COOKED YIELDS, COOKED COLOR, TENDERNESS, AND SENSORY TRAITS OF BEEF ROASTS DIFFERING IN CONNECTIVE TISSUE CONTENT COOKED IN AN OVEN WITH STEAM GENERATION VERSUS A COMMERCIAL CONVECTION OVEN TO DIFFERENT ENDPOINT TEMPERATURES.

by

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Abstract

The CVap steam generation oven was compared to a Blodgett forced-air, convection oven to examine effects of cooking method on yields, cooked color, tenderness, and sensory traits of beef *Longissimus lumborum* (LL), *Deep pectoralis* (DP), and *Biceps femoris* (BF) muscles cooked to three endpoint temperatures (65.6, 71.1, and 76.7°C). For each cooking treatment, four roasts were cooked in the CVap oven for a pre-determined, average amount of time, and two roasts were cooked in the Blodgett oven until they reached desired internal endpoint temperature. Cooking yields were higher ($P \leq 0.05$) for BF and LL roasts cooked in the CVap. Slice shear force (SSF) for BF roasts cooked in the CVap were lower ($P \leq 0.05$), whereas, SSF values for DP roasts cooked in the Blodgett were lower ($P \leq 0.05$). No oven difference ($P > 0.05$) was found for LL roasts. Sensory tenderness scores for BF roasts cooked in the CVap were slightly higher ($P \leq 0.05$) than roasts cooked in the Blodgett. Sensory scores for LL roasts cooked in the CVap were slightly higher but were also drier (both $P \leq 0.05$). The CVap oven offers tenderization and cooking yield advantages for certain muscles.

Key Words: Beef, Cooking Method, Tenderness, Yield

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Dedication

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CHAPTER 1 - Review of Literature

Meat cookery

Introduction

Meat cookery is perhaps the most common method of enhancing beef palatability. Boles (2010) explained that cooking of meat augments palatability by intensifying flavor and changing the blood-like taste of raw meat to a pronounced cooked flavor. Moreover, meat cookery further enhances palatability by altering the texture and tenderness of meat. In addition, cooking of meat also decreases the incidence of spoilage through destruction of bacteria (Boles, 2010).

Effects of Heat on Tenderization

Cooking of meat generally improves palatability by enhancing tenderness, although improper cooking can cause toughness. Davey and Neiderer (1977) determined that heat tenderizes meat in three distinct stages. The first tenderization stage occurs at temperatures up to 65°C as a result of increased proteolytic breakdown of myofibrillar components. The second stage of tenderization occurs between 70 and 100°C through the solubilization or destruction of collagen with little loss of myofibrillar strength. The third stage occurs at temperatures exceeding 100°C from a combination of collagen and myofibrillar degradation. The authors also found that cooking beef *Sternomandibularis* in the range of 70 to 100°C reduced shear force values by half and was as effective as aging in increasing tenderness (Davey and Neiderer, 1977). However, these findings are not entirely relevant because meat is not normally cooked to temperatures greater than 100°C and the Sternomandibularis muscle is not cooked as steaks or roast. .

While cooking of meat is commonly thought of as a tenderization process, toughening may also occur. Davey and Gilbert (1974) found that two distinct toughening phases occurred in beef *Sternomandibularis* muscle during cooking. The first toughening phase occurred between 40 and 50°C and resulted in a three-to four-fold toughening. The second toughening phase occurred between 65 and 75°C and resulted in a further doubling in toughening. They also determined that the toughening phases occurred separately as the result of different actions occurring within the tissue. In addition, the authors believed the second phase was closely related to collagen shrinkage with the first visible onset of collagen shrinkage occurring between 62 and 68°C. However, I question the validity of the results of the Davey and Gilbert (1974) study due to the manner in which the experiment was conducted. The authors cooked small cores of *Sternomandibularis* muscle in water baths for 1 hr. Therefore, their results are not applicable to the cooking of steaks and roasts. In addition, Davey and Neiderer (1977) and Davey and Gilbert (1974) contradict each other because Davey and Neiderer state that tenderization occurs after 70°C, but Davey and Gilbert state that toughening occurs between 65 and 75°C. Obuz, Dikeman, Grobbel, Stephens, and Loughin (2004) conducted research examining the effects of endpoint temperature, cooking method, and USDA quality grade on Warner-Bratzler shear force (WBSF) of beef *Longissimus lumborum* (LL), *Biceps femoris* (BF), and *Deep pectoralis* (DP) muscles. These authors reported that muscles with larger quantities of connective tissue (BF and DP) underwent distinct WBSF tenderization between 45 and 65°C, which is likely due to collagen solubilization. These muscles then underwent toughening between 65 and 80°C, likely because of increased myofibrillar toughening/hardening at higher temperatures. However, this tenderization effect was not observed for the LL, which has less collagen. These results contradict the findings of Davey and Gilbert (1974) and are much more relevant.

Muscle Changes

Meat cooking causes a variety of changes to occur both visually and chemically. Meat proteins are predominantly those of muscle and connective tissue. The largest proportion of total muscle proteins are those of the myofibrils. Sarcoplasmic proteins, consisting of muscle enzymes and myoglobin, comprise the second largest fraction, followed by connective tissue proteins (Aberle, Forrest, Gerrard, and Mills, 2001). Cooking has been defined as the heating of meat to a satisfactorily high temperature to denature proteins (Davey and Gilbert, 1974). Therefore, cooking meat will influence protein structure. Tornberg (2005) reported that the application of heat to meat proteins denatures them. This denaturation then causes structural changes, such as the destruction of cell membranes, shrinkage of meat fibers, the aggregation and gel formation of myofibrillar and sacroplasmic proteins, and shrinkage and solubilization of connective tissue (Tornberg, 2005). However, the exact nature of denaturation and coagulation is not completely understood, but distinct physical changes are known to occur in meat proteins during cooking (Boles, 2010).

With increasing temperatures, decreases in the solubility of the myofibrillar fraction are observed (Hamm and Deatherage, 1960; Lyon, Greene, and Davis, 1986; Barbut, Gordon, and Smith, 1996). This decrease in solubility is greatest between 40 and 60°C, with the proteins being virtually insoluble above 60°C (Hamm and Deatherage, 1960; Lyon et al., 1986). Hamm and Deatherage (1960) determined that denaturation of protein occurs in multiple stages. Protein denaturation is initiated by the unfolding of the tertiary structure of the protein. The second stage involves the aggregation of protein chains, which causes the coagulation of proteins. These two initial changes are limited to the meat surface. However, the subjection of meat to heat for longer times and at higher temperatures causes changes to the interior of the meat as well (Hamm and Deatherage, 1960). Cookery method will, therefore, impact the denaturation of proteins due to differences in rate of heat penetration. McCrae and Paul (1974) found that microwave heating gave the most rapid heat penetration, followed by oven broiling, braising, and roasting. The slowest heating rates generally occurred in the 60 to 70°C interval, with the 50 to 60°C interval next. These are the temperature ranges during which part of the energy is thought to be utilized for denaturation of proteins and for evaporation of water (McCrae and Paul, 1974).

Muscle structure also undergoes changes during cooking. Davey and Gilbert (1974) found extractability of myofibrils remained at a maximum (48% of the myofibrillar protein) with cooking temperatures up to 30°C (which is not even body temperature). Thereafter, at a cooking temperature of 60°C, extractability diminished to nearly zero. The authors also hypothesized that sarcoplasmic protein, which has no structural function in live muscle, could form a cementing matrix in cooked meat that would link structural components and intensify cooking toughening (Davey and Gilbert, 1974). The extent of structural changes from cooking is determined by the internal endpoint temperature achieved during the cooking process. Leander, Hedrick, Brown, and White (1980) showed that cooking to an internal temperature of 63°C caused slight disfigurement of the myofibrils and some swelling of the perimysial connective tissue. An internal temperature of 68°C caused more swelling in the A-band due to thermally induced contraction of the sarcomeres. Muscle fibers remained intact, but sheaths of connective tissue underwent coagulation and assumed a granular appearance. The investigators also noted that the greatest effects were observed in samples heated to 73°C, and sarcomeres demonstrated thermally induced contraction and breakage at the Z-line. Coagulation of the sarcolemma and exposure of myofibrils were also observed as final internal temperature was increased (Leander, et al., 1980).

Bramblett and Vail (1964) cooked beef round muscles from USDA Good and Standard carcasses to an endpoint temperature of 65°C at two oven temperatures (68.3 and 93.3°C). They compared the length, width, and thickness of each muscle before and after cooking. These authors reported that 94% of beef round muscles decreased in volume along the length of the fibers; 68% decreased in width, and 77% decreased in thickness, whereas 30% increased in width and 22% gained in thickness. Reid and Harrison (1971) saw very little change in muscle fiber width from raw to cooked tissue among four heat treatments. The mean decrease for all heat treatments ranged from 8.9% for pressure braising to 11.2% for oven broiling, a difference of 2.3 percentage points between these two moist heat treatments. The decrease for oven roasting and frying (dry heat treatments) was 9.3% and 10.2% respectively, or a small difference of 0.9 percentage points between two dry heat methods. Therefore, heating, regardless of method, decreased fiber width approximately 10%. Cooking meat also causes changes to occur in fiber length. Bouton, Harris, and Shorthose (1976) explained that the changes in meat fiber length occur in three stages. The first stage occurs at temperatures between 40 and 45°C. Within this temperature range, reductions in fiber length are the result of modifications to the myofibrillar structure. The second stage occurs between 55 and 60°C, and changes in collagen cause the reduction in meat fiber length. The third stage occurs at temperatures beyond 70°C, with shrinkage being the result of myofibrillar and connective tissue changes. However, Bendall and Restall (1983) observed no change in sarcomere length when fibers were heated in an aqueous medium to final temperatures ranging from 40 to 90°C, but fiber diameter decreased. These authors concluded that the observed decrease in volume was the result of moisture loss because water was slowly but incompletely expelled from the myofibers between 40 and 52.5°C. However, volume rapidly increased to maximal rate between 57.5 and 60°C as collagen was gelatinized (Bendall and Restall, 1983). In addition to dimensional changes, disintegration also occurs. Hearne, Penfield, and Goertz (1978) reported that increased final temperatures were associated with greater fiber disintegration. They also determined that faster cooking rates to a temperature of 60°C, when compared with slow rates of cooking, resulted in greater fiber disintegration. Disintegration of muscle fibers was associated with an increased number of cracks, breaks, and granulation in the fibers, which was also associated with a decrease in WBSF value.

While muscle fibers are undergoing changes during cooking, the external shape also undergoes some changes. During cooking, the shape and size of meat changes, and these alterations are caused by moisture loss and changes at the myofibrillar level (Boles, 2010). Obuz and Dikeman (2003) observed that the *Biceps femoris* decreased in width and thickness, while *Longissimus lumborum* decreased in length and thickness during cooking. The authors attributed the differences observed between the two muscles to differences in fiber orientation and muscle composition. The authors also reported that endpoint temperature did not affect ($P > 0.05$) the changes that occurred in cooked density, width, length, or thickness of steaks but explained that observed decreases in length, width, or thickness might be accredited to loss of water. Bouton et al. (1976) reported that meat structure could be considered a two component system, with the two components being the myofibrillar and connective tissue structures. The effects of heat would then be dependent upon the interaction between these two structures. These authors further reported that connective tissue influenced external, dimensional changes. As cooking temperature was increased, collagen shrinkage contributed to observed dimensional decreases in sample length and cross-sectional area (Bouton et al., 1976). Furthermore, external, dimensional decreases may also be influenced by muscle type in addition to spatial orientation of collagen fibers, which would also be different for various muscles. Boles and Shand (2008) found that dimensional changes of stir-fry slices were affected by muscle utilized and slice thickness. They determined that the greatest dimensional reductions occurred in slices taken from the inside and outside round. Moreover, samples that had intact connective tissue around the slices were found to have less dimensional changes, which led the researchers to conclude that connective tissue that had not yet been gelatinized may have some impact on observed changes in dimension (Boles and Shand, 2008).

Shrinkage of collagen during cooking is important to achieving a tender end product. García-Segovia, Andrés-Bello, and Martínez-Monzó (2007) reported that temperature and cooking time affect the physical properties of meat that determine eating quality. The components of muscle that control toughness are the myofibrillar proteins and the connective tissue proteins (collagen and elastin). The destruction of the fibrous structure of collagen is initiated by the breakage of hydrogen bonds (Welke et al., 1982). In addition, Tornberg (2005) determined that collagen not stabilized by intermolecular bonds will dissolve and form gelatin upon further heating. Bear (1952) reported that chemical properties such as ionic strength and pH affect collagen shrinkage.

Method of cooking may also impact the solubilization of connective tissue. It is well known that the application of heat causes the solubilization of connective tissue, which causes tenderization. However, heat also hardens myofibrillar proteins, which causes toughening (Obuz et al., 2004). Moist heat cookery methods have often been recommended for cuts with larger quantities of connective tissue. Cover and Smith (1955) conducted a study involving moist and dry heat cookery methods. Their results indicated that collagen content was associated with tenderness when *Biceps femoris* (BF) was cooked by different methods, but when the tenderness of two muscles (BF and LD) was compared by the same method of cooking (broiling) collagen content was not associated with tenderness. Moreover, when two muscles, (BF and LD) were prepared by the same method of cooking (broiling), the LD was found to be more tender and to have less connective tissue than the BF.   Because collagen content was found to be associated with tenderness, additional research was conducted to determine a method for tenderizing connective tissue. Braising to 100°C and holding at that temperature for 25 min appeared to be the best method for tenderizing connective tissue (Cover, Bannister, and Kehlenbrink, 1957). However, it has been reported that the rate at which heat penetrates meat is less influential in the solubilization of collagen than the manner in which the energy is supplied to produce the heating effect. Collagen reportedly denatures between 53 and 63°C, and the denaturation includes the destruction of the fibrous structure (McCrae and Paul, 1974). The application of heat to connective tissue causes it to solubilize and improves tenderness.

Changes in Appearance

Heating of meat will alter the external appearance through changes to myoglobin. Davey and Gilbert (1974) reported that heat starts to modify color from red to brown around 43 to 44°C. Oven temperature and internal temperature of the meat obviously will affect changes in appearance. Hamouz, Mandigo, Calkins, and Janssen (1995) found internal color assessments to differ directly with increases in oven temperature. Thus, oven temperature had a large impact on internal color accounting for 77% of the variation. García-Segovia et al. (2007) also reported several changes in the appearance and physical properties of meat that occur due to heating processes. These alterations include discoloration of meat as a result of oxidation of pigment heme groups. The authors used average visible spectra reflectance of beef steaks to determine that, with increasing cooking time, peak intensity of the wavelength decreases ~~to~~ deoxymyoglobin and oxymyoglobin (loss of reddish color), and increases metmyoglobin (brownish red) and sulfmyoglobin (greenish). Furthermore, an increase in the cooking temperature will yield a decline in deoxymyoglobin and oxymyoglobin peak intensity and an amplification of metmyoglobin and sulfmyoglobin. This research involved cook-vide, sous-vide, and atmospheric cooking conditions. The cook-vide treatment utilized a vacuum cooking setup in which a pressure cooker with an inner basket was attached to a vacuum pump. The atmospheric treatment used the pressure cooker without the vacuum pump. For the sous-vide treatment, steaks were packaged in nylon/polyethylene bags before cooking, and the bags were immersed in water for cooking. The authors reported that meat cooked by sous-vide treatment exhibited a more intense reddish color and a less intense brownish-green color than those cooked by atmospheric pressure or cook-vide conditions (García-Segovia et al., 2007).

Meat Cookery Methods

A variety of cooking methods exist for meat products including roasting, braising, broiling, grilling, and others. The type of cookery method utilized will impact the rate of heat penetration (Seideman and Durland, 1984). Cooking time has been found to vary with the size of the muscle as well as with the temperature of cooking. For example, muscles cooked at 68.3°C required 2 to 4 times longer to cook as did muscles cooked at 93.3°C. On the other hand, smaller muscles required a longer time per unit weight to cook than did larger muscles (Bramblett and Vail, 1964).

Degree of doneness is determined by the final temperature of the meat product. Common degree of doneness ratings are rare, medium rare, medium, medium well, and well-done. Degree of doneness also impacts palatability of the product for consumers. Endpoint temperature and cooking rate will determine the degree of doneness (Obuz, Dikeman, Erickson, Hunt, and Herald, 2004). A beef customer-satisfaction survey was conducted to evaluate the consumer-controlled factors of cooking method and degree of doneness on Top Choice, Low Choice, High Select, and Low Select top loin steaks. Respondents were asked to prepare the steaks as they would when buying the same cut in the grocery store. Respondents evaluated the cuts for sensory characteristics of overall like, tenderness, juiciness, flavor desirability, and flavor intensity. Respondents were also asked to describe degree of doneness based on cooked color. Results of the survey found that consumer ratings tend to be the highest for steaks cooked to lower degrees of doneness. They also found that steaks cooked “well done or more” were more closely related in the categories of overall like and tenderness to those cooked “medium” than those cooked “medium well.” Therefore, in the higher degrees of doneness, flavor may play a stronger role in determining consumer satisfaction than does tenderness (Lorenzen et al., 1999).

Different beef muscles may respond differently to various cooking methods. Kolle, McKenna, and Savell (2004) determined that responses to heating treatments were largely muscle-dependent because some muscles improved in tenderness regardless of heating treatment. Cover (1937, 1941, and 1943) ascertained that roasting meat at a very low temperature created a more tender product than cooking meat in water at the same low temperature or roasting at higher temperatures. Cover (1937, 1941, and 1943) also found that tenderness was improved with decreases in rate of heat penetration and doubted that moist heat was needed for making tough meat tender. Griswold (1954) conducted a study to compare 14 different cooking methods to a standard braising method to determine the best method for cooking Commercial and Prime grade beef rounds. Results indicated that roasting at 121°C was a superior method for cooking beef round despite the dry appearance of the surface. They also found no significant differences in the palatability or shear values of beef from the top and bottom muscles of the round. Bramblett and Vail (1964) found the development of tenderness in less tender cuts appeared to be an adjunct to a low temperature and long cooking time.

Advances in technology have also affected meat cookery methods because new ovens have also been developed. Funk, Aldrich, and Irmiter (1965) investigated what was then a new approach to meat cookery that was brought to the attention of food service operators; the development of the forced-air, convection oven, which supposedly had the ability to reduce cooking times and cooking losses. A reduction in cooking time and cooking losses would result in improved yields and enhanced palatability. Furthermore, cooking time and temperature relationships are associated with flavor, aroma, color, tenderness, and juiciness of the cooked product. The investigators found the forced-air, convection oven was able to maintain a more constant temperature during roasting. The authors also identified three factors to explain the faster heat penetration rates in the forced-air, convection oven. The first factor was the velocity of the circulating air, “which tended to wipe off the stagnant air film adhering to the surface of the roast,” which allowed heat to penetrate at a faster rate. The second factor was the presence of moisture from a pan of water in the bottom of the forced-air, convection oven during roasting. The third factor was diminished fluctuations in temperature in the forced-air, convection oven than in the conventional oven. Therefore, heat penetration rates were faster in a forced-air, convection oven than in a convection oven at the same oven temperature. As a result, roasts cooked by the forced-air, convection required 18% less cooking time than conventional roasting of similar cuts at the same oven temperature (Funk~~,~~ et al., 1965).

The forced-air, convection oven was further examined by McCammon-Davenport and Meyer (1967). These investigators examined the effects of roasting U.S. Good, boneless beef sirloin butts by forced-air convection at 93.3°C and 148.9°C. Roasts were cooked to an internal temperature of 73.9°C. McCammon-Davenport and Meyer (1967) reported that an oven temperature of 93.3°C was found to increase cooking time per unit weight but decrease total cooking losses ($P < 0.001$), which resulted in a greater yield of usable meat ($P < 0.05$)~~.~~ Moreover, oven roasting and oven broiling have not been found to differ significantly from each other in time required for the temperature at the center of the muscle to rise 5°C (Schock, Harrison, and Anderson, 1970). In oven broiling, the rate of heat penetration was somewhat constant throughout the cooking cycle. However, heat was found to penetrate oven roasted pieces most rapidly between internal temperatures of approximately 12 and 40°C but slowed slightly between 40 and 50°C. After 88 min of cooking, the internal temperature of both oven-broiled and oven-roasted pieces was approximately 65°C. Thereafter, the rise in temperature of oven roasted pieces slowed.

As previously mentioned, moist-heat cookery has often been recommended for cuts with larger quantities of connective tissue, but dry-heat cooking methods are recommended for cuts that have smaller quantities of connective tissue. Considerable research has been conducted to determine appropriate cooking methods for beef muscles. Shaffer, Harrison, and Anderson (1973) reported that cooking in an oven film bag (moist heat) or roasting in an open pan (dry heat) have both been deemed acceptable methods for cooking beef top round from the frozen state. The palatability of the meat was comparable for roasts cooked by either method at either 177 or 205°C. However, the utilization of a cooking bag required significantly less total time to cook meat to an endpoint temperature of 80°C. On the other hand, roasting in an open pan produced significantly less weight loss from roasts cooked to an endpoint temperature of 80°C at the same oven temperatures (Shaffer, Harrison, and Anderson, 1973).

Locker and Daines (1974) studied rate of heating as a factor in cooking loss and shear force in *Sternomandibularis* muscle. Samples were subjected to both a normal fast cook (40 min to 80°C) and a slow cook, starting with a water bath at room temperature and rising to 80°C in 55 min followed by an extra 30 min at 80°C. The slow cooking resulted in significantly higher cooking losses for *Sternomandibularis* muscle, but shear force was significantly lower. However, I do not think the *Sternomandibularis* muscle is relevant to typical steaks and roasts because of its large quantity of connective tissue. As a result of this connective tissue quantity, the *Sternomandibularis* muscle is not used for steaks or roasts. McCrae and Paul (1974) also investigated moist-heat and dry-heat cooking methods. They determined that steam cookery and other moist-heat cookery methods caused an increase in the rate of heat penetration and more rapid increases in surface temperature when compared with dry-heat cookery methods. Yet, they also found that cooking method did not impact cooking losses or tenderness for the *Semitendinosus* muscle. Powell, Dikeman, and Hunt (2000) found that conventional dry-heat cooking resulted in less tender meat from high-connective tissue cuts such as those from beef *Semitendinosus* muscle than from low-connective tissue cuts such as those from beef *Longissimus* muscle. However, surface browning, which has been shown to contribute to the aroma of cooked meat, does not develop when moist-heat cookery methods are utilized (Drummond and Sun, 2006).

Evaporation also occurs during cooking and may have more of an impact when moist-heat cookery methods are utilized. Bengtsson, Jakobbson, and Dagerskog (1976) developed an evaporation curve that was nearly linear, which implies that evaporation occurs from a wet surface (first order dehydration) for the duration of the cooking cycle at an oven temperature of 160°C. Surface temperature, therefore, remains slightly below the wet bulb temperature in the oven atmosphere. The wet bulb temperature increased as a result of the accumulation of steam from evaporated meat juice.

Many consumers remove external fat from meat products prior to cooking, which may impact how the meat reacts to the cooking treatment. Belk, Luchak, and Miller (1993) reported that reduced levels of external fat did not significantly affect yields or relative changes in composition due to cooking but did increase cooking time per unit weight. In addition, Belk et al. (1993) investigated various cooking methods including forced air/steam combination ovens, which reportedly reduced the required length of cooking per unit raw weight. On the other hand, conventional ovens may increase cooking time. Rapid cooking of larger roasts with moist heat increased post-cooking temperature rise. Belk et al. (1993) found during their preliminary trials with forced air/steam ovens, that roasts (less than 5 kg) would cook too quickly if steam was continually applied during cooking, especially when muscles were trimmed of fat or cooked to lower endpoint temperatures. However, Jeremiah and Gibson (2003) recommended low temperature, dry-heat cookery to consumers to improve the palatability of roasts from the beef round. However, the utilization of this method would require consumers to spend twice the amount of time to cook roast cuts. Jeremiah and Gibson (2003) concluded that the best method was cooking at high temperature initially and subsequently reducing the temperature. The investigators also advised cooking roasts uncovered after brushing with 5 ml of a bottled kitchen condiment and placing roasts in a cold oven, turned on to 260°C. The authors further advised that consumers add 250 ml of water after the roasts had been in the oven for 30 min. Adhikari, Keene, Heymann, and Lorenzen (2004) reported that grilling to medium-rare at 65°C was most appropriate for the *Complexus, Dorsalis oblique, Longissimus capitas atlantis, Longissimus dorsi, Multifidus* and *Spinalis, Serratus ventralis, Splenius,* and *Subscapularis* muscles because grilling yielded a product with more juiciness and roasted flavor than other cooking method x temperature combinations (Adhikari et al., 2004). Therefore, different cookery methods are more appropriate for different muscles.

Cooking Yields

Product yield is an important part of beef marketing. Moisture loss during cooking causes product yield to decrease. Cooking method will have a great effect on product yield. Cover and Smith (1955) conducted a study to determine the effects of broiling and braising beef steaks on weight losses. Broiled steaks were cooked individually in a gas oven at 175°C. Braised steaks were cooked on a wire rack above a boiling liquid in a heavy pot that was pre-heated to 246.1°C. They reported weight losses during cooking for broiled loin, broiled bottom round, and braised bottom round that averaged 42, 41, and 44%, respectively. At the time that the above research was conducted, braising and broiling were commonly utilized as in-home cooking methods. It should also be mentioned that the cooking losses observed by Cover and

Smith (1955) are unusually high. Funk et al. (1965) compared two different oven types, a forced-air, convection oven and a conventional oven. These authors reported average total cooking losses for conventionally cooked roasts were 12.49% compared with 15.22% for forced-air, convection cooked roasts. The authors hypothesized that the circulating fan in the forced-air convection oven may have dried the surface of the meat, which resulted in an increase in cooking losses. It should be pointed out that these losses are much lower than in most other citations. Shaffer et al. (1973) found percentages of drip cooking losses were less ($P < 0.001$) for roasts cooked by dry heat than for those cooked by moist heat, whereas percentage of total moisture loss was greater ($P < 0.001$) in roasts cooked by dry heat.

Research clearly demonstrates the impact of oven temperature and endpoint temperatures on cooking losses. Bengtsson et al. (1976) showed evidence that oven temperature, relative humidity, sample dimensions and initial sample temperature play an important role in the resulting temperature development and yield during oven cooking of beef. The authors also demonstrated that increasing the oven temperature from 175 to 225°C resulted in steeper temperature gradients and shorter cooking times but reduced cooking yields. Cooking yields may also influence palatability.

The maintenance of moisture in a product during cooking improves juiciness (Ritchey and Hostetler, 1965). As endpoint temperatures are increased, myofibrillar contraction has been found to increase, which resulted in increased cooking losses (Bouton et al., 1976). Belk et al. (1993) found that a fast cooking rate compared to a slow cooking rate increased ($P < 0.05$) total cooking losses for clods, tenderloins, inside rounds, gooseneck rounds, and steamship rounds by 8.6, 5.0, 5.7, 7.2, and 7.6%, respectively. This study also compared three different oven types: a gas, still-air conventional oven; a gas, forced-air convection oven; and an electrical forced air/steam combination oven. Oven type was only associated with decreased ($P < 0.05$) cooking yields for ribeyes and inside rounds when a forced-air convection oven was used. Bengtsson et al. (1976) also found that at temperatures exceeding 70°C, drip losses increased rapidly. The authors implied that drip loss could be kept to a minimum if internal temperatures were kept below 65°C, and evaporative losses could be minimized by increasing the relative humidity of the cooking environment.

Moisture loss during cooking is obviously related to water holding capacity. It has been suggested that decreases in water holding capacity/cooking losses are the result of changes in charges and unfolding of proteins, which causes the isoelectric point to shift to a more basic pH (Hamm and Deatherage, 1960). Moreover, aging time (time of postmortem storage) may also impact cooking yields/losses. Boles and Swan (2002) reported that cooked yields of inside rounds and flats decreased as refrigerated storage increased to 8 weeks. The authors also determined that pH of the inside rounds and flats increased during the storage period and was related to the decrease in cook yields. Palka (2003) produced similar results showing that cooking yields were less when meat was aged for 7 days compared with 12 days postmortem.

Cooking and Tenderness

Cooking of meat can also be a method of tenderizing meat. Tenderness is commonly measured on cooked meat products in two ways: instrumentally or sensory-panel evaluation. Sensory panels can be conducted with trained and untrained individuals. Tenderness can be measured instrumentally using both Warner-Bratzler shear force and slice shear force methods. Shaffer et al. (1973) reported that roasts cooked by dry heat were scored more tender and juicier ($P < 0.05$) by panelists than those cooked by moist heat. They also found significant interactions between type of heat and endpoint temperature for the sensory characteristics of flavor and apparent degree of doneness. The panelists preferred the flavor of meat cooked to an internal temperature of either 60°C or 70°C by moist heat. The difference between dry and moist heat was significant ($P < 0.05$) at 60°C. However, when meat was cooked to an internal temperature of 80°C, panelists preferred meat cooked by dry heat rather than meat cooked my moist heat. Apparent degree-of-doneness scores for meat cooked by dry heat were less ($P < 0.05$) than those for roasts cooked by moist heat to internal temperatures of 60 and 70°C. However, Hamouz et al. (1995) reported that taste panel assessment of tenderness and juiciness improved with a reduction in oven temperature ($P < 0.05$), yet oven temperature accounted for only 7.22 and 12.87% of tenderness and juiciness variation, respectively. They concluded that low temperature cookery is a beneficial method for preparing roast beef in the foodservice industry.

