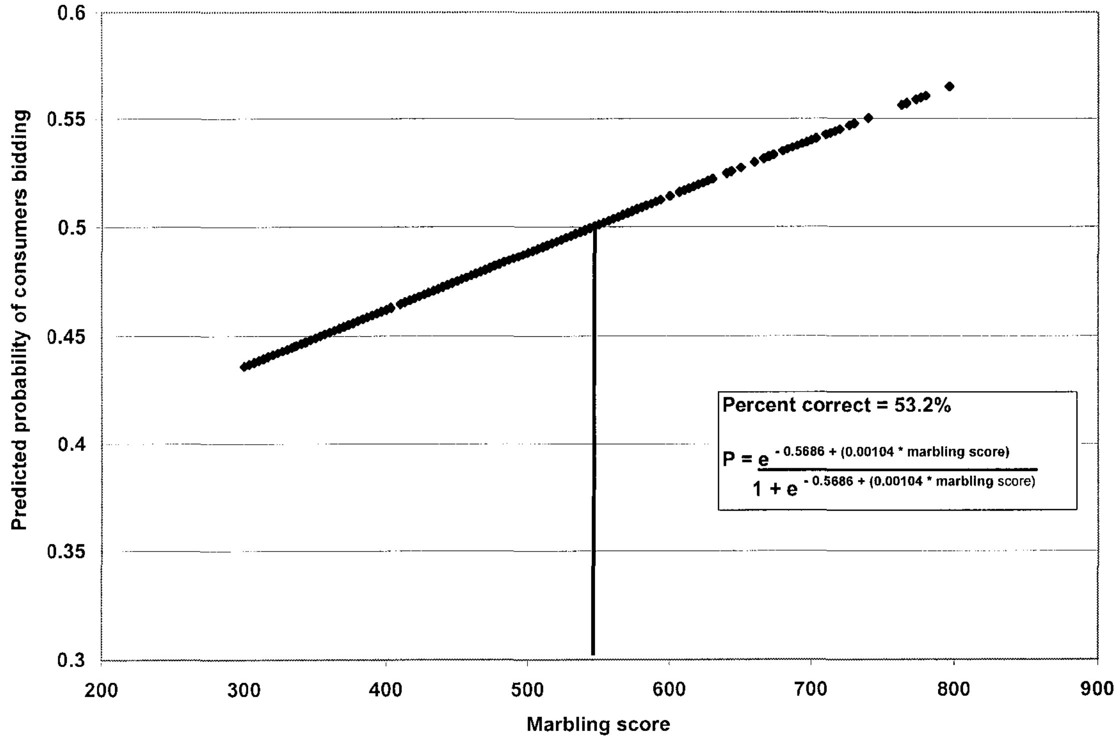


**Figure 5.1. Predicted probability of consumers submitting bids on steaks during the experimental auction by mean marbling score of steaks. Marbling score: 200 = traces, 300 = slight, 400 = small, 500 = modest, 600 = moderate, and 700 = slightly abundant. Percent correct is the percentage of observations in the dataset correctly classified by the logistic regression equation. The symbol "P" represents the predicted probability of consumers submitting bids on steaks during the experimental auction. The constant "e" equals the base of the natural logarithm (2.718282).**

**Table 5.3. Logistic regression equation[a] for the probability of consumers bidding on steaks in the experimental auction based on Warner-Bratzler shear force (WBSF) values and consumer demographic information**

