FUNCTIONAL PROPERTIES OF RESTRUCTURED BONELESS PORK PRODUCED FROM PSE AND RFN PORK UTILIZING NON-MEAT ADJUNCTS

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Abstract

FUNCTIONAL PROPERTIES OF RESTRUCTURED BONELESS PORK PRODUCED FROM PSE AND RFN PORK UTILIZING NON-MEAT ADJUNCTS

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Boneless cured pork was produced from combinations of pale, soft, and exudative (PSE) and red, firm, and non-exudative (RFN) *semimembranosus* muscle differing in amount of modified food starch (MFS), sodium caseinate (SC), and soy protein concentrate (SPC). Response Surface Methodology was utilized to determine the effects of these adjuncts on water holding capacity, color, and texture. Both RFN pork and PSE pork were selected based on visual color for the following five treatments for processing: 100 % PSE, 75% PSE +25 % RFN, 50 % PSE+ 50 % RFN, 25 % PSE +75 % RFN, and 100 % RFN. Fifteen ingredient combinations for each PSE and RFN treatment combination yielded 75 treatments per replication. Three replications of each treatment were completed. Chemical composition and color of raw materials also were measured and used as covariates to determine their effect on the above-mentioned responses.

Utilization of SC decreased ($p<0.05$) cooking loss, lightness, and cohesiveness. SPC incorporation decreased ($p<0.05$) cooking loss, cohesiveness, and redness, and MFS inclusion decreased ($p<0.05$) expressible moisture and cohesiveness. Utilization of SC and MFS increased ($p<0.05$) redness and SPC incorporation increased ($p<0.05$) yellowness. Results indicated that combining soy protein concentrate and modified food starch together in formulations demonstrated the greatest potential of these adjuncts to improve water binding, color, and texture in pale, soft, and exudative pork. Utilization of combinations of these adjuncts demonstrates potential to improve protein functionality in PSE as well as RFN pork. This research also demonstrated that diluting RFN pork with no more than 25 % PSE pork allows the formation of a high quality boneless deli ham roll.

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Chapter 1

1.1 Introduction

Pigs were first introduced to North America in 1539 when Hernando de Soto brought them to the Florida mainland (NPPC, 2000). After this event, Europeans began importing pigs throughout Colonial times. This set the foundation for the modern U.S. pork industry that occurred when farmers began to finish off imported pigs with maize produced in America.

From the late 1880's through the 1940's, a large consumer demand for lard existed because of cooking and cleaning practices that encouraged pork producers to grow fat pigs. The fat derived from the pig was also utilized in nitroglycerine formation for use in explosives during World War II (NPPC, 2000). In the 1950's, consumers demand for lard decreased since new oils and soaps were available for cooking and cleaning. This was the first impetus for the production of leaner pork, which led to increased stress susceptibility and detection of the Napole gene. Homozygous recessive expression of this gene causes the single point mutation that is termed Porcine Stress Syndrome (PSS) in the live animal (Fuji et al., 1991). This condition either leads to death or yields pale, soft, and exudative (PSE) raw material that is undesirable to consumers. PSE meat was first documented in Germany by Herter (1914), but the term did not originate until 1954 in Denmark. Pale, watery meat existed in the early 1900's, but did not become prevalent until the 1950's due to changing consumer demand. In the 1970's, the trend for consumers to be more health conscious led to a second increase in production of leaner pork.

Producers have been able to grow lean pigs while simultaneously eliminating the Napole gene from breeding stock. Elimination of this gene has reduced the incidence of PSE meat but has not completely eradicated it. Scientists have realized that selection for leaner pigs causes a higher percentage of white muscle fibers, immature connective tissue, and other characteristics that increase stress susceptibility and lead to PSE production. Mechanization of slaughter plants and slaughtering practices also cause increased stress susceptibility. These factors demonstrate the difficulty that the meat industry faces in reducing the incidence of PSE meat while simultaneously producing lean pork.

Kauffman et al. (1992) audited pork slaughter plants in the U.S. and stated that it is clear that the U.S. has a significant pork quality problem. Cannon et al. (1996) and Carr et al. (1997) reported that PSE and red, soft, and exudative (RSE) pork results in approximately $100 million

in annual losses for the pork industry. Kauffman et al. (1992) proposed that the U.S. pork industry could minimize quality variations through establishing guidelines for pork production, eliminating stress to carcasses post-slaughter, and recording pork quality measurements for each carcass in order to provide information that can improve breeding stock. These authors also stated that providing price differentiation in live animals based on quality variation would encourage producers to be more careful in their raising and handling practices. Though these options exist, their implementation may not be practical since the industry usually exhibits a reactionary attitude instead of a preventative attitude towards problems. This makes it necessary to explore the possibilities that exist for utilizing PSE pork.

Due to the low value of PSE meat, it is often blended into sausage manufacture, but this is unacceptable for high value cuts such as the *longissimus* and *semimembranosus* muscles. This problem provides the challenge of adding value to these two muscles if they exhibit PSE. One possible approach is through investigating the possibility of incorporating PSE meat into boneless cured pork such as a chunked and formed product. Solomon et al. (1998) reported that boneless, cured products formulated with PSE meat exhibit poor cohesiveness and water-holding capacity. Therefore, to increase the viability of this technique, two things must occur. The amount of PSE pork that can be incorporated into a product must be determined, and possibilities to improve color, texture, and water-holding capacity must be explored. If successful in this endeavor, it would be possible to incorporate PSE raw material into a deli ham that yields 6-10 $/kg more than the product that it is presently diluted into.

Motzer et al. (1998) demonstrated that a sectioned and formed product cannot be produced from 100 % PSE raw material due to lack of functionality, but that it may be possible to formulate a product from 50 % PSE meat. Their research reveals the importance of determining what percentage between 0 and 50 of PSE pork can be incorporated into boneless cured products so that they are acceptable in quality and add maximum value to the raw material.

Non-meat adjuncts including sodium caseinate (SC), soy protein concentrate (SPC), modified food starch (MFS), and kappa-carageenan (KC) have demonstrated the potential to improve protein functionality characteristics of processed meat products. SC is desirable because of its amphiphilic structure that allows it to bind well to both water and fat (Swaisgood, 1996). SPC is utilized for its gelation ability, ability to bind water and fat, and its inexpensive nature when compared to animal derived binders (Hermannson, 1986; Ashbridge, 1995). MFS

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functions by entrapping and binding water through structural constraints and hydrogen bonding (Whistler and Daniel, 1985). KC has optimal water-binding capacity, but it is often undesirable because it causes a gel-like precipitate to form on the surface of the product.

It appears that SC, MFS, and SPC have the optimal potential to improve functionality in restructured meats. It is important to recognize that SC, MFS, and SPC can only be incorporated at levels of 2, 3.0, or 3.5 % into finished products, respectively. These low percentages prevent the ingredients from impacting functionality in products formulated with 100 % PSE raw material since there is severe myosin, actin, and myoglobin denaturation and these proteins are present in meat at much higher percentages that SC, SPC, and MFS can be incorporated at. This suggests that SC, SPC, and MFS can only improve quality when it is able to function synergistically with myosin and actin that has not been denatured. It is probable that at least 50 % red, firm, and non-exudative (RFN) pork is necessary to provide enough functional meat protein to formulate a quality product. Therefore, the crux of this research is to determine the possibility of incorporating a combination of these adjuncts in the formation of boneless cured pork to obtain a product consisting of 25 or 50 % PSE raw material that is similar in quality to a 100 % RFN product with no adjuncts.

Utilization of Response Surface Methodology (RSM) allows for the determination of optimal adjunct combinations for boneless cured pork that is formulated with different percentages of PSE raw material. RSM combines experimental design and multiple linear regression so that orthogonality and equal spacing exist for the explanatory variables (Myers and Montgomery, 1995). This condition allows for near independence among estimated equation coefficients and good prediction of the responses within the design space.

This research is valuable to the industry since it will provide information pertaining to the usability of PSE pork in high value processed meats, the percentage of PSE meat that can be incorporated into products, variations in functionality among quality classifications, and effects of non-meat adjuncts on PSE meat functionality. This research may reveal processing possibilities that add value to PSE pork raw material and save the industry millions of dollars per year.

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Chapter 2
Literature Review

2.1 Pork Quality

2.1.1 History

The definition of pork quality has evolved dramatically over the years to meet changing consumer demand. In the early 1900's, hogs were bred for high fat content due to the value of lard (McLaren and Schultz, 1992). Selection based on this demand yielded high quality meat that consisted of protein and an abundance of intramuscular fat. This product would be considered too high in lipid content for today's consumer, but the product was rarely ever pale, soft, and exudative (Herter et al., 1914). The animals were less stress susceptible than those bred in the current industry due to their genetic and physical composition. Even though pale, watery meat was first documented in Europe during the early 1900's, there was low prevalence in the industry (Wiseman, 1986). After World War II, consumer demand for pork evolved dramatically to curtail changes occurring in the United States. In the 1950's, lard was no longer needed for cooking and soap due to the invention of new cooking oils and soap products (McLaren and Schultz, 1992). This trend caused emphasis on the production of leaner meat. In the 1970's, consumers desired leaner meat again due to the new found health conscious attitude in the United States. This trend in demand forced the pork industry to produce hogs to grow rapidly into heavy muscled, low-fat animals resulting in high meat yields. But it led to serious quality problems that have plagued the pork industry since the 1950's (Boles et al., 1992).

Kauffman et al. (1992) performed an audit of pork slaughter plants in the U.S. and stated that it is clear that the U.S. has a significant pork quality problem. Antemortem factors, slaughtering practices, and postmortem factors that affect biochemical processes in the carcass were the alleged cause of the quality problem. This condition leads to poor color, water holding capacity, and texture and is termed pale, soft, and exudative (PSE) meat (Briskey, 1964). The extent of these quality problems are evaluated through color, water-holding capacity, pH, and glycolytic potential, and indirectly evaluated through protein and moisture contents (Kauffman et al. 1992). PSE pork is identified by ultimate pH<5.6, CIE L* > 50, and drip loss > 5 %.

2.1.2 Quality Classifications

The National Pork Producer's Council has accepted four quality classifications of pork that are described by muscle color, muscle firmness/wetness, and marbling. Kauffman et al. (1992) reported that fresh pork should be reddish pink, free of fluids, firm to the touch, and have a slight amount of marbling. Bendell and Swatland (1989) have stated that there is no doubt that pork classified as PSE is universally regarded as a meat industry problem. Both meat traders and processors have become aware of how much even mild PSE is costing them. Though, PSE pork is the quality classification that causes an estimated $ 100,000,000/year, the greatest financial loss to the meat industry (Cannon et al., 1996). Dark, firm, and dry (DFD) and red, soft, and exudative (RSE) pork are also classified as poor quality pork. Red, firm, and non-exudative (RFN) is the quality of pork that is ideal in color, water-holding capacity, and texture.

DFD pork is appreciably darker than the ideal, reddish pink color. It is obtained from animals that have been exposed to long-term preslaughter stress (Faustman, 1994). One example where this condition occurs is through penning strange animals together prior to slaughter for periods of time greater than 4 h. The long-term stress causes animals to utilize the majority of their stored glycogen. This inhibits the extent to which anaerobic metabolism can occur (Faustman, 1994), leading to final a final pH in the muscle of more than 6.0. Kauffman and Marsh (1987) report that this pH is considerably above the isoelectric point of myofibrillar proteins, allowing water molecules to tightly bind to these proteins. This structure reflects less light, causing an undesirable, darker color. DFD meat is very juicy due to its high water holding capacity, but increased pH and water holding capacity enhance bacterial spoilage. Kauffman et al. (1992) reported in a survey of U.S. pork plants that there was an abnormally high incidence of DFD pork (10 %) found in their study. Although DFD pork is a significant concern to the industry, it is not nearly as severe as the problem of PSE. This may result since short term stress is much more common than long term stress. DFD pork is classified by the following characteristics; ultimate pH>6.0, CIE L*< 42, drip loss < 5 %.

Recently, a quality classification that is ideal in color but has excessive exudation has been described as red, soft, and exudative (RSE) (Kauffman, et al. 1992; Warner et al., 1993; van Laack et al., 1996; Joo et al, 1995). Kauffman, et al., (1992) indicated that over 60 % of the carcasses he surveyed were identified as RSE, demonstrating the severity of the pork quality problem in the United States. Warner et al. (1997) examined muscle protein changes

postmortem in relation to pork quality traits. These authors concluded that RSE samples have unacceptably high water loss, but muscle protein denaturation was minimal and was not the cause of the low water-holding capacity. This observation demonstrated that color should not be used as the only indicator of water-holding capacity.