With multiple methods for assessing meat tenderness, the question arises as to whether one method is better for evaluating tenderness than the other methods. Adhikari et al. (2004) determined that descriptive sensory analysis is a successful method of differentiating among cooking conditions for individual muscles. Their results clearly demonstrated that sensory methods were more sensitive than Warner-Bratzler shear force (WBSF) analysis in discerning the toughness and toughness-related attributes in muscle foods. The authors found no differences ($P > 0.05$) in WBSF for four cooking methods (grilling, roasting, slow roasting, and braising) and three endpoint temperatures (65, 70, and 75°C) for the *Complexus, Dorsalis oblique, Longissimus capitas atlantis, Longissimus dorsi, Multifidus and Spinalis, Serratus ventralis,* and *Splenius* muscles. However, for the *Subscapularis* muscle, WBSF was higher ($P < 0.05$) for 75°C compared with 65°C. In contrast, results from sensory panels showed that sensory attributes were different ($P < 0.05$) for all cooking methods and for each muscle. Within each cooking combination (method x temperature), sensory attributes were significant ($P < 0.05$) for doneness, beefy flavor, livery flavor, burnt flavor, chewiness, stringiness, and juiciness. Moreover, Berry, Wheeling, and Carpenter (1977) determined that the non-significant ($P > 0.05$) differences in shear force among their methods of cookery seemed to indicate that sensory panel tenderness ratings and shear force values were not assessing the same components of tenderness. Furthermore, it would appear that palatability scores assigned to roasted *Semimembranosus* (SM) samples were not very indicative of what might be scored for palatability of braised SM samples (Berry et al., 1977).

Marbling

Besides the factors of muscle type, collagen content, endpoint temperature, and cooking methods, marbling also impacts how meat will respond to cooking. Higher marbling degree (higher USDA quality grade) provided an assurance for tenderness at endpoint temperatures of 60°C and higher (Obuz et al., 2004). Miller (1994) concluded that muscles with more intramuscular fat content are more protected against the harmful effects of overcooking (high heat) on protein denaturation, and higher fat content also diminishes the strength of connective tissue, which enhances tenderness.

Meat Tenderness

Tenderness and flavor are the most important palatability characteristics relating to consumer satisfaction with beef (Calkins and Sullivan, 2007). Beef tenderness is a multifaceted trait. Structural components of muscle strongly influence the perception of tenderness (Calkins and Sullivan, 2007). Belew, Brooks, McKenna, and Savell (2003) reported that numerous factors influence the tenderness of meat. Each factor is supported by an assortment of theories that attempt to explain how it affects tenderness. However, four common characteristics considered most important are postmortem proteolysis, intramuscular fat, connective tissue, and the contractile state of the muscle. These factors also contribute to the difference in tenderness between different muscles within the same beef carcass. For example, retail cuts from the rib and loin have been highly marketable, but those from the chuck and round are often less popular because of real or perceived problems with tenderness. Some of the chuck and round muscles are reduced to ground products as a way to improve their marketability, but usually at a lower price than most steaks or roasts (Belew et al., 2003). Savell and Cross (1988) reiterated the commonly used categorization factors influencing meat tenderness: an actomyosin effect, a background effect, and a bulk density or lubrication effect.

Calkins and Sullivan (2007) stated that the actomyosin effect refers to facets of meat tenderness influenced by the state of the sarcomeres in the muscle fibers. Sarcomeres are the smallest unit of muscle contraction, and they comprise the bulk of muscle fibers (cells). The proteins actin and myosin are the main components of the sarcomere. These proteins unite during contraction and during rigor mortis to form actomyosin. Contracted sarcomeres are shorter and are less tender than sarcomeres that are not contracted. The position of the muscle during rigor mortis influences the length of sarcomeres. Stretched muscles have longer sarcomeres. Moreover, the temperature at which rigor mortis occurs also impacts the length of the sarcomeres. Cold pre-rigor muscle temperature results in short sarcomeres. Rhee, Wheeler, Shackelford, and Koohmaraie (2004) reported that the mean for sarcomere lengths of the muscles evaluated was 2.3 µm. The *Psoas major* (PM) had the longest ($P < 0.05$) sarcomere length (2.94 µm), followed by *Triceps Brachii* (TB), *Infraspinatus* (IS), *Rectus femoris* (RF) and *Semitendinosus* (ST). Each of those muscles has a sarcomere length greater than 2.0 µm. The BF, LD, and SM had comparatively short sarcomere lengths, but the *Gluteus medius* (GM) has the shortest ($P < 0.05$) sarcomere length (1.66 µm). Calkins and Sullivan (2007) also described a second attribute of sarcomeres, the ease with which they might be fragmented after cooking. This weakness is most often the result of proteolytic degradation of main proteins in muscle fibers through conditions that contribute to proteolysis, such as warmer temperatures during storage and an extended period of time under refrigeration. Cooler aging is recognized as one of the easiest and most effective ways to improve tenderness.

Connective tissue maintains most of its strength even during extended periods of cooler aging. Therefore, even when the actomyosin effect is low, connective tissue can cause background toughness (Calkins and Sullivan, 2007). Two characteristics of connective tissue have an impact on tenderness. A larger quantity of connective tissue, which is comprised primarily of the protein collagen, results in less tender meat. Locomotion muscles located in the thoracic and pelvic limbs of animals have more connective tissue and are less tender. Connective tissue also possesses heat-induced solubility. Upon cooking, especially slow cooking under moist heat conditions, collagen softens and solubilizes, which reduces the contribution of connective tissue to beef tenderness. Older animals have more cross-links within collagen than younger animals, and the addition of cross-links causes collagen to be less soluble when heated. Therefore, older animals provide meat that is less tender (Calkins and Sullivan, 2007).

The final effect that influences meat tenderness is the bulk density or lubrication effect, which was explained by Smith and Carpenter (1974). This effect is the result of intramuscular fat within muscle. They believed that fat could dilute protein in a given, bite-sized portion of meat. This decreases the bulk density and causes an increase in tenderness. They also suggested that fat located between the cells of muscle, or within the connective tissue, could shrink the connective tissue to an adequate degree as to reduce the amount of force required to shear the meat. Moreover, fat provides lubrication between the fibers of a muscle and could enhance the perception of tenderness. Fat may also provide some protection against overcooking (Calkins and Sullivan, 2007).

Tenderness has been found to vary from muscle to muscle. Rhee et al. (2004) determined that tenderness and tenderness-related traits tend to be highly variable within and among major beef muscles, with the source for this variation in tenderness being the multifaceted interaction of various biochemical traits that change from muscle to muscle. Furthermore, many of these biochemical traits are associated with the structure of the muscle. Greaser (1991) reported that costameres provide the structural framework responsible for the attachment of the myofibrils to the sarcolemma. Proteins that comprise, or are associated with the intermediate filaments and costameres include desmin, filamin, and synemin. Young (1980) reported that three cytoskeletal structures are degraded when meat is tender. One of these structures is the Z- to Z-line attachments by intermediate filaments. Desmin is the primary protein responsible for Z- to Z-line attachment and is also a good postmortem substrate for calpain. Taylor (1995) considered titin and desmin to be the most important substrates that influence meat tenderness. Rhee et al. (2004) observed variation in one such biochemical trait when they found a broad range among muscles in the mean percentage of desmin that was degraded postmortem. Desmin degradation was greatest ($P < 0.05$) for the PM and *Supraspinatus* (SS). The IS, *Adductor* (AD), and RF were found to have less than 30% desmin degradation. The proximal location of the BF had higher ($P < 0.05$) desmin degradation than the other locations within the BF.

Because individual muscles also vary in tenderness, tenderness categories have often been created. Calkins and Sullivan (2007) reviewed a variety of papers to create a ranking of muscles by tenderness. Muscles were placed in the following categories: tender (WBSF < 3.9 kg), intermediate (3.9 kg < WBSF ≤ 4.6 kg) and tough (WBSF > 4.6 kg). The major muscles that were classified in the tough group (WBSF > 4.6 kg) were the BF, SS, ST, DP, GM, *Vastus lateralis* (VL), *Rhomboideus*, and the LD from the chuck region. McKeith et al. (1985) studied 13 major muscles of beef carcasses and discovered differences in composition, sarcomere length, and collagen content in conjunction with sensory panel ratings and WBSF values. Furthermore, Belew et al. (2003) concluded that historic generalities, such as support muscles being more tender than locomotive muscles, to be less applicable when an array of individual muscles are evaluated for tenderness. Several muscles, such as the *Biceps brachii* (BB) from the forearm, were shown to be more tender than some support muscles such as the LL and LT (Belew et al., 2003).

Tenderness is frequently measured instrumentally using two methods, WBSF and slice shear force (SSF). Calkins and Sullivan (2007) described WBSF analysis as the objective method utilized most often in the measurement of tenderness. This instrument records the quantity of force required to shear ~~a~~ cores of cooked meat. Berry (1993) reported that peak load is the most commonly utilized shear force characteristic, but results indicated that if modulus, which considers stress and strain, and peak energy were not measured, some effects of cooking on shear force would not be detected. Shackelford et al. (1996) determined that the longitudinal location within the *Longissimus thoracis et lumborum* did not affect ($P > 0.05$) WBSF or any sensory trait measured. Wulf, Morgan, Tatum, and Smith (1996) reported that WBSF increased linearly with degree of doneness (evaluated visually) in strip loin steaks. Because of the relatively low collagen content of the LL muscle, the solubilization of collagen that occurs with increased temperature above 55°C is overridden by increased myofibrillar toughening. Shackelford et al. (1997) concluded that WBSF can be used to assess tenderness differences among treatments, such as *Bos taurus* versus *Bos indicus,* within a given round muscle with little loss of accuracy compared to trained sensory panel tenderness evaluation.

Slice shear force (SSF) is a newer method of measuring tenderness. Shackelford, Wheeler, and Koohmaraie (1999a&b) conducted experiments to develop the most advantageous protocol for measurement of SSF and to evaluate SSF as an objective method of assessing beef *Longissimus* tenderness. Lorenzen, Calkins, Green, Miller, Morgan, and Wasser (2010) described the differences between the two methods are that WBSF requires a minimum of six 1.27-cm cores from throughout the steak and cooling of the steak to a consistent temperature (AMSA, 1995), whereas, SSF uses a 1 cm x 5 cm slice from the lateral end of the steak. Furthermore, SSF can be conducted immediately after the steak has reached final endpoint temperature (Shackelford et al., 1999b). For either method, samples are removed parallel to the muscle fiber orientation and sheared across the fibers. WBSF utilizes a V-shaped blade, while SSF uses a flat blade. The blades are the same thickness (1.016 mm) and possess the same degree of bevel (half-round) on the shearing edge. Results of the study indicated that hot SSF was more strongly correlated with WBSF and trained sensory panel (TSP) tenderness rating than cold SSF. The correlation of hot SSF with TSP tenderness rating was slightly stronger than the correlation of WBSF with TSP tenderness rating. And, the correlation of hot SSF with TSP tenderness rating was not influenced by the belt grill cooking rate used for SSF steaks These researchers concluded that SSF seemed to be a more accurate method of assessing shear force than the WBSF technique because SSF was more strongly correlated with sensory panel tenderness rating than was WBSF. These researchers reached this conclusion based on the tendency of individual WBSF values to be grouped close to the overall mean WBSF value may impede the capacity of WBSF to predict TSP tenderness ratings (Shackelford et al., 1999b). Therefore, an additional experiment was conducted to appraise the repeatability of SSF over a broader range in tenderness. The CV of SSF was greater than the CV of WBSF, which means individual WSBF values were grouped closer to their respective means than were individual SSF values. For WBSF, 82% of values were within ± 30% of the mean WBSF value, whereas 71% of SSF values were within ± 30% of the mean SSF value. Due to the tendency of WBSF values to be grouped close to the overall mean, WBSF value could potentially limit the ability of WBSF to predict TSP tenderness rating. Therefore, the authors recommended SSF as a better method of instrumentally measuring tenderness. However, one would only expect a lower CV with WBSF because the numerical values are much lower (2-7 kg, for example) than for SSF (8-50 kg, for example). Lorenzen et al. (2010) determined that correlations among WBSF and SSF were highly significant when both shear force measurements were performed on the same steak. However, the degree of the relationship was dependent on steak location within the top loin.

Shackelford et al. (1999a&b) concluded that the SSF method is technically simpler and less laborious. The authors also believed that SSF would be a more precise tenderness measurement because it is technically easier to complete than WBSF, which would cause SSF values to be less operator-dependent than WBSF values because of consistent cores by different operators can be an issue. As a result, the authors hypothesized that implementation of the SSF technique would assist in the collection of more accurate tenderness data and permit the exposure of treatment differences with reduced numbers of observations and time requirements, which would reduce research costs (Shackelford et al., 1999a&b).

A second method commonly utilized in the measurement of tenderness is sensory panelist evaluation. Cover et al. (1962) helped to define at least six features of meat tenderness that can be perceived by highly trained sensory panels. This includes softness to tongue and cheek, softness to tooth pressure, ease of fragmentation, mealiness of muscle fibers, adhesion between muscle fibers, and tenderness of connective tissue. With tenderness being such a complex and multidimensional trait, it should come as no surprise that there is not always complete agreement between tenderness determined from a WBSF analysis and that determined from a trained sensory panel. Berry (1993) found correlations between WBSF expressed as peak load and tenderness scores were highest in cores that were more similar in degree of doneness to sensory evaluation samples, which is only logical. Moreover, Shackelford et al. (1996) found sensory tenderness ratings to be slightly more repeatable than WBSF. This may have resulted from the opportunity to average any cooking errors for two steaks used in the sensory tenderness measurement that was not accessible with a single steak used for WBSF measurement. Shackelford et al. (1997) also found sensory panel tenderness ratings that were slightly more repeatable than WBSF for BF (R = 0.50 vs. 0.30) and ST (R = 0.60 vs. 0.56).

Postmortem Aging

Aging is a common practice of the beef industry. Brewer and Novakofski (2008) defined aging as the practice of holding meat at low temperatures to improve tenderness. The authors found WBSF values to decrease with aging time. Consumers perceived most changes in tenderness during the first 7 d of aging, but WBSF values were found to be similar during the first 7 d and after 14 d of aging. Juiciness, flavor, pH, lipid content and water content of steaks were not affected ($P > 0.05$) by aging (Brewer and Novakofski, 2008). Gruber, Tatum, Scanga, Chapman, Smith, and Belk (2006) found WBSF values of all muscles decreased with increasing time of postmortem storage, which contradicts the results of Novakofski. However, there was no improvement ($P > 0.05$) in WBSF past 21 d postmortem for 9 of 16 Select grade muscles (BF, RF, SM, ST, *Serratus Ventralis*, SP, SU, TF and FM), whereas WBSF of the remaining 7 Select muscles (CP, GM, IF, LM, PM, TB and VL) improved ($P < 0.05$) up to 28 d postmortem. Of the 17 muscles removed from premium Choice carcasses, 6 muscles (CP, IF, SM, SU, TM and VM) showed no improvement ($P > 0.05$) in WBSF past 14 d postmortem. Warner-Bratzler shear force of premium Choice BF and SP only improved up to 4 and 10 d postmortem, respectively. In general, WBSF of premium Choice muscles decreased more rapidly from 2 to 10 d postmortem than corresponding Select muscles. Aging responses were categorized as follows: ≥ 2.2 kg (high); 2.1 to 1.8 kg (moderately high); 1.7 to 1.1 kg (moderate); 1.0 to 0.7 kg (moderately low); and ≤ 0.6 kg (low). These results show that individual muscle, length of postmortem aging, and USDA quality grade affected beef tenderness. Results from this study may assist retail and foodservice operators establish appropriate postmortem aging times for a variety of beef muscles that differ in quality grade and allow muscle-to-muscle tenderness comparisons for differing quality grades and lengths of postmortem storage (Gruber et al., 2006).

Conclusion

In conclusion, cooking of meat causes a variety of changes both externally and internally. A variety of factors influence how meat will react to cooking. Moreover, many factors, such as oven temperature, influence rate of heat penetration. Different muscles react differently to different cooking methods. Cooking is also a method of tenderizing meat or toughening if improper cooking occurs. Meat tenderness can be assessed by WBSF, SSF, or sensory panel evaluation. Muscle is a complex structure that requires cooking in order to be consumed. The best method of cooking is dependent upon multiple factors: muscle type, collagen content, marbling, endpoint internal temperature, oven temperature, and oven environment.

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CHAPTER 2 - Cooked Yields, Cooked Color, Tenderness, and Sensory Traits of Beef Roasts Differing in Connective Tissue Content Cooked in an Oven with Steam Generation versus a Commercial Convection Oven to Different Endpoint Temperatures

Abstract

A CVap steam generation oven was compared to a Blodgett forced-air, convection oven to examine effects of cooking method on yields, cooked color, tenderness, and sensory traits of beef *Longissimus lumborum* (LL), *Deep pectoralis* (DP), and *Biceps femoris* (BF) muscles cooked to three endpoint temperatures (65.6, 71.1, and 76.7°C). For each cooking comparison, four roasts were cooked in the CVap oven for a pre-determined amount of time, and two roasts were cooked in the Blodgett oven until they reached target internal endpoint temperatures. Cooking yields were higher ($P \leq 0.05$) for BF and LL roasts cooked in the CVap. Slice shear force (SSF) for BF roasts cooked in the CVap were lowest ($P \leq 0.05$), whereas, SSF values for DP roasts cooked in the Blodgett were lowest ($P \leq 0.05$). No oven difference ($P > 0.05$) was found for LL roasts. Sensory tenderness scores for BF roasts cooked in the CVap were higher ($P \leq 0.05$) than roasts cooked in the Blodgett. Some sensory scores for LL roasts cooked in the CVap were slightly higher but were also drier (both $P \leq 0.05$). The CVap oven offers tenderization and cooking yield advantages over forced-air convection cooking for certain muscles.

1. Introduction

Food service managers strive to control factors that affect yield, serving cost, and palatability of beef. Beef is traditionally roasted at temperatures ranging from 163 to 176°C for both home and institutional uses. Low temperature roast beef cookery provides considerable economic advantages as well as improved eating quality of roasts similar in size to those cooked in the foodservice industry (Hamouz, Mandigo, Calkins, and Janssen, 1995). Mass transfer occurs during cooking by diffusion of water through the roast and evaporation from the roast surface, and additional transfer occurs through physical expulsion caused by constriction of muscle bundles during cooking (Offer and Knight, 1988), otherwise known as cooking losses. Hunt, Seidler, and Wood (1962) reported that roasts cooked to 60, 70 and 80°C could be expected to have cooking losses of approximately 38%, 43%, and 52%. It should be noted that these cooking losses are unusually high. Milligan et al. (1997) cooked USDA Standard inside round roasts in a convection oven (250°C) to internal endpoint temperatures of 60, 70, and 80°C and reported cooking losses of 26.1%, 34.7%, and 42.2%, respectively.

Cooking roasts in a forced-air convection oven involves simultaneous heat and mass transfer in a continuously changing, complex porous structure (Obuz, Powell, and Dikeman, 2002). Kolle et al. (2004) reported that moist-heat cooked steaks had a greater initial frequency of steaks rated as "very tender" (*Adductor*) or "tender" (*Rectus femoris*, *Semitendinosus*, and *Semimembranosus*, proximal portion) than did control steaks cooked with dry-heat.

Cooking losses are a major issue in the food service industry. Bengtsson, Jakobsson, and Dagerskog (1976) showed evidence that oven temperature, relative humidity, sample dimensions and initial sample temperature play an important role in the resulting temperature development and yield during oven cooking of beef. The authors also demonstrated that increasing the oven temperature from 175 to 225°C resulted in steeper temperature gradients and shorter cooking times but reduced cooking yields. Cooking yields might also influence palatability. Belk, Luchak, and Miller (1993) compared three different oven types: a gas, still-air conventional oven; a gas, forced-air convection oven; and an electrical forced air/steam combination oven. Decreased ($P < 0.05$) cooking yields in ribeyes and inside rounds in forced-air convection ovens were increased over those cooked in the air/steam combination oven.

The issue of cooking loss drove Winston Industries to develop the CVap Cook and Hold Vapor Oven. Because some foods are mostly water, the control of food quality is dependent upon the control of moisture in food. CVap technology controls evaporation by creating a moisture-laden environment. This moisture-laden environment encases meat with moisture, which creates an opposing vapor pressure that minimizes moisture loss. The CVap Cook and Hold Oven has the ability to independently control meat temperature by controlling the temperature of the water vapor, which is generated by a reservoir in the bottom of the oven. Based on these features, cooking with the CVap oven should improve cooking yields (Winston Industries, 2009). Therefore, the objectives of this research were to compare the effects of moist (CVap) and dry-heat (Blodgett) cookery methods on cooking yields, cooked color, tenderness, and sensory attributes of beef roasts from three different muscles at different endpoint temperatures.

2. Materials and Methods

2.1 Muscles

Beef subprimals (beef round, outside round-flat, NAMP 171B; beef brisket, boneless, NAMP 120; beef loin, strip loin, boneless, NAMP 180; *n* = 22) from USDA Choice carcasses were obtained from commercial processors. Vacuum-packaged subprimals were received at the Kansas State University meat laboratory and were aged in a cooler for 28 to 32 days postmortem at 0°C.

2.2 Preliminary Research

Cooking times to be utilized for the CVap oven were determined through preliminary research trials. The CVap oven utilizes technology to generate a heating curve based on user input for cooking time, desired endpoint temperature (doneness temperature), and browning level. The user can input a cooking time up to 24 h. The CVap also allows for doneness temperature to be set from 32 to 93°C. The browning scale ranges from 0 to 10 and determines the air temperature in the oven. A setting of 0 is recommended for highest yield, and a setting of 10 is recommended for ultimate browning. Based on this design, it was necessary to determine a cooking time for each endpoint temperature for each of the 3 muscles to be used. It was determined that the cooking time would be based on the average amount of time each muscle took to reach the target internal endpoint temperatures in a Blodgett, forced-air, convection oven at an oven temperature of 93.3°C. The Blodgett oven cooking temperature could not be set as low as for the CVap, so times required to reach the three endpoint temperatures in the Blodgett were determined in preliminary research and those times were used for the CVap cooking cycle so that direct comparisons could be made between the two ovens. Roasts were also cooked in the CVap oven during preliminary trials to investigate the browning level. It was determined that a browning level of 4 would be used, which has an equivalent air temperature of -1.1°C.

2.3 Roast Preparation and Cooking

Roasts were cut from each subprimal in order to evaluate two different cookery methods. Roasts were cut, and fat trimmed to 0.6 cm just prior to cooking. From each bottom round, two 1.8-kg *Biceps femoris* (BF) roasts were removed from the center to obtain roasts that were uniform in shape. From the brisket, two 1.4-kg *Deep pectoralis* (DP) roasts were removed. The point end of the brisket was removed, and the flat end was cut in half diagonally to yield two roasts. From the strip loin, two 1.8-kg *Longissimus lumborum* (LL) roasts were removed from the anterior end. Roasts were weighed using an Ohaus Explorer Pro Balance (Ohaus Explorer Pro, Ohaus, Brooklyn, NY, U.S.A.).

Two cooking phases occurred during this project. For both phases, ovens were allowed to pre-heat for approximately 15 min prior to cooking. During cooking phase I, eight roasts of each muscle x treatment combination were cooked per the recommendation of Winston Industries. Roasts from each of the three muscles were cooked to an internal endpoint temperature of 71.1°C. *Biceps femoris* roasts were cooked for 7 h and 30 min. *Deep pectoralis* roasts were cooked for 8 h, and LL roasts were cooked for 7 h and 30 min. Eight roasts of each were cooked in the CVap oven according the recommendations of Winston Industries. The browning level was set at 4, which was considered acceptable by the recommendations of Winston Industries. The temperature in the Blodgett oven was set at 93.3°C to attempt to match the lower temperatures in the CVap. Therefore, the only way to directly compare the two ovens was to cook roasts in the CVap for a constant time that matched the average times to reach the three endpoint temperatures for the three muscles in the Blodgett established in a preliminary study. For cooking phase II, two roasts from different subprimals for each target endpoint temperature were placed in a Blodgett forced air convection oven (Blodgett Dual Flow, Blodgett

Oven Company, South Burlington, VT, U.S.A.). Roasts were removed when they reached the target endpoint temperatures (+/- 2°) of 65.6°C, 71.1°C, and 76.7°C for all three muscles; irrespective of time. Four roasts were cooked in the CVap Oven (CVap Cook and Hold Vapor Oven CAC 507, Winston Industries, Louisville, KY, U.S.A.). Two of the roasts placed in the CVap oven were from different subprimals, and the remaining two were from the same subprimal. Cooking cycles for roasts cooked in the CVap were based on pre-determined average times to match the target endpoint temperatures in the Blodgett oven. Therefore, roasts cooked in the CVap oven were cooked for a constant amount of time for each muscle x temperature combination. The CVap oven automatically determines a heating curve based on inputs by the operator. Inputs included a cooking time, target endpoint temperature and browning level. The browning level was set at 4 for all cooking cycles, which was ascertained during preliminary research. Roasts were placed on trays to allow juices to drip into a pan below the roasts for both ovens.

Cooking times for roasts cooked in the CVap oven were determined during preliminary research, and actual cooking times for the Blodgett varied from those determined in the preliminary research. Exact cooking times for cooking phase II for each roast are reported in Appendix A.

2.4 Temperature Measurement

A data acquisition system was used for recording of temperatures during the cooking cycles. A data logger with a serial interface (Doric Minitrend 205, Doric Scientific, San Diego, CA, U.S.A.) was connected to a laptop computer equipped with Microsoft Excel. Temperature data were recorded every 5 min during cooking. Temperatures were measured with 30-gauge copper-constantan thermocouples. Thermocouples were placed in the geometric center of each roast. One thermocouple was placed inside the Blodgett oven to measure oven temperature during cooking. In the CVap oven, one thermocouple was used to measure air temperature, and a second thermocouple was placed in a sock that was subsequently placed in the water reservoir at the bottom of the oven to measure wet bulb temperature.

2.5 Cooking Yield

Roasts were weighed prior to cooking. Following cooking, roasts were removed from the ovens and allowed to cool for approximately 5 min and then weighed on the same balance. The equation used for calculation of cooking yield was:

Cook yield = (cooked weight/raw weight) x 100

2.6 Cooked Color

After weighing, cooked color (L*, a* and b*) was measured instrumentally on external lean, external fat, and internal lean surfaces using a Hunter Miniscan (HunterLab Miniscan EZ, HunterLab, Reston, VA, U.S.A.). Three readings were taken on the external lean surface, and two readings were taken on external fat surfaces. Sections, 2.54-cm thick, were cut from the roasts perpendicular to the fiber orientation. Internal lean cooked color was measured instrumentally with the Miniscan on the first section. Three readings were taken on internal lean surfaces of the sections. Readings were taken on the medial, lateral, and center of the sections. One section was removed for slice shear force and a second steak was removed for Warner-Bratzler shear force.

2.7 Instron Analyses

Slice shear force (SSF) measurements were taken shortly after cooking. For SSF evaluations of the BF and DP, a 1-cm thick by 5-cm long slice was excised from the center of each section with a double-bladed knife. For LL, the 1-cm thick x 5-cm long slice was removed from the lateral half of each section. Each slice was sheared once perpendicular to the muscle fibers. A slice shear force attachment (beveled blade) was connected to an Instron® Universal Testing Machine (Model 5569, Instron Corp., Canton, MA, U.S.A.).

For Warner-Bratzler shear force (WBSF), one 2.54-cm cooked section per roast was cooled for 24 h at 4°C. Eight (1.27 cm) round cores were removed from each steak parallel to muscle fiber orientation (AMSA, 1995). Each core was sheared once through the center. A Warner-Bratzler shear attachment (V-notch blade) was connected to an Instron® Universal Testing Machine (Model 5569, Instron Corp., Canton, MA, U.S.A.). A 50-kg compression load cell was utilized at a crosshead speed of 250 mm/min.

2.8 Sensory Evaluation

Roasts for sensory evaluation were stored in a cooler until 28 d postmortem. After the aging period, two 1.8-kg roasts were cut from bottom round (n=18) and strip loin (n=18) subprimals. Roasts were then vacuum packaged and frozen at -40°C until sensory panels were conducted. Roasts were removed from the freezer 24 h prior to sensory panels and allowed to thaw in a refrigerator (2°C). A minimum of 6 trained panelists (AMSA, 1995) participated in each sensory panel session. Panels were held over several weeks with one panel per day. Twelve panels were held with two replications of three treatment combinations per panel. Treatment combinations included cooking roasts in the Blodgett to 71.1°C, cooking roasts in the Blodgett to 76.7°C, cooking roasts in the CVap to 71.1°C, and cooking roasts in the CVap to 76.7°C. After cooking, 2.54 cm × 1.27 cm × 1.27 cm samples were cut, kept warm in blue-enamel, double-boiler pans with warm water in the bottom pan, and served warm to panelists. Panelists evaluated samples in duplicate for myofibrillar tenderness, juiciness, connective tissue amount, beef flavor intensity, overall tenderness, and off-flavors. The scale used for myofibrillar and overall tenderness was, 1) extremely tough, 2) very tough, 3) moderately tough, 4) slightly tough, 5) slightly tender, 6) moderately tender, 7) very tender, and 8) extremely tender. For juiciness, the scale was 1) extremely dry, 2) very dry, 3) moderately dry, 4) slightly dry, 5) slightly juicy, 6) moderately juicy, 7) very juicy; and 8) extremely juicy. The scale used for beef flavor was, 1) extremely bland, 2) very bland, 3) moderately bland, 4) slightly bland, 5) slightly intense, 6) moderately intense, 7) very intense, and 8) extremely intense. The scale used for connective tissue and off flavor intensity was, 1) abundant, 2) moderately abundant, 3) slightly abundant, 4) moderate, 5) slight, 6) traces, 7) practically none, and 8) none. Scores were given to the nearest half-point increment.