| Variable | Effect coefficient[b] | SE estimate[c] | Wald p-value | Odds ratio[d] |
|---|---|---|---|---|
| Intercept | 0.1029 | 0.1824 | 0.5724 | - |
| WBSF, kg | -0.2106 | 0.0325 | <0.0001 | 0.810 |
| Age, yr | 0.0126 | 0.0021 | <0.0001 | 1.013 |
| Male | 0.2230 | 0.0307 | <0.0001 | 1.562 |
| Female | - | - | - | - |
| Income class 1[e] | 0.1691 | 0.0748 | 0.0239 | 1.162 |
| Income class 2[e] | -0.2013 | 0.0557 | 0.0003 | 0.802 |
| Income class 3[e] | 0.0130 | 0.0532 | 0.8063 | 0.994 |
| Income class 4[e] | - | - | - | - |
| Household size, n = 1 | 0.0673 | 0.0597 | 0.2592 | 1.159 |
| Household size, n = 2 | 0.1978 | 0.0493 | <0.0001 | 1.320 |
| Household size, n = 3 | -0.1852 | 0.0626 | 0.0031 | 0.900 |
| Household size, n = ≥ 4 | - | - | - | - |
| Prefer steaks cooked to 60 to 71.1°C[f] | 0.1204 | 0.0329 | 0.0003 | 1.272 |
| Prefer steaks cooked to 73.9 to 76.7 °C[f] | - | - | - | - |
| Beef consumption light[g] | -0.2733 | 0.0517 | <0.0001 | 0.579 |
| Beef consumption heavy[g] | - | - | - | - |
| Poultry consumption light[g] | 0.0740 | 0.0347 | 0.0328 | 1.160 |
| Poultry consumption heavy[g] | - | - | - | - |
| Fish consumption light[g] | -0.1845 | 0.0426 | <0.0001 | 0.691 |
| Fish consumption heavy[g] | - | - | - | - |
| Vegetarian meal consumption light[g] | 0.1281 | 0.0377 | 0.0007 | 1.292 |
| Vegetarian meal consumption heavy[g] | - | - | - | - |

[a]Model classified 60.1% of the observations correctly.

[b]Change associated in the log odds of consumers bidding on steaks.

[c]Standard error of the estimate for the effect coefficient.

[d]The coeffiecient for the change in the original odds of consumers bidding on steaks.

[e]Income classification (annual total household income): 1 = < $20,000; 2 = $20,000 to 39,999; 3 = $40,000 to 59,999; 4 = ≥ $60,000.

[f]60 to 71.1°C = steaks cooked to a rare, medium rare, or medium degree of doneness; 73.9 to 76.7 °C = steaks cooked to a medium well or well done degree of doneness.

[g]Light consumption = consume product one time or less per week as part of an evening meal; heavy consumption = consume product two or more times per week as part of an evening meal.