There is positive correlation between amount of color and water-holding capacity but not an identified causation. These results infer that there is a more significant problem in the industry with water-holding capacity than color. One possible explanation for the lower water holding capacity could be that pH decline in muscle is not rapid enough to denature a majority of myofibrillar proteins and myoglobin. But, pH decline is rapid enough to alter the sarcomere structure, preventing the myofibril from containing water in its structure. This is similar to the mechanism that Offer and Trinnick (1983) described in which rapid pH decline caused shrinking of the filament lattice in muscle fibers. RSE pork is classified as ultimate pH< 5.6, 43<CIE L*<50, and drip loss % > 5.0.

Red, firm, and non-exudative (RFN) pork is ideal in color, texture, and water-holding capacity. Kauffman et al. (1992) reported that only 16 % of pork surveyed in the audit they conducted was classified as RFN. This demonstrates the severity of the lack of quality pork produced by the industry. RFN pork is most often produced from animals that do not test positive for the halothane gene, do not experience short-term stress, and are not stress susceptible. RFN pork is classified by ultimate pH= 5.6-5.9, 43<CIE L*<50, and drip loss % <5.0.

2.1.3 Glycolytic Potential

Identification of the RN carrier pigs is based on their glycolytic potential (GP = 2 x (glucose + glycogen + glucose-6-phosphate) +lactate). GP greater than 180 to 200 μmol/g of meat indicates animals as RN carriers (Monin and Sellier, 1985; Fernandez et al., 1992). van Laack and Kauffman (1999) demonstrated that glycolytic potentials varied for different quality classifications of pork. These authors reported a mean of 161 micromolar lactate/g of muscle for PSE and 137 and 110 for RSE and RFN pork. Glycolytic potential correlates well with both color and water holding capacity, two of the three attributes defined as important in pork quality. Greater glycolytic potential increases the possibility of RSE and PSE pork (Kauffman and van Laack, 1999). Greater than 180 micromol lactate/g of muscle was utilized as an indicator for

presence of the Halothane, RN gene. Thirty-two percent of the PSE group were RN gene carriers but only 10 % of the RSE group suggested presence of the RN gene. The authors suggested that these results demonstrate that the occurrence of RSE is not related to the presence of the RN gene. Glycolytic potential measured at 1 d postmortem can be used to indicate meat quality. These authors also concluded that poor meat quality is minimal at pH above 5.7 so further studies on determinants of ultimate pH, other than glycogen concentration, are needed. Color, pH decline, ultimate pH, and glycolytic potential are the known determinants of water holding capacity. Studies utilizing all of these factors to explain pork quality through mathematical modeling would be beneficial. However, it is essential for scientists to keep searching for attributes that explain ultimate pH so that it can be increased in pork carcasses, resulting in quality improvement (van Laack and Kauffman, 1999)

2.2 PSE Pork

2.2.1 Color

Young (1996) stated that consumers will not buy a gray, wet product, and that appearance of pork is the most important attribute to the consumer. The poor water holding capacity and pale color of PSE meat lower its value. The lack of water holding capacity yields a product unacceptable in juiciness. Lack of juiciness causes the perception of less tender meat, another undesirable trait.

Pork that is considered pale in color is synonymous with low CIE L* and CIE a* values indicating a light color that is lacking redness. Zhu and Brewer (1998) found that PSE pork is lighter than RFN and DFD, and has lower a* values that decrease more rapidly over time. These scientists indicated that PSE pork was also more yellow than RFN at day 0, but not at storage times from 1 to 7 days. Through sensory and instrumental analysis, these authors concluded that the CIE L* value was the best single instrumental indicator of sensory redness. Brewer and McKeith (1999) reported that purchase intent paralleled overall acceptability. These authors demonstrated that color, wet/dry appearance, and overall acceptability all contributed to purchase intent. Pink PSE samples received high intent to purchase scores as did all DFD samples. These results infer that consumers do not perceive dark pork as poor in quality, and they only perceive very pale PSE pork as poor in quality.

2.2.2 Antemortem Causes

Pork quality is a direct result of antemortem and postmortem factors that occur during the production of meat as food (Topel et al., 1975; Chea et al., 1984). Genetics and short-term stress affect the rate that biochemical processes occur in the muscles of hog carcasses after slaughter (Solomon et al., 1998), determining pork quality. The genetic causes of PSE pork can be attributed to two factors. Homozygous recessive for halothane gene causes a single frame mutation in hogs (O'Brien, 1986). This single frame mutation substitutes a cysteine for an arginine in each ryanodine receptor in muscle cells (Fuji et al., 1991). The substitution prevents the ryanodine receptor from regulating the influx of calcium that is sequestered from the sarcoplasmic reticulum by the sarcomere during muscle contraction. Since the muscle cell cannot regulate calcium influx through the ryanodine receptor, the animal is unable to control muscle contraction. This mutation causes susceptibility to stress and is termed Porcine Stress syndrome (PSS) (Briskey, 1964).

Some animals affected by PSS never reach slaughter age due to the susceptibility to stress on their body caused by this condition. Other animals reach slaughter age, but yield poor quality meat due to their increased stress susceptibility. Hogs that are heterozygous dominant for the Halothane (Napole or RN) gene yield increased PSE meat when compared to animals that are homozygous dominant for the gene (Christian, 1995; Velarde et al., 2001), but yield less PSE meat then homozygous recessive. McLaren and Schultz (1992) argue that heterozygous dominant animals should be produced because they have been shown to have a 0.4 % higher dressing percentage and increase loin eye area by 1.9 cm^2. Christian (1995) disagrees and suggested that homozygous dominant animals should be used for meat production since the muscle is not as pale and has superior water holding capacity.

2.2.3 Structural Irregularities

PSS evokes a high incidence of PSE meat, and eliminating the homozygous recessive expression of this gene from the breed stock reduces incidence of PSE pork (Solomon et al., 1988; Sosnicki, 1995). Eliminating the gene expression cannot eradicate it completely due to another genetic factor affecting quality (Solomon et al., 1998). The second factor contributing to the production of PSE pork is genetic selection for rapid lean muscle growth in animals (Solomon et al., 1998). Animals achieve rapid muscle growth for six months prior to slaughter,

leading to structural irregularities that enhance stress susceptibility (Swatland, 1989; Swatland, 1990; Solomon et al., 1998).

One structural irregularity that occurs is immature connective tissue proteins that cannot support the rapid growth of muscle fibers (Swatland, 1990). Another structural irregularity results from a greater proportion of white muscle fibers in the animal than optimum for the allowance of aerobic metabolism (Bandman, 1985; Maruyama and Kanemaki, 1991). β red muscle fibers contain large quantities of myoglobin, high amounts of large mitochondria, and exhibit many other characteristics optimizing oxidative metabolism (Peter et al., 1972). α white muscle fibers contain low amounts of myoglobin, large amounts of glycogen, are much larger than red muscle fibers, and function predominantly through glycolysis (Peter et al., 1972). A third classification of muscle fibers is α red muscle fibers that function through both oxidative metabolism and glycolysis.

All muscles consist of combinations of β red, α red, and α white muscle fibers (Gauthier, 1987), but pigs that contain high amounts of "giant" or normal size white muscle fibers in their muscles become stressed easily due to inefficiency in removing lactate (Cassens et al., 1969; Cooper et al., 1969; Dutson, et al., 1982). In comparison, pigs with a lower concentration of "giant" white muscle fibers do not become stressed as easily due to efficiency in removing lactate. Handel and Strickland (1986) reported that difference in stress susceptibilities occur through increased activity stimulated in occasional muscle fibers. These researchers also reported that increased activity could be caused by a structural defect such as an inadequate amount of sarcoplasmic reticulum in the muscle fiber. In addition, Kauffman and Marsh (1987) have reported that *longissimus, gluteus medius, and semimembranosus* muscles are much more likely to become PSE than those that are predominantly red-fibered due to their high proportion of white muscle fibers.

2.2.4 Environmental Factors

Environmental conditions that pigs are exposed to influence pork quality. Nutrition, feed withdrawal, heat stress, transportation, movement, utilization of hot shots, stunning, as well as other factors contribute to the quality of pork. Nutritionally, utilization of tryptophan, vitamin E, creatine monohydrate, and magnesium aspartate have demonstrated potential quality improvements. Feeding tryptophan and creatine monohydrate to pigs weeks prior to slaughter

demonstrated decreased incidence of PSE meat production. Tryptophan is an essential amino acid, and its deficiency in the diet leads to increased stress susceptibility (Henry et al., 1992). Creatine monohydrate helps provide the muscles with creatine phosphate, a high-energy source inherent in muscle. Creatine phosphate assists in preventing rapid build up of lactic acid prior to slaughter (Berg et al., 2000), decreasing production of PSE meat. This is similar to how creatine phosphate supplementation assists people during intense physical exercise.

Cheah et al. (1995) and Kerth et al. (2001) demonstrated the ability of Vitamin E to improve meat quality through its ability to stabilize membranes. Increased membrane integrity was reported in isolated mitochondria partially due to Vitamin E inhibiting phospholipase A_2 activity. Dietary Magnesium aspartame supplementation increases plasma magnesium levels, causes lower norepinephrine concentrations, and lower glycogen concentrations (D'Souza et al., 1998.). These factors improve meat quality through reducing the incidence of PSE pork.

Eikelenboom et al. (1991) reported that a fasting period with access to water for 24 h prior to slaughter caused increased ultimate pH in loins and hams. Their results demonstrated that fasting 16-24 h is sufficient in reducing incidence of PSE meat, but also showed an increase in Dark, Firm, and Dry (DFD) meat. This observation suggests the potential for improvement of pork quality through the reduction of PSE pork, but Jones et al. (1985) reported that fasting time should be minimized to avoid losses in carcass weights. Pork producers would tend to agree with Jones et al. (1985) since losses in weight in live animals reduce their value. It has also been demonstrated by Park et al. (1985) that PSE incidence increased with elevated slaughter weight. These results provide no incentive for producers to fast or produce lower weight hogs since both incur decreased profits.

Forrest et al. (1963) and Dalrymple and Kelly (1969) were the first researchers to report that a higher incidence of low quality pork was produced during hot seasons. These researchers discovered that large temperature fluctuations during spring and fall increased the production of pale pork. Park et al. (1985) performed an observational study demonstrating a 22.0 % incidence of PSE in January and 48.7 % in September. Park et al. (1985) and Nishio (1976) both reported that summer and winter had the highest and lowest incidence of PSE pork, respectively. Their results infer that hot temperatures cause high stress for pigs. Nishio (1976) surveyed variation in PSE incidence during different seasons and reported 34.2, 46.0, 41.3, and 26.4 percent incidence for spring, summer, fall, and winter.

Galloway et al. (1973) demonstrated that lactic acid accumulation occurred more rapidly in the Poland China breed than Chester Whites inferring that Poland China animals were affected more by heat stress than Chester White animals. Their results suggest that pigs with slow glycolyzing muscles are more resistant to heat stress than those with fast glycolyzing muscles. Results also infer that breeds such as Hampshires that are naturally heavy muscled yield a lower percentage of quality meat.

The journey of pigs prior to slaughter can induce short-term stress that negatively affects pork quality. Mixing animals from different pens during collection, transport, and holding areas prior to slaughter all increase stress for the animal, increasing the probability of that animal yielding poor quality meat (Karlsson and Lundstrom, 1992). Other stressful conditions such as making hogs walk downhill prior to slaughter, use of electricity by hot shots or other means to move the pigs all cause stress and should be avoided. Fortin (1989) revealed that trucking the pigs for more than 1 h caused stress on the animals. Guise and Warriss (1989) stated that each pig must have enough room on the truck to lay down or stress can result. Grandin (1994) recommends 2-4 h rest upon arrival for hogs prior to slaughter to reduce the incidence of PSE. All actions that could cause short-term stress prior to slaughter increases incidence of PSE, and combinations of these stresses increase both incidence and severity. Honkavaara (1989) reported that 15-18 ^{o} C, 59-65 % Relative Humidity, and 3-5 h of holding time are optimum conditions for the production of pork, resulting in decreased PSE incidence and increased ultimate pH. Owen et al. (2001) reported that hogs should be rested between 1-2 h for optimum quality. These authors also stated that hot-fat trimming also improves muscle quality since it causes rapid carcass chilling.