2.9 Statistical Analysis

Statistical analyses for muscle responses after cooking were conducted separately for each muscle, with two sub-analyses being conducted. The first sub-analysis compared oven types and temperatures common to both ovens. The experimental design was a split-plot in a completely randomized design with subsampling. The whole plot treatment was temperature (at levels 65.6°C, 71.1°C, and 76.7°C), the whole plot experimental unit was replication (nested within temperature), and subprimal (nested within replication and temperature) was the subsample term. Both replication and subprimal were considered as random effects. Oven type (Blodgett or CVap) was the split-plot treatment factor. The split-plot also included the oven by temperature interaction, the oven-type by replication within temperature random effect, and the random residual term. For significant temperature main effect F-tests, pairwise comparisons between temperature means were performed using Tukey's test ($P \leq 0.05$). In addition, simple-effect pair-wise comparisons (using Tukey's P value ≤ 0.05) were done to compare oven types within temperatures when the temperature by oven interaction was significant. It should be noted that more roasts were cooked in the CVap oven (n = 72) than were cooked in the Blodgett oven (n = 36) for all treatment combinations. For each combination, four roasts were cooked in the CVap oven and two roasts in the Blodgett. When a temperature x oven interaction was significant, ovens within a temperature were compared to each other rather than making all possible comparisons.

Sensory data were analyzed as a sub-analysis of the above. For sensory data, panelists' ratings were averaged to obtain a mean rating per day x temperature x oven combination. The experimental design was a randomized complete-block design with day as the block. Treatments were in a two-factor factorial with temperature and oven as the two factors. The actual internal temperature reading was included as a covariate. Pairwise comparisons on the temperature main effect and the temperature by oven interaction were conducted as for the analysis of the muscle characteristic data.

3. Results and Discussion

3.1 Actual versus target cooking times

Not unexpectedly, there was variation between actual mean versus target mean cooking times for most muscle x endpoint temperature combinations cooked in the Blodgett, with some actual times being longer and some being shorter than target times. The greatest difference was 112.5 minutes longer for the BF cooked to 76.7ºC than for the target time.

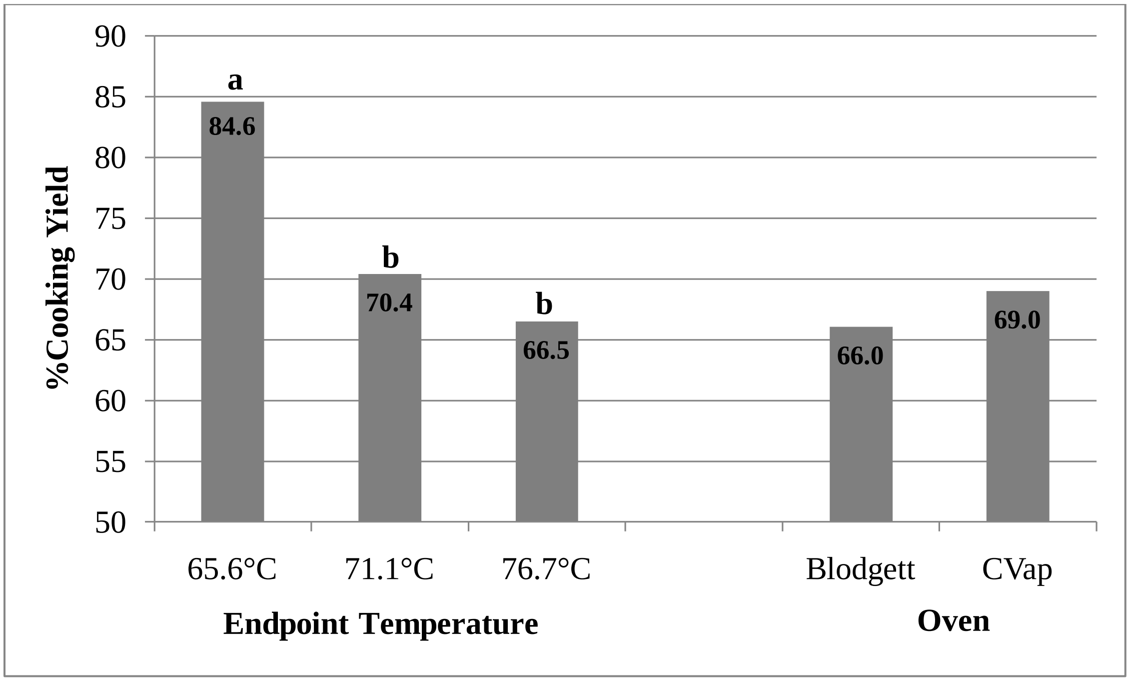
Table 3.1 Actual versus target cooking times for muscle x endpoint temperature combinations for roasts cooked in the Blodgett oven.

Muscle	Endpoint Temperature (°C)	Preliminary Research Average Cooking Time (Min)	Actual Research Average Cooking Time (Min)	Standard Deviation
BF	65.6	225	230	6.5
BF	71.1	330	327.5	4.0
BF	76.7	360	472.5	55.4
DP	65.6	165	146.25	18.8
DP	71.1	240	272.5	34.5
DP	76.7	330	366.25	28.2
LL	65.6	230	202.25	16.9
LL	71.1	350	330	27.1
LL	76.7	360	377.5	30.5

3.2 Cooking yield percentages

Figure 3.1 contains cooking yield main effect means by endpoint temperature and oven for BF roasts. My results demonstrate that cooking yields decreased with increasing endpoint temperatures. *Biceps femoris* roasts cooked to the lowest internal endpoint temperature (65.6°C) had the highest ($P \leq 0.05$) percent cooking yield (84.6%), while roasts cooked to 71.1 and 76.7°C had lower ($P \leq 0.05$) percent cooking yields (70.4 and 66.5%). When averaging across endpoint temperatures, there were no differences between ovens; however, BF roasts cooked under moist-heat conditions in the CVap oven had higher ($P > 0.05$) numerical cooking yields (69.0%) than roasts cooked in the Blodgett oven under dry-heat conditions (66.0%). It should be noted that the differences in these means could be attributed to differences in cooking time, especially at the highest endpoint temperature (76.7°C) when roasts cooked in the Blodgett were cooked an average of 112.5 min longer than roasts in the CVap oven. However, this contradicts Belk et al. (1993) who reported decreased ($P < 0.05$) cooking yields in ribeyes and inside rounds in forced-air convection ovens were increased over those cooked in the air/steam combination oven.

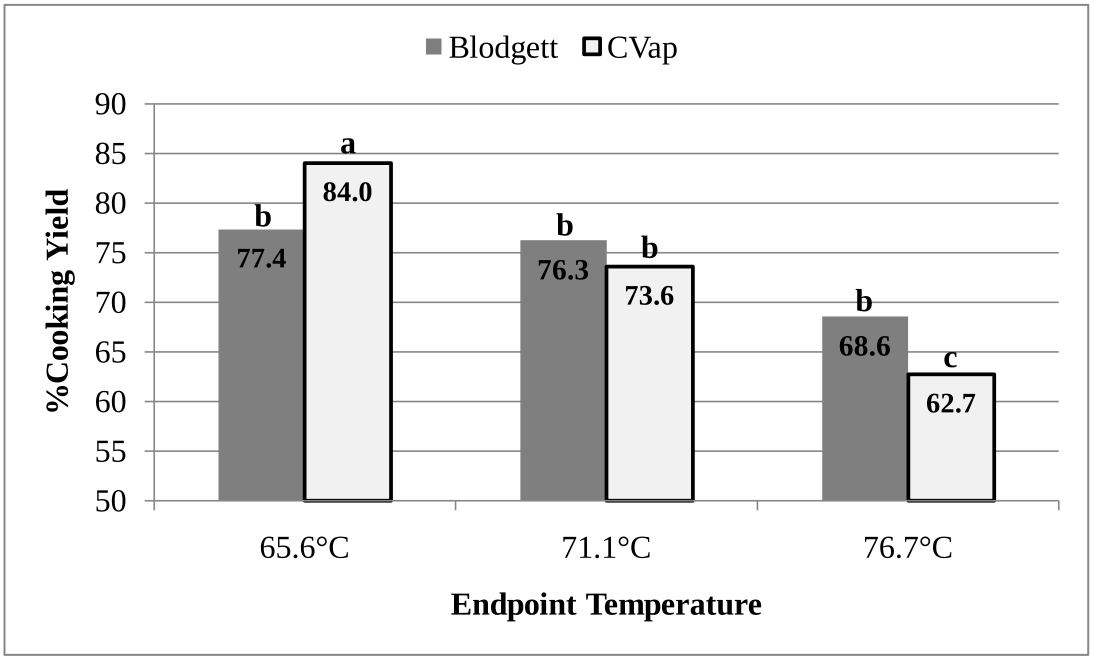
Figure 3.1 Endpoint temperature and oven main effect means for percent cooking yields of *Biceps femoris* roasts cooked to three different endpoint temperatures and in two different ovens.



^{ab}Means with different superscript letters within endpoint temperature differ ($P \leq 0.05$).
Standard Errors: Endpoint temperature = 14.16; Oven = 5.99 (highest standard errors reported)

For the DP muscle, there was a model temperature x oven interaction ($P \leq 0.05$) for percent cooking yield; however, within the 71.7 and 76.7°C temperatures, there were no differences among ovens (Figure 3.2). When cooking DP roasts to 65.6°C, roasts cooked in the CVap oven had a higher ($P \leq 0.05$) mean percent cooking yield (84.0%) than roasts cooked to the same endpoint temperature in the Blodgett oven (77.4%). When cooking DP roasts to an internal endpoint temperature of 71.1°C, there was no difference in percent cooking yield between the CVap and Blodgett ovens. There was also no difference in percent cooking yield between the Blodgett and the CVap when DP roasts were cooked to an internal endpoint temperature of 76.7°C. Roasts cooked to 76.7°C in the Blodgett oven had higher ($P > 0.05$) numerical cooking yields than roasts cooked to the same internal endpoint temperature in the CVap oven (68.6 versus 62.7%). Cooking yields of DP roasts generally decreased with increasing endpoint temperatures in both the Blodgett and the CVap.

Figure 3.2 Oven within temperature means for percent cooking yield of *Deep pectoralis* roasts cooked to three endpoint temperatures in two different ovens.

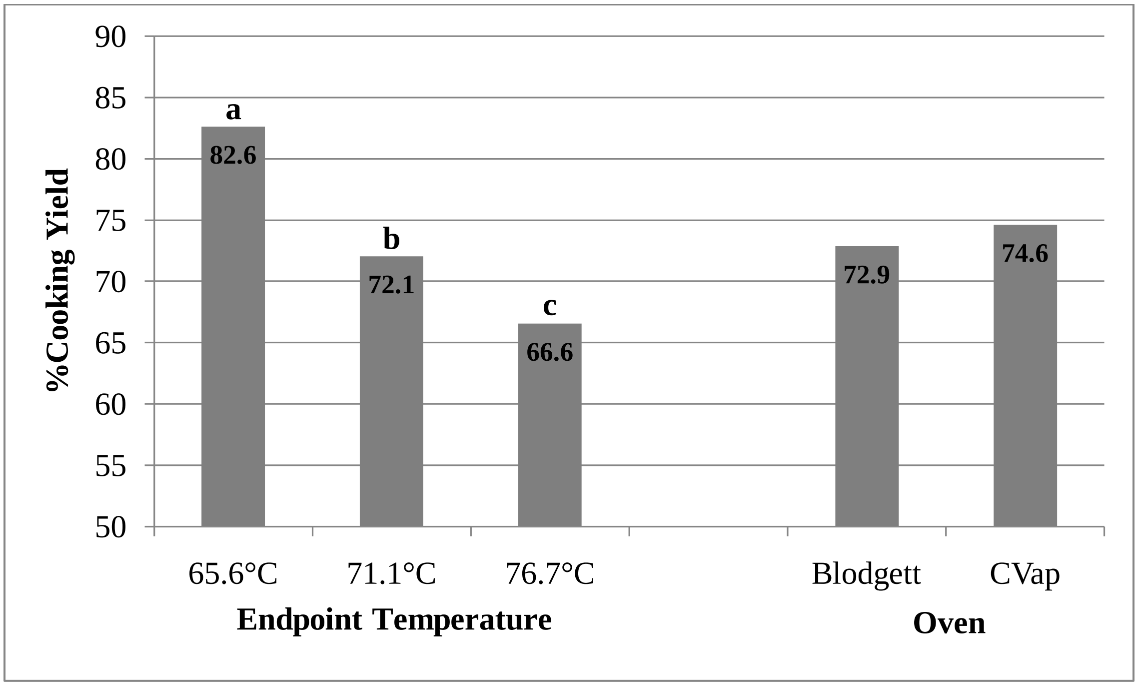


^{abc}Means with different superscript letters differ ($P \leq 0.05$).

Standard Error = 2.84

Longissimus lumborum roasts cooked to the lowest endpoint temperature had the highest cooking yields (82.6%; Figure 3.3), whereas roasts cooked to 76.7°C had the lowest ($P \leq 0.05$) mean percent cooking yield (66.6%). Roasts cooked to the intermediate temperature (71.1°C) had cooking yields of 72.1%. There were no cooking yield differences due to cooking method.

Figure 3.3 Endpoint temperature and oven main effect means for percent cooking yields of *Longissimus lumborum* roasts cooked to three endpoint temperatures in two different ovens.



^{abc}Means with different superscript letters within endpoint temperature differ ($P \leq 0.05$).

Standard Errors: Endpoint temperature = 1.47; Oven = 1.22 (highest standard errors reported)

Ritchey and Hostetler (1965) and Bengtsson et al. (1976) observed that as internal temperature increased, cooking yields decreased. Bramblett, Hostetler, and Vail (1959) reported greater cooking yields for meat cooked to 63.0°C than for meat cooked to 68.0°C. Furthermore, Adhikari, Keene, Heymann, and Lorenzen (2004) found that changes in cooking losses tended to be linear with the time and increase in temperature. My results also show that increasing endpoint temperatures led to decreases in cooking yields. Shaffer, Harrison, and Anderson (1973) reported lower ($P < 0.0001$) percentages of total and drip cooking losses for roasts cooked by dry heat than those cooked by moist heat. My results, with the exception of DP roasts cooked to internal endpoint temperatures of 71.1°C and 76.7°C, support this finding. For BF and LL roasts, cooking in the Blodgett oven tended to result in slightly lower percent cooking yields. Belk et al. (1993) found that cooking roasts in a forced air/steam combination oven led to decreases in cooking yield. Vittadini et al. (2005) reported lower ($P < 0.05$) percent cooking yields for pork *Longissimus dorsi* (LD) when cooked in a forced convection/steam combination oven compared to pork LD cooked in natural convection and forced convection ovens. Furthermore, Vittadini et al. attributed the higher cooking yields achieved in the natural convection and forced convection ovens to the formation of a crust on the product surface that allowed water to be trapped in the interior of the product, but the presence of steam at the product surface in the forced convection steam oven prohibited the formation of a crust and allowed for more water loss. Our results indicated that cooking under moist-heat conditions in the CVap oven tended to result numerically in slightly higher percent cooking yields for BF and LL roasts and DP roasts cooked to an internal endpoint temperature of 65.6°C. Kerth, Blair-Kerth, and Jones (2003) reported that placing steaks in pans during oven roasting allowing steaks to cook in their oven juices, may have resulted in less moisture being removed from the steak than if the juices were allowed to drain. Therefore, it is possible that our percent cooking yields may have been improved if we had not placed the roasts on trays and allowed juices to drip into a pan below the roasts.

Roasts from all three muscles were also cooked according to the recommendations of Winston Industries during cooking phase I, and these cooking methods cannot be directly compared to cooking phase II because of differences in statistical design. *Biceps femoris* roasts cooked according to the recommendations of Winston Industries (7h and 30 min to an internal endpoint temperature of 71.1°C had a mean percent cooking yield of 72.5% (SE = 0.81). *Biceps femoris* roasts cooked in the CVap oven for a specified amount of time (cooking phase II) had a similar mean percent cooking yield of 69.0%, while roasts cooked in the Blodgett oven had a mean percent cooking yield of 66.0%. Therefore, cooking BF roasts in the CVap oven according to the recommendations of Winston Industries appears to offer a cooking yield advantage. *Deep pectoralis* roasts cooked according to the recommendations of Winston Industries (8.0h to an internal endpoint temperature of 71.1°C) had a mean cooking yield of only 61.8% (SE = 0.86), whereas DP roasts cooked in the CVap oven during cooking phase II for a pre-determined amount of time had a mean percent cooking yield of 73.6%, and DP roasts cooked in the Blodgett oven had a numerically similar mean percent cooking yield of 76.3%. Therefore, cooking DP roasts according the recommendations of Winston Industries seemed to reduce cooking yields compared to cooking for a constant time. *Longissimus lumborum* roasts cooked according by Winston Industries guidelines (7h 30min to an internal endpoint temperature of 71.1°C) had a mean percent cooking yield of 73.58% (SE = 1.19). In comparison, LL roasts cooked in the CVap oven for cooking phase II had a similar mean percent cooking yield of 74.6%, and roasts cooked in the Blodgett oven had a mean percent cooking yield of 72.9%. Therefore, cooking LL roasts according to the recommendations of Winston Industries in the CVap oven did not offer a cooking yield advantage.

3.2 Cooked Color

Visual observations of external cooked color indicated distinct differences between the two cooking methods at all temperatures and for all muscles. Roasts cooked in the CVap oven were observed to be tan in color with more moisture on the external surface. In contrast, roasts cooked in the Blodgett oven were observed to be a dark, mahogany-red color, a more caramelized appearance, and the surface was drier. External fat color was also different in appearance. Fat color from the steam oven was whiter in appearance, while that of the dry heat oven was more yellow in appearance. Internal cooked color from visual observations did not seem to differ.

Endpoint temperature and oven main effect means for Hunter Lab color values of external lean and external fat surfaces of BF roasts are reported in Table 3.2. For external lean surfaces of BF roasts, endpoint temperature did not affect L* values. Roasts cooked to an endpoint temperature of 76.7°C had the highest ($P \leq 0.05$) mean L* value (44.5) and were lighter in color, while BF roasts cooked to 71.1°C had the lowest ($P \leq 0.05$) numerical mean L* value (32.6). Endpoint temperature had no effect on a* values of external lean surfaces of BF roasts. Oven did affect ($P \leq 0.05$) a* values of external lean surfaces with roasts cooked in the Blodgett oven having a mean a* value of 10.0, while roasts cooked in the CVap oven had a mean a* value of 6.4. Therefore, roasts cooked in the Blodgett oven were more red in their external appearance than roasts cooked in the CVap oven, which concurs with visual observations. Neither endpoint temperature nor oven affected b* values of external lean surfaces of BF roasts. For external fat surfaces of BF roasts, there were no differences in L* values among endpoint temperatures. However, roasts cooked to the highest endpoint temperature (76.7°C) had the lowest numerical mean L* value (37.3), or a lighter appearance. Neither endpoint temperature nor oven affected b* values of external fat surfaces of BF roasts; however, roasts cooked to the lowest endpoint temperature (65.6°C) tended to have the lowest ($P > 0.05$) mean numerical b* value (24.2).

Table 3.2 Endpoint temperature and oven main effect means for Hunter Lab color values of external lean and external fat surfaces of *Biceps femoris* roasts cooked to three endpoint temperatures and in two different ovens.

	65.6°C	**71.1°C**	**76.7°C**	**SE^1**	**Blodgett**	**CVap**	**SE^1**
L* External Lean	37.8^{ab}	32.6^{b}	44.5^{a}	3.9	36.3	40.4	2.4
a* External Lean	8.2	5.0	11.5	1.8	10.0^{h}	6.4^{i}	1.2
b* External Lean	19.9	16.1	18.5	4.3	16.5	19.9	3.0
L* External Fat	47.3	47.3	37.3	7.1	40.4^{i}	47.5^{h}	4.3
a* External Fat	7.9	4.7	9.9	2.2	9.0	6.0	1.4
b* External Fat	24.2	23.7	14.8	2.8	18.9	22.8	2.1

^{ab}Means with different superscript letters in the same row for endpoint temperature differ ($P \leq 0.05$).

^{hi}Means with different superscript letters in the same row for cooking method differ ($P \leq 0.05$).

^{1}Largest standard errors reported.

Table 3.3 contains endpoint temperature and oven main effect means for Hunter Lab color values of internal lean surfaces of BF roasts. Neither endpoint temperature nor oven affected L* values, but there was a rather large numerical difference (12.0) between roasts cooked to 76.7°C and those cooked to 71.7°C, indicating a lighter color for the 76.7°C temperature. For a* values, there was no difference among endpoint temperatures. Roasts cooked in the Blodgett oven had higher ($P \leq 0.05$) a* values than roasts cooked in the CVap oven. For b* values, neither endpoint temperature nor oven had an effect.

Table 3.3 Endpoint temperature and oven Hunter Lab main effect means for L*, b*, and a* of internal lean surfaces of *Biceps femoris* roasts cooked to three endpoint temperatures in two different ovens.

	65.6°C	71.1°C	76.7°C	SE[1]	Blodgett	Oven	SE[1]
L* Internal Lean	42.1	39.4	51.4	4.4	44.6	44.1	2.7
a* Internal Lean	9.8	6.0	13.7	1.3	12.3^{h}	7.3^{i}	0.8
b* Internal Lean	23.4	18.3	17.0	3.9	19.9	19.2	2.4

^{hi}Means with different superscript letters within row for oven differ ($P \leq 0.05$).

[1] Highest standard errors reported.

Table 3.4 contains endpoint temperature and oven main effect means for Hunter L* and a* color values of external lean and external fat surfaces of DP roasts. For external lean surfaces of DP roasts, there were no differences among endpoint temperatures and no differences between ovens for L* values although roasts cooked to 76.7°C had a 13.4 higher value than those cooked to 65.6°C suggesting that external lean surfaces of DP roasts became darker as internal endpoint temperature increased. For a* values of external lean surfaces, neither endpoint temperature nor oven had an effect.

Table 3.4 Endpoint temperature and oven main effect means for Hunter L* and a* color values of external lean and external fat surfaces of *Deep pectoralis* roasts cooked to three endpoint temperatures in a Blodgett oven and a CVap oven.

	65.6°C	71.1°C	76.7°C	SE[1]	Blodgett	CVap	SE[1]
L* External Lean	32.9	39.8	46.3	4.6	40.1	39.3	3.7
a* External Lean	9.1	6.2	5.5	2.0	7.6	6.2	1.5
L* External Fat	44.9	48.9	46.9	6.8	43.1	50.7	5.1
a* External Fat	7.9	5.7	6.2	2.0	8.2	5.0	1.6

Means without superscript letters within row do not differ ($P > 0.05$).

[1] Highest standard errors reported.

Temperature x oven interaction means for b* values of external lean and external fat surfaces of DP roasts are reported in Table 3.5. Roasts cooked to 65.6°C in the Blodgett oven had a lower ($P < 0.05$) mean b* value (12.9) for external lean than roasts cooked to the same endpoint temperature in the CVap (19.7) and lower values than those cooked to 7.1C in either oven and those cooked to 76.7C in the Blodgett. For external fat, there were no main effects or interactions for b*, although there was a trend ($P = 0.07$) for b* to be higher at 65.6ºC than at 76.7ºC for roasts cooked in the Blodgett.

Table 3.5 Endpoint temperature x oven interaction means for Hunter b* color values of external lean and external fat surfaces of *Deep pectoralis* roasts cooked to three endpoint temperatures in a Blodgett oven and a CVap oven.

	65.6°C Blodgett	**65.6°C CVap**	**SE^1**	**71.1°C Blodgett**	**71.1°C CVap**	**SE^1**	**76.7°C Blodgett**	**76.7°C CVap**	**SE^1**
b* External Lean	12.9^b	19.7^a	2.6	26.5^a	25.4^a	4.0	23.5^a	19.0^{ab}	2.0
b* External Fat	31.0^a	20.7^a	3.0	22.3^a	25.3^a	5.8	18.6^a	21.0^a	2.1

^{ab}Means with different superscript letters within row differ ($P \leq 0.05$).

[1] Highest standard errors reported.

Temperature x oven interaction means for internal lean surfaces of DP roasts are reported in Table 3.6. For internal lean surfaces of DP roasts, the temperature x oven interaction was significant for L* values. For roasts cooked to 65.6°C, there was no difference in L* values between the Blodgett and the CVap. For roasts cooked to 71.1°C, those cooked in the CVap oven had a higher ($P < 0.05$) mean L* value than those cooked in the Blodgett oven, indicating a lighter color for roasts cooked in the CVap. However, at 76.7C, L* values were higher for those cooked in the Blodgett than for those in the CVap. For both a* and b* values of internal lean surfaces, neither endpoint temperature nor oven had an effect. However, we had anticipated increasing endpoint temperatures to cause a decrease in a* values as degree of doneness increased.

Table 3.6 Endpoint temperature x oven interaction means for Hunter L* values of internal lean surfaces of *Deep pectoralis* roasts cooked to three endpoint temperatures in a Blodgett oven and a CVap oven.

	65.6°C Blodgett	**65.6°C CVap**	**SE[1]**	**71.1°C Blodgett**	**71.1°C CVap**	**SE[1]**	**76.7°C Blodgett**	**76.7°C CVap**	**SE[1]**
L* Internal Lean	41.4^{bc}	47.4^{ab}	3.6	40.9^{bc}	49.8^{a}	3.1	47.7^{ab}	40.2^{c}	2.8

^{abc}Means with different superscript letters within row differ ($P \leq 0.05$).

[1] Highest standard errors reported.

Endpoint temperature and oven main effect means for internal lean surfaces of DP roasts are reported in Table 3.7. For a* values of internal lean surfaces, neither endpoint temperature nor oven had an effect. However, I had anticipated increasing endpoint temperatures to cause a decrease in a* values as degree of doneness increased. For b* values of internal lean surfaces, neither endpoint temperature nor oven affected b* values.

Table 3.7 Endpoint temperature and oven main effect means for Hunter Lab color values of internal lean surfaces of *Deep pectoralis* roasts cooked to three endpoint temperatures in a Blodgett oven and a CVap oven.

	65.6°C	**71.1°C**	**76.7°C**	**SE[1]**	**Blodgett**	**CVap**	**SE[1]**
a* Internal Lean	13.1	7.4	9.6	2.3	8.8	11.2	1.7
b* Internal Lean	25.5	21.5	21.7	3.3	22.6	23.2	2.5

Means without superscript letters within row do not differ ($P > 0.05$).

[1] Highest standard errors reported.

Table 3.8 contains endpoint temperature and oven main effect means for Hunter Lab color values of external lean and external fat surfaces of LL roasts. For both external lean and fat surfaces of LL roasts, neither endpoint temperature nor oven had an effect on L*, a*, or b* values. I had anticipated differences in L* values between cooking methods based on visual observations. I had expected roasts cooked to higher internal endpoint temperatures to have lower a* values. For LL roasts, cooking to different endpoint temperatures did not significantly affect the external appearance, nor did cooking in a dry-heat environment (Blodgett) or a moist-heat environment (CVap), which contradicts visual observations.

Table 3.8 Endpoint temperature and oven main effect means for Hunter Lab color values for external lean and external fat surfaces of *Longissimus lumborum* roasts cooked to three endpoint temperatures in two different ovens.

	65.6°C	**71.1°C**	**76.7°C**	**SE[1]**	**Blodgett**	**CVap**	**SE[1]**
L* External Lean	43.7	34.6	42.8	4.0	40.0	40.8	3.3
a* External Lean	8.0	11.6	8.9	2.4	10.4	8.6	2.0
b* External Lean	15.5	13.8	14.5	3.0	13.7	15.6	1.9
L* External Fat	41.0	41.6	44.1	5.6	40.6	43.8	3.7
a* External Fat	8.5	10.6	9.1	3.1	10.2	8.6	2.1
b* External Fat	15.1	16.1	15.4	4.0	14.3	16.8	2.5

Means without superscript letters do not differ ($P \leq 0.05$).

[1] Highest standard errors reported.

Table 3.9 contains endpoint temperature and oven main effect means for Hunter Lab color values of internal lean surfaces of LL roasts. There were no differences in L*, a* or b* values among endpoint temperatures or between ovens.

Table 3.9 Endpoint temperature and oven main effect means for Hunter Lab color values of internal lean surfaces of *Longissimus lumborum* roasts cooked to three endpoint temperatures in two different ovens.

	65.6°C	**71.1°C**	**76.7°C**	**SE[1]**	**Blodgett**	**CVap**	**SE[1]**
L* Internal Lean	46.6	46.0	46.9	8.1	47.0	45.9	4.7
a* Internal Lean	11.6	10.9	9.7	2.8	10.6	10.8	1.7
b* Internal Lean	15.6	15.2	13.5	3.7	15.0	14.6	2.1

Means without superscript letters do not differ ($P > 0.05$).

[1] Highest standard errors reported.

It is important to note that the instrumental color data for our results do not always support what I observed visually (no workable or satisfactory scoring system could be developed) on the external lean surface. It is a well-known fact that fresh meat color is affected by cooking. When meat is heated, the globin or protein portion of myoglobin is denatured or broken down to a liquid with other meat proteins. Denaturation of myoglobin and other proteins begins between 55°C and 65°C in meat. The majority of the denaturation has taken place by 75°C or 80°C (Varnam and Sutherland, 1995; Hunt et al., 1999). Hamouz et al. (1995) reported that internal color assessments vary directly with increases in degree of doneness, which had a large impact on internal color. Oven temperature was found to account for 77% of the variation in internal color. Furthermore, Lyon et al. (1986) found that increases in final temperature caused subjective color scores to change, which were indicative of less redness and a more obvious degree of doneness. The authors supported the subjective observations with objective observations and reported that Hunter L* values were found to increase with increasing internal temperature. However, Hunter a* and b* values were found to decrease with increasing internal temperature. Boles and Swan (2002) observed similar increases in lightness and decreased redness and yellowness of cooked beef roasts as final temperature was increased. However, the color data obtained in our study did not always follow this pattern. This could be a result of differences in cooking method. When comparing rapid cooking and slow cooking of ground beef patties to the same endpoint temperature, rapid cooking resulted in a pinker, less well-done cooked appearance (Ryan et al., 2006).