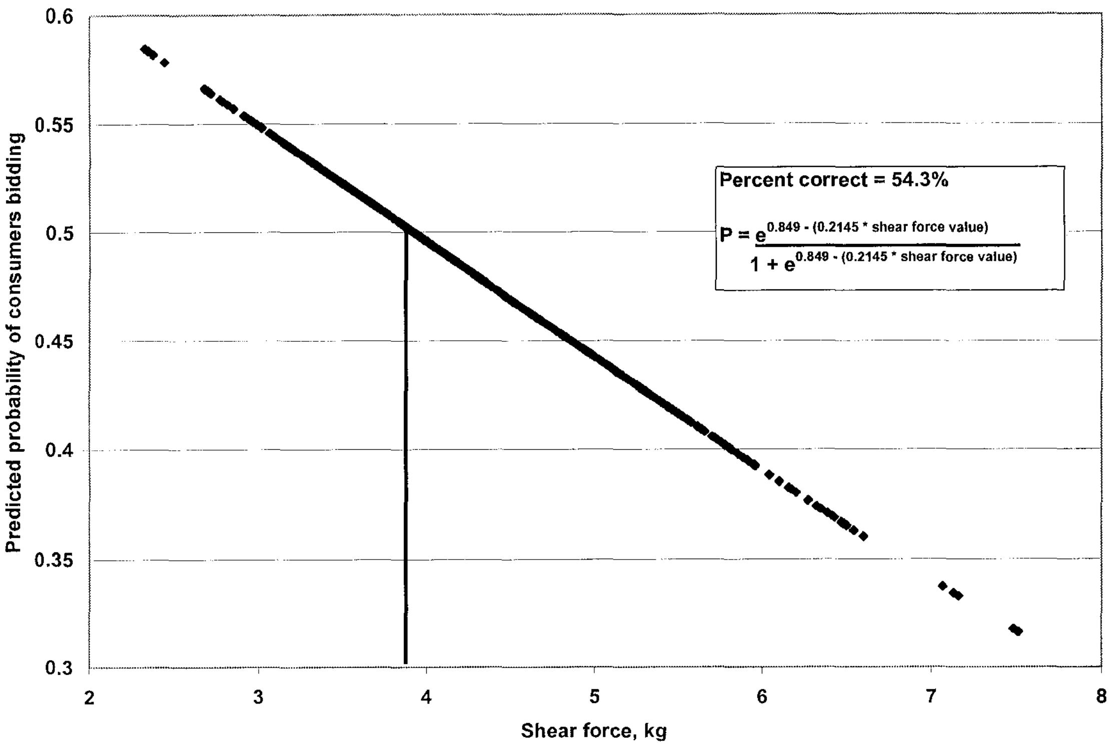


**Figure 5.2. Predicted probability of consumers bidding on steaks during the experimental auction by mean Warner-Bratzler shear force value of steaks. Percent correct is the percentage of observations in the dataset correctly classified by the logistic regression equation. The symbol "P" represents the predicted probability of consumers submitting bids on steaks during the experimental auction. The constant "e" equals the base of the natural logarithm (2.718282).**

**Table 5.4. Percentage of bids by consumers that were zero and least squares mean bid price for steaks stratified by USDA quality grade marketing classes**

| | Bids | Zero bid % | | Steaks | Bid price by steak | |
|---|---|---|---|---|---|---|
| Quality grade marketing class | n | Mean % | Difference from Select | n | Mean bid $/kg | Difference from Select |
| Select | 1207 | $36.70^{x}$ | - | 170 | $2.44 \pm 0.09^{z}$ | - |
| Low Choice | 1491 | $33.47^{x}$ | - 3.23 | 216 | $2.67 \pm 0.12^{yz}$ | + 0.23 |
| Premium Choice | 903 | $28.68^{y}$ | - 8.02 | 129 | $2.84 \pm 0.14^{y}$ | + 0.40 |
| Prime | 165 | $23.03^{y}$ | - 13.67 | 23 | $3.56 \pm 0.27^{x}$ | + 1.12 |

$^{x,y,z}$Means in the same row lacking a common superscript letter differ ($P < 0.05$).