During slaughter, certain procedures affect meat quality (Lee and Choi, 1999), first of which is stunning. Electrical stunning is the most widely used form in the U.S. It renders the animal insensible quickly if levels of at least 1.25 amps pass through the brain (Troeger and Waltersdorf, 1990). This stunning method is more effective than captive bolt stunning because it renders the animal senseless more quickly, decreasing stress. CO_2 Stunning has been shown to reduce stress in Denmark if it is performed in a way that multiple pigs are stunned simultaneously. Keeping the pigs together during stunning reduces strain since stress increases due to separation from other hogs. Velarde et al. (2001) also demonstrated decreased PSE incidence when comparing CO_2 to electrical stunning. After stunning and bleeding, scalding and

dehairing are performed. Scalding includes placing the animal in a vat filled with hot water (140-142 ^{o} F). The hot water loosens hair from the animal but causes acceleration of anaerobic glycolysis, leading to increased lactic acid formation (Carr, 1985). Skinning hogs decreases incidence of PSE meat but is impractical in large slaughter facilities due to time constraints. Dehairing impacts physical stress on the sacrificed animal and increases the rate of glycolysis causing protein denaturation, resulting in low quality pork (Troeger and Woltersdorf, 1987).

2.2.5 Postmortem Effects

Pork quality is affected by antemortem factors, and postmortem factors that occur between the time slaughter takes place and energy is depleted in the muscle. Storage temperature of carcasses post-slaughter affects the rate of biochemical reactions in the muscles. In the live animal, the pH of the muscle is buffered near 7.0, by blood carrying oxygen, ATP, and waste in and out of the muscle. After slaughter, bleeding the animal cuts off the oxygen supply to muscles, resulting in the depletion of residual energy present at the time of slaughter. The rate and extent of energy depletion determines meat quality. Rapid glycolysis, and hence energy depletion results in protein denaturation caused by the creation of an acidic environment when the carcass temperature has not cooled sufficiently.

Water and proteins are the first and second largest constituents of raw meat, respectively. Protein structures are responsible for containing water in the myofibrillar structure and binding water outside of the sarcomere. Denaturation and shrinkage of myofibrillar proteins devastate the meat system through reduction of water holding capacity, causing an undesirable soft texture. Denaturation causes lack of myofibrillar protein solubility (Joo et al., 1999), indicating poor functionality. Since 1960, the critical value for pH that will cause protein denaturation, leading to PSE meat production is below 6.0 at 45 min post-slaughter (Bendell et al., 1966). Battle et al. (2000) reported that early postmortem detection of exudative pork can be achieved based on nucleotide content. These authors demonstrated that at 2 h postmortem, PSE meat was characterized by significantly lower amounts of ATP and significantly higher amounts of adenosine monophosphate and inosine monophosphate when compared to normal pork. Dransfield (1993) reported that the rapid decline in pH of carcasses that exhibit the PSE condition inhibit calpain activity. Calpain I is important in tenderization of meat (Dransfield, 1992), and the lack of its activity causes PSE meat to be less tender than RFN meat.

The sarcoplasmic protein, myoglobin is also affected by acidic, high temperature conditions. Myoglobin is either denatured itself, or adsorbed onto other denatured, myofibrillar proteins (Kauffman and Marsh, 1987). The latter theory proposes that denatured myofibrillar proteins conceal myoglobin, resulting in an extremely pale and unpleasant appearance. The acid conditions also hasten oxidation of the pigments causing the color to be paler in the semi-opaque background of the denatured proteins (Fox, 1987). Joo et al. (1999) reported that sarcoplasmic protein solubility for PSE meat is lower than that of other quality classifications and that 71 % of the variation of lightness can be explained by sarcoplasmic protein solubility.

Pork packing facilities have options for chilling carcasses to refrigeration temperature depending on what quality problems they perceive as the least detrimental. Rapid chilling slows down postmortem glycolysis, inhibiting production of PSE meat (Borchert and Briskey, 1964; Woltersdorf and Troeger, 1988; Long and Tarrant, 1990; Gundlach et al., 1992; Kerth et al., 2001). But rapid chilling also causes cold shortening, a problem that has been seen traditionally in red meats (beef and lamb). When warm muscles, containing high amounts of ATP are exposed to cold temperature and declining pH, the sarcoplasmic reticulum is unable to sequester again and bind the excess of previously released Ca^{2+}. The presence of calcium in the intracellular spaces causes myosin and actin to bind together which leads to sarcomere shortening, resulting in less tender meat (Cornforth et al., 1980). Commercial slaughter plants presently operate post-slaughter chilling within two extreme cases. These extremes consist of rapid or slow chilling after slaughter. Both options possess positive and negative attributes. Rapid chilling decreases production of PSE, but it causes sarcomere shortening, resulting in less tender meat. Moderate chilling rate yields a larger incidence of PSE meat, but also yields a product that is more acceptable in tenderness than slow chilling. An option presently utilized is to chill the carcasses rapidly, and inject the pork with water and phosphate solution after fabrication. The fast chilling decreases the incidence of PSE and the phosphate tenderizes the meat, resulting in the optimum quality possible (Brewer, et al., 1999).

Kauffman et al. (1998) utilized sodium bicarbonate injection to prevent PSE in halothane-sensitive positive pigs through retarding the rate or extent of postmortem pH decline in order to decrease drip loss and lightness. The bicarbonate anion functions as a buffer by increasing pH so that acid conditions are unable to result in the muscle within 45 min of slaughter, thus preventing protein denaturation. These authors concluded that injecting sodium

bicarbonate at 15 min after slaughter does prevent PSE pork. This process appears to be feasible, but it includes some drawbacks. Increased pH results in lower shelf life. Sodium content in the meat is increased (Kauffman et al., 1998), and excess sodium bicarbonate may cause a soapy taste (Lindsay, 1995).

Antemortem and postmortem factors that have been explored demonstrate that much science is known about the causes of pork quality. This vast knowledge provides many options that can be executed to reduce the PSE pork problem. This knowledge must be implemented into practical solutions so that the industry can utilize it to prevent PSE pork.

2.2.6 Implications and Utilization of PSE

Cannon et al. (1996) and Carr et al. (1997) reported that PSE and RSE pork production results in an approximately $100 million in annual losses for the pork industry. Kauffman et al. (1992) concluded that PSE pork is undesirable due to its appearance, shrinkage caused by drip loss, and lack of functionality in processed products. Their survey also indicated that 16 % of pork produced was ideal in quality (N= 10,753). This low percentage of ideal pork demonstrates that proactive steps must be implemented to improve pork quality. Kauffman et al. (1992) discussed four recommendations on how the U.S. pork industry could minimize quality variations. First, guidelines need to be established to insure acceptable production, management, and welfare procedures at all times. Second, more attention needs to be stressed towards already mentioned post-slaughter processing steps that will minimize quality variations. Third, color, water-holding capacity, ultimate pH, and marbling content should be recorded for each carcass. This information should be included in every packer report so appropriate steps can be taken to improve breeding stock. Lastly, pricing differentials should exist for variations in quality so producers are rewarded for producing hogs that will yield quality pork. These four recommendations would improve pork quality but implementation may not be practical due to the mindset of industry. Cassens (2000) reported that there is scientific understanding and tools available to attack the problem of PSE pork, but solving the problem may require further impetus-such as strong and unified resolution by producers, industry associations, and governmental agencies. Though these options exist, the utilization problem of existing PSE pork must be addressed.

Presently, PSE pork has little consumer appeal and is normally incorporated into sausage manufacture. Li and Wick (2001) studied the effects of incorporating PSE meat and mechanically deboned turkey meat (MDTM) into a value added pork sausage product. These researchers were able to improve cooking yields and firmness, inferring that mixing PSE pork with MDTM has the potential to add economic value to both of these low value raw materials. Torley et al. (2000) reported similarly that high ionic strength and utilization of polyphosphates in an emulsion product formulated with PSE pork improves cooking yield so that it is similar to that of product made from RFN pork. But they also reported that texture was still undesirable due to lack of cohesiveness. Utilization in sausage is acceptable for low value cuts, but the *semimembranosus* and *longissimus* muscles are too valuable to be utilized in sausage production. A current challenge exists to add value to PSE pork obtained from these two muscles. One possible approach is through investigating the possibility of PSE pork utilization in the production of chunked and formed products. To increase the viability of this technique, color, water-holding capacity, bind, texture, and sensory attributes need to be improved from the raw material to the finished product. Deli hams formulated from chunked or sectioned and formed processes yield an increase in value of $3-$5 per pound, but sausage products where PSE meat is incorporated yield much less value. Differences in biochemical and physical properties between RFN and PSE pork make it risky to utilize PSE meat in processed products. Lack of functionality in myosin makes it impossible to formulate processed products formulated with 100 % PSE pork (Motzer et al., 1998; Schilling et al., 2001). PSE meat from the *longissimus* muscle is either sold as fresh meat, canadian bacon, or is relegated to sausage manufacture. Utilizing this raw material as fresh meat or canadian bacon yields poor quality product, discouraging consumers from purchasing pork. The only feasible alternative is to sell it in a sausage product, but this greatly lowers the value of the raw material. The *semimembranosus* muscle is from the wholesale cut termed ham, in which 75 % is processed in some way. It is usually made into boneless deli ham (sectioned and formed or chunked and formed), or whole cured ham. PSE meat utilized in deli hams yield poor quality products due to lower water holding capacity, poor cohesiveness, and a lighter and less red color (Solomon et al., 1998). Whole cured hams also demonstrate low water holding capacity and an undesirable color.

Motzer et al. (1998) investigated the effects of PSE utilization and non-meat adjuncts on the protein functionality of restructured pork. These authors demonstrated that modified food

starch and carageenans improved functionality of PSE pork and that products consisting of 50 % PSE pork yielded better quality pork than 100 % PSE treatments. These results suggest that research should be performed testing two hypotheses. First, effects of adjuncts such as modified food starch, soy proteins, sodium caseinate, whey proteins, carageenans and collagen on protein functionality of restructured hams must be explored. Second, percentage of PSE meat that can be incorporated into products without negatively affecting protein functionality needs to be evaluated. This information would be invaluable in explaining possibilities to increase the value of PSE meat.

2.3 Protein functionality

2.3.1 Protein Properties in Processed Meats

Fukawaza et al. (1961a) established that proteins are largely responsible for the functionality characteristics of muscle foods. According to Xiong and Kenney (1999), protein functionality is any inherent or process-generated property of proteins that affects physical and sensory characteristics of raw and finished products. Functionality of meat proteins has been shown to determine the properties of further processed products, including restructured meats (Schmidt, 1981). In processed meat products, the ability of muscle pieces to form a protein matrix at their surface, bind fat, and retain natural and added water are some of the most important functional properties (Xiong and Kenney, 1999). These authors stated that these properties influence product texture, integrity, physical stability, cooking yield, appearance, and hence palatability and consumer acceptability. Similarly, Samejima et al. (1985) reported that water-holding and binding properties are the important factors that determine the quality of comminuted meat products. Schmidt (1987) defined binding strength as the force per unit cross-sectional area required to pull apart bound pieces of meat. It includes a measure of both the cohesive force exerted between the binding matrix and the meat pieces and the strength of the binding matrix itself. Ashgar et al. (1985) stated that the consensus for the mechanism of gelation is that polypeptide chains cross-link to form five to six crystalline regions per molecule during gelation. Other molecules can move in between these links or strands, and they account for the flexibility of the gel.

Proteins within the muscle are generally classified into three groups: myofibrillar, sarcoplasmic, and stromal (Acton et al., 1983). Myofibrillar proteins constitute between 50 to 55 % of the total protein content, while the sarcoplasmic proteins account for approximately 30 to 34 % of the total protein. Gordon and Barbut (1992) conducted a study that indicated that the gel forming ability of the myofibrillar proteins was a major factor in stabilizing the fat in a comminuted product. Rust (1987) reported that myofibrillar proteins serve two functions in comminuted products: (1) to encapsulate or emulsify fat and (2) to bind water. Sufficient myofibrillar proteins are necessary in the comminuted product so that both of its functions are served. If all of the protein is used in emulsification, the water binding of the final product is low (Rust, 1987). Myosin in prerigor muscle and actomyosin in postrigor muscle are the principal myofibrillar proteins and are important in protein functionality (Acton et al., 1983). MacFarlane et al. (1977) expands this definition to myosin or actomyosin being the most important myofibrillar protein responsible for water holding capacity and binding of meat pieces. Myoglobin, a sarcoplasmic protein is functionally responsible for the color of fresh and cured meats (Acton et al., 1983).

Schmidt (1981) stated that information in the literature demonstrates that the mechanism of binding in sectioned and formed meats depends on similar protein functionality to that of emulsion type sausages. Kotter and Fischer (1975) described emulsion product as systems consisting of one or a combination of genuine solution, gel solution, suspension, or emulsion. Emulsions are not formed in whole muscle and coarsely comminuted restructured products, but myofibrillar proteins are responsible for water and protein binding, and the separation of fat from water in the product. The cured color reaction that occurs with myoglobin in emulsion type sausages occurs in restructured products.