Color data were also obtained during cooking phase I when roasts were cooked according to the recommendations of Winston Industries. Table 3.10 contains Hunter Lab color values for BF, DP, and LL roasts cooked in the CVap oven during cooking phase I and cooking phase II (for a pre-determined amount of time); however, no statistical comparisons can be made because the Blodgett oven could not be set at low enough temperatures to match those of the CVap. For BF roasts based on the Lab values for the external lean surface, external fat surface, and internal lean surface, there is very little difference in color appearance. This is also true for DP and LL roasts.

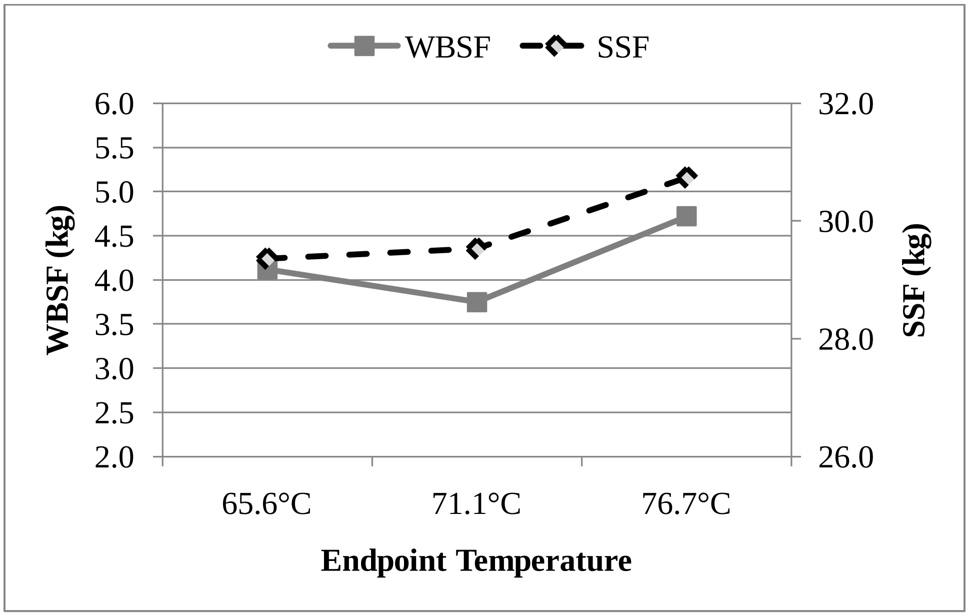
Table 3.10 Hunter Lab color values for external lean, external fat, and internal lean for roasts cooked in the CVap oven during cooking phase I, according to the recommendations of Winston Industries, and Cooking Phase II, in which roasts were cooked in the CVap oven for a pre-determined amount of time. No statistical comparisons could be made.

	Biceps femoris		***Deep pectoralis***		***Longissimus lumborum***	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
External Lean L*	37.3	40.4	34.9	39.3	41.2	40.8
External Lean a*	5.6	6.4	5.2	6.2	5.6	8.6
External Lean b*	22.1	19.9	21.8	21.3	14.9	15.6
External Fat L*	47.6	47.5	49.4	50.7	48.8	43.8
External Fat a*	4.2	6.0	4.4	5.0	6.0	8.6
External Fat b*	26.6	22.8	27.2	22.4	20.8	16.8
Internal Lean L*	46.2	44.1	50.0	45.8	50.3	45.9
Internal Lean a*	7.9	7.3	6.6	11.2	6.1	10.8
Internal Lean b*	21.5	19.2	22.8	23.2	16.7	14.6

3.3 Warner-Bratzler and slice shear force

Neither endpoint temperature nor oven type affected ($P > 0.05$) SSF or WBSF of BF roasts (Figure 3.4), even though there appears to be an increase for both measurements from 71.7 to 76.7ºC. Appendix B contains endpoint temperature and oven main effect means for SSF and WBSF. Obuz et al. (2004) reported WBSF tenderization for beef BF between 45 and 65°C and toughening between 65 and 80°C. However, our results suggest a trend for toughening between 71.1 and 76.7°C for BF roasts. I had expected the dry-heat environment of the Blodgett oven to produce significantly less tender roasts because it has been reported that conventional dry-heat cooking can result in less tender meat from muscles with larger quantities of connective tissue, such as beef *Semitendinosus* muscles, than from cuts with less connective tissue, such as beef LL muscles (Powell et al., 2000).

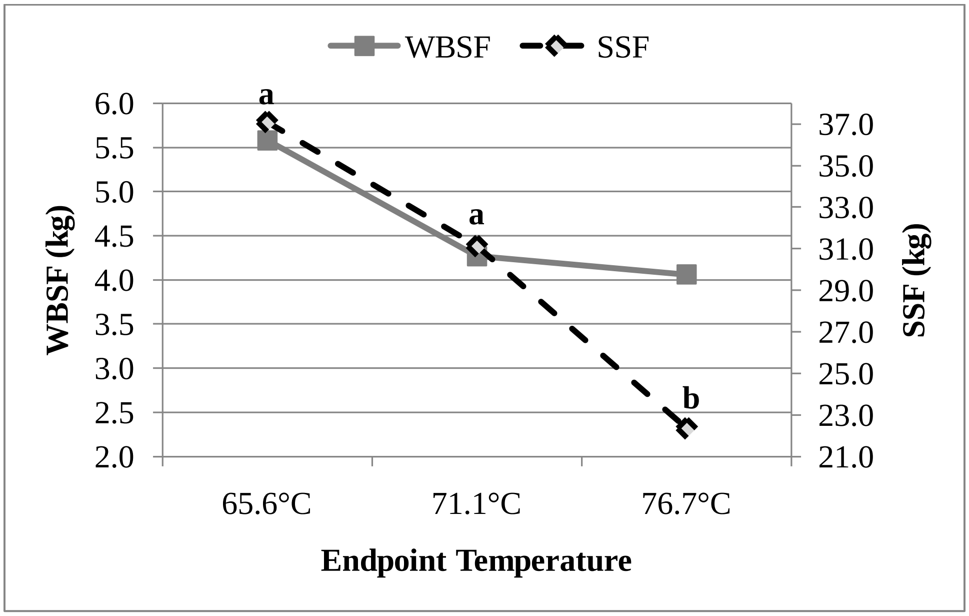
Figure 3.4 Endpoint temperature main effect means for Warner-Bratzler (WBSF) and slice shear force (SSF) of *Biceps femoris* roasts cooked to three endpoint temperatures and in two different ovens.



Means without superscripts within endpoint temperature for WBSF and SSF do not differ ($P > 0.05$).

Figure 3.5 contains endpoint temperature main effect means for both SSF and WBSF of DP roasts. Slice shear force values of DP roasts were lower ($P \leq 0.05$) for those cooked to 76.7°C than for the two lower temperatures and a trend for SSF at 71.1°C to be lower (31.1 kg) than at 65.6°C (37.1 kg). There was no difference in SSF values between ovens. The two measures of tenderness are shown in the same Figure to allow for convenient comparisons. For WBSF, there was a temperature x oven interaction (Appendix B contains WBSF interaction means) in which roasts cooked in the CVap to 76.7ºC had lower (3.13 kg, $P \leq 0.05$) WBSF than those cooked in the Blodgett to 76.7ºC (4.99). Wulf, Morgan, Tatum, and Smith (1996) reported that collagen solubilization occurs with increasing temperatures above 55°C. Therefore, it is likely that collagen solubilization is responsible for the improvement in tenderness observed in the DP roasts as endpoint temperature was increased.

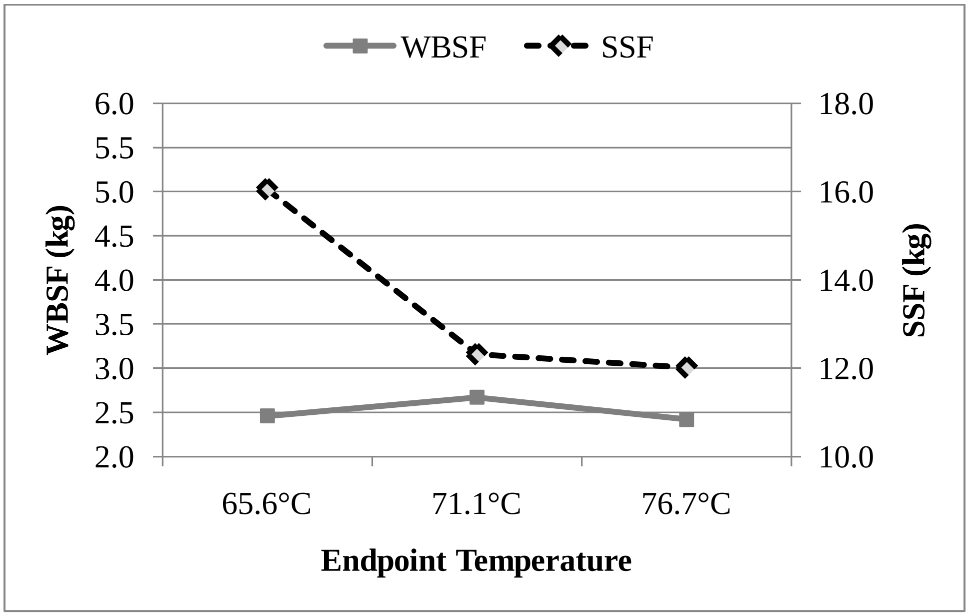
Figure 3.5 Endpoint temperature main effect means for Warner-Bratzler (WBSF) and slice shear force (SSF) of *Deep pectoralis* roasts cooked to three endpoint temperatures and in two different ovens.



^{ab}Means with different superscript letters across endpoint temperatures for SSF differ ($P < 0.05$). Means without superscripts across endpoint temperatures for WBSF do not differ ($P > 0.05$).

There was a temperature x oven interaction for WBSF of LL roasts in which WBSF was lower ($P \leq 0.05$; 2.26 kg) for roasts cooked in the CVap oven than those cooked in the Blodgett oven (2.77 kg), whereas there was no temperature x oven interaction ($P > 0.05$) for SSF (data is located in Appendix B). Mean SSF value of LL roasts cooked to 65.6°C was 16.1 kg versus 12.3 kg for those cooked to 76.7ºC (Figure 3.6). Although we cannot statistically compare muscles, it should be mentioned that LL roasts had SSF values that were about half as high as those for the DP and BF. Also, the differences among the three temperatures for the LL were much lower than for the DP. Furthermore, the DP became distinctly more tender ($P \leq 0.05$) as endpoint temperature increased, whereas the BF showed no tenderization as endpoint temperature was increased.

Figure 3.6 Endpoint temperature main effect means for Warner-Bratzler (WBSF) and slice shear force (SSF) of *Longissimus lumborum* roasts cooked to three endpoint temperatures in two different ovens.



Means without superscripts across endpoint temperatures for WBSF and SSF do not differ (*P* > 0.05).

Davey and Gilbert (1974) described two distinct toughening phases that occur during meat cookery. The first toughening phase occurs between the temperatures of 40 and 50°C, and the second toughening phase occurs between 65 and 75°C. This distinctly contradicts my results for the DP and LL. Of course, the results of Davey and Gilbert (1974) are not relevant to the cooking of steaks and roasts because the results were obtained by cooking cores of Sternomandibularis muscle in a water bath at 100°C for 1 hr. Furthermore Powell et al. (2000) reported that conventional dry-heat cooking will yield less tender meat from cuts high in connective tissue, such as beef BF, than from cuts that have less connective tissue, such as the beef LL. The results of my study for the BF concur with the findings of Powell et al. (2000). No difference was found between the two cooking methods for LL roasts, which coincide with the results of Obuz et al. (2004). These authors reported that the tenderization and toughening phases observed in cuts high in connective tissue did not occur in LL muscles due to the low collagen content.

Biceps femoris roasts cooked according to the recommendations of Winston Industries had a mean SSF value of 17.9 kg (SE = 2.58), which is lower (more tender) than for roasts cooked in the Blodgett (30.5 kg) during cooking phase II and lower (29.2 kg) for roasts cooked in the CVap oven during cooking phase II. Therefore, cooking BF roasts according to the recommendations of Winston Industries provides an advantage in SSF tenderness. *Deep pectoralis* roasts cooked according to the guidelines of Winston Industries had a mean SSF value of 12.0 kg (SE = 1.50), which is dramatically lower than for those cooked in the Blodgett (29.3 kg) during cooking phase II and CVap (31.1 kg) when cooked for a pre-determined amount of time. Therefore, cooking DP roasts according to the recommendations of Winston Industries provides an advantage for SSF tenderness. *Longissimus lumborum* roasts cooked by Winston Industries recommendations had a mean SSF value of 14.9 kg (SE = 1.96), which is similar to those cooked in the Blodgett (13.3 kg) and in the CVap (13.6 kg) during cooking phase II. Therefore, cooking LL roasts in a moist-heat environment does not offer a SSF tenderness advantage as it appears to do for cuts with larger quantities of connective tissue.

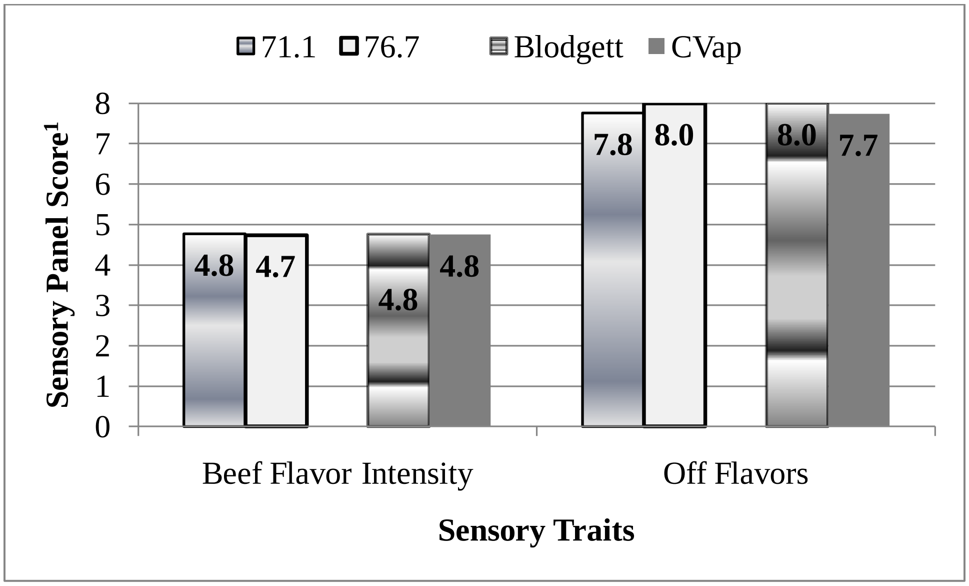
Roasts cooked during cooking phase I, according to the recommendations of Winston Industries, were also subjected to WBSF measurements. *Biceps femoris* roasts were found to have a mean WBSF value of 3.4 kg (SE = 0.25). *Biceps femoris* roasts cooked in the Blodgett oven during cooking phase II had a mean WBSF value of 4.1 kg, and BF roasts cooked in the CVap during cooking phase II had a mean WBSF value of 4.3 kg. Therefore, cooking according to the recommendations of Winston Industries offered a slight advantage in WBSF tenderness. *Deep pectoralis* roasts cooked per the guidelines of Winston Industries had a mean WBSF value of 2.5 kg (SE = 0.07), whereas those cooked during cooking phase II in the Blodgett oven had a mean WBSF value of 4.9 kg, and DP roasts cooked in the CVap oven during cooking phase II had a mean WBSF value of 4.3 kg. Therefore, cooking DP roasts according to the recommendations of Winston Industries offered an advantage in WBSF tenderness. *Longissimus lumborum* roasts cooked according to the guidelines of Winston Industries had a mean WBSF value of 3.3 kg (SE = 0.33), whereas those cooked in the Blodgett oven during cooking phase II had a mean WBSF value of 2.8 kg, and roasts cooked in the CVap oven for a pre-determined amount of time had a mean WBSF value of 2.3 kg. In contrast to the BF and DP, cooking according to the recommendations of Winston Industries offered no WBSF tenderness advantage for LL roasts. This was also found to be true with SSF tenderness.

Kolle, McKenna, and Savell (2004) found the *Adductor, Rectus femoris,* and *Semitendinosus* muscles had lower WBSF values, or were more tender, when cooked with moist heat rather than dry heat. My results do not always coincide with their results. My WBSF results show the CVap oven to have lower ($P \leq 0.05$) mean WBSF values for DP roasts cooked to 76.7°C and for LL roasts for endpoint temperatures combined. Obuz and Dikeman (2003) reported higher WBSF values ($P = 0.025$) for BF steaks than for LL steaks and concluded that the difference was likely due to quantity of connective tissue within the muscle, which concurs with my results. Shin et al. (1993) found that different heating rates and variation in internal temperature at the end of the cooking cycle contributed to variation in tenderness within a muscle. Furthermore, Berry (1993) reported that various Instron measurements (peak load, peak energy, and modulus) were higher in more lateral than medial cores of steaks and also reported that steaks were more well-done in the more lateral core positions and less well-done in the more medial core positions. This could explain the differences in results between SSF and WBSF because WBSF would take into account doneness differences at the various locations within slices, while SSF would not.

3.5 Sensory Evaluation

Sensory panels were conducted on BF roasts, which were cooked in the CVap to endpoint temperatures of 71.1°C and 76.7°C based on the average times ascertained from preliminary research. Roasts were also cooked in the Blodgett oven until they reached internal endpoint temperatures of 71.1 and 76.7°C. Figure 3.7 contains endpoint temperature and oven main effect means for beef flavor intensity and off flavors of BF roasts. There were no differences between endpoint temperatures or oven for beef flavor intensity or off flavors.

Figure 3.7 Endpoint temperature and oven main effect means for sensory panel scores of *Biceps femoris* roasts cooked to two endpoint temperatures in two different ovens.

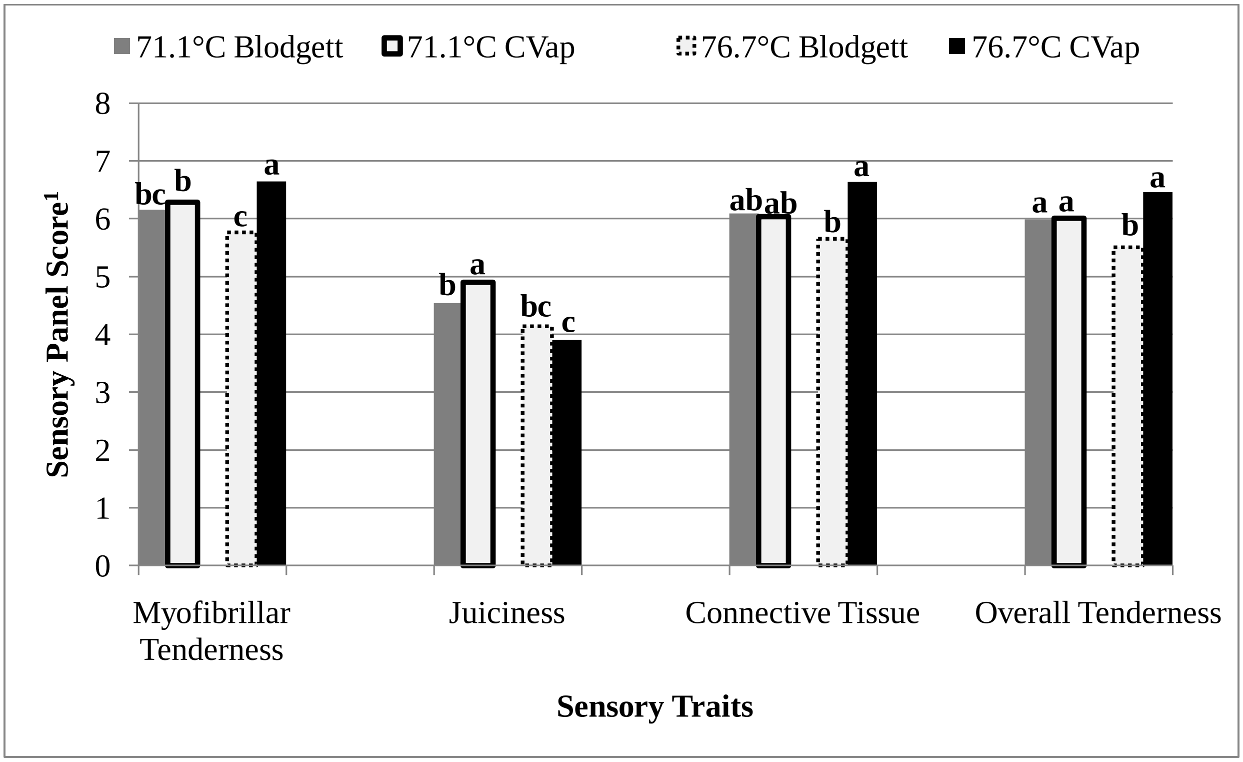


[1] Beef flavor intensity scale: 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, 8 = extremely intense; Off flavor intensity scales: 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, 8 = none.

Standard Errors: Beef flavor = 0.09; Off flavors = 0.78 (highest standard errors reported)

Figure 3.8 contains temperature x oven interaction means for sensory evaluation means for myofibrillar tenderness, juiciness, connective tissue, and overall tenderness of BF roasts. Roasts cooked to an internal temperature of 76.7°C in the Blodgett oven had a lower ($P < 0.05$) myofibrillar tenderness score (5.8) than those cooked in the CVap (6.7). Scores for roasts cooked to 71.7ºC regardless of oven were not different than those cooked to 76.7ºC. In a similar pattern, overall tenderness scores were lower ($P < 0.05$) for roasts cooked in the Blodgett than those cooled in the CVap oven (5.5 versus 6.5) to 76.7ºC. Connective tissue scores followed a similar pattern (5.5 versus 6.0; $P < 0.05$) for the two ovens at 76.7ºC. In addition, the juiciness score was higher ($P < 0.05$) for roasts cooked to 71.1ºC in the CVap than for the other oven x temperature combinations. The juiciness score for roasts cooked in the Blodgett to 76.7ºC was lowest of all combinations. Based on sensory evaluation of BF roasts, there appears to be a tenderness advantage for cooking BF roasts in the CVap oven at the higher temperature but not at the lower temperature.

Figure 3.8 Temperature x oven interaction means for sensory evaluation scores of *Biceps femoris* roasts.



[1] Myofibrillar and overall tenderness scale: 1 = extremely tough, 4 = slightly tough, 6 = moderately tender, 8 = extremely tender; Juiciness scale: 1 = extremely dry, 4 = slightly dry, 6 = moderately juicy, 8 = extremely juicy; Connective tissue amount scale: 1 = abundant, 4 = moderate, 6 = traces, 8 = none

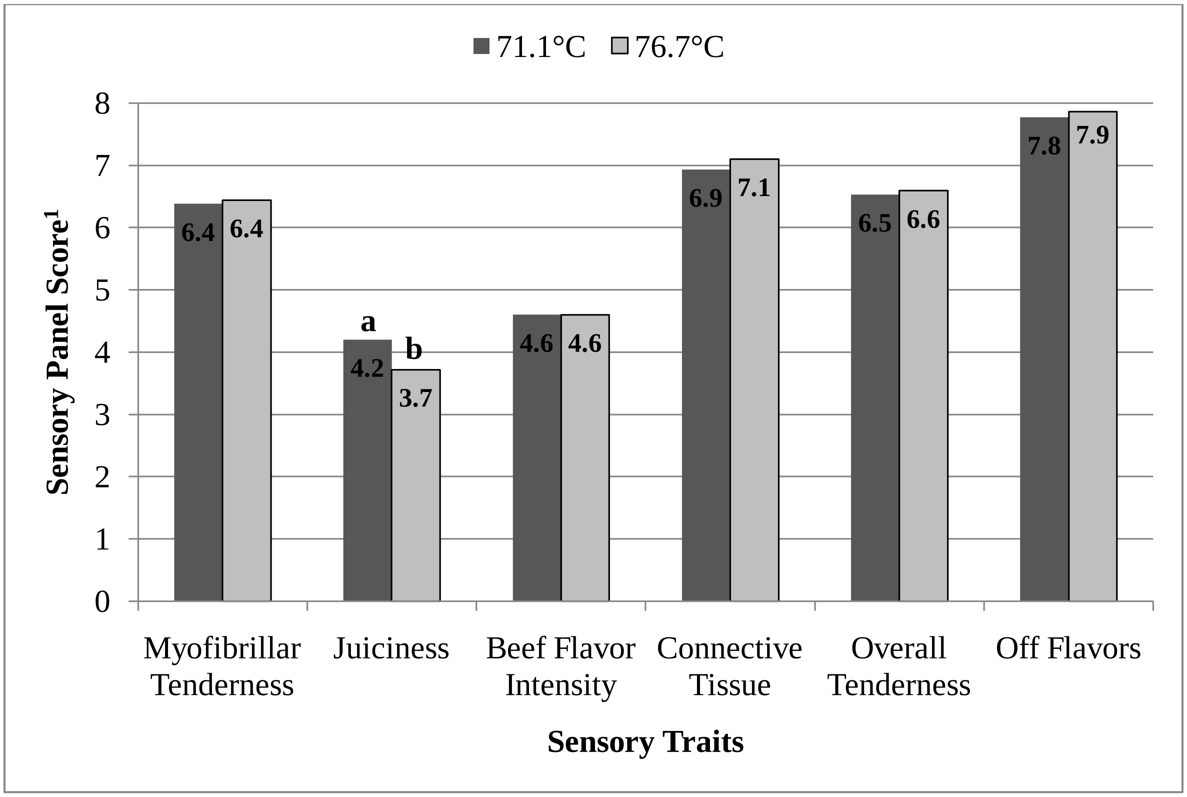
^{abc}Means within a sensory trait with different superscript letters differ ($P \leq 0.05$).

Standard Errors: Myofibrillar tenderness = 0.23; Juiciness = 0.22; Connective tissue = 0.24; Overall tenderness = 0.23 (highest standard errors reported)

Figure 3.9 contains endpoint temperature main effect means for sensory evaluation scores of LL roasts. No differences among endpoint temperatures were observed for myofibrillar tenderness, beef flavor intensity, connective tissue, overall tenderness, or off flavor intensity.

However, roasts cooked to an internal endpoint temperature of 71.1°C had a higher ($P \leq 0.05$) mean juiciness score (4.2) than roasts cooked to an endpoint temperature of 76.7°C (3.7).

Figure 3.9 Endpoint temperature main effect means for sensory evaluation scores of *Longissimus lumborum* roasts cooked to two endpoint temperatures for combined cooking method.



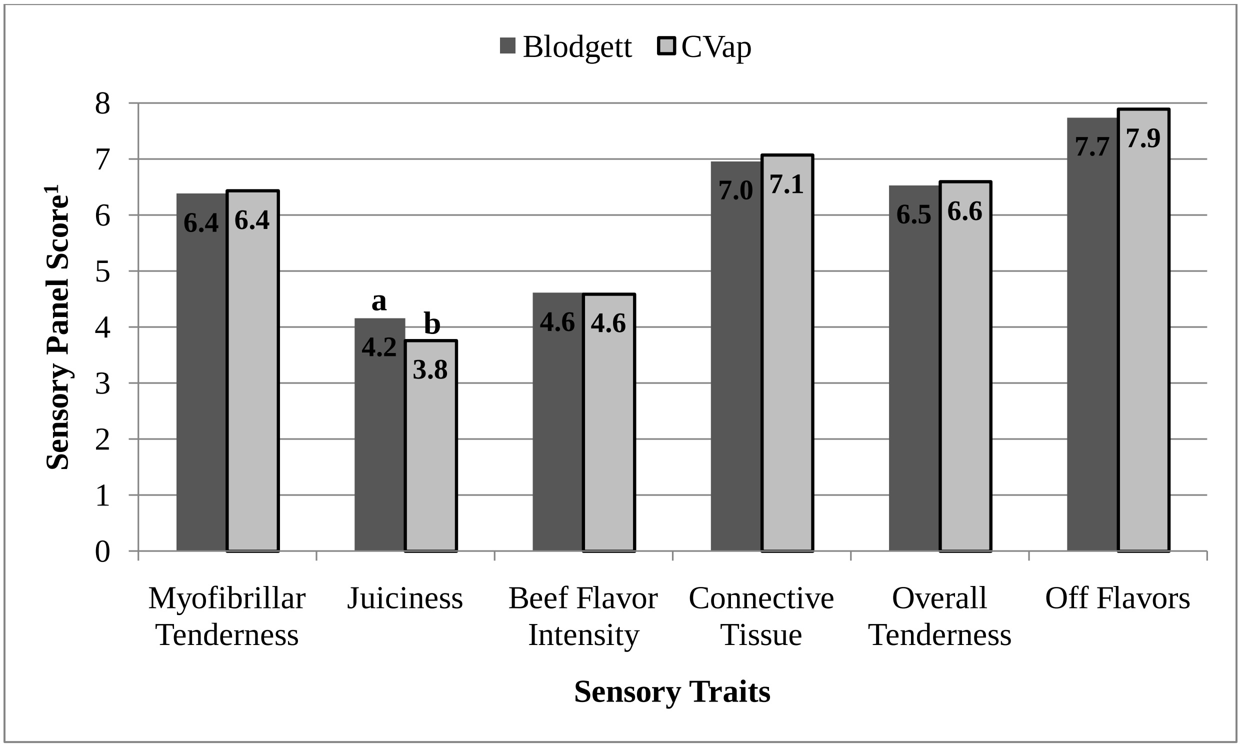
[1] Myofibrillar and overall tenderness scale: 1 = extremely tough, 4 = slightly tough, 6 = moderately tender, 8 = extremely tender; Juiciness scale: 1 = extremely dry, 4 = slightly dry, 6 = moderately juicy, 8 = extremely juicy; Beef flavor intensity scale: 1 = extremely bland, 4 = slightly bland, 6 = moderately intense, 8 = abundant; Connective tissue amount scale: 1 = abundant, 4 = moderate, 6 = traces, 8 = none; Off flavor intensity scale: 1 = abundant, 4 = moderate, 6 = traces, 8 = none.