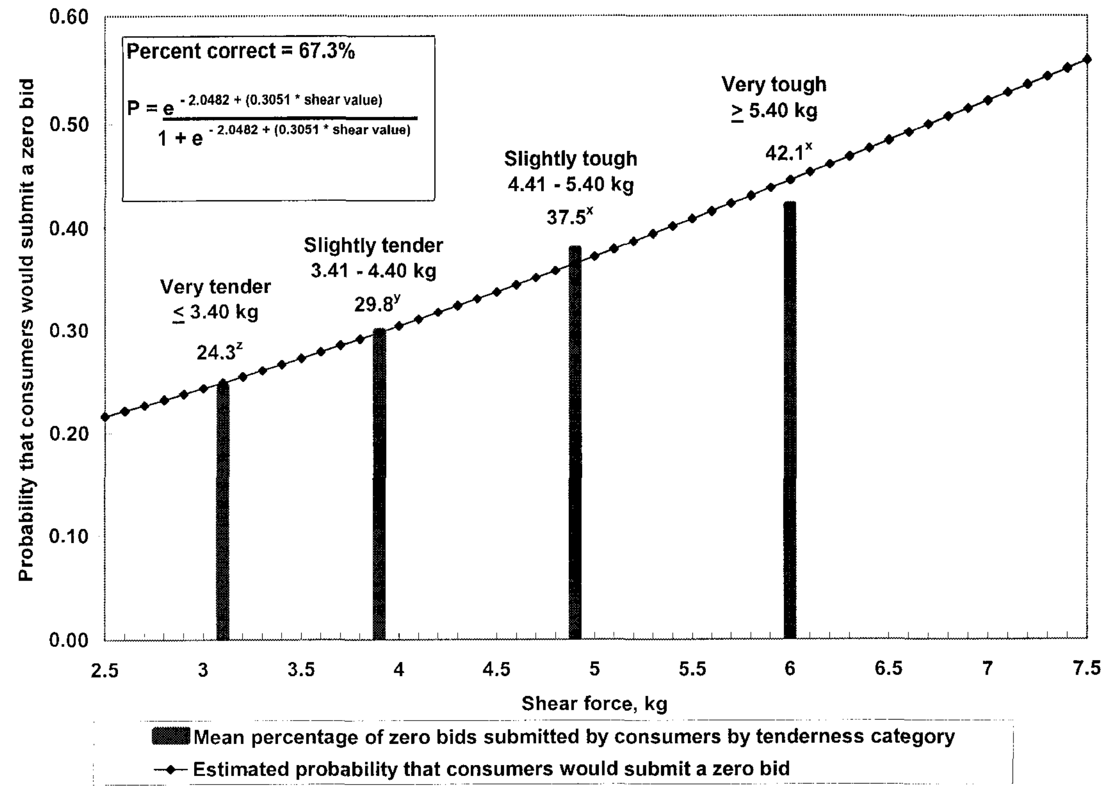


**Figure 5.3. Predicted probability of consumers submitting a zero bid on a steak by Warner-Bratzler shear force value and mean percentage of zero bids for steaks by Warner-Bratzler shear force marketing categories, calculated from responses made by consumers that were designated as "buyers" in the experimental auction.**

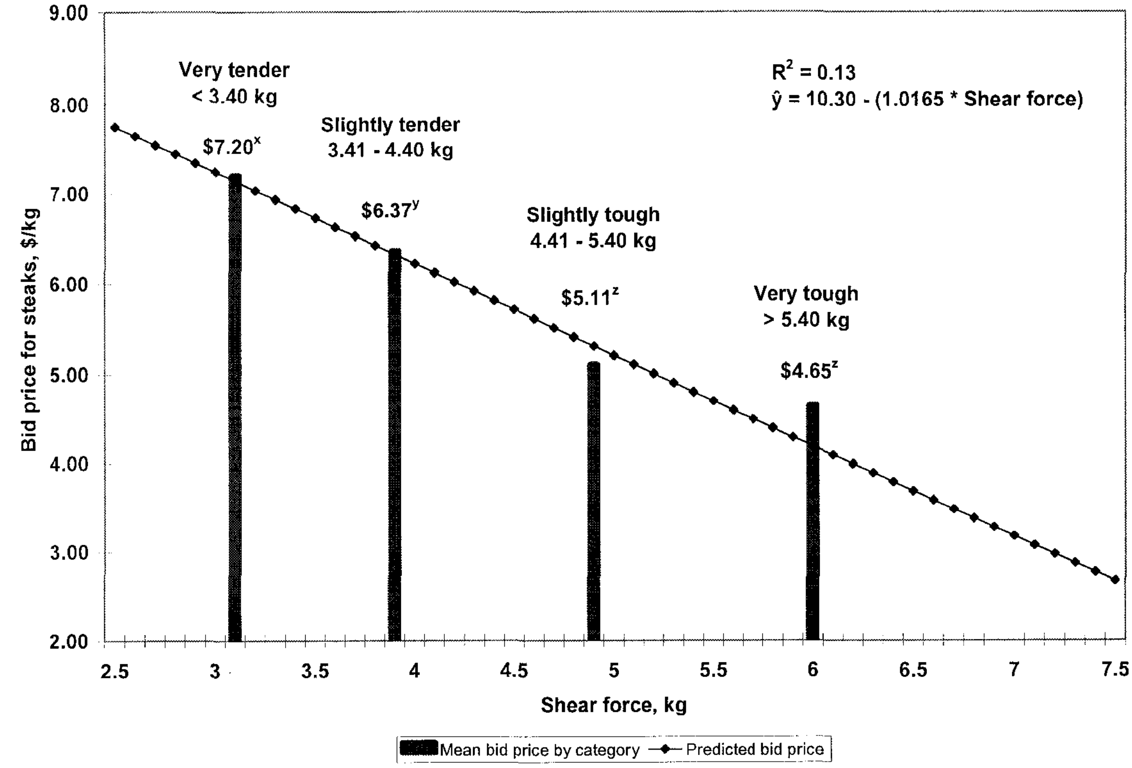


**Figure 5.4. Least squares mean bid price for steaks stratified by Warner-Bratzler shear force marketing classes and estimated mean bid price for steaks by mean Warner-Bratzler shear force value.**

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