2.3.2 Myosin and Actomyosin

Fukawaza et al. (1961a and 1961b) studied the effects of myofibrillar proteins on binding in sausage. These results were the first to demonstrate that myofibrils without Myosin A had less binding strength than myofibrils with Myosin A. These were the first results that deemed myosin as the most important protein responsible for binding strength in further processed products. MacFarlane et al. (1977) compared myosin, actomyosin, and sarcoplasmic proteins as binding agents in restructured beef. It was determined that the binding strength of myosin was

superior to that of actomyosin in salt solutions up to 1 M. The binding strength of sarcoplasmic proteins was too low to be measured. These results inferred that prerigor muscle has more protein functionality in the production of further processed products than postrigor muscle. Gordon and Barbut (1992) stated that myosin appears to act as an emulsifier even in its native state and formed a film of defined viscoelastic and mechanical properties at the oil-water interface. Yasui et al. (1980) studied the heat-induced gelation of myosin in the presence of actin. It was determined that a specific myosin to actin ratio was essential in developing a stronger gel than formed by myosin alone. The maximum strength was observed at a myosin:actin ratio (filamentous) of 2.7 which corresponds to the weight ratio of myosin to actin of 15.

Seigel and Schmidt (1979a) stated that myosin and actomyosin are the most important myofibrillar proteins in developing binding properties in sectioned and formed products. They demonstrated that when proportion of myosin went up with all other extracting conditions stayed the same, protein-protein bind improved. The heavy chain core of the myosin molecule plays an important role in the heat induced binding of myosin (Seigel and Schmidt, 1979b), demonstrating utilization of myofibrillar proteins derived from the chunks or pieces of meat themselves during product formation (Pearson and Gillett, 1996).

2.3.3 Myoglobin

Myoglobin is responsible for 50 - 80 % of meat pigmentation, depending on the muscle (Fox, 1987). In fresh meat, the iron atom's 6th binding site on the porphyrin ring determines meat color. The iron atom at the center of the porphyrin ring can either exist in a reduced state, Fe^{2+} or an oxidized state, Fe^{3+}. Deoxymyoglobin exhibits a purple color in the reduced state. Oxymyoglobin is a bright cherry red color in the reduced state, and metmyoglobin causes a brown color and is in the oxidized state. Meat below the surface exists as deoxymyoglobin since it has not been exposed to oxygen. Metmyoglobin forms either in relatively low partial pressures of oxygen or when meat has been exposed to oxygen for long periods of time and is beginning to spoil.

Myoglobin is also responsible for color formation in cured meats. The porphyrin rings containing Fe in the myoglobin molecules react with nitric oxide (NO) at the 6th position to form Nitric Oxide Myoglobin. The reaction occurs through the utilization of sodium nitrate ($NaNO_3$)

or sodium nitrite (NaNO$_2$), adjuncts dissolved in the brine solution when curing a product. Both chemicals are highly soluble in water. Sodium nitrate is utilized when one wants to slowly cure a product such as in country hams, pepperoni, or salami. Sodium nitrite is utilized when one desires cured color to form more quickly as in frankfurters, injected whole hams, or deli meats. Sodium erythorbate or an ascorbate must be added to provide an electron source that functions as a reductant in the reaction forming nitric oxide from nitrite (Claus et al., 1994). This adjunct is necessary since nitrite is a strong oxidizer and cannot be reduced without the assistance of a cure color accelerator. Nitrous acid is one of many intermediates that can form in the cured color reaction that permits the reduction to occur that causes the formation of nitric oxide (Fox, 1987; Aberle et al., 2001). Nitric oxide is a volatile gas that forms an unstable compound by binding with myoglobin to form nitric oxide myoglobin. Nitric oxide myoglobin is stabilized into nitrosylhemochrome when the meat product is heated. Nitrosylhemochrome is a desirable pink pigment that prevents warmed over flavor, extends shelf-life, inhibits *Clostridium botulinum* growth, and provides desirable flavor (Aberle et al., 2001). Nitrite is limited to 156 ppm in comminuted or sectioned and formed products and 120 ppm in bacon since residual nitrite forms nitrosamines, a carcinogenic substance when heated in a meat product (Claus et al., 1994).

2.3.4 Restructured Meats

Mandigo (1974) stated that restructuring pork may increase quality resulting in increased consumption. This is due to lack of portion control, inconsistent quality, and lack of shelf life in raw pork products. All of these attributes can be achieved through restructuring. Restructured meat products include sectioning and forming, flaking and forming, chunking and forming, and tearing and forming (Pearson and Gillett, 1996). The first three procedures listed are widely used in industry with sectioning and forming being the largest category in both volume and value (Pearson and Gillett, 1996). Sectioning and forming most resembles intact muscles, while chunking and forming and flaking and forming are advantageous in that they have large surface areas to work with. The protein functionality characteristics of restructured meats are all very similar. Most research on restructured meats has been performed on sectioned and formed meats, but the findings usually display trends that are evident in chunked and formed and flaked and formed products.

2.3.5 Sectioned and Formed Meats

Sectioned and formed meats are intact muscles or sections of muscles that are bonded together to form a single piece (Pearson and Gillett, 1996). Binding does not occur in raw meat. Meat only demonstrates binding ability during heating, which facilitates gelation of myofibrillar proteins at the muscle surfaces (Schnell et al., 1970; Vadhera and Baker, 1970). Binding is affected by water holding capacity, cell disruption, meat surface area, meat quality, and the releasing of intracellular material prior to heating. Utilization of an alkaline phosphate and NaCl during tumbling releases the intracellular, salt-soluble proteins to the meat surface (Theno et al., 1978). Woolen (1971) stated that these proteins become tacky when extracted, and then interact and coagulate together during the application of heat, causing binding together of the meat pieces through gelation.

2.3.6 Tumbling and Massaging

Tumblers were the first type of equipment specifically designed to produce sectioned and formed meat products (Pearson and Gillett, 1996). Tumbling generally refers to placing meat in a stainless steel drum containing inside baffles (Schmidt, 1981). Tumblers accelerate the extraction of meat proteins through two mechanisms. First, when meat pieces are tumbled with salt and phosphate, the agitation caused by the tumbler breaks up the meat pieces allowing for increased extraction of proteins, increased water-holding capacity, and tenderization (Rejt, et al., 1978). When meat formulations are tumbled under vacuum conditions, the meat pieces expand allowing for increased protein extraction and improved mixing of adjuncts that improves protein-protein bind. Other advantages of tumbling are creation of products with uniform shape, weight, sliceability, portion control, decreased cooking losses, use of variety of cuts, and uniformity of color (Schmidt, 1981). Pearson and Gillett (1996) stated that tumbling intermittently for times of 10 to 30 min has demonstrated improved protein functionality. This is due to the meat pieces ability to absorb the brine more effectively when the tumbler is not moving, and the ability of the tumbler to break open the surfaces of the meat when the tumbler is in motion. Krause et al. (1978) determined that tumbling significantly improved external appearance, sliceability, taste, aroma, and yield.

Massagers were designed to mimic mixers utilized for emulsion type products. Larger pieces of meat cannot be manipulated with a mixer, so massagers were developed for this

purpose. Massaging functions in a similar manner to tumbling, but it is a less severe treatment, which leaves the meat surface more intact. This can be undesirable if the batch is not properly manipulated, resulting in insufficient cure distribution, lower cooking yields, and decreased bind. Research demonstrates that this will not occur if proper schedules are used (Theno et al, 1978). Gillett et al. (1981) reported that hams that were massaged and pumped to 30 % above boneless green weight improved bind, color uniformity, color intensity, and moisture retention when compared to samples pumped to 30 % that had not been massaged.

2.3.7 Protein-Protein Bind Measurements

Methods to measure binding strength of restructured products include utilizing a trained sensory panel (Acton, 1972a, b), breaking force of meat rolls (Pepper and Schmidt, 1975), breaking force of slices (Siegel et al., 1978b; Field et al., 1984), and tensile strength between two meat particles (MacFarlane et al., 1977) . In the sensory study, eight panelists were selected from a group of 14 based on their abilities to evaluate binding ability. The above instrumental methods measure maximum peak force to describe binding ability, with increasing maximum peak force representing increasing binding ability.

2.4 Other Factors Affecting Protein Functionality

Gillett at al. (1977) studied the parameters affecting meat protein extraction effects on meat emulsion formation. An increase in NaCl concentrations and mixing time was responsible for greater salt soluble protein extraction. These authors also concluded that salt soluble protein from fresh, uncooked frozen meat sources was highly correlated with emulsifying ability. Also, freezing lowered the emulsifying ability of the meat. The maximum protein extraction signifying the greatest emulsifying ability occurred at 7.2 C. Xiong and Blanchard (1993) studied the effects on viscoelastic properties of gels when polysaccharide gums (xanthan gum and alginates) are combined with salt soluble proteins (SSP). Using chicken breasts, both xanthan gum and alginates hindered the gelation of SSP. Using 0.6 M NaCl, pH around 6.0, a typical ionic environment for meat processing, sodium alginate and xanthan gum at 0.5 to 2.0 % decreased gel strength (gel rupture force). These gums had no effect on water binding.

2.4.1 Salt

Salt is the most common nonmeat adjunct added to further processed products. It contributes flavor, preserves the product, and solubilizes myofibrillar proteins (Rust, 1987). It is the only ingredient necessary for curing, and it acts by dehydration and altering of the osmotic pressure to inhibit bacterial growth and subsequent spoilage (Pearson and Gillett, 1996). The ability of salt to solubilize the myofibrillar proteins is of vital importance to the successful manufacture of further processed products (Rust, 1987). Salt solubilizes myofibrillar proteins by increasing the electrostatic repulsion between the filaments, and it alleviates some of the structural constraints of myofibrillar proteins. Barbut and Findley (1991) tested the effects of using different salts in the stabilization of meat batters. Results suggested that Mg^{2+} ions destabilized the batter mainly by causing extensive precooking protein matrix aggregation and poor fat stabilization because of insufficient protein film formation. In this study, calcium ions destabilized batters by causing widespread protein aggregation during cooking, which led to extensive fat and water losses. However, the use of NaCl and KCl to form stable meat batters was successful because they are monovalent cations. KCl is not readily used in further processed products because it causes an astringent taste in the product (Claus et al., 1994; Hand et al., 1982).

NaCl is a crucial component in the formulation of restructured products. Moore et al. (1976) showed that 1 % salt treatments in beef rolls demonstrated 79 % cook yield, but the 3 % salt treatment showed yields of 93 % due to increased salt-soluble protein extraction. These results are similar to those of Theno et al. (1978) who demonstrated that binding junctions exhibited good binding when greater than 2 % salt was utilized in the presence of 0.5 % alkaline phosphate. Salts function by causing myofibrillar proteins to unfold and release to the surface through the electrostatic repulsion of the Cl^- ions and the solubilizaton of the proteins in the water and salt solution (Rust, 1987).

2.4.2 Phosphates

Alkaline phosphates are utilized in brine solutions at no more than 0.5 % of the finished product weight for the purpose of increasing water-binding capacity. Phosphates improve water retention through increasing the pH further away from its isoelectric point and by causing an unfolding of muscle proteins, making more sites available for water binding (Pearson and Gillett,

1996). Wong (1989) demonstrated that preventing actomyosin from disassociating through increasing ionic strength and complexing with protein-bound magnesium and calcium expose more binding sites for hydration. Barbut et al. (1989) state that in addition to increased water holding capacity, phosphates also influence color, coagulation, and emulsification as well as protect against microbial growth and oxidation. Seigel et al. (1978) concluded that phosphate exerts its greatest affect on myosin, actin, and actomyosin. Its action occurs predominantly on the surface before massaging or tumbling occurs.

The most common phosphates that are utilized in brine solutions are sodium tripolyphosphates, sodium pyrophosphate and sodium hexametaphosphate. Sodium pyrophosphates and diphosphates work best in emulsion products because phosphates are only active in the diphosphate form and sodium pyrophosphate is most easily hydrolyzed into that form (Pearson and Gillett, 1996). Mixtures of tripolyphosphates and sodium hexametaphosphate are utilized in curing brines for restructured and whole muscle products. They are dissolved in water, incorporated into hams and bacons, and are slowly hydrolyzed to diphosphate. This delays their activity and allows for use in slower curing processes (Pearson and Gillett, 1996). Sodium hexametaphosphate is utilized in bacon where it reduces formation of nitrosamines during frying (Gray et al., 1982). Blends of phosphates are generally utilized in processed meat products because they have demonstrated increased functionality, and one phosphate in the blend can counteract negative effects of other phosphates.

Tetrasodium pyrophosphate allows for the greatest bind in emulsion products, but it is highly caustic at pH 11 and produces soap in the presence of any fat. For this reason, it should never be utilized outside of a blend (Pearson and Gillett, 1996). Sodium acid pyrophosphate should also never be used outside of a blend since its acid nature causes poor water binding and leads to a green off-color caused by rapid-curing. Blends should be alkaline in nature, capable of being hydrolyzed to form diphosphate, and product dependent based on length of the curing process. Desirable properties for blends include proper alkaline pH, good solubility, calcium compatibility, and a high degree of protein modifier effect (Townsend and Olson, 1987).