[ab] Means within a sensory trait with different superscript letters differ ($P \leq 0.05$).

Standard Errors: Myofibrillar tenderness = 0.14; Juiciness = 0.08; Beef flavor = 0.08; Connective tissue = 0.10; Overall tenderness = 0.12; Off flavors = 0.08 (highest standard errors reported)

Figure 3.10 contains oven main effect means for sensory panel scores of LL roasts. No differences were observed for myofibrillar tenderness, beef flavor intensity, connective tissue, overall tenderness, or off flavors. However, LL roasts cooked in the Blodgett had a mean juiciness score (4.2) that was higher ($P \leq 0.05$) than LL roasts cooked in the CVap (3.8). Therefore, LL roasts cooked by dry heat were slightly juicier than roasts cooked by moist heat.

Figure 3.10 Oven main effect means for sensory evaluation scores of *Longissimus lumborum* roasts cooked in two different ovens for combined endpoint temperatures.



[1] Myofibrillar and overall tenderness scale: 1 = extremely tough, 4 = slightly tough, 6 = moderately tender, 8 = extremely tender; Juiciness scale: 1 = extremely dry, 4 = slightly dry, 6 = moderately juicy, 8 = extremely juicy; Beef flavor intensity scale: 1 = extremely bland, 4 = slightly bland, 6 = moderately intense, 8 = abundant; Connective tissue amount scale: 1 = abundant, 4 = moderate, 6 = traces, 8 = none; Off flavor intensity scale: 1 = abundant, 4 = moderate, 6 = traces, 8 = none

[ab] Means within sensory traits with different superscript letters differ ($P \leq 0.05$).

Standard Errors: Myofibrillar tenderness = 0.15; Juiciness = 0.09; Beef flavor = 0.09; Connective tissue = 0.11; Overall tenderness = 0.13; Off flavors = 0.09 (highest standard errors reported)

Cover et al. (1957) reported that juiciness scores decreased with increasing doneness within each of their cooking methods of broiling and braising. Our results are consistent with this assessment. Cover et al. (1957) also reported that connective tissue was found less frequently and was more tender in LD than in BF. Our sensory panel scores showed that BF roasts did indeed have more connective tissue than LL roasts. Shaffer et al. (1973) compared the effects of moist-heat and dry-heat cookery methods on USDA Good grade whole beef rounds. The authors reported that roasts cooked by dry heat were scored more tender ($P < 0.05$) than those cooked by moist heat. This contradicts my results because BF roasts were found to be more tender when cooked in the CVap oven under moist-heat conditions than under dry-heat conditions. Furthermore, I observed no difference in myofibrillar tenderness of LL roasts and only a very small difference in overall tenderness between dry-heat and moist-heat conditions. Jeremiah and Gibson (2003) reported that roasts cooked by moist heat with a dry-heat finish were considered less desirable than their counterparts prepared with low temperature, dry heat, particularly for initial and overall tenderness, juiciness, and overall palatability. My results contradict these findings because overall tenderness of LL roasts was not different due to cookery method. However, it is likely that my results would not concur with many studies because the CVap oven is a relatively newer oven that has not been the source of many scientific investigations.

3.6 Heating Curves

Appendix B contains heating curves generated for each muscle cooked to each of three endpoint temperatures with two replications. These graphs demonstrate that the CVap oven generally brings the roasts to endpoint temperature faster and maintains a nearly constant internal temperature throughout the remainder of the cooking cycle. Vittadini et al. (2005) and Laakonen et al. (1970) reported that a faster cooking cycle, sharper increase in temperature, and a higher temperature gradient for pork LD cooked in a forced convection/steam combination oven when compared to natural convection and forced convection ovens.

4. Conclusion

My results confirm that CVap moist heat cookery has a place in the foodservice industry. However, caution should be utilized as to which cuts are cooked with moist heat. Although there was no statistical comparison between cooking phase I (Winston recommendations) and cooking phase II, my results suggest that cooking according to the recommendations of Winston Industries provides some advantages for BF and DP roasts. Cooking per the guidelines of Winston Industries may provide a slight advantage in percent cooking yield and tenderness of BF roasts but cooking according to the recommendations did not offer a percent cooking yield advantage for DP or LL roasts. However, cooking DP roasts according to the recommendations of Winston Industries may offer a tenderness advantage. There was no advantage to cooking LL roasts in the CVap oven either according to the recommendations of Winston Industries or for a pre-determined amount of time. Nonetheless, the CVap oven is a unique piece of equipment that has the potential to benefit the foodservice industry. This research involved utilizing the oven in a manner for which it was not specifically designed. It was designed for low-temperature, long-time cooking rather than the shorter cooking times and higher endpoint temperatures to which my cooking phase II roasts were cooked so that we could compare it to the Blodgett dry-heat forced-air convection oven.

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Appendix A - Cooking Times

Cooking phase II – Cooking times for *Biceps femoris* roasts cooked in the Blodgett and CVap ovens

Muscle	Replication	Endpoint Temperature	Oven	Cooking Time
BF[1]	1	65.6°C	CVap	**225 min**
BF[1]	1	65.6°C	Blodgett	220 min
BF[1]	1	65.6°C	Blodgett	220 min
BF[1]	2	65.6°C	CVap	**225 min**
BF[1]	2	65.6°C	Blodgett	240 min
BF[1]	2	65.6°C	Blodgett	240 min
BF[1]	1	71.1°C	CVap	**330 min**
BF[1]	1	71.1°C	Blodgett	325 min
BF[1]	1	71.1°C	Blodgett	325 min
BF[1]	2	71.1°C	CVap	**330 min**
BF[1]	2	71.1°C	Blodgett	320 min
BF[1]	2	71.1°C	Blodgett	320 min
BF[1]	1	76.7°C	CVap	**360 min**
BF[1]	1	76.7°C	Blodgett	475 min
BF[1]	1	76.7°C	Blodgett	475 min
BF[1]	2	76.7°C	CVap	**360 min**
BF[1]	2	76.7°C	Blodgett	470 min
BF[1]	2	76.7°C	Blodgett	470 min

[1] *Biceps femoris*

Cooking phase II – Cooking times for *Deep pectoralis* roasts cooked in the Blodgett and CVap ovens

Muscle	Replication	Endpoint Temperature	Oven	Cooking Time
DP[1]	1	65.6°C	CVap	**165 min**
DP[1]	1	65.6°C	Blodgett	115 min
DP[1]	1	65.6°C	Blodgett	140 min
DP[1]	2	65.6°C	CVap	**165 min**
DP[1]	2	65.6°C	Blodgett	140 min
DP[1]	2	65.6°C	Blodgett	190 min
DP[1]	1	71.1°C	CVap	**240 min**
DP[1]	1	71.1°C	Blodgett	295 min
DP[1]	1	71.1°C	Blodgett	345 min
DP[1]	2	71.1°C	CVap	**240 min**
DP[1]	2	71.1°C	Blodgett	225 min
DP[1]	2	71.1°C	Blodgett	225 min
DP[1]	1	76.7°C	CVap	**330 min**
DP[1]	1	76.7°C	Blodgett	330 min
DP[1]	1	76.7°C	Blodgett	405 min
DP[1]	2	76.7°C	CVap	**330 min**
DP[1]	2	76.7°C	Blodgett	330 min
DP[1]	2	76.7°C	Blodgett	400 min

[1] *Deep pectoralis*

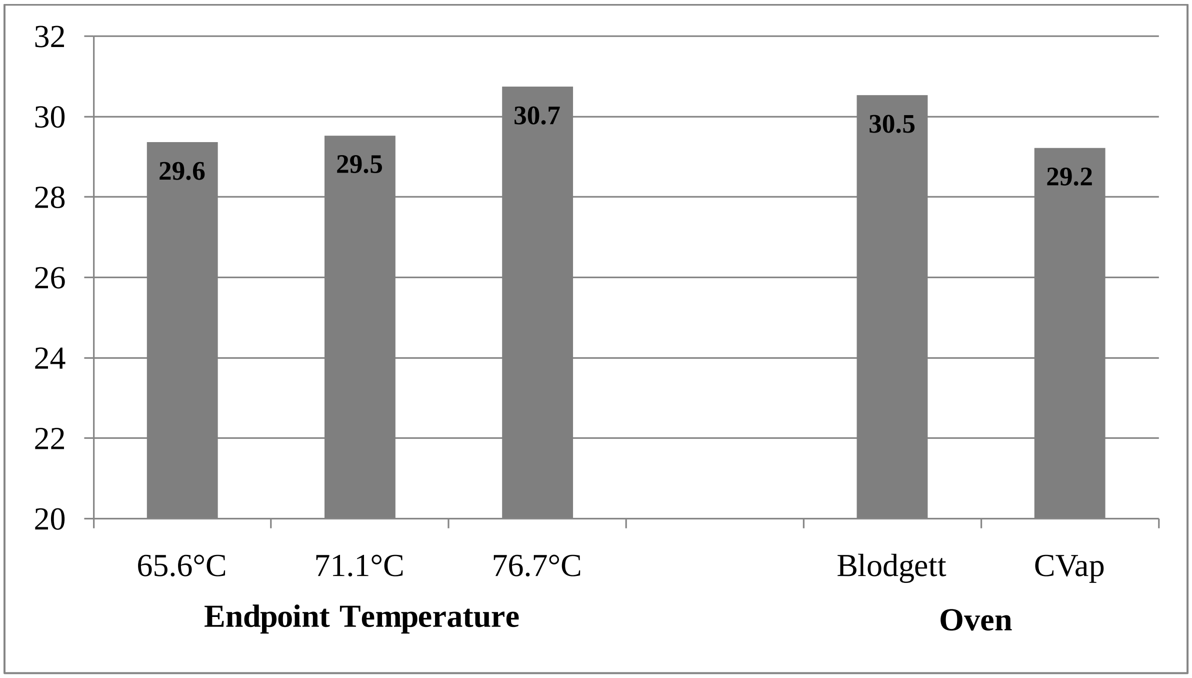
Cooking phase II – Cooking times for *Longissimus lumborum* roasts cooked in the Blodgett and CVap ovens

Muscle	Replication	Endpoint Temperature	Oven	Cooking Time
LL[1]	1	65.6°C	CVap	**230 min**
LL[1]	1	65.6°C	Blodgett	195 min
LL[1]	1	65.6°C	Blodgett	210 min
LL[1]	2	65.6°C	CVap	**230 min**
LL[1]	2	65.6°C	Blodgett	180 min
LL[1]	2	65.6°C	Blodgett	220 min
LL[1]	1	71.1°C	CVap	**350 min**
LL[1]	1	71.1°C	Blodgett	335 min
LL[1]	1	71.1°C	Blodgett	390 min
LL[1]	2	71.1°C	CVap	**350 min**
LL[1]	2	71.1°C	Blodgett	290 min
LL[1]	2	71.1°C	Blodgett	305 min
LL[1]	1	76.7°C	CVap	**360 min**
LL[1]	1	76.7°C	Blodgett	400 min
LL[1]	1	76.7°C	Blodgett	295 min
LL[1]	2	76.7°C	CVap	**360 min**
LL[1]	2	76.7°C	Blodgett	395 min
LL[1]	2	76.7°C	Blodgett	420 min

[1] *Longissimus lumborum*

Appendix B – Warner-Bratzler Shear Force and Slice Shear Force

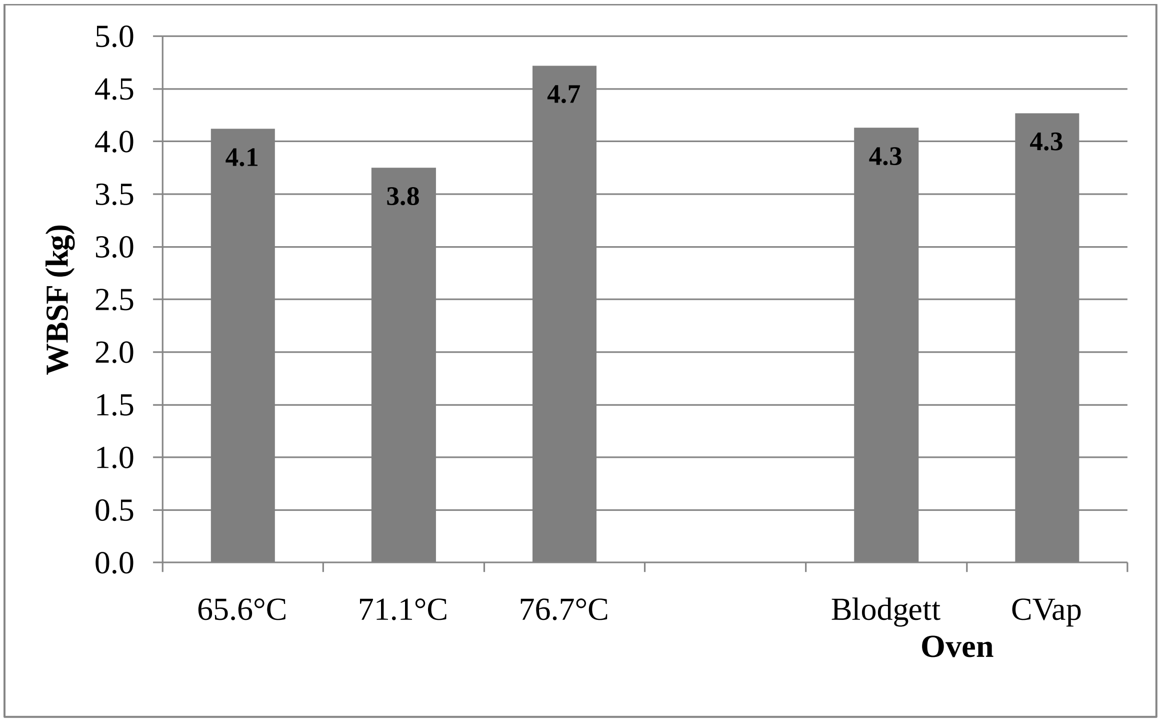
Endpoint temperature and oven main effect means for slice shear force (SSF) of *Biceps femoris* roasts cooked to three endpoint temperatures in two different ovens.



Means without superscript letters within endpoint temperature and oven do not differ ($P > 0.05$).

Standard Errors: Endpoint temperature = 4.93; Oven = 3.67 (highest standard errors reported)

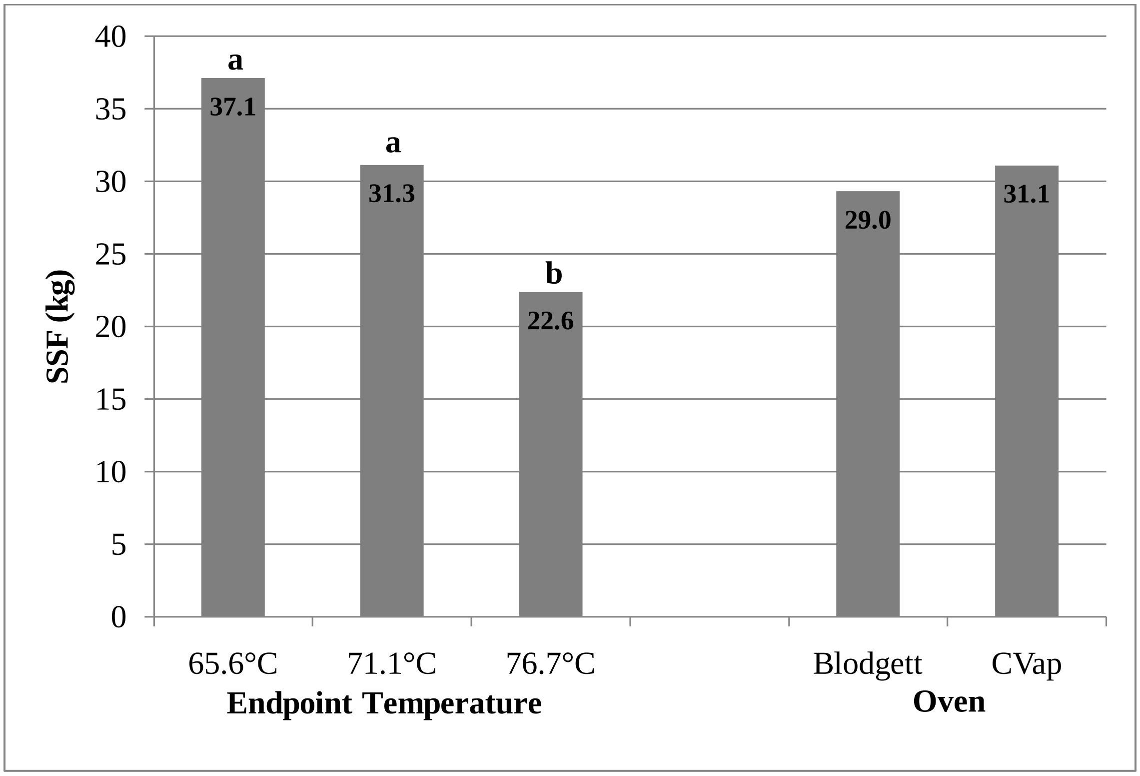
Endpoint temperature and oven main effect means for Warner-Bratzler shear force (WBSF) of *Biceps femoris* roasts cooked to three endpoint temperatures in two different ovens.



Means without superscript letters do not differ ($P > 0.05$).

Standard Errors: Endpoint temperature = 0.57; Oven = 0.42 (highest standard errors reported)

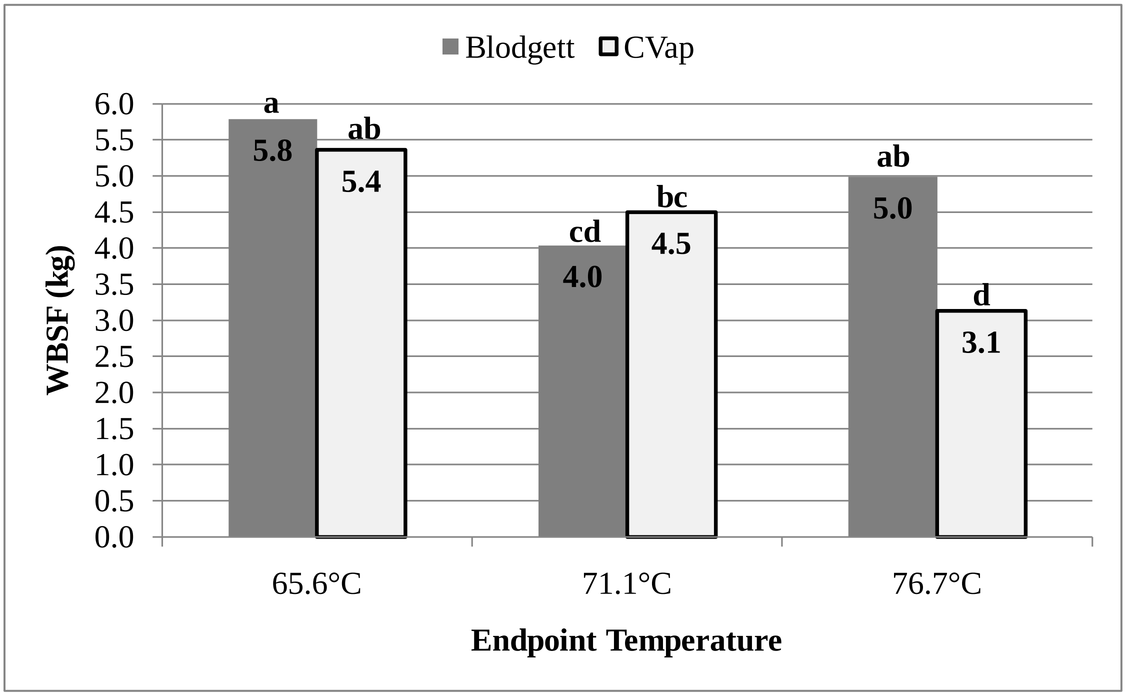
Endpoint temperature and oven main effect means for slice shear force (SSF) of *Deep pectoral* roasts cooked to three endpoint temperatures in two different ovens.



[ab]Means with different superscript letters within endpoint temperature differ ($P \leq 0.05$).

Standard Errors: Endpoint temperature = 4.52; Oven = 3.87 (highest standard errors reported)

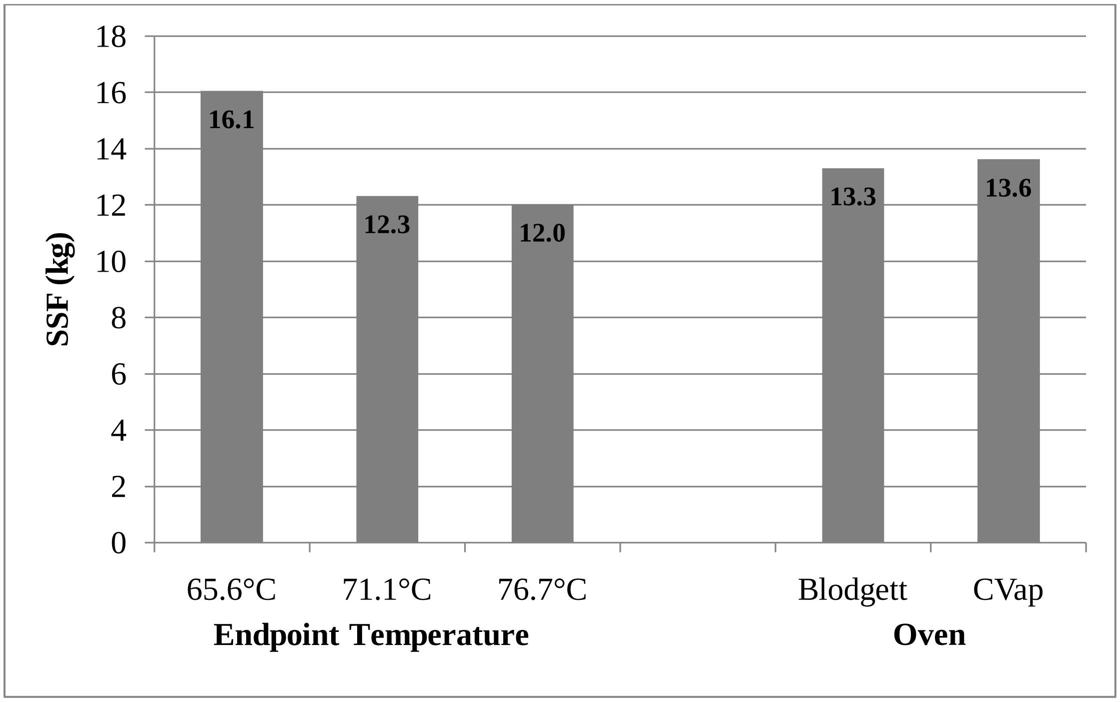
Temperature x oven interaction means for Warner-Bratzler shear force (WBSF) of *Deep pectoral* roasts cooked to three endpoint temperatures in two different ovens.



^{ab}Means with a different superscript letter differ ($P \leq 0.05$).

Standard Errors: 65.6°C = 0.36; 71.1°C = 0.49; 76.7°C = 0.35 (highest standard errors reported)

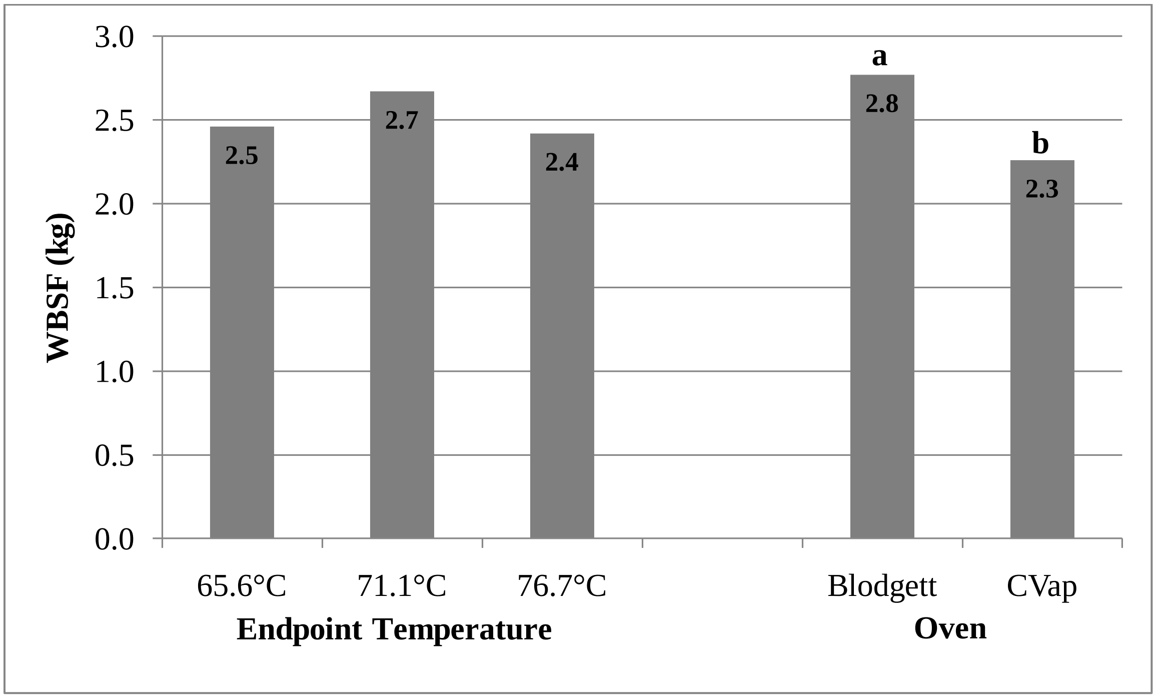
Endpoint temperature and oven main effect means for slice shear force (SSF) of *Longissimus lumborum* roasts cooked to three endpoint temperatures in two different ovens.



Means without superscript letters do not differ ($P > 0.05$).

Standard Errors: Endpoint temperature = 1.57; Oven = 1.24 (highest standard errors reported)

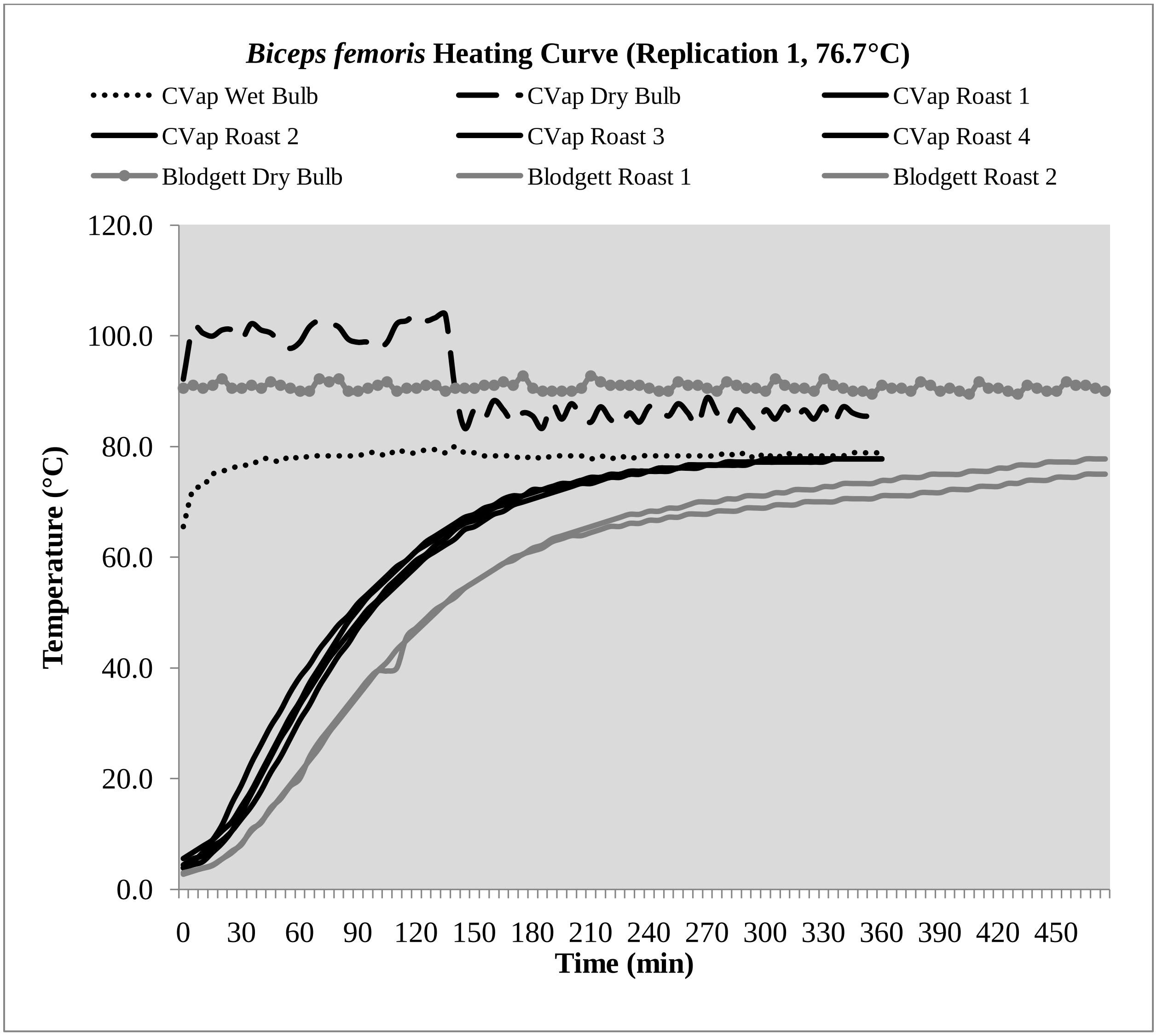
Endpoint temperature and oven main effect means for Warner-Bratzler shear force (WBSF) of *Longissimus lumborum* roasts cooked to three endpoint temperatures in two different ovens.

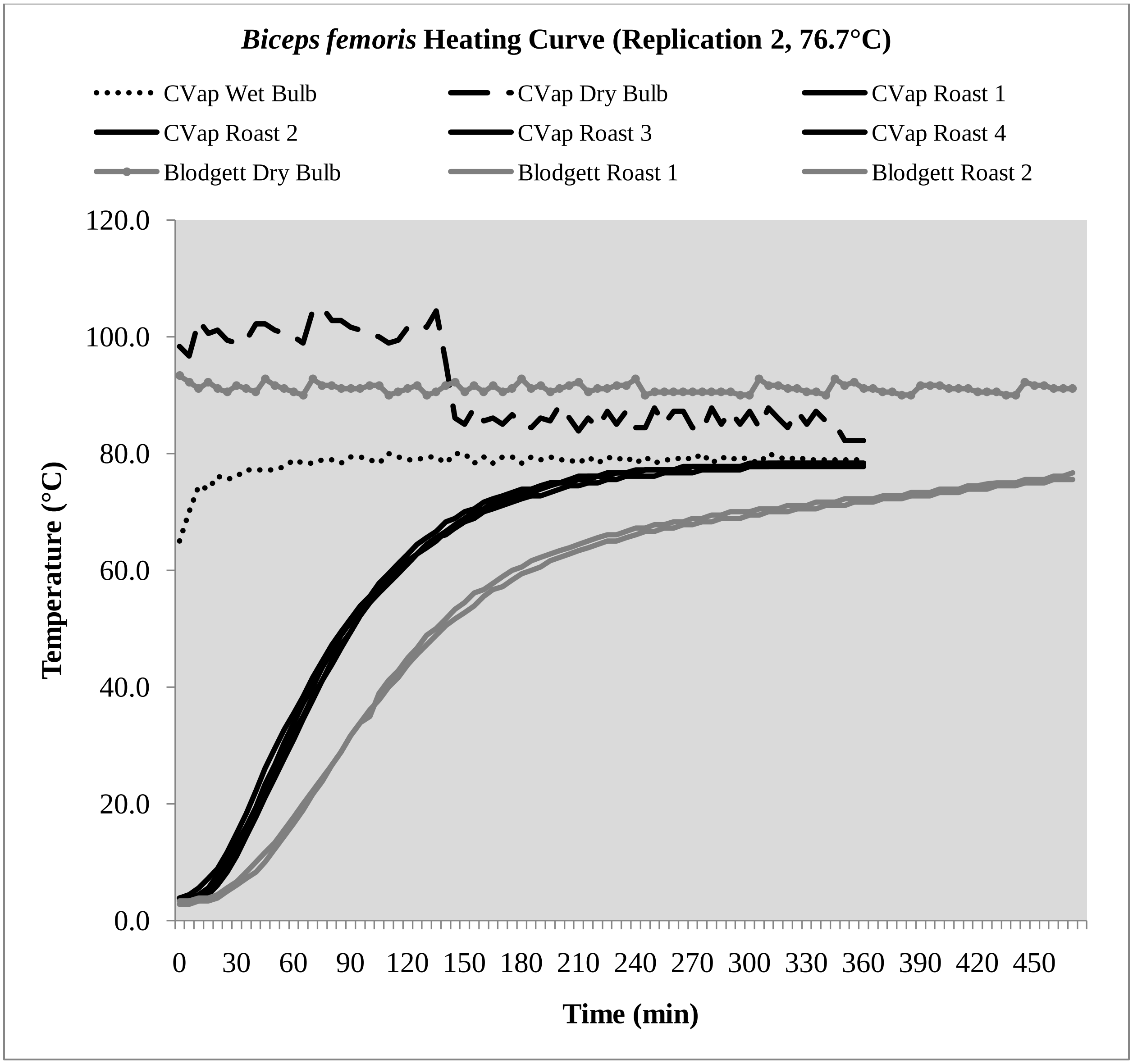


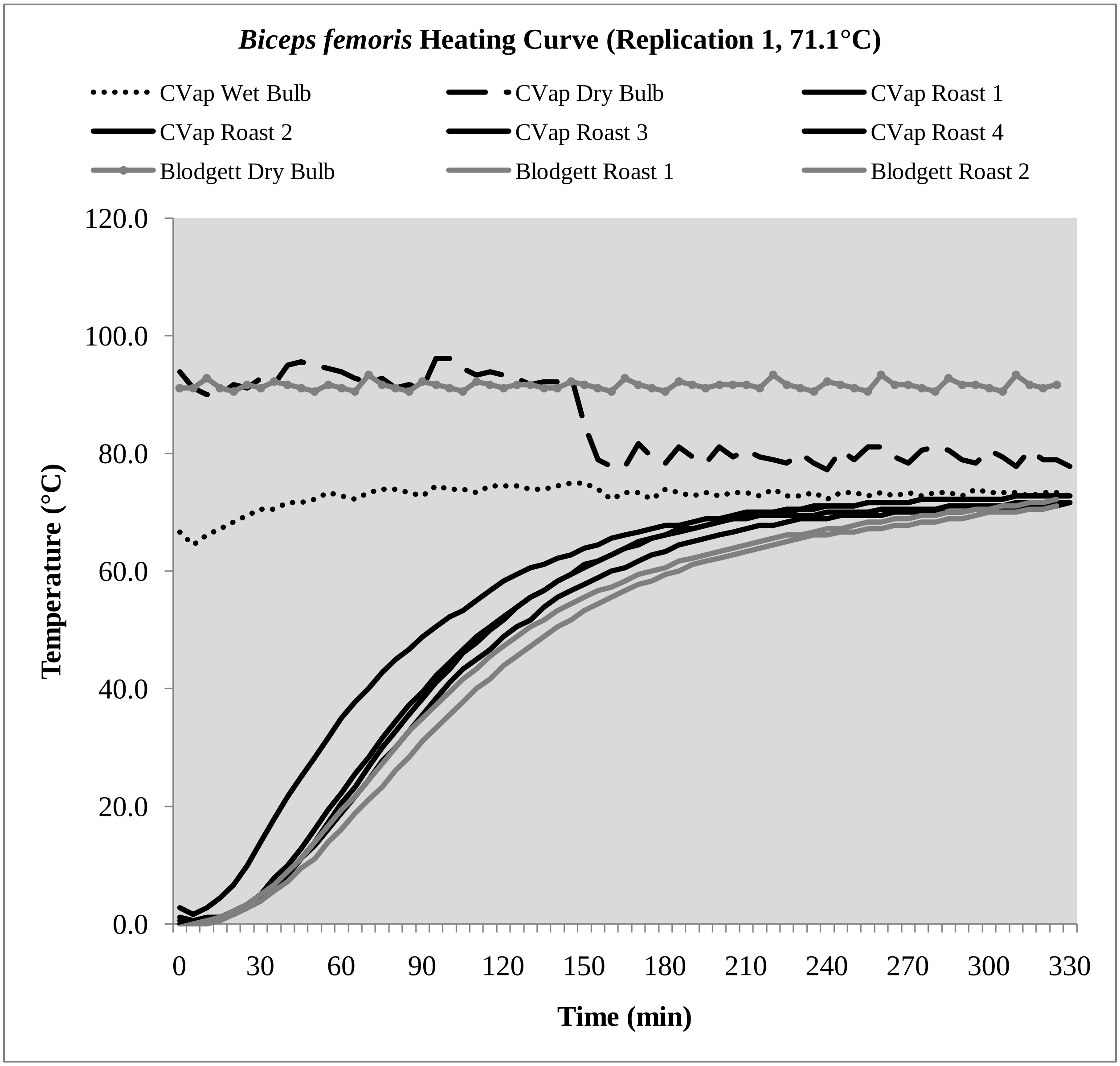
^{ab}Means within oven with different superscript letters differ ($P \leq 0.05$).

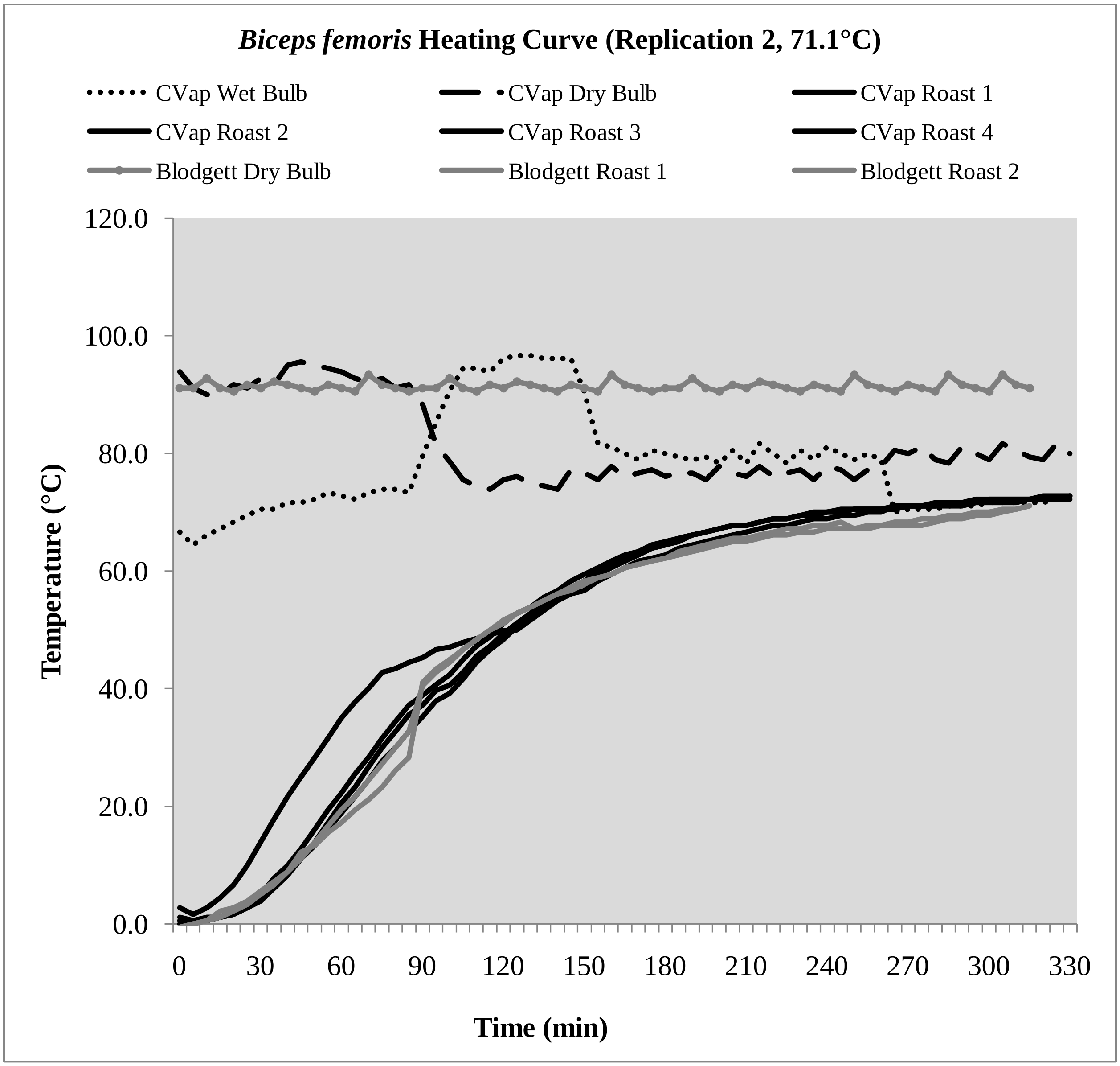
Standard Errors: Endpoint temperature = 0.21; Oven = 0.17 (highest standard errors reported)

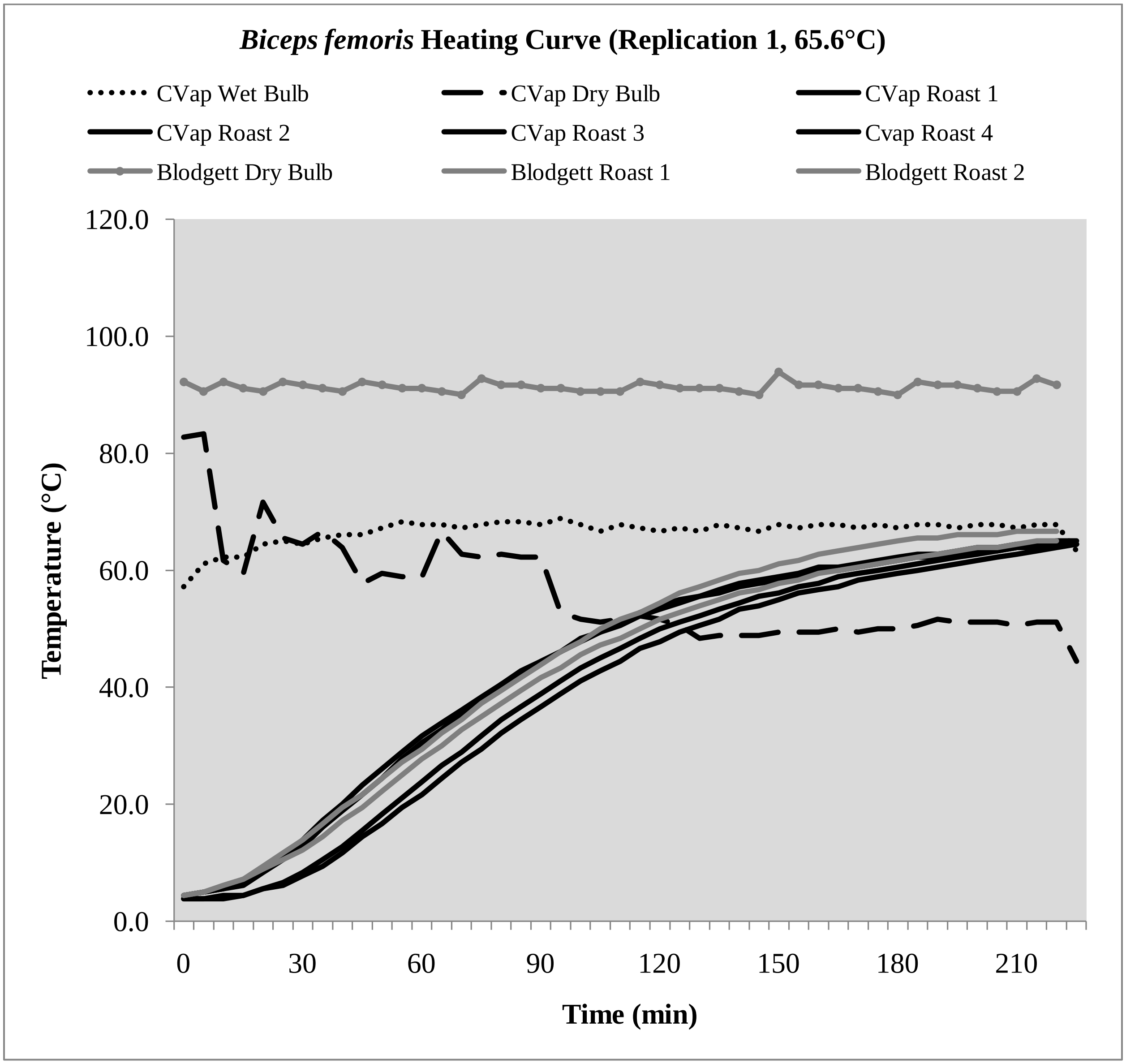
Appendix C – Heating Curves

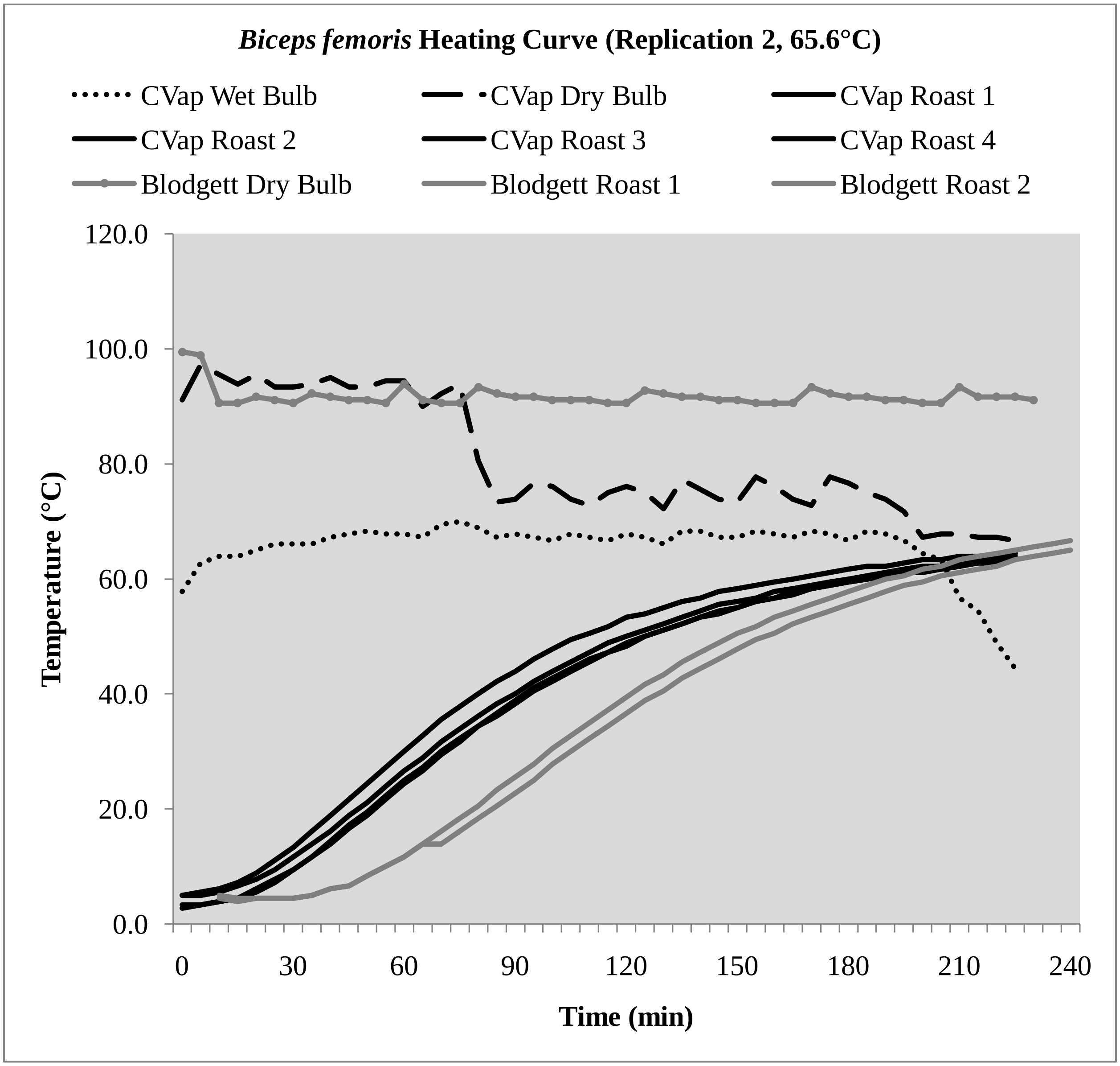


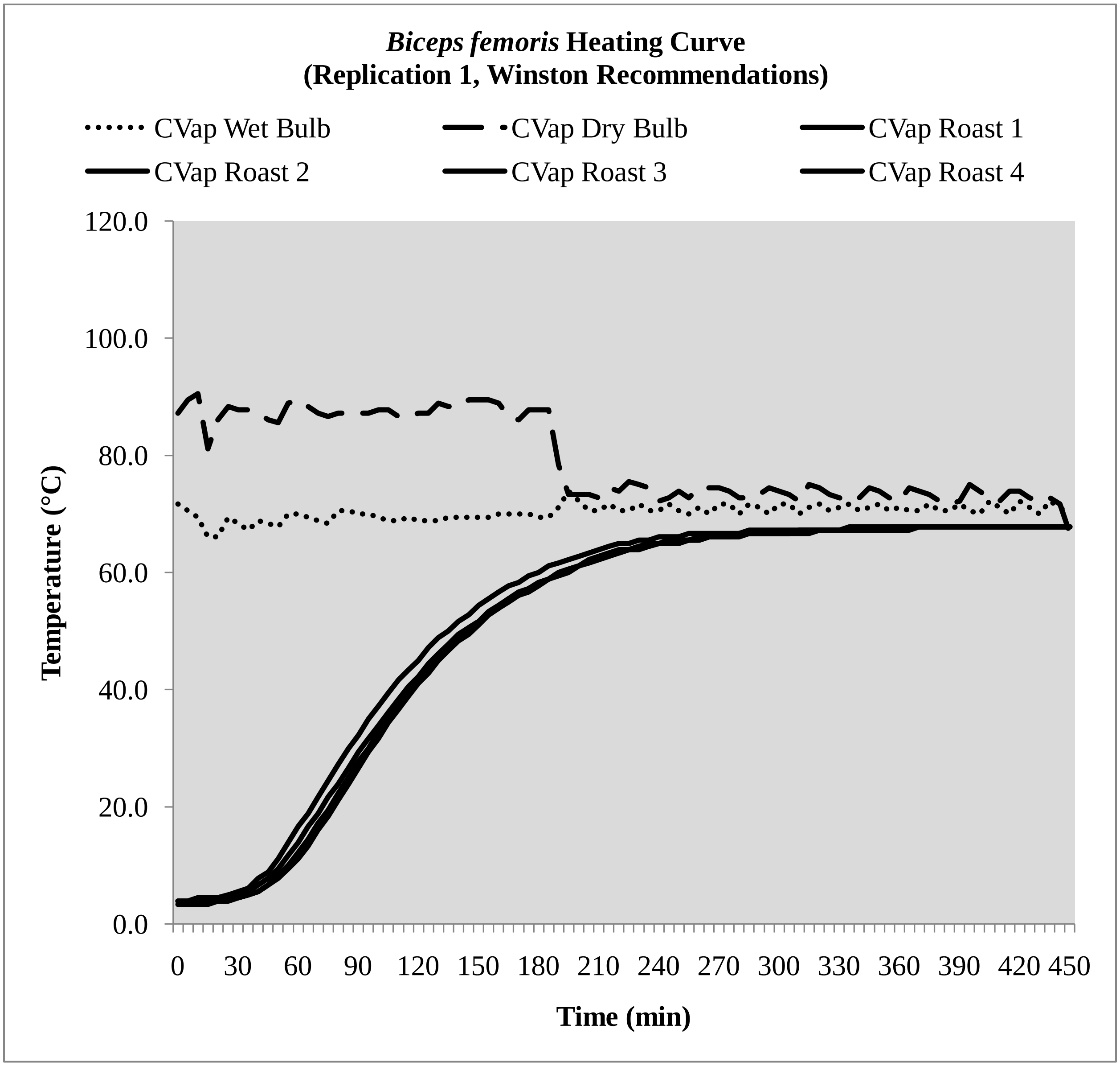

Biceps femoris Heating Curve (Replication 2, 76.7°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
Time (min)

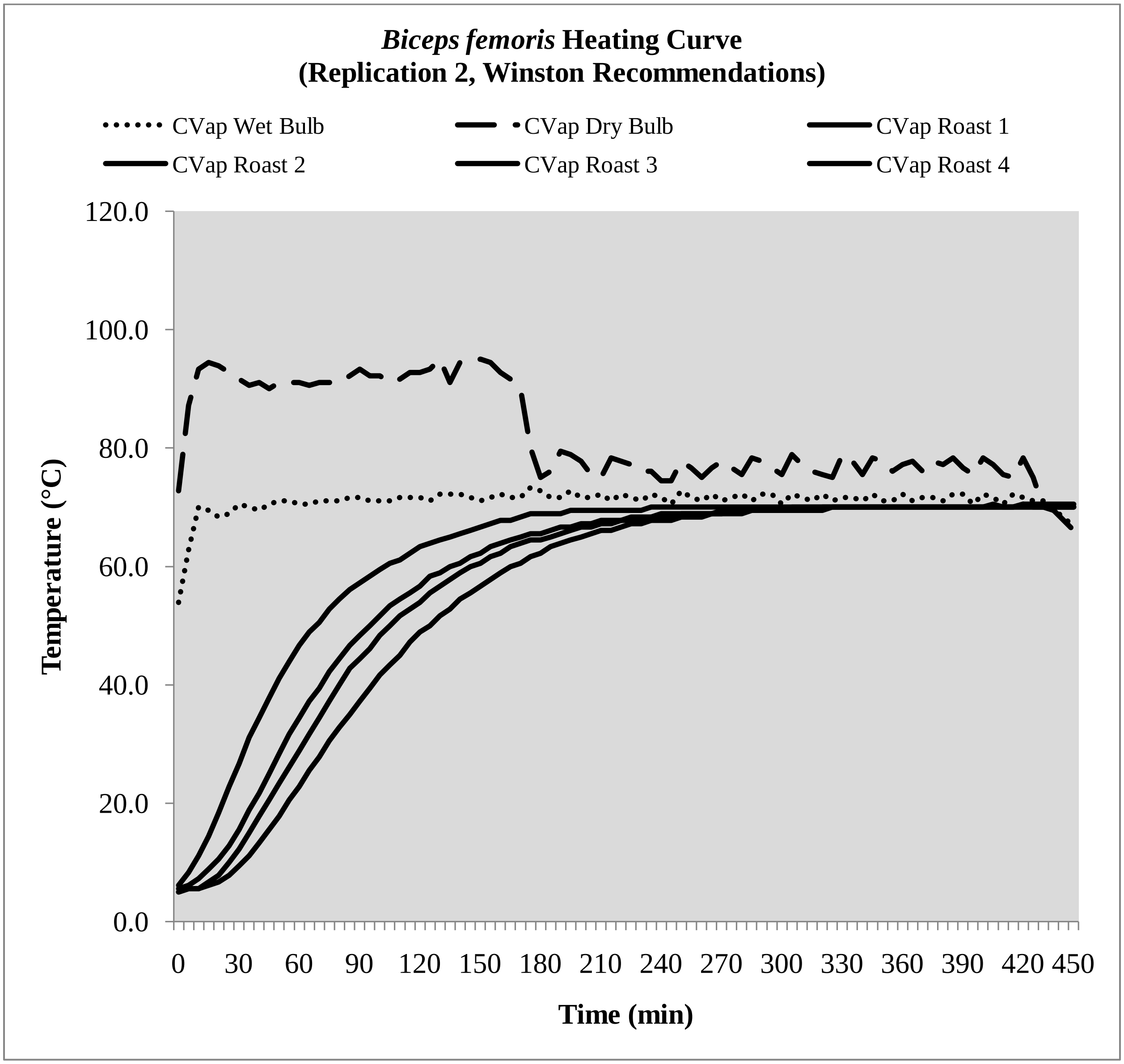

Biceps femoris Heating Curve (Replication 1, 71.1°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
Time (min)

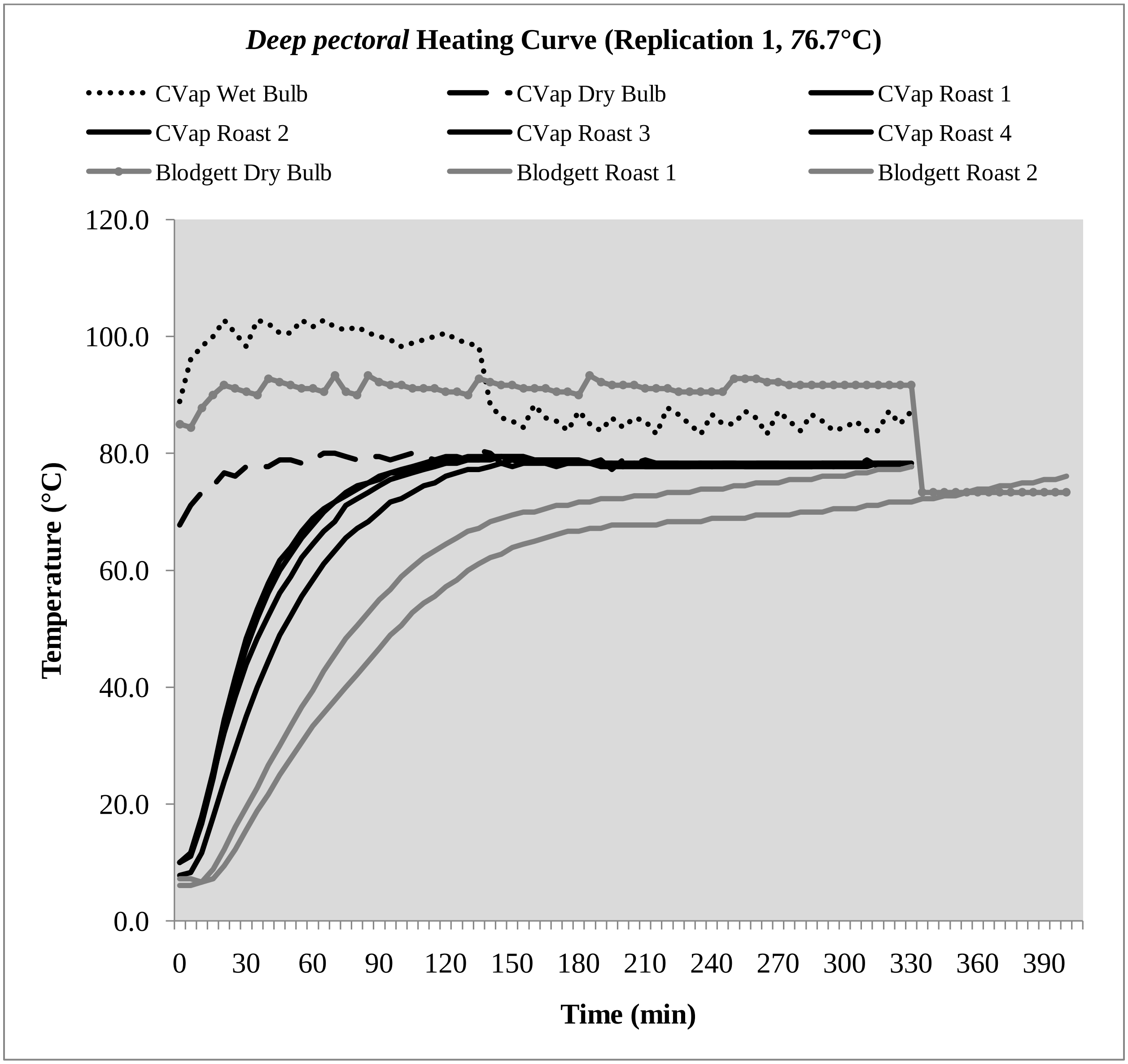

Biceps femoris Heating Curve (Replication 2, 71.1°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Temperature (°C)
0
30
60
90
120
150
180
210
240
270
300
330
Time (min)