2.4.3 Nitrite

Nitrate was first utilized in cured meats by accident as an impurity in saltpeter (Townsend and Olson, 1987). Nitrate was the form that was originally used in curing but it is seldom used

today because of slow reactivity. Nitrate has since been replaced with nitrite due to Polenske's (1891) discovery that nitrate is the source of nitrite. Hoagland (1908) and Kerr et al. (1926) demonstrated that nitrate was converted to nitrite by microbial action in the meat. The functions of nitrite include stabilization of color, contribution to characteristic flavor of cured meat, inhibition of food poisoning and spoilage microorganisms, and to retard development of rancidity (Pearson and Gillett, 1996). Nitrite is reduced to nitric oxide and reacts with the myoglobin in the meat, stabilizing color. This mechanism was described in the section pertaining to myoglobin in the Protein functionality in Processed Meats section. Not all factors that lead to the inhibition of *Clostridium botulinum* are known, but Duncan and Foster (1968) and Johnston et al. 1969 have shown that nitrite does not prevent the true spore germination process. It inhibits the growth and division of cells. Attempts to identify specific constituents responsible for cured flavor has not been successful, but nitrite is clearly related to flavor as first demonstrated by Brooks et al. (1940). Nitrite acts as an antioxidant in the curing process by immobilizing iron in the nitrosylhemochrome complex, preventing iron from catalyzing the oxidation of unsaturated fatty acids (Aberle et al., 2001). Oxidation of unsaturated fats is responsible for undesirable warmed-over flavor, a characteristic that is prevented through utilization of nitrite.

2.4.4 Muscle Fiber Type

Xiong and Brekke (1991) determined that fast twitch (legs) and slow twitch (breast) myofibrils in chicken muscle are affected differently by rigor state, pH, and heating properties. Muscle fiber type affected protein extractability and gelation properties of myofibrils. Postrigor breast myofibrils demonstrated greater protein extractability and gel strength than prerigor breast myofibrils, but the reverse was found for leg myofibrils. Optimum pH for gelation of chicken breast and leg myofibrils were 6.00 and 5.50, respectively. In comparison, a pH value of 6.0 is considered optimal for gelation in pork and beef species (Yasui et al., 1980). Heating at 1° C /min produced a stronger gel with chicken breast myofibrils than isothermal heating at 70° C (Xiong and Brekke, 1991). The reverse was true in leg myofibrils. It was concluded that muscle rigor state had more effect on protein extractability and gel strength for breast myofibrils than leg myofibrils. Similarly, using rabbit skeletal muscle, Boyer et al. (1996) studied differences in heat-induced gelation of myofibrillar proteins and myosin from fast and slow-

twitch rabbit muscles. Proteins from slow-twitch muscle exhibited higher thermostability and lower gel strength than proteins from fast twitch muscle. Slow twitch myosin's gelling ability decreased in the absence of actin, but fast twitch myosin's gelling ability increased in its presence.

Samejima et al. (1992) studied effects of the postmortem aging period on the extractability of myofibrillar proteins from pork cardiac and rabbit skeletal muscles. Results indicated that pork cardiac myofibrils always exhibited lower solubility than those from rabbit skeletal muscles under identical conditions of pH, ionic strength, and temperature. Under these same conditions, cardiac myofibrils formed much weaker heat-induced gels than those produced by skeletal myofibrils. Myofibrils from 0 and 7 days postmortem muscles formed more rigid gels than those isolated from 3 days postmortem for both cardiac and skeletal muscles. Differences in cardiac and skeletal muscle gel formation is due to muscle fiber type. Cardiac muscle consists of red muscle fibers with poor functionality, and has only two forms of myosin to encapsulate fat. Skeletal muscle has three variations of myosin.

2.4.5 pH

Schmidt (1987) stated that protein extractability increases with pH elevation from 5.5 to 6.0, with 6.0 being the optimum (Yasui et al., 1980; Ishioroshi et al., 1979). Use of phosphates in meat batters increases pH to enhance protein extractability and to offset the decrease in pH caused by NaCl (Schmidt, 1987). Samejima et al. (1985) conducted a study to predict binding in comminuted meat products by characterizing myofibrils (beef) properties with respect to gel formation and protein extractability. Ionic strength of the solution up to 0.6 M NaCl increased gel strength and the addition of pyrophosphate in 0.3 M and 0.6 M NaCl ionic strength batters increased protein extractability and gel strength myosin composition.

2.5 Non-Meat Binders for Processed Meats

2.5.1 Milk Proteins

2.5.1.1 Sodium Caseinate

Sodium caseinate is desirable due to its amphiphilic structure (Swaisgood, 1996). Caseinate consists of large regions of predominantly polar amino acids and large regions of hydrophobic amino acids. These properties allow caseinates to be used for fat binding, water

binding, and emulsification making them valuable adjuncts in the production of emulsion and restructured meats (Swaisgood, 1996; Pearson and Gillett, 1996). One problem with sodium caseinate is its' lack of solubility in brine solutions (DMV USA, 1997). When caseinate is removed by acid separation and then alkali treated with sodium hydroxide, its' solubility increases (Swaisgood, 1996). However, it is still difficult to dissolve in a brine solution. In comparison to plant proteins used for similar functions in meats, caseinates are superior nutritionally, but they are more expensive then these plant proteins causing discouragement of some caseinate use.

2.5.1.2 Whey protein concentrates

Whey protein concentrates consisting of Beta lactoglobulin and alpha lactalbumin are valuable in meat processing for three reasons. First, they are much less expensive than caseinates, but they still have good water binding ability. Second, they have great nutritional value due to their high concentration of sulfur containing amino acids (Swaisgood, 1996). Third, whey proteins have much greater solubility than caseinates due to their very good protein solvent interactions (Damodaran, 1996). This solubility is caused by equal distribution of polar and hydrophobic amino acids with the hydrophobic amino acids buried in the middle. Whey protein solubility can additionally be improved through the addition of lactose (Swaisgood, 1996). Solubility is dependent on the proteins not being heat denatured, the most important factor in whey protein separation (Swaisgood, 1996). These properties of whey proteins make them very useful in the incorporation of caseinate mixed with whey protein, which offer lower cost proteins, with increased solubility that can be used in the production of processed meat products.

2.5.1.3 Processing Effects on Milk Proteins

Pearson and Gillett (1996) state that whey protein concentrates are generally produced from whey generated from cheese production. According to (Banks, 1998), milk used for cheese processing is pasteurized at a temperature of at least 72° C for a period of at least 15 seconds. High temperature short time pasteurization (HTST) is defined as 72° C for 15 seconds. HTST denatures very little or no whey proteins (Walstra et al., 1999). HTST has no effect on caseins due to their small size and simple tertiary and quaternary structures (Fox and McSweeney, 1998). However, Fox and McSweeney (1998) also stated that ultrahigh temperature pasteurization

(UHT), 30 seconds at 130$^{\text{o}}$ C denatures the majority of whey proteins including β-lactoglobulin and α-lactalbumin. This process can have detrimental denaturing effects on casein according to Walstra et al. (1999). Yet, Fox and McSweeney (1998) state that UHT might not greatly affect caseinates. In conclusion, these whey proteins have their molecular structure altered due to heat denaturation caused by UHT. This alteration in structure decreases the protein solubility and inhibits its ability to function in processed meat products. Whey protein concentrates should only be used from milk that has been HTST pasteurized. Caseinates could possibly be used from milk that has been either HTST or UHT. However, it is this author's opinion that only caseinates from HTST pasteurized milk should be used in the production of processed meats due to the possibility of UHT causing molecular structure damage causing decreased water binding and emulsifying capacity.

Acidification, as in cheese making separates the casein from the rest of the skim milk product by decreasing the pH of the milk to the isoelectric point of casein (Walstra et al., 1999). Acidification produces a casein gel product that can be separated by either centrifugation or through a vibrating sieve. The acid casein produced is at its isoelectric point making it insoluble in water and alkaline solutions. Insolubility gives acid casein no significant functionally in processed meats. The molecular structure has not been denatured, and the product is pure (>90 % protein). Taking this acid casein and diluting it with an alkali solution such as sodium hydroxide purifies it and increases its solubility. Titrating acid casein to between 6.6 and 7.0 gives the greatest solubility of sodium caseinate and allows for its best water binding and emulsifying properties (Swaisgood, 1996).

Kerry et al. (1999) demonstrated that inclusion of 1 % sodium caseinate in restructured, cured pork decreased bind strength. Mills (1995) demonstrated an increased cook yield and decreased purge for restructured cook-in-bag and smoked hams with inclusion of 2 % caseinate in the brine. Su et al. (2000) utilized 2 % sodium caseinate in frankfurters and revealed that it increases shear force and thermal stability. Atughona et al. (1998) demonstrated that 2 % caseinate increased protein content, cooking yield, and decreased fat content. Electron micrographs demonstrated that sodium caseinate was able to bind to meat protein forming a protein-fat matrix with less coalescence of fat droplets.

Acidification has little effect on the whey proteins, B-lactoglobulin and α-lactalbumin. The whey protein that is separated from the casein can be used to make a whey protein product,

but its molecular structure is intact, and the protein is left with the water, lactose, and minerals due to the resistance of whey proteins to isoelectric precipitation (Swaisgood, 1996). These whey proteins are not yet purified, but that can occur through ultrafiltration as well as other processes.

Ultrafiltration is a process used in the food industry to separate whey protein from the water, lactose, and minerals left in solution after casein has been separated in the acidification step (Fox and McSweeney, 1998). The pores in the membrane are small enough that whey proteins and caseins cannot pass through as can lactose and salts. Nanofiltration has much smaller pores (10^{-3}-10^{-2} μm) than membranes used in ultrafiltration (10^{-2}-10^{-1} μm) (Early, 1998). This smaller pore size permits the passage of monovalent ions achieving desalted whey protein in the presence of lactose and a small percentage of fat. This smaller pore size means that whey proteins produced by ultrafiltration have a higher purity than by nanofiltration. Another way to keep minerals, fat, and lactose in whey protein concentrates is to use ultrafiltration on a percentage of the whey solution and combine it with the rest of the unfiltered whey solution (Early, 1998). Other methods used to demineralize whey are, reverse osmosis, electrodialysis, and ion exchange.

Caseinates are produced from isoelectric precipitation lowering the pH of the skim milk to 4.6, holding at 2° C for 30 min, and warming up to 30-35° C. Casein is recovered by filtration or centrifugation and is washed thoroughly to remove lactose and salt (Fox and McSweeney, 1998). This acid casein has functions in some food products, but is not usable in a meat product due its low solubility and low water binding ability. This product is very pure with 94 % protein, and its molecular structure is also intact.

Spray drying can produce a whey protein concentrate with greater than 90 % purity, but whey protein concentrates consisting of as little as 35 % purity are also produced as a mixture of whey protein and lactose. These whey protein concentrates consist of mostly β-lactoglobulin and α-lactalbumin. These proteins can be slightly heat denatured during spray drying, but this denaturation does not significantly affect solubility and functionality (Swaisgood, 1996). Isoelectric precipitation is not useful in the production of WPC used in meat products but it can be done by precipitation using carboxymethylcellulose or hexametaphosphate.

Caseinates and whey protein concentrates (β-lactoglobulin and α-lactalbumin) are useful in the production of processed meat products. If little heat denaturation occurs during

preparation, these proteins can be used for water binding and emulsification, but they first must go through the spray drying process. As a meat processor, it is important to have specifications stating how these proteins were produced and to know their purity. It is also crucial to experiment on a small scale before utilizing these products on your production line.

2.5.2 Soy Protein Binders/Extenders

Soy proteins are utilized in processed meat products as soy flour, soy protein concentrates, and soy protein isolates (Pearson and Gillett, 1996). The impetus for use of soy proteins is that they provide more desirable functionalities in meat applications than more expensive animal source alternatives such as casein or dried milk. Soy proteins provide water absorption and binding, gelation, cohesion-adhesion, emulsification, and fat absorption when formulated in processed meats (Fulmer, 1989). Soy flour contains at least 50 % protein and is predominantly utilized in sausage products. It is the cheapest of the three products, but it has a beany off-flavor and causes flatulence due to the high percentage of carbohydrates that it contains. Soy flour is also widely used as meat extenders in ground meat that is prepared for the United States Armed Forces and the school lunch program. Soy protein can be incorporated into meat products at levels up to 3.5 % of the finished product in frankfurters, deli hams, and other processed products (Pearson and Gillett, 1996).