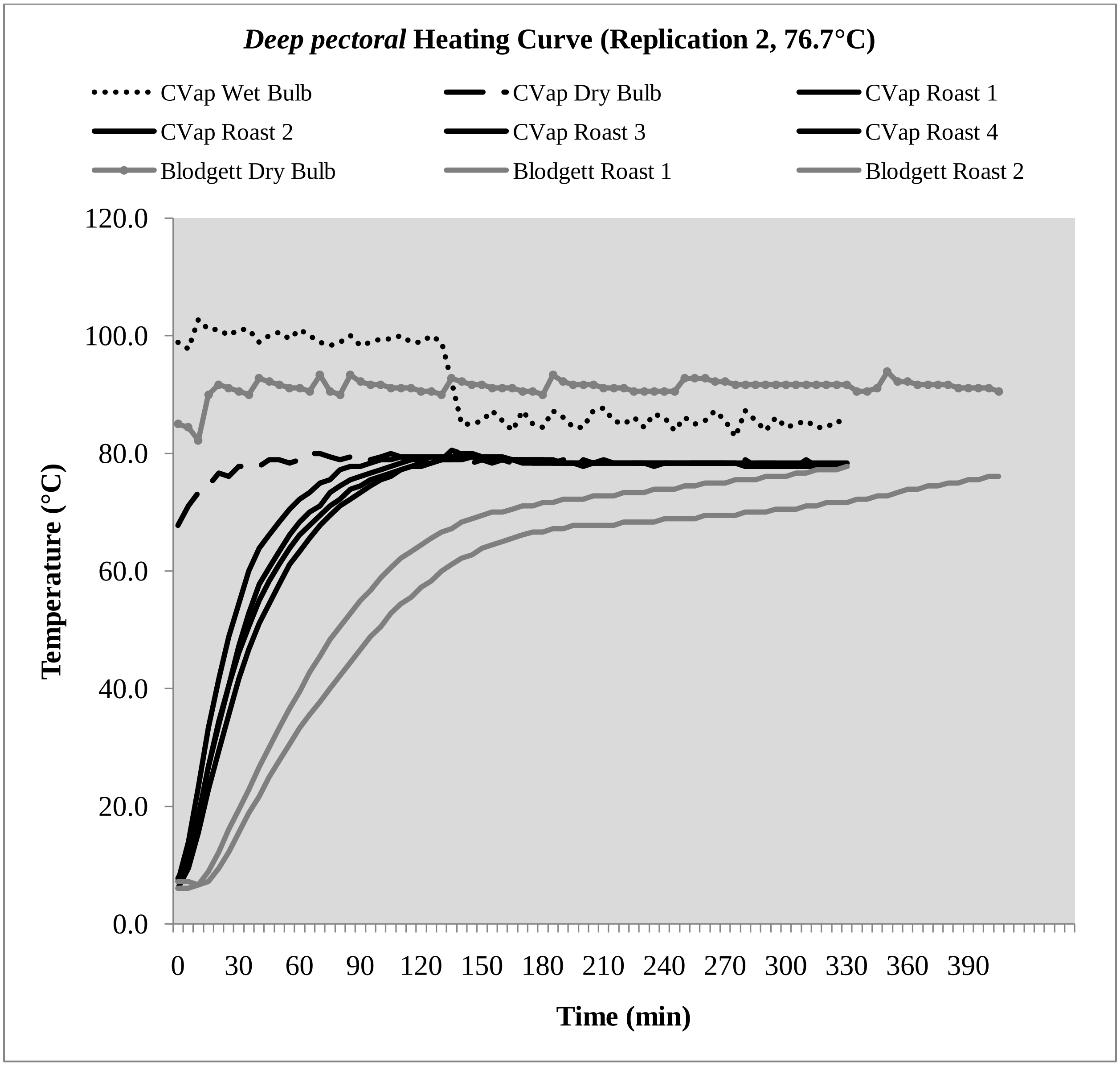

Biceps femoris Heating Curve (Replication 1, 65.6°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
Cvap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
Time (min)

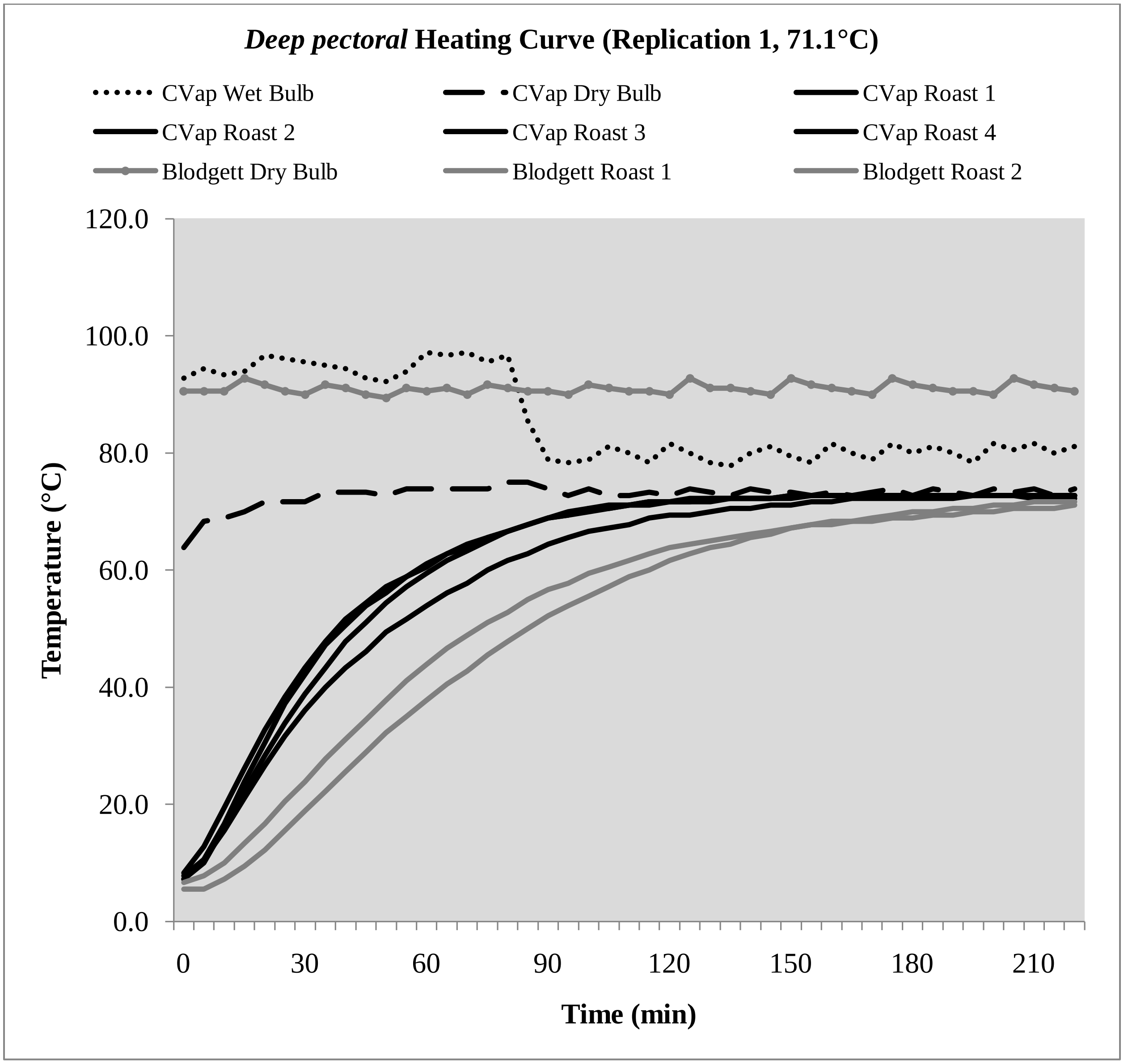

Biceps femoris Heating Curve (Replication 2, 65.6°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
Time (min)

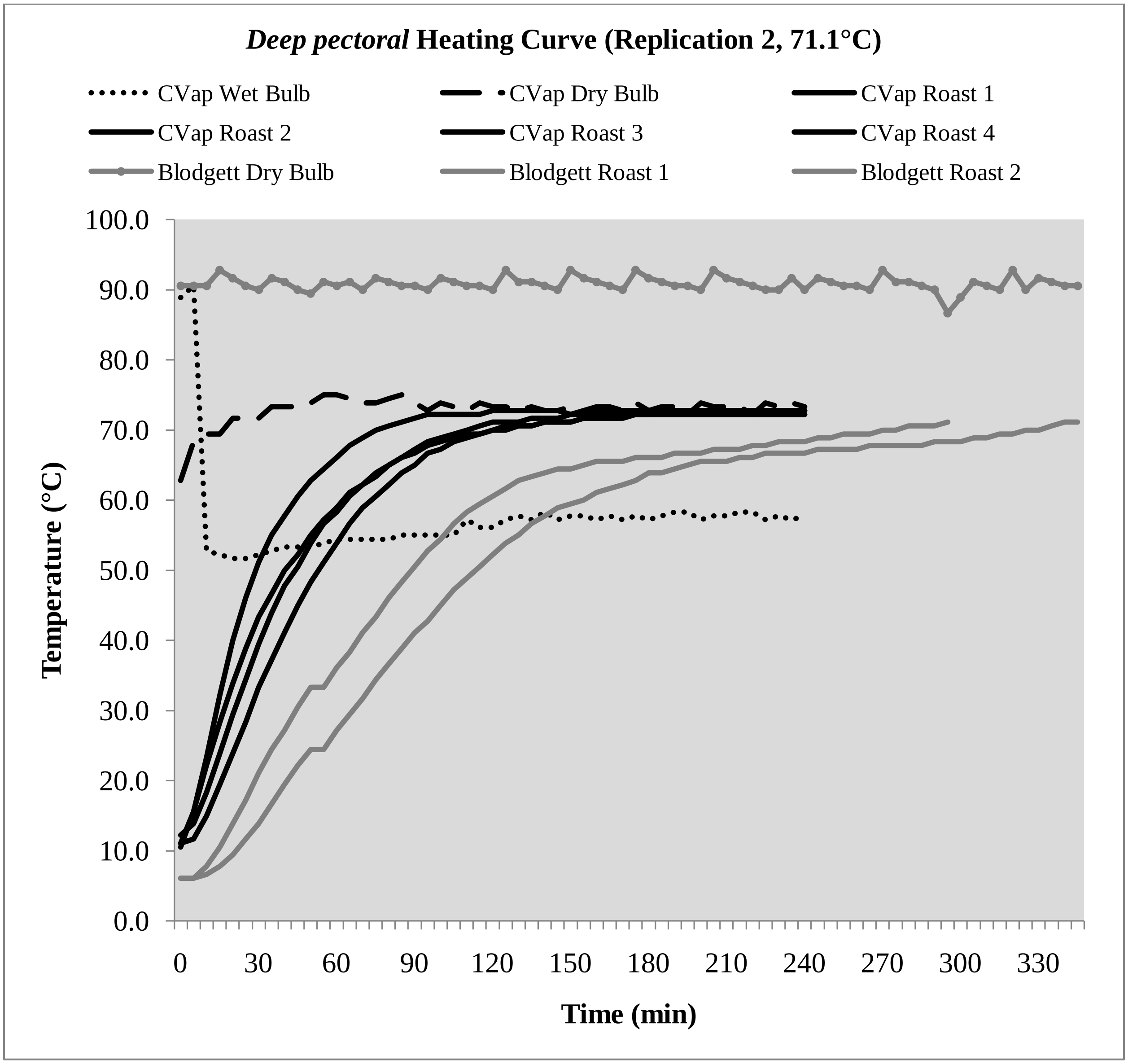

Biceps femoris Heating Curve
(Replication 1, Winston Recommendations)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
Time (min)

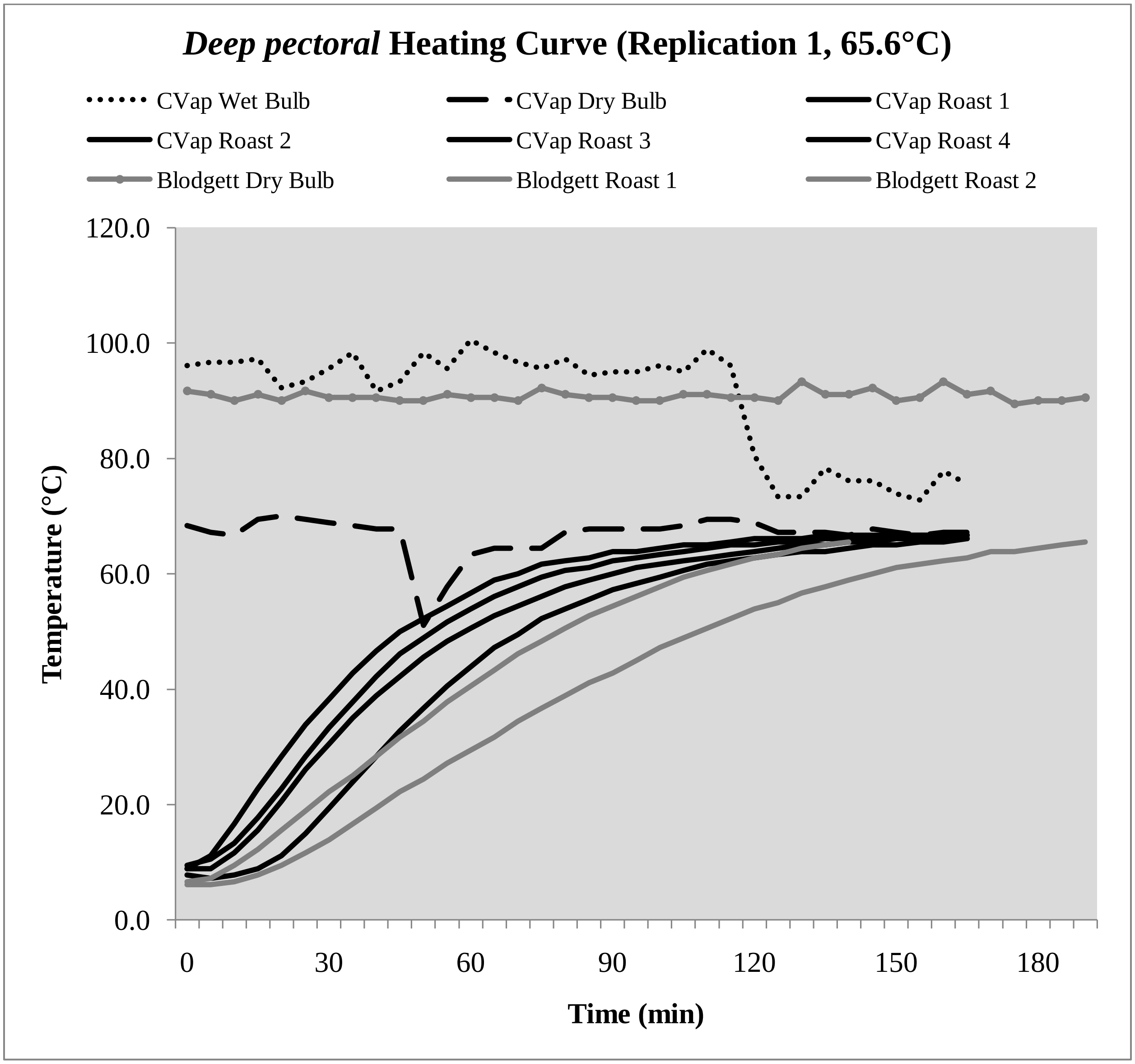

Biceps femoris Heating Curve
(Replication 2, Winston Recommendations)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
Time (min)

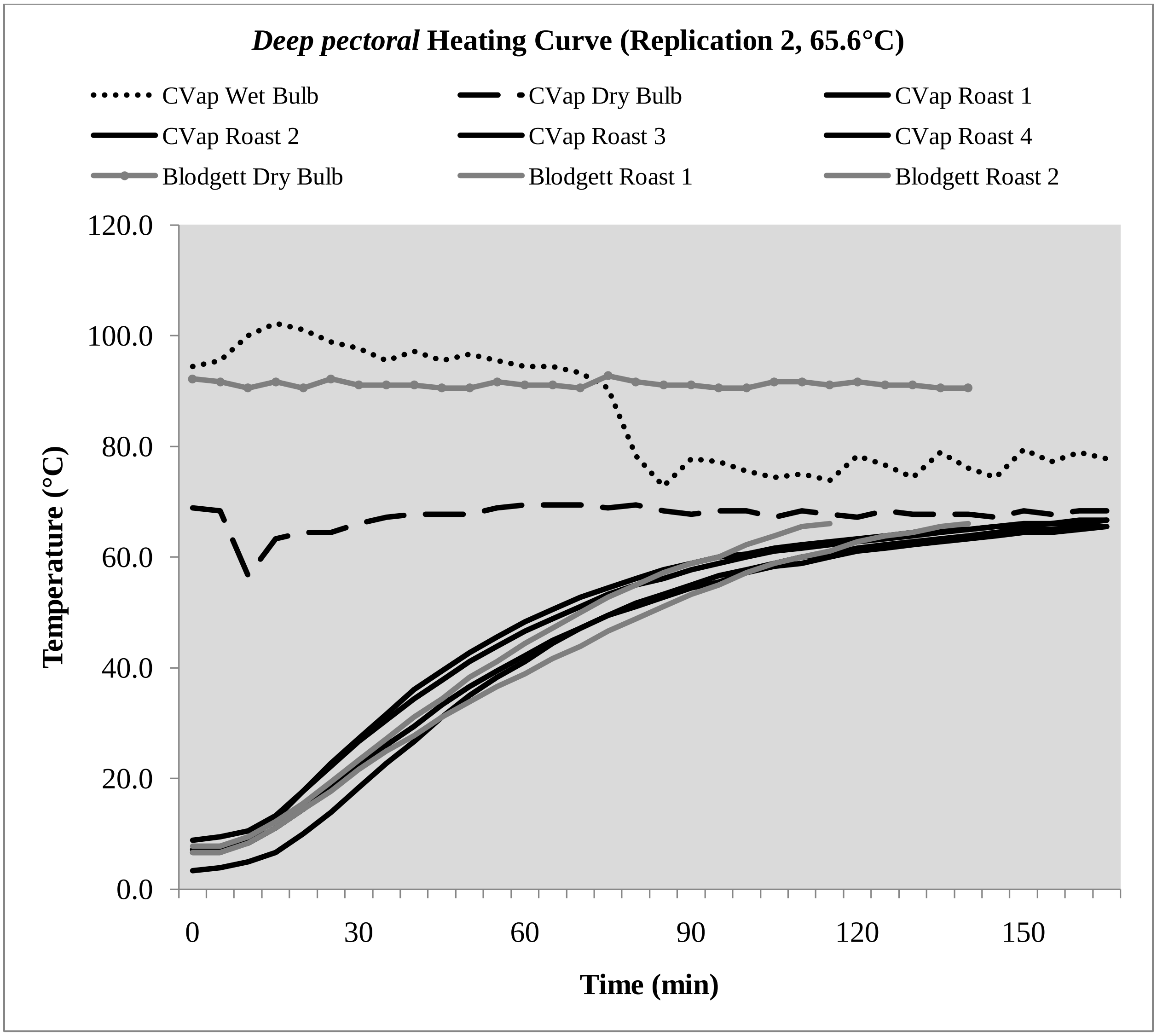

Deep pectoral Heating Curve (Replication 1, 76.7°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
Time (min)

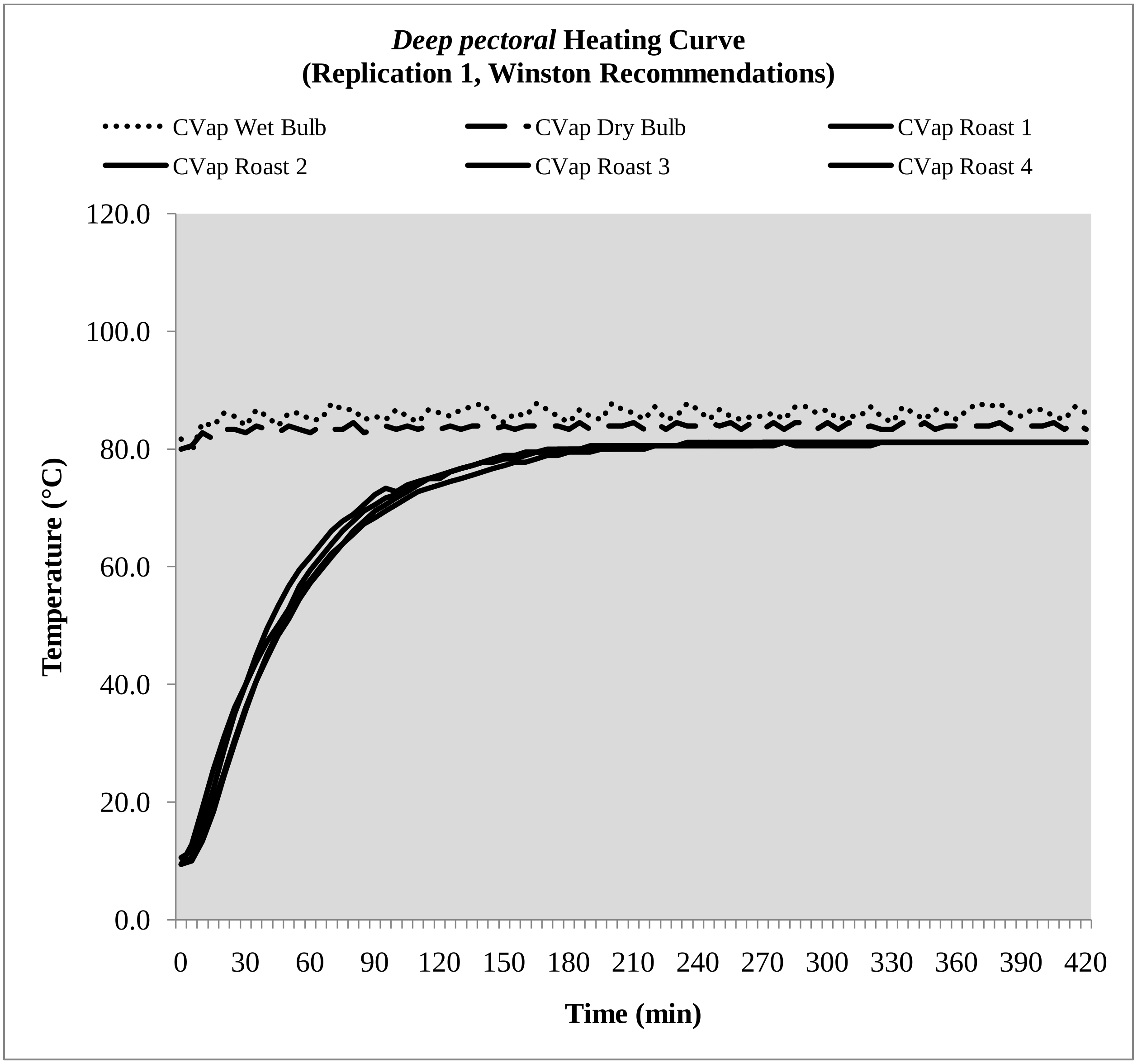

Deep pectoral Heating Curve (Replication 2, 76.7°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
Time (min)

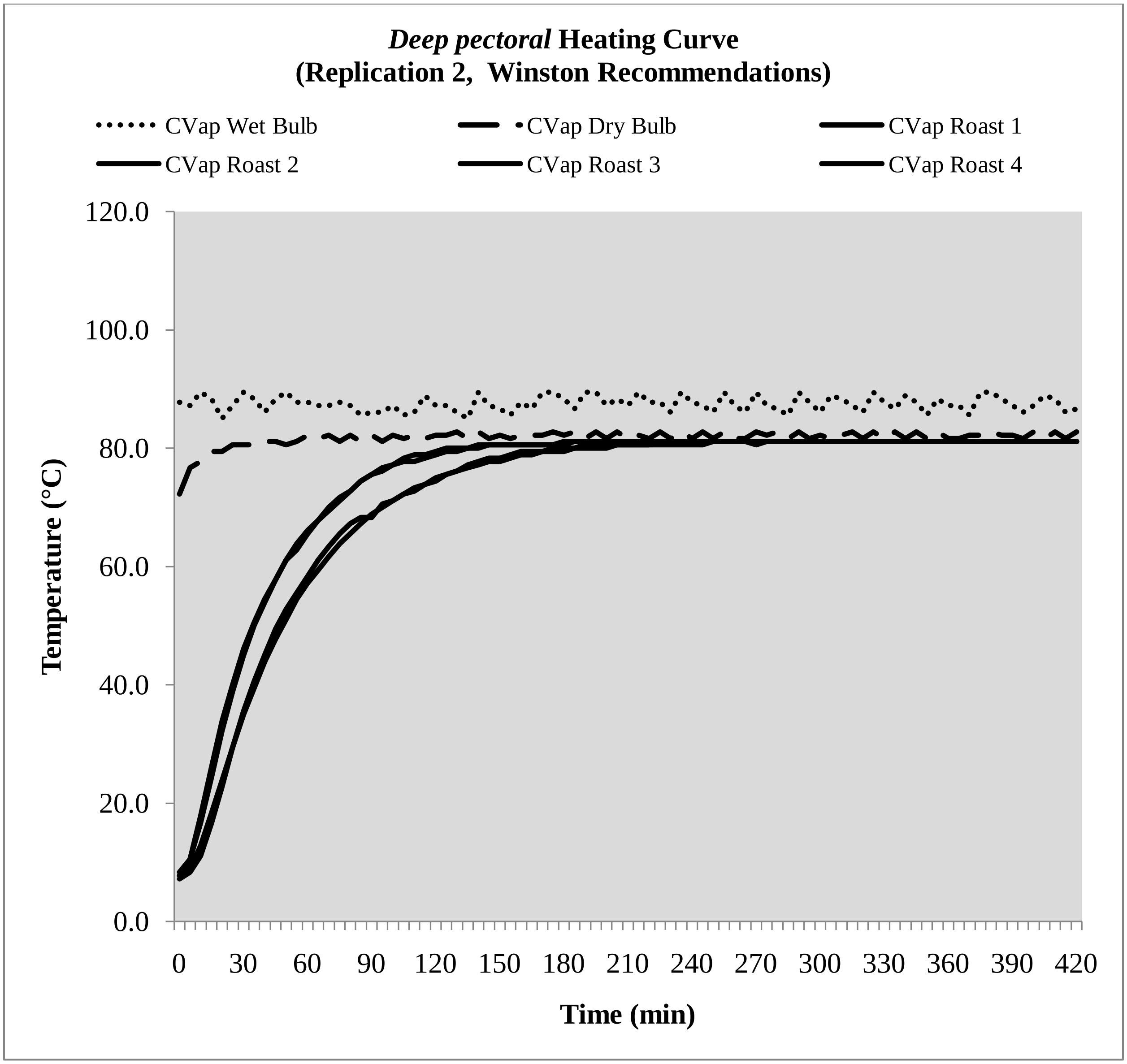

Deep pectoral Heating Curve (Replication 1, 71.1°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Temperature (°C)
0
30
60
90
120
150
180
210
Time (min)