Soy protein concentrates contain at least 70 % protein, have less off flavor than soy flour, but are more expensive. These proteins are ideal for utilization in restructured meats for two reasons. First, they are relatively inexpensive when compared to meat and milk proteins. Second, soy protein concentrates have special gelling properties that aid in binding chunks of meat together (Hermannson, 1986; Pearson and Gillett, 1996) and enhance water and fat binding. Soy protein isolate is made up of at least 90 % protein. It has practically no off-flavor, with excellent gelation, water binding, and fat binding characteristics. Its functionality is superior to that of soy protein concentrate, but it is not as practical to use since the increase in cost outweighs the increase in functionality. Hermannson (1986) reported that soy protein gelation due to heating occurs by association of molecules into strands in an ordered arrangement. This provides good functionality for protein and fat interactions in processed products ranging from emulsions to sectioned and formed products.

Seigel et al. (1979) evaluated the effects of utilizing between 0 and 3.8 % soy protein isolate in a ham injected with brine. These authors concluded that soy protein increased cooking loss and improved bind. Soy protein is able to improve functionality by binding fat and water and gelling upon heating (Rakowsky, 1974). Soy protein improves functional proteins in emulsion type sausages, but it has been reported to decrease sensory acceptability (He and Sebranek, 2000). Motzer et al. (1998) tested the effects of isolated soy protein (ISP) in a restructured ham formulated with finely ground tissue. These authors concluded that ISP was able to decrease expressible moisture but that cooking loss was not significantly greater than the control product for PSE, RFN, and combinations of the two raw materials. It can be inferred that soy protein concentrates and isolates have the potential to improve functionality in restructured products such as chunked and formed products made from both PSE and RFN meat.

Soy proteins are extracted from soybeans for utilization in processed products. Soybeans are a favorable crop for by-product use since they are plentiful and inexpensive (Ashbridge, 1995). Ashbridge (1995) stated that the single most important factor pertaining to soybeans is the amount of high quality protein produced, of which only 2 % is formulated into edible products. Components of soybeans include lipids (21 %), protein (40 %), carbohydrates (34 %), and ash (5 %). Lipids are refined into soybean oil. Carbohydrates are not desirable in human food products because flatulence is caused by humans' inability to hydrolyze the oligasaccharides, raffinose and stachyose.

Production of soy proteins utilized in foods first involves removing the cotyledons from the hull and germ. Soybeans must then be thoroughly cleaned so that as little microbial contamination as possible occurs. The cotyledons are milled to specific sizes to make full-fat soy flours and grits. Defatted soy flours and grits are prepared by milling solvent extracted flakes of dehulled soybeans (Lucas and Rhee, 1995). Defatted soy flour is generally utilized in sausages. Soy protein concentrates are essentially flours from which the water or alcohol soluble components, including flatulence-promoting carbohydrates and strong flavor components have been leached before drying (Lucas and Rhee, 1995). Soy protein isolates are then formed from removing fiber from soy protein concentrate.

2.5.3 Modified Food Starch

Starch is the food reserve that the plant embryo uses as energy until it can germinate and begin photogenerating its own carbohydrate source (Whistler and Daniel, 1985). Starches are available from many plants including wheat, rice, tapioca, potato, and corn. Modified corn starch is most often utilized in meat processing since it is the least expensive alternative, and provides excellent functionality improvements through water binding (Whistler and Daniel, 1985). Upon heating, starch granules swell allowing water to enter the granules. The swelling is initiated by heat and causes the starch molecules to vibrate vigorously, breaking intermolecular bonds which allows hydrogen-bonding sites to engage more water molecules (Whistler and Daniel, 1985). Swelling also permits granules to constrict the water structurally, a property that is solidified by modification. Most starches contain roughly 25 % amylose and the rest amylopectin. But waxy cornstarch is predominantly amylopectin, which imparts a natural fat-like sensory response, a quality making it desirable in low-fat meat products. Amylose is linear, a property leading to retrogradation susceptibility, the loss of water binding ability due to the insolubility of starch, a characteristic caused by crystallization. This often occurs when cooling previously heated systems. Amylopectin is branch, which prevents susceptibility to retrogradation. Retrogradation occurs in meat systems when starch has not been modified through either esterification (Whistler and Daniel, 1985), hydroxypropal addition, acetylation, or succinylation (Pearson and Gillett, 1996). Modification by esterification entails a low degree of substitution of ester groups for hydroxyl groups which increases rate of granule swelling (Harsveldt, 1962), thus preventing retrogradation.

Davies (1995) reported that starches must contain four characteristics to bind water, form films and add texture to meat products. The starch must be native, crosslinked, pregelatanized, and have crosslinked substitutions. Native starch implies that no modification of the starch has occurred. This is not practical for meat systems since modification must occur to prevent retrogradation, and since crosslinking and substitution are both modifications. Crosslinked refers to covalently bonded inter- and intramolecular bridges between starch polymers. Substitution includes the addition of a chemical blocking group between starch polymers and involving derivatization with a monofunctional reagent through ester or ether formation (Thomas, 1999). Blocking groups include acetate, phosphate, and ethers (hydroxypropyl groups) that stabilize the

starch structure, preventing retrogradation. The most common blocking group in meat products is hydroxypropylated starches.

Thomas (1999) defined gelatinization as a combination of the following attributes: disruption of molecular order, irreversible, initially increasing the size of the granules, resulting in increased solution, differing with respect to cooking conditions, and differing with respect to granule type. Due to the insolubility of starch in water, gelatinization is necessary to render the starch soluble so that it can be used in food systems. These characteristics lead to the ability of starch to bind water through hydrogen binding and contain water structurally.

Motzer et al. (1998) demonstrated that modified food starch (MFS) contains the greatest potential of all adjuncts to improve functionality in restructured ham formulated from a percentage of PSE meat. It accomplishes this through reducing moisture losses and improving texture. Mills (1995) reported that MFS improved cook yield in restructured cook-in-bag-hams but not in restructured smoked hams. The results of these researchers imply that MFS is more effective at improving functionality in meat when cooked in water than when smoked.   Research should be designed to determine the parameters of use that will maximize the benefits of MFS on boneless cured products utilizing all quality classifications of pork, with an emphasis on effects on PSE meat.

2.5.4 Miscellaneous Binders

Colloids and gums are utilized to retain texture and juiciness in low fat products (Pearson and Gillett, 1996). Most of these gums are carageenans that are derived from seaweed. Iota carageenan is used in low fat ground beef, and Kappa carageenan is used in low fat processed meats because of its excellent gelling and water binding ability. This functionality has been evident in research that demonstrated increased cook yields and decreased purge loss in restructured hams (Mills, 1995; Motzer et al., 1998). These researchers utilized k-carageenan in PSE meat formulations. It increased functionality, but the finished product was not similar in quality to the product made from RFN meat with no binder. One negative attribute of carageenan is that it leaves a slimy gel like precipitate on the surface of the product. Alginates have also been used as binders in fresh meat products, and transglutimase is an example of an enzyme isolated from seeweed that has been utilized to restructure fresh meat into more attractive products.

Kenney et al. (1992) reported on the effects of connective tissue and gelatin on the properties of low-salt, low-fat, restructured beef. Raw and preheated connective tissue was useful for increasing tensile strength when added as 10 % of the formulation. When used as 5 % of the formulation, only raw connective tissue was effective for increasing tensile strength. Comparatively, Jones (1984) illustrated that the addition of collagen can improve yields and increase brittleness of a batter-type product, but a large amount of collagen can reduce stability, causing product defects such as fatting out and gel pockets. In comparison, Samejima et al. (1969) reported that the addition of stromal proteins in the form of collagen reduced the gel strength of myofibrillar protein formulations.

2.6 Response Surface Methodology

Response surface methodology is an application of multiple linear regression that has been designed to find optimum operating parameters for industrial applications. Response surface methodology combines knowledge of multiple linear regression with experimental design knowledge to perform the best possible experiment (Myers and Montgomery, 1995). Experiments are designed with equal spacing and orthogonal independent variables so that excellent prediction can be made over the area of interest and so that little to no multicollinearity exists. Multicollinearity is a term used to describe a situation where independent variables are highly correlated. Multicollinearity is dangerous because it prevents researchers from knowing which independent variables are truly explaining the responses. Quadratic models are generally used because they have been shown to work well in real life situations and because they allow for estimation of the maximum and minimum in your design space when these points are not located in the corners (Myers and Montgomery, 1995).

Mixture designs are utilized when one is utilizing ingredients that add up to a fixed value (usually 100 %), such as when baking a cake (Myers and Montgomery, 1995). Percentages can be altered for the different ingredients to see their effect on a response that is of interest. Constraints are included if there is a maximum and minimum range for the sum of some subsets of ingredients or individual ingredients.

2.7 Implications

Information in the literature demonstrates the necessity for experimentation designed to provide options that add value to PSE pork. This research is imperative in determining the usability of PSE pork in high value processed meats, the percentage of PSE meat that can be incorporated into products, variations in functionality among quality classifications, and effects of non-meat adjuncts on PSE meat functionality.

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Chapter 3
Use of Response Surface Modeling to Evaluate the Effects of Non-meat Adjuncts and Combinations of PSE and RFN Pork on Water Holding Capacity in the Production of Boneless Cured Pork

3.1 Abstract

Boneless cured pork was produced from combinations of pale, soft, and exudative (PSE) and red, firm, and non-exudative (RFN) *semimembranosus* muscle. Response Surface Methodology was utilized to determine the effects of soy protein concentrate (SPC), sodium caseinate (SC), and modified food starch (MFS) on cooking loss and expressible moisture. Fifteen ingredient combinations were replicated three times for each PSE and RFN combination giving 75 treatments per replication. Utilization of SP decreased cooking loss (p<0.01) and MFS decreased (p<0.01) expressible moisture. Product formulations using these adjuncts demonstrate potential to improve the water holding capacity in PSE as well as RFN pork. This research also demonstrated that diluting RFN pork with no more than 25 % PSE pork permits the formation of a high quality boneless deli ham roll.

3.2 Introduction

Consumer desire for leaner meats has mandated the manufacture of pork with less fat. The rigorous selection for leaner pigs in combination with stressful pre-slaughter and slaughter conditions has resulted in inferior pork quality (Lee & Choi, 1998). This selection practice has been responsible for the discovery of genetic material that yields porcine muscle with a low pH, light color, and very soft and watery tissue.

Genetic selection and pre-slaughter stress cause rapid postmortem glycolysis that results in increased lactic acid production and decreased pH. Decreased pH combined with high muscle temperature (Camou & Sebranek, 1990) causes protein denaturation that exceeds that observed in normal muscle (Briskey & Wismer-Pedersen, 1961; Charpentier, 1969; Goutefongea, 1971; Bowker et al., 2000) leading to the production of pale, soft, and exudative (PSE) pork. Because of this protein denaturation, there is an increase in water loss that is detrimental to product quality (Offer, 1991).

Young (1996) stated that customers will not buy a pale, watery product, and that appearance of pork is the most essential attribute to the consumer when making purchasing decisions. Since consumers will not accept fatter pork, this industry is challenged with the task

of reducing the incidence of poor water-holding capacity without sacrificing leanness. Two ways to reduce PSE of lean pork are to select for leaner pigs while eliminating the halothane gene from breeding stock, and to reduce the amount of stress hat pigs are subjected to before slaughter. Though these options exist, the optimal utilization of PSE pork should be addressed. A current challenge exists to add value to PSE pork since it has little consumer appeal and is normally relegated to sausage manufacture. One possible approach is through investigating the possibility of PSE pork utilization in the production of chunked and formed products. To increase the viability of this technique, water holding capacity needs to be improved from the raw material to the finished product to increase cook yields and enhance product juiciness.

Optimal PSE pork utilization needs to be examined for incorporation into restructured products. Non-meat adjuncts addition to improve the water-holding capacity of PSE pork should be explored. It also will not be possible to formulate a satisfactory product from 100 % PSE pork. To manufacture an acceptable restructured product, the concentration of RFN pork that should be added to PSE pork and non-meat adjuncts must be established. Motzer et al. (1998) have previously explored the effects of combining PSE and RFN pork and beneficial adjuncts in the formulation of restructured ham. These researchers evaluated the effectiveness of water binders and an alkaline phosphate in increasing the protein binding and water holding capabilities of processed hams made with differing amounts of PSE pork. Their results revealed that the combination of normal and PSE pork and the addition of binders enhanced water holding capacity of restructured ham slices when compared to that made from only PSE meat. It was concluded that modified food starch demonstrated the greatest potential to improve water holding capacity and that restructured ham could be produced with a percentage of PSE pork. This research suggested two questions that follow. How much RFN pork should be added to PSE pork to make an acceptable product? What will happen if non-meat adjuncts such as starch, milk protein, and soy protein are combined in the processing of a restructured product? Answers to these two questions are the crux of this research.

The use of three adjuncts in the production of a boneless restructured pork product with the potential of improving functional characteristics of PSE pork was investigated in this research. These adjuncts include sodium caseinate (SC), soy protein concentrate (SPC), and modified food starch (MFS). SC is desirable due to its amphiphilic structure (Swaisgood, 1996), an arrangement consisting of large regions of predominantly polar amino acids and large regions

of hydrophobic amino acids. These properties allow caseinates to be used for water binding and emulsification, making them valuable adjuncts in the production of emulsion and restructured meats (Swaisgood, 1996; Pearson and Gillett, 1996). One problem with sodium caseinate is its' lack of solubility in brine solutions (DMV USA, 1997). When caseinate is removed by acid separation and then alkali treated with sodium hydroxide, its' solubility increases (Swaisgood, 1996). However, it is still difficult to dissolve in a brine solution. In comparison to plant proteins used for similar functions in meats, caseinates are superior nutritionally, but they are more expensive then these plant proteins causing discouragement of some caseinate use.

SPC's are ideal for utilization in restructured meats for two reasons. First, they are relatively inexpensive when compared to meat and milk proteins. Second, SPC's have special gelling properties that aid in binding chunks of meat together (Hermannson, 1986; Pearson and Gillett, 1996) and enhance water binding. These functionalities can be attributed to the association of molecules into strands in an ordered arrangement during heat processing (Hermannson, 1986).

MFS increases water binding and protein-protein binding in processed products (Pearson and Gillett, 1996). Modified corn starch is the starch that is most often utilized in meat processing since it is the least expensive alternative, and provides excellent functionality improvements through water binding (Whistler and Daniel, 1985). Upon heating, starch granules swell allowing water to enter the granules. The swelling is initiated by heat and causes the starch molecules to vibrate vigorously, breaking intermolecular bonds which allows hydrogen-bonding sites to engage more water molecules (Whistler and Daniel, 1985). Swelling also permits granules to constrict the water structurally, a property that is solidified by modification.

Our search revealed that no research has been reported which addresses how the combination of these adjuncts would affect the water-holding capacity of a restructured product made from PSE pork. Determination of the utility of the non-meat adjuncts for improvement of the acceptability of 25 % PSE+75 % RFN and 50 % PSE+ 50 % RFN ham rolls to approach the quality of ham rolls made with 100 % RFN pork was performed.

This research is vital to the pork industry because the acceptability of PSE pork should be enhanced. Since sources report that 10-16% of the pork being produced has this quality defect and up to 60 % of pork being produced is Red Soft and Exudative (RSE) (Kauffman et al., 1992,

McKeith et al., 1994), the acceptability of these raw materials must be improved. Thus, the functional properties of PSE pork should be enhanced so that it can be incorporated in products containing pork to upgrade its value and increase its use in processed meats. Improved consumer acceptability will enhance the value of pork with increased income to the meat industry.

3.3 Materials and Methods

3.3.1 Porcine Raw Materials

Porcine *semimembranosus* and *adductor* muscles were obtained from a pork processing plant in Virginia. All samples were taken from National Pork Development (NPD) pork carcasses produced from market age pigs that weighed 110-125 kg. Both RFN pork and PSE pork were selected based on visual color such that the following treatment combinations could be processed: 100 % PSE, 75% PSE +25 % RFN, 50 % PSE+ 50 % RFN, 25 % PSE +75 % RFN, and 100 % RFN. pH, percentage moisture, fat, and CIE L*, a*, b* values were measured for each *semimembranosus/adductor* muscle upon arrival. RFN samples were identified as having a CIE L* < 50 and PSE samples were identified as having a CIE L* > 53. Chemical analyses data were used as covariates to provide additional information about the water holding capacity of the muscles.

3.3.2 Sample Processing

Porcine *semimembranosus* and adductor muscles were hand diced into 2.5 cm by 2.5 cm cubes and 1.36 kg of these muscles were incorporated in the formulation of each treatment. Ten percent of the meat was ground with a food processor (Model HC3000, Black & Decker, Shelton, CT) to increase bind. The brine solution was formulated consisting of added water (18 % meat weight basis (MWB)), sodium chloride (2 % MWB)), sodium tripolyphosphate (0.5 % MWB), dextrose (1 % MWB), sodium nitrite (156 ppm), and sodium erythorbate (0.042 % MWB). Ice was added to reduce the brine temperature to 4-6° C. Modified Food Starch (MFS, Pure-Gel B990, Grain Process Corporation, Muscatine, IA), Soy Protein (SP, Promine DS, Central Soya, Fort Wayne, IN), and Sodium Caseinate (SC, Alanate 191, New Zealand Milk Products Inc. Santa Rosa, CA) were added to the brine in appropriate treatments based on the MWB. Each treatment was placed in a vacuum tumbler (Model Inject Star MC 20/40/60/80-226, Inject Star of the Americas, Brookfield, CT), and the brine for each treatment was poured onto

the meat samples. The samples and brine were then tumbled under vacuum for 1.5 hr at 4° C, stopping every 15 min for a rest period of 10 min to enhance brine absorption. Each ham treatment was stuffed into the casings (Model Reg Fib CSG 5*25 Light PS, Viskase, Chicago, IL) manually, and a Tipper Tie (Model PRA65L, Tipper Tie, Apex, NC) was used to seal the casings. The samples were set in a meat lug (3502 58961, Koch Equipment LLC, Kansas City, MO) for approximately 16 hrs (4° C). The next day, the product was processed in a smokehouse (Model 1000, Alkar, Lodi, Wisconsin) to an internal temperature of 69 ^{o} C. The smokehouse schedule was 1 hr for dry bulb 54 ^{o}C and no wet bulb, 2 hr for 66 ^{o}C dry bulb and 47 ^{o}C wet bulb, 1 hr for 71 ^{o}C dry bulb and 57 ^{o}C wet bulb, and approximately 1 hr 15 min for 88 ^{o}C dry bulb and 74 ^{o}C wet bulb. The boneless hams were immediately cold showered for 15 min (10 ^{o}C <) and then stored in plastic lugs (3502 58961, Koch Equipment LLC, Kansas City, MO) at 4 ^{o}C for 16 hr prior to cooking loss determinations. Ham rolls were sliced into 12.7 mm thick slices, packaged aerobically, and stored (4° C) for expressible moisture measurements to be performed within 72 hr.

3.3.3 Treatment Combinations

Treatment combinations were formulated within legal values as described by USDA (9 CFR, 318 and 319) of combinations of SC, SP, and MFS that would obtain the maximum amount of information about how these ingredients affect water-holding capacity. Fifteen ingredient combinations (Table 3.1) within the design space (Figure 3.1) were chosen to optimize the design (Design-Expert 5, Stat Ease Inc., Minneapolis, MN), and all combinations were applied to each PSE and RFN combination. This provided 75 treatments per replication, and the experiment was replicated 3 times.

3.3.4 pH, Moisture, and Protein Analysis

The pH of each *semimembranosus/adductor* muscle was taken in triplicate. pH was determined by removing three 2-g samples from three similar anatomical locations on each of the muscles and homogenized (Virtishear Model.225318, The Virtis Company, Inc., Gardener, NY) for 1 min in 20 mL of distilled deionized water. pH was measured for the individual samples with a calibrated pH meter (Model AR25, Fisher Scientific, Pittsburgh, PA) and a pH electrode (Model 13-620-298, Fisher Scientific, Pittsburgh, PA).

Percentage moisture was measured (39.1.02, AOAC, 1995) in triplicate for each muscle using a drying oven (Model OV-490A-2, Blue, Blue Island, IL). Percentage protein was

measured (39.1.02, AOAC, 1995) in duplicate with a Kjeldahl extraction apparatus (Model Rapid Still II, Laconic Corp., Kansas City, MO). All of these chemical analyses were repeated for each treatment of processed ham rolls.

3.3.5 Cooking Loss

Percentage cooking loss was reported as (raw weight – cooked weight/raw weight) x 100. The product was cooked in a smokehouse (Model 1000, Alkar, Lodi, Wisconsin) as described previously.

3.3.6 Expressible Moisture

The Instron Universal Testing Machine (Model 1011, Instron Corp., Canton, MA) was used to determine expressible moisture for two randomly selected ham slices from each treatment. Four cores (19 mm diameter) were taken from each 12.7 mm slice. They were individually weighed and then placed on and under two 12.5 cm Whatman #1 Filter papers to absorb excess moisture. The cores were axially compressed between plates to a height of 3.2 mm (75% compression) and were held for 15 s once the deformation point had been reached. After removing the force, the core was reweighed. The Instron was programmed with a 500 kg compression load cell and a crosshead speed of 100 mm/min. Expressible moisture was expressed as a percentage:[(initial wt – final wt)/initial wt)] x 100.

3.3.7 Statistical Analysis

The experimental design is a constrained modified simplex mixture (Figure 3.1) with 15 combinations of 3 factors (MFS, SC, SP) crossed with the 5 treatment combinations of PSE and RFN. Each of these combinations was replicated 3 times. This type of Response Surface Design allows the fitting of a second order model to test main, interaction, and quadratic effects for all factors of interest as well as makes it possible to estimate a combination of factors to optimize a variety of responses. Percentage raw moisture and protein, raw pH, and raw color were also included in the regression model as main effects to provide as much explanation of the model as possible. Analysis with the statistical package SAS (Version 8.12, 2001, SAS, Cary, NC) was conducted to determine water-holding capacity at various percentages of PSE pork.

3.4 Results and Discussion

3.4.1 Muscle Variation

All RFN samples had CIE L* values below 49, and all PSE samples had CIE L* values greater than 53. The average CIE L* value was 45.8 for the RFN samples and 57.6 for the PSE samples. All PSE samples were light in color and highly exudative while all RFN samples were light red with moist surfaces. Means and standard deviations for color and chemical data are reported in Table 3.2.

The pH values ranged from 4.9-6.3. All PSE samples were below 5.5 while all RFN samples were above 5.6. Raw materials with low ultimate pH exhibited low moisture and high protein values. The majority of RFN samples were much lower than 6.3, but 6.6 % of the observations were outliers that could be characterized as RFN by color and water holding capacity, but their pH was too high to meet the specifications for RFN (5.6<pH<5.9) (Kauffman et al., 1992.) pH data is similar to the data of Warner et al. (1997). These authors reported ultimate pH's of below 6.0 as RFN or PSE depending on CIE L* value. Motzer et al. (1998) characterized PSE and RFN raw material as between 5.4 and 5.6 and 5.8-6.1 respectively. These authors also selected hams with CIE L* values greater than 59 and less than 50 as PSE and RFN samples.

Percentage moisture and protein ranged from 72.5-76.7 and 18.5-25.0, respectively. The lower moisture and higher protein values were more representative of PSE samples and the opposite ends of the spectrum were more representative of RFN samples, but averages for each classification were similar. A sample size of 32 for each of PSE and RFN raw materials was measured to estimate fat percentage. The fat percentage of PSE (2.18$\pm$1.27) and RFN (1.83$\pm$0.70) samples were very low resulting in a small variation in fat among muscles. According to Rust (1987), as fat percentage increases in further processed products, protein percentage decreases which inhibits ability to bind fat and water. Excluding a few RFN samples with pH over 6.0, all samples that were used as PSE and RFN met the criteria for their quality classification according to acceptable methods by the National Pork Producers Council (Kauffman et al., 1992).

Larger variation in chemical composition and color existed among raw material than was desirable. This accounted for a reduced amount of uniformity in experimental units. Data for

raw material demonstrates difficulty in obtaining a sample that has small variation within quality classifications. This variation is a problem since difference in responses of processed meats may be due not only to experimental treatments but also due to differences in raw material. Similarly, Joo et al. (1995) reported that color correlates with protein solubility, but that other factors must contribute to protein functionality of pork. Therefore, color and chemical composition do not completely explain functionality. This result makes it difficult to completely predict the functionality of raw material that is utilized in processed products.

3.4.2 Water Holding Capacity Models

No interaction ($p>0.05$) existed between PSE and sodium caseinate, modified food starch, or soy protein concentrate. This lack of interaction deemed it appropriate to utilize the models for data collected from all levels of PSE instead of creating different models for each level. These models were statistically significant ($p<0.05$) and were successful in explaining cooking loss and expressible moisture (eqns. 1,2), and partial F tests were performed to determine if quadratic terms and covariates were needed in the models to help explain water-holding capacity. Quadratic terms were not needed ($p>0.05$) in the models but covariate terms (raw CIE L*, raw CIE a*, raw CIE b*, raw pH, raw moisture, and raw protein percentage) did add ($p<0.05$) significant information to the models (SAS, 1999). The final models were selected as linear models with covariates added. The R^2 for the models are 0.34 and 0.40 for cooking loss and expressible moisture, respectively. This suggests that there was high variation among experimental units in each quality classification. This variation is undesirable for experimental purposes, but this design was necessary since the industry would formulate a chunked and formed product similarly, and one research goal was to provide a product that the industry could utilize.

Four (% PSE, SPC, raw CIE L*, and raw pH) and two (MFS and % PSE) independent variables were significant ($p<0.05$) in explaining cooking loss and expressible moisture, respectively. But all terms were included in the models since there was so much unexplained variation in the model due to variability in the raw material (Myers and Montgomery, 1995). The models take the form of the following multiple linear regression model:

$y = B_0+B_1X_1+B_2X_2+B_3X_3+B_4X_4+B_5X_5+B_6X_6+B_7X_7+B_8X_8+B_9X_9+B_{10}X_{10} + \varepsilon$. The explanation of these terms is included in Table 3.3. The assumptions of the model are that the $E(\varepsilon) = 0$, Var

(ε) = constant, and that ε_i's are independent of each other and follow a normal distribution. These assumptions allow appropriate tests to be performed to determine if the variables are statistically significant ($p<0.05$). Under these assumptions, the B hats are the maximum likelihood estimators, and the models for cooking loss and expressible moisture are estimable.

3.4.3 Cooking Loss

Equation 1: Cooking loss = 11.8 + **0.97*PSE** + 0.025*MFS – **0.27*SPC** - 0.085*SC + 0.37*moisture - 0.17* prot + **1.9*CIE L*** - 0.15*CIE a* - 0.23*CIE b* - **1.1 *pH raw**

Soy protein concentrate improved ($p<0.01$) cooking yields. Cooking loss decreased ($p<0.05$) as raw material pH increased, and cooking loss increased ($p<0.05$) as CIE L* value of the raw material and percentage of PSE pork incorporated into the product increased. Figures 3.2,3.3, and 3.4 were produced for 0, 25 and 50 % treatments with covariates held constant at their means to demonstrate how cooking loss values are affected by MFS, SPC, and SC incorporation. Figure 1 reveals that the optimal adjunct combination for minimizing cooking loss is 3.5 % soy protein concentrate (SPC) inclusion resulting in estimated cooking loss of 10.15 %. Motzer et al. (1998) reported no difference in chill yields between the control and restructured ham formulated with 1.5 % isolated soy protein (ISP). They produced a sectioned and formed product with a cooking loss of 6.3 % when ISP was incorporated and a cooking loss of 7.8 % for the control. Their results differ from our data in that ISP did not significantly decrease ($P>0.05$) cooking loss.

Utilization of 25 % PSE pork decreased minimum cooking loss predictions by 0.50 to 10.65 % when compared to 0 % PSE. This result suggests that minimal profit losses would be caused by incorporation of 0 to 25 % PSE pork into the product. These results will vary depending on the type of processed product being formulated and the severity of the PSE condition in the raw material. The maximum predicted values of 10.65 % (Figure 3.3) and 11.2 % (Figure 3.4) for 25 and 50 % PSE incorporation is similar to the 11.0 % (Figure 3.2) value that was obtained for the 0 % PSE treatment with no adjuncts incorporated. This result shows the potential of SPC to improve cooking yields with products formulated with 25 or 50 % PSE to values greater than or similar to 0 % PSE with no adjuncts.

Results demonstrated that utilization of 25 or 50 % PSE in the experimental restructured product did increase cooking loss. However, it may still be practical to incorporate these

products since the decreased cooking loss may not outweigh the changes in value that could be induced through using this low value raw material since boneless deli hams yield roughly twice as much per pound (4-6$) as the sausage products (1-3$) that PSE is presently incorporated into. If the percentage added water was increased in the product, there may have been larger differences in cooking loss among different levels of PSE. This is due to the inability of denatured myofibrillar proteins to bind water in PSE meat.

Motzer et al. (1998) demonstrated that soy protein isolate was not successful in improving cook yield, but reported that modified food starch was successful. Differences in our results can be attributable to the utilization of different soy proteins, surface area of raw material, and cookery method. In accordance with our results, these researchers demonstrated that 50 % PSE products with binders exhibited similar cooking yields to 0 % treatments.

It is not practical to formulate products with 50 % PSE because the raw material would increase product paleness and yellowness (Zhu and Brewer, 1998), and SPC increases yellowness (Chapter 4). But 25 % PSE pork would be practical, and some values between 25 and 50 % could also be used. Although, our data demonstrates the practicality of utilizing 25 % PSE, it is impractical to incorporate 50 % PSE into products since it causes paleness and poor cohesiveness (Chapters 4 and 5). However, no research has been done to determine the exact percentage of PSE pork that would be acceptable in a product. Therefore, further experimentation would need to be designed and performed to determine usable values.

3.4.4 Expressible Moisture

Equation 2:
Expressible Moisture = 19.5 + **1.2*PSE** - **0.51*MFS** – 0.043*SPC - 0.20*SC + 0.56*moisture
                              - 0.51*prot + 1.9*CIE L* +1.8*CIE a* - 1.3*CIE b* - 0.25*pH raw

Modified food starch demonstrated potential to decrease ($p<0.01$) expressible moisture, and the incorporation of PSE meat in product formulations increased ($p<0.05$) expressible moisture. The ability of MFS to entrap water and form hydrogen bonds with water makes it an excellent water binder and explains its success in decreasing expressible moisture. Figures 3.5,3.6, and 3.7 were produced for 0, 25 and 50 % treatments with covariates held constant at their means to demonstrate how cooking loss values are affected by MFS, SPC, and SC incorporation. As amount of MFS included in the experimental product increases from 0 to 3 %, expressible moisture predictions decrease from 18.4 % to 17.0 % (Figure 3.5). No other adjuncts

improved (p>0.05) expressible moisture, but predictions for both expressible moisture and cooking loss showed slight improvements for inclusion of 1 or 2 % SC when compared to no inclusion for all % PSE combinations (Figures 3.2-3.7). These predictions infer that SC does have potential to improve water holding capacity in a chunked and formed product, but not as much potential as SPC and MFS.

Utilization of 3 % MFS in 25 and 50 % PSE treatments yields the minimum predicted expressible moistures for those PSE levels at 17.0 (Figure 3.6) and 18.0 % (Figure 3.7). These values are lower than expressible moisture for 100 % RFN treatments with no adjuncts included (18.4 %). This observation substantiates the ability to utilize 25 % PSE incorporation in chunked and formed products when MFS, SPC, or a combination of these adjuncts is formulated into the brine solution. Figures 3.4, 3.5, and 3.6 were produced for 0, 25 and 50 % treatments with covariates held constant at their means to demonstrate how expressible moisture values are affected by MFS, SPC, and SC incorporation.

Motzer et al. (1998) revealed that modified food starch increases cooking yields and decreases expressible moisture because of its ability to bind water. These results may have occurred due to formulation of their product from raw material with a larger surface area than what was used in our experiment. Larger surface area decreases the importance of gelation and brine distribution. This condition improves the water-holding capacity of MFS since it does not function similarly to meat proteins and SPC, which bind water through gelation. Their results suggest that MFS may function better with PSE meat in sectioned and formed products that are water cooked and SPC may function better in chunked and formed products that are processed in a smokehouse.

Decreased expressible moisture by MFS and decreased cooking loss through SPC utilization can be attributable to their mechanism of functionality. Starch granules hydrate during meat processing, a procedure that becomes irreversible at gelation temperatures (Thomas and Atwell, 1999), and SPC binds water in its protein matrix (Hermannson, 1986). Expressible moisture measures loosely bound water in the system. This observation implies that SPC may have a higher expressible moisture value because it may be easier for water inside a protein matrix to be compressed out than water that is hydrated in a starch granule. SPC may decrease cooking loss by synergistically working with meat proteins to bind water in the products protein matrix, but hydration of starch granules may prevent decreases in cooking loss since it binds

water by a different mechanism. A combination of SPC and MFS can be utilized to increase water holding capacity through decreasing cooking loss and expressible moisture.

3.5 Conclusions

Utilization of 2 % soy protein concentrate (SPC) and at least 1 % modified food starch (MFS) in product formulation appears to give optimal results for increasing water-holding capacity. Utilizing 3.5 % SPC maximizes improvement in cooking yield, but if concerns exist about juiciness and color, MFS should be incorporated along with 2-2.5 % SPC to decrease yellowness and increase juiciness. Utilizing 25 % PSE pork with 1.5 % MFS and 2 % SPC inclusion provides predictions that are similar to 0% PSE treatments with no adjuncts for expressible moisture and cooking loss. This observation demonstrates that it is economically favorable to incorporate PSE pork into chunked and formed products at 25 %. However, it is also important to note that utilization of 1.5 % MFS and 2 % SPC was the most favorable combination for any level of PSE incorporation.

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Table 3.1 - Ingredient combinations[a] of meat adjuncts used in the processing of restructured ham roll.

Treatment Combination #	Ingredients		
	Modified Food Starch	Soy Protein	Sodium Caseinate
1	0 %	3.5 %	0 %
2	0 %	0 %	0 %
3	3 %	0 %	0.5 %
4	0 %	1.5 %	2 %
5	0 %	0 %	2 %
6	2 %	0 %	0 %
7	2 %	1.5 %	0 %
8	0 %	2 %	0 %
9	1.5 %	0 %	2 %
10	1.33 %	0.7 %	0.81 %
11	0.67 %	2.1 %	0.42 %
12	0.67 %	0.35 %	0.42 %
13	0.5 %	0.5 %	2 %
14	0 %	1.25 %	1 %
15	1.5 %	1.16 %	0 %

[a] All combinations were used for each treatment combination of red, firm, and non-exudative (RFN) and pale, soft, and exudative (PSE) meat.

Table 3.2: Chemical and physical properties of pale, soft, and exudative (PSE) and red, firm, and non-exudative (RFN) raw material that was incorporated into boneless cured pork.

	PSE		RFN	
Covariate Data	Mean	Standard Deviation	Mean	Standard Deviation
Moisture %	74.6	0.91	75.3	0.85
Protein %	21.4	1.45	21.4	1.60
Fat %	2.18	1.27	1.83	0.70
CIE L*	57.6	2.30	45.8	1.36
CIE a*	19.0	0.96	21.7	0.88
CIE b*	7.29	1.02	6.57	1.08
PH	5.36	0.15	5.99	0.17

Table 3.3: Explanation of the terms in the multiple linear regression (response surface) model associated with cooking loss and expressible moisture.

Variable	Definition
B_0 = Intercept	The predicted value of the response when no adjuncts are added and all covariates are at their means
B_1	The amount that the response is predicted to change when PSE is changed from 0 to 1 in the product and all other variables remain constant
B_2	The amount that the response is predicted to change per additional 1 % MFS incorporation into the product when all other variables remain constant
B_3	The amount that the response is predicted to change per additional 1 % SPC incorporation into the product when all other variables remain constant
B_4	The amount that the response is predicted to change per additional 1 % SC incorporation into the product when all other variables remain constant
B_5	The amount that the response is predicted to change per 1 unit change in the moisture value on a standardized –1 to 1 scale when all other variables remain constant
B_6	The amount that the response is predicted to change per 1 unit change in the protein value on a standardized –1 to 1 scale when all other variables remain constant
B_7	The amount that the response is predicted to change per 1 unit change in the CIE L* value on a standardized –1 to 1 scale when all other variables remain constant
B_8	The amount that the response is predicted to change per 1 unit change in the CIE a* value on a standardized –1 to 1 scale when all other variables remain constant
B_9	The amount that the response is predicted to change per 1 unit change in the CIE b* value on a standardized –1 to 1 scale when all other variables remain constant
B_{10}	The amount that the response is predicted to change per 1 unit change in the pH value on a standardized –1 to 1 scale when all other variables remain constant
X_1	% PSE incorporated into product on 0 to 1 scale
X_2	MFS incorporated into product on 0 to 3 scale
X_3	SPC incorporated into product on 0 to 3.5 scale
X_4	SPC incorporated into product on 0 to 2 scale
X_5	Percentage moisture on a –1 to 1 standardized scale
X_6	Percentage protein on a –1 to 1 standardized scale
X_7	CIE L * value on a –1 to 1 standardized scale
X_8	CIE a * value on a –1 to 1 standardized scale
X_9	CIE b * value on a –1 to 1 standardized scale
X_{10}	pH on a –1 to 1 standardized scale

Figure 3.1 - Modified Simplex Design Structure for the Response Surface Design Utilized. This is the region where predictions can be estimated based on inclusion of modified food starch (MFS), soy protein concentrate (SPC), and sodium caseinate (SC).

Figure 3.2 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage cooking loss (values reported within