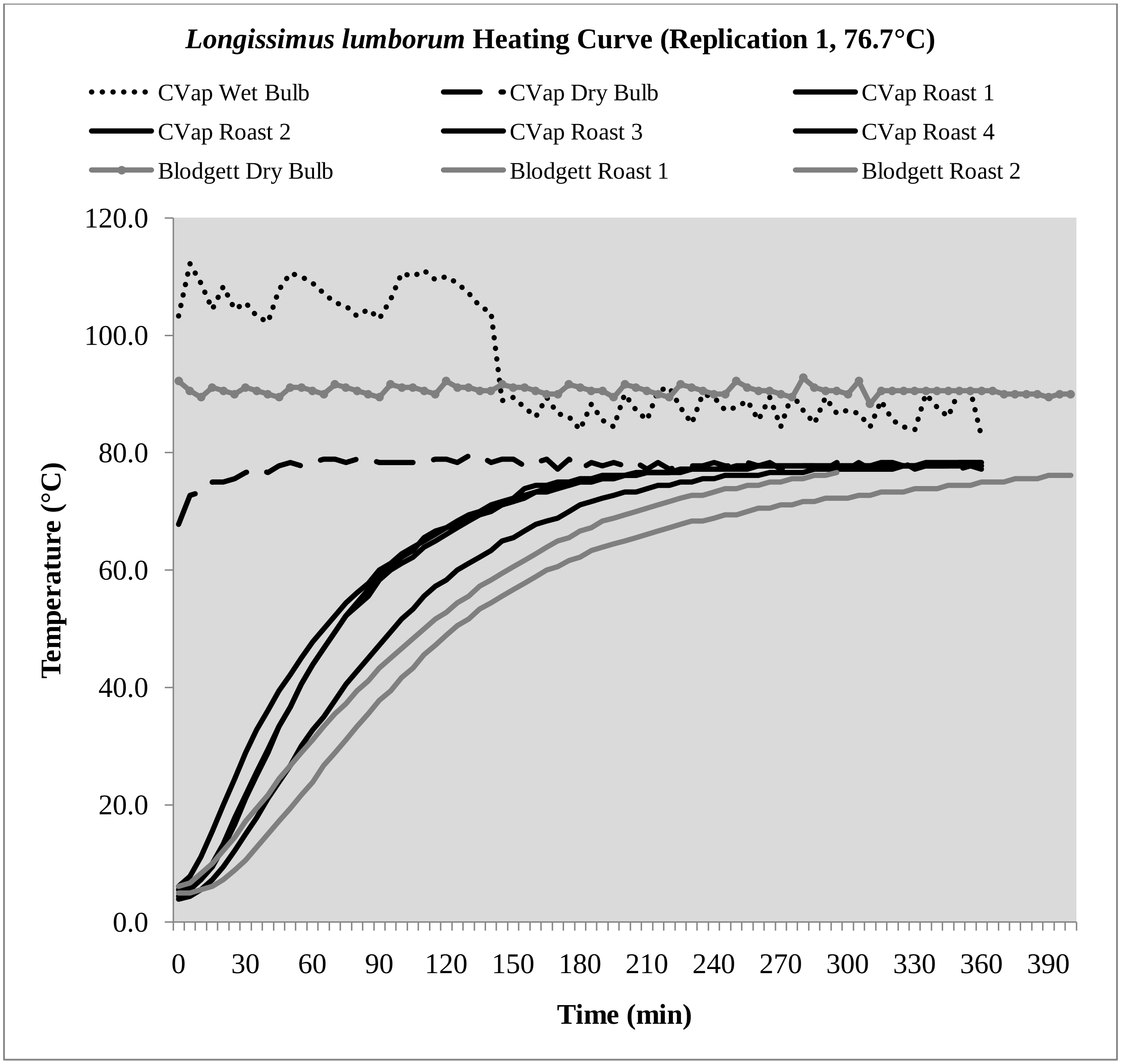

Deep pectoral Heating Curve (Replication 2, 71.1°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Temperature (°C)
0
30
60
90
120
150
180
210
240
270
300
330
Time (min)

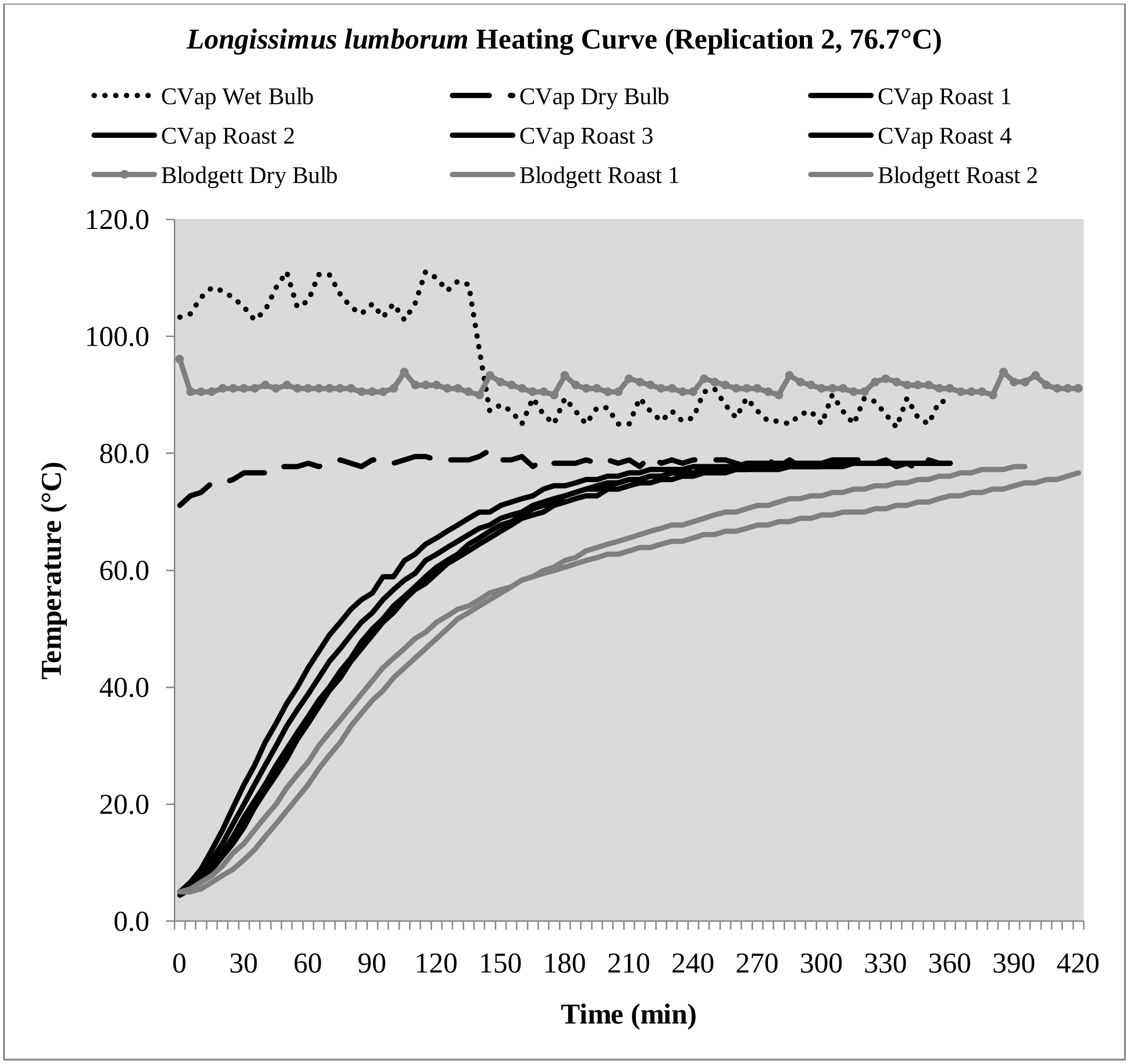

Deep pectoral Heating Curve (Replication 1, 65.6°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
Time (min)

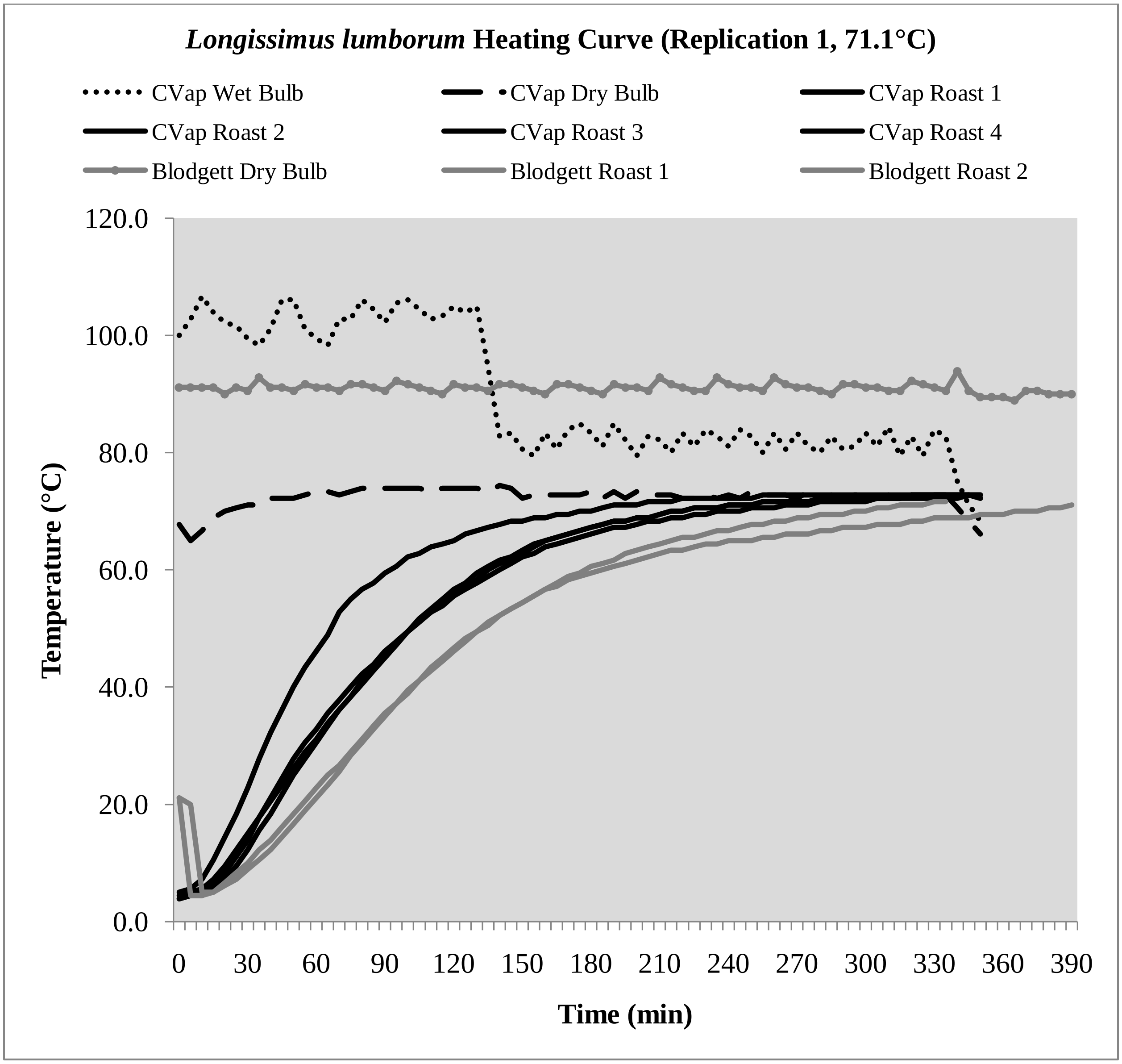

Deep pectoral Heating Curve (Replication 2, 65.6°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
Time (min)

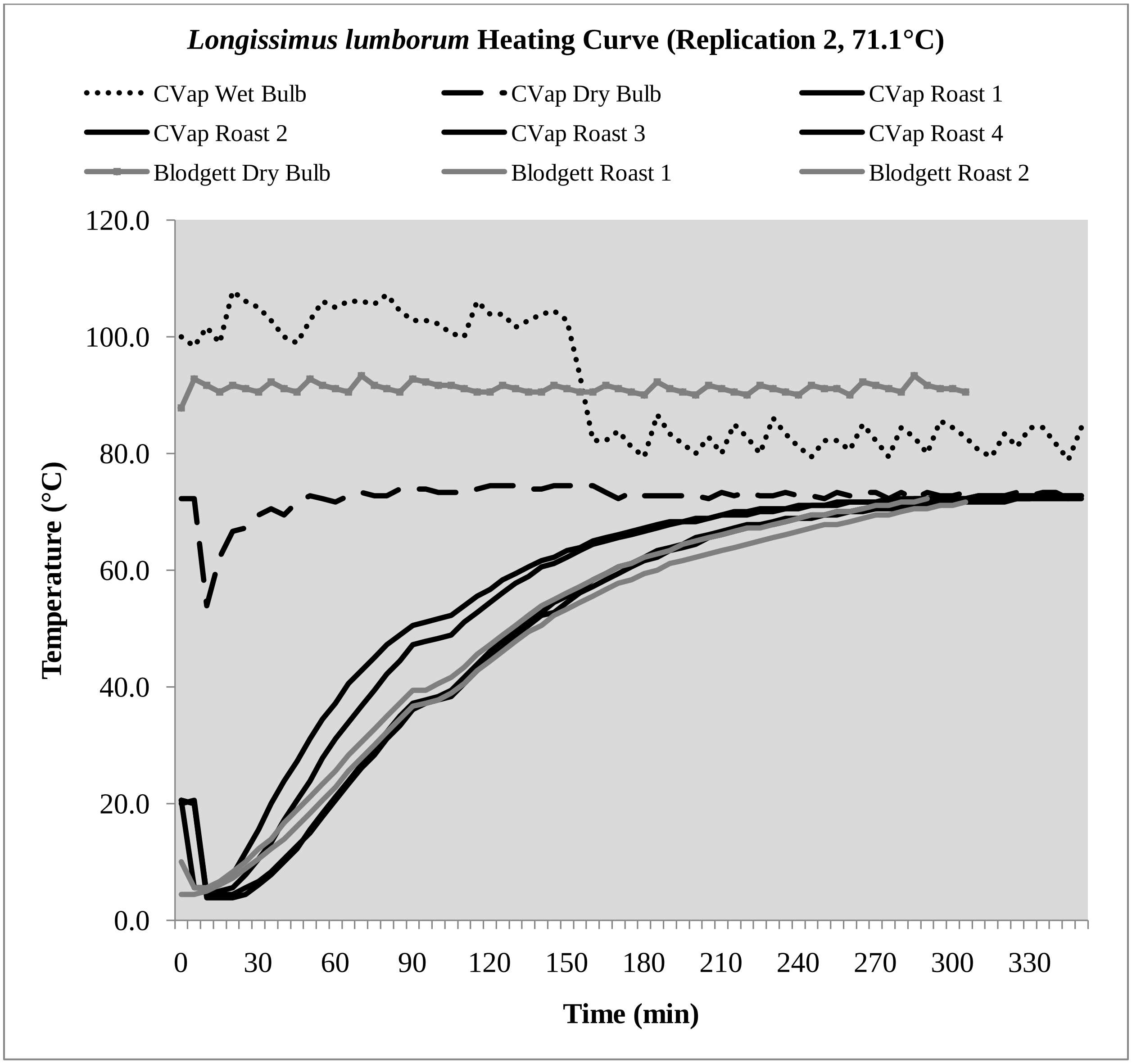

Deep pectoral Heating Curve
(Replication 1, Winston Recommendations)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
Time (min)

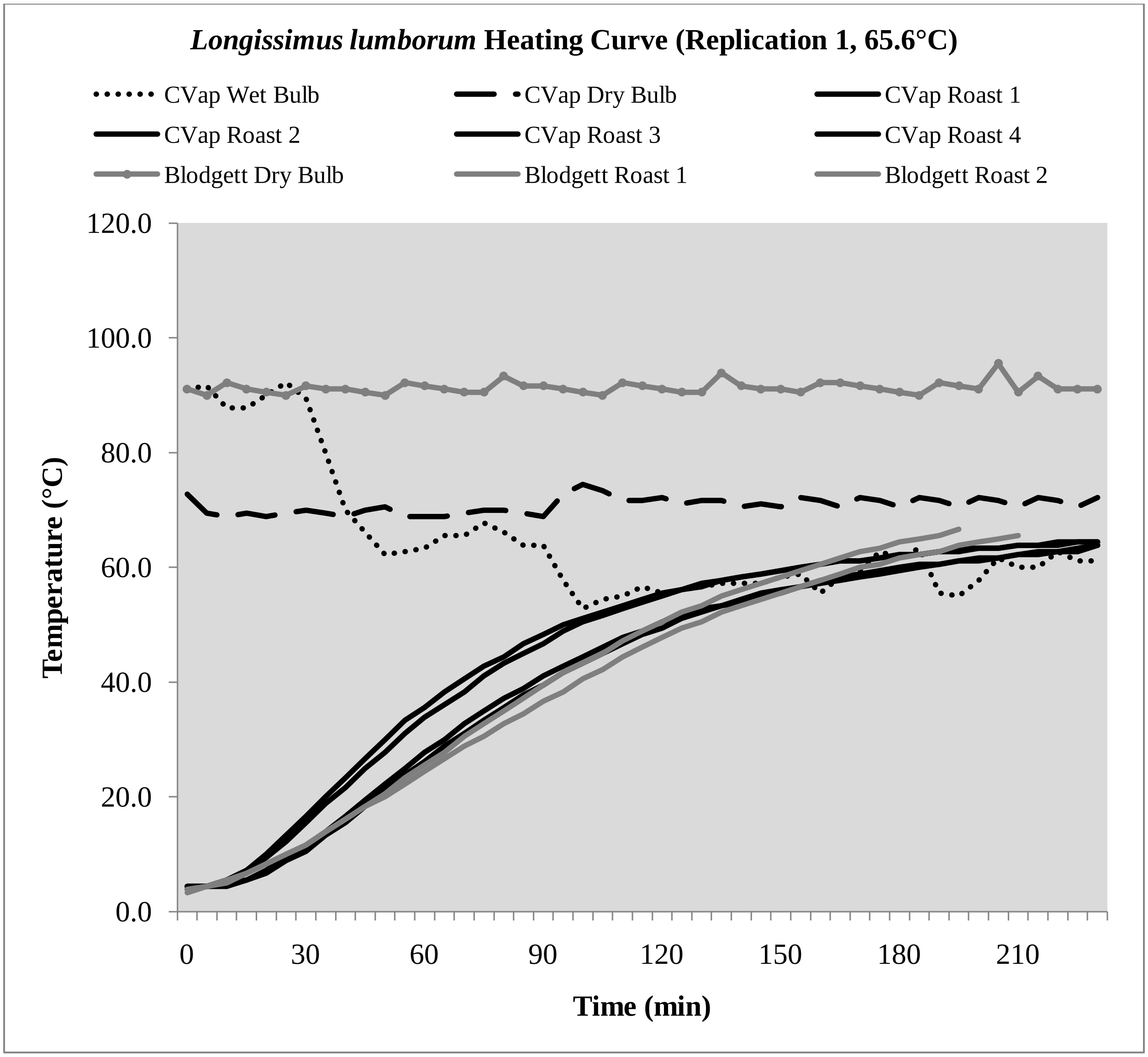

Deep pectoral Heating Curve
(Replication 2, Winston Recommendations)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
Time (min)

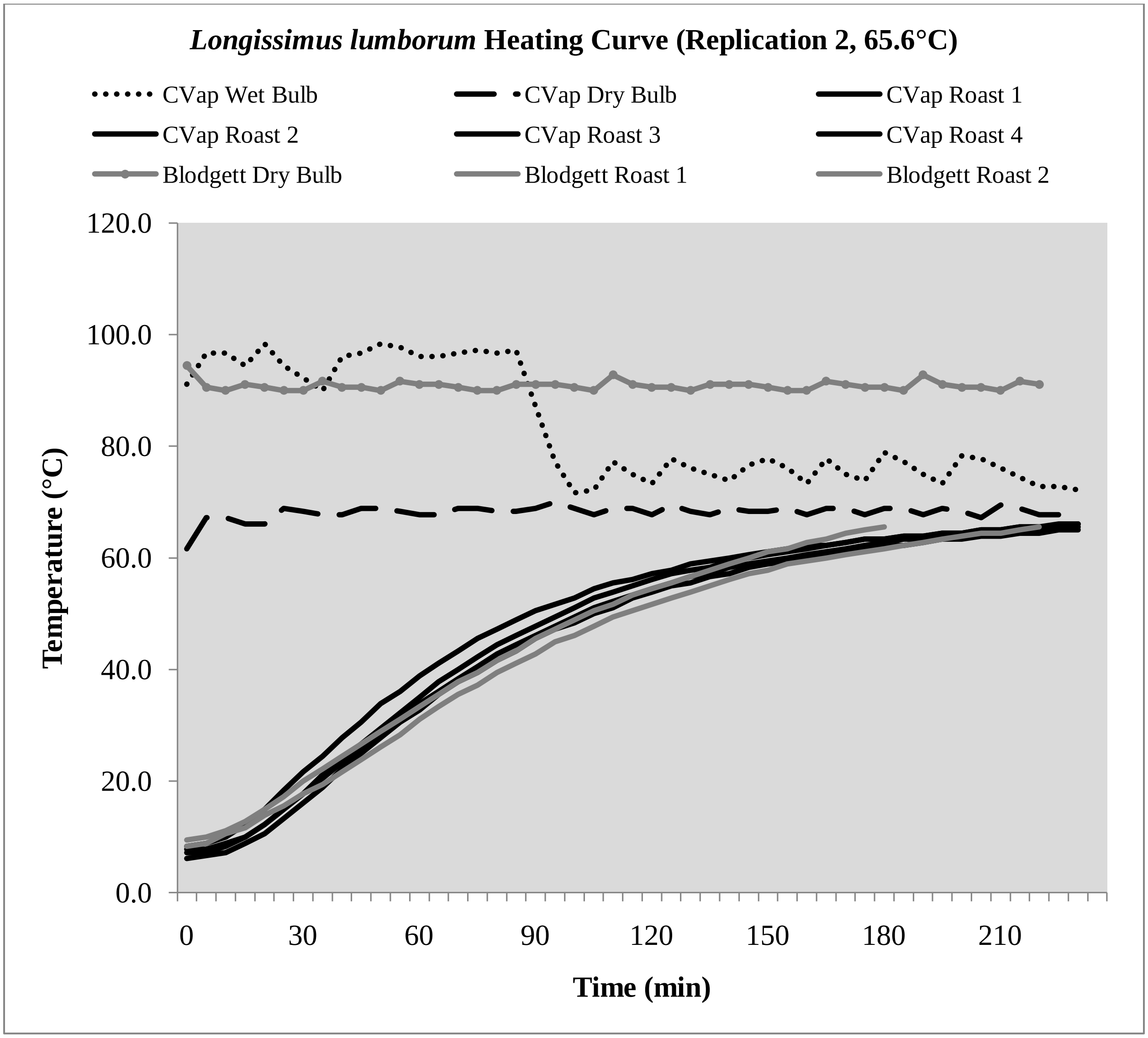

Longissimus lumborum Heating Curve (Replication 1, 76.7°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
Time (min)

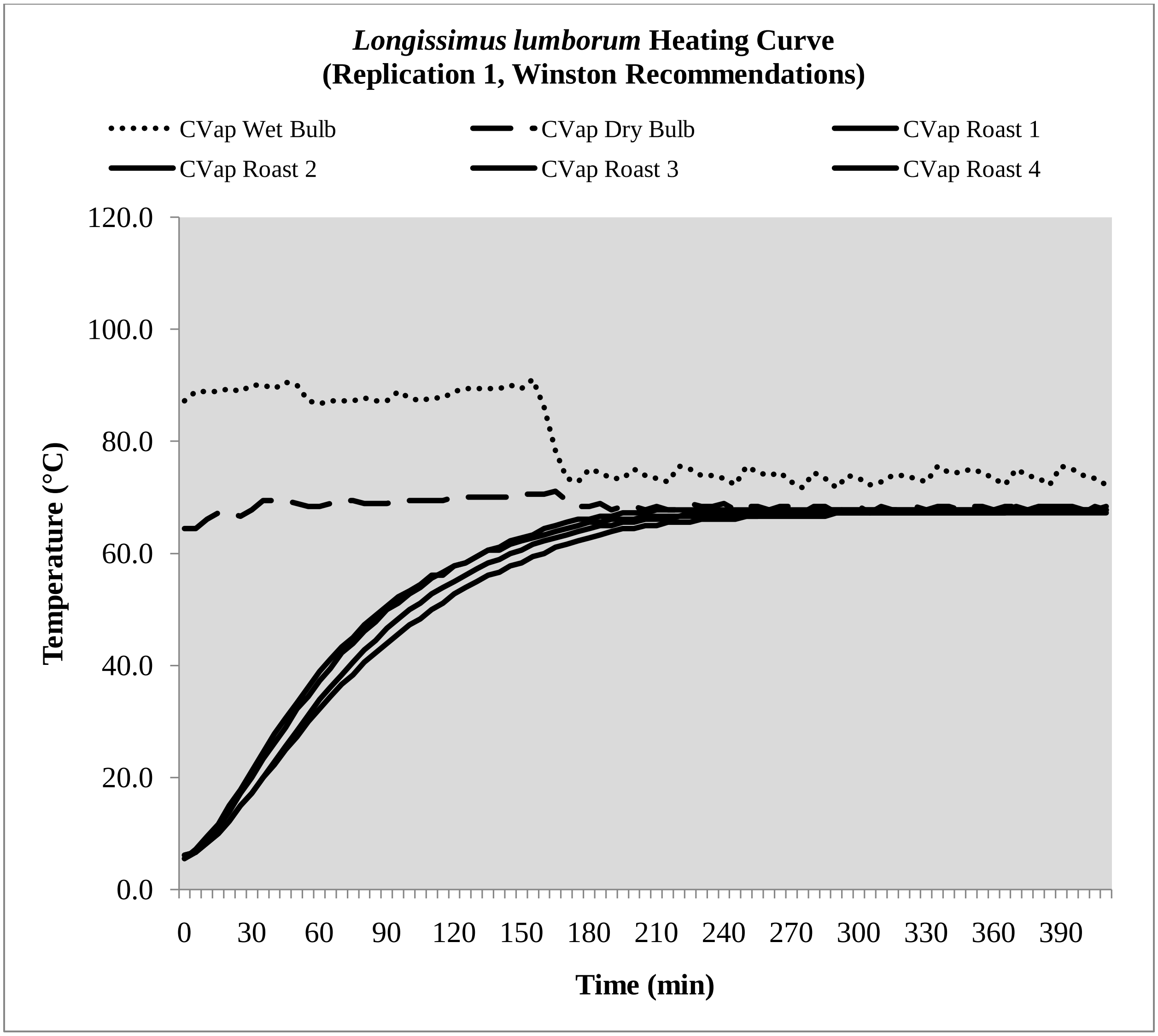

Longissimus lumborum Heating Curve (Replication 2, 76.7°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
Time (min)

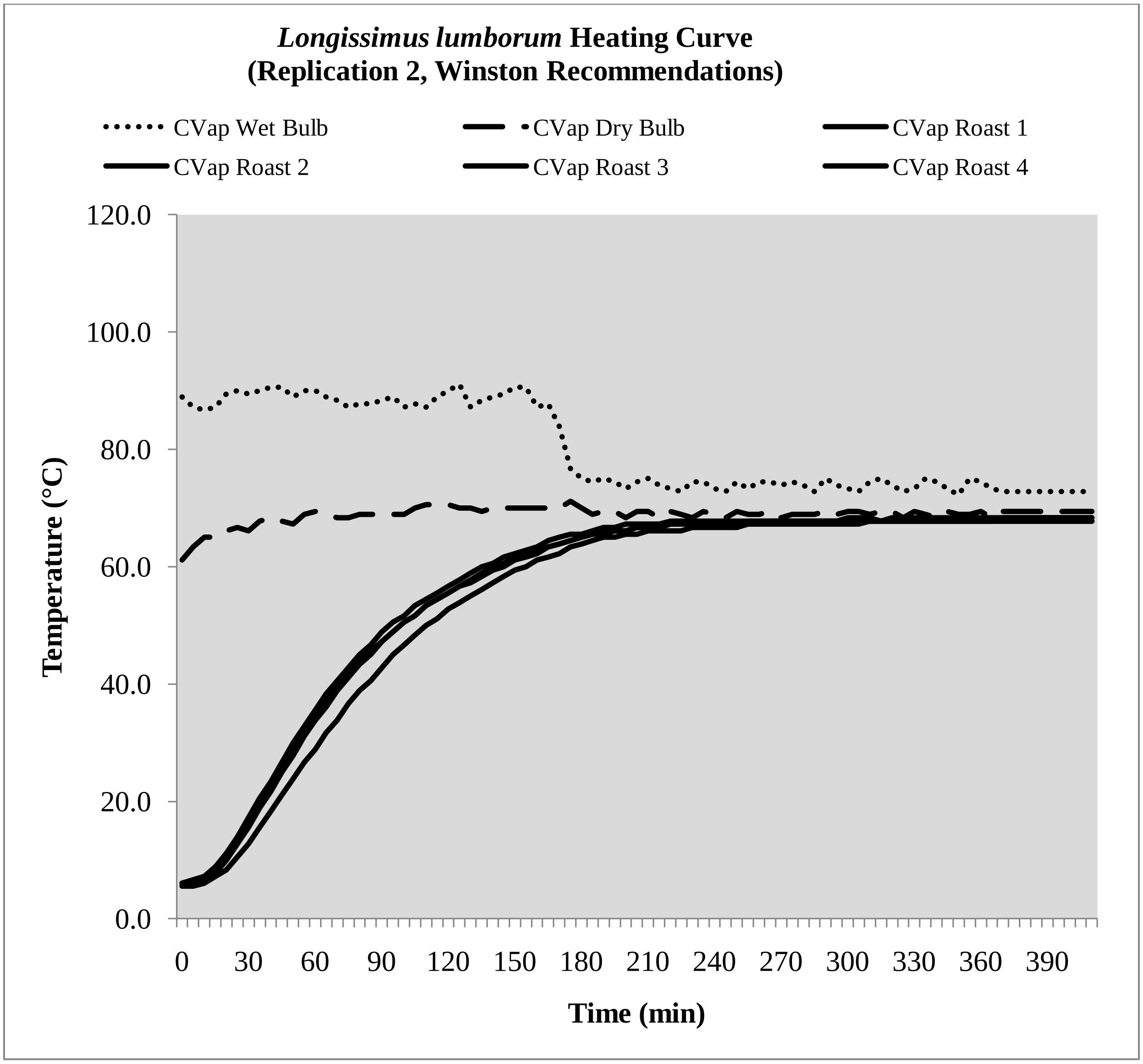

Longissimus lumborum Heating Curve (Replication 1, 71.1°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
Time (min)


Longissimus lumborum Heating Curve (Replication 2, 71.1°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Temperature (°C)
0
30
60
90
120
150
180
210
240
270
300
330
Time (min)


Longissimus lumborum **Heating Curve (Replication 1, 65.6°C)**
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Temperature (°C)
0
30
60
90
120
150
180
210
Time (min)


Longissimus lumborum Heating Curve (Replication 2, 65.6°C)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Blodgett Dry Bulb
Blodgett Roast 1
Blodgett Roast 2
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
Time (min)


Longissimus lumborum Heating Curve
(Replication 1, Winston Recommendations)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
Time (min)


Longissimus lumborum Heating Curve
(Replication 2, Winston Recommendations)
CVap Wet Bulb
CVap Dry Bulb
CVap Roast 1
CVap Roast 2
CVap Roast 3
CVap Roast 4
Temperature (°C)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
Time (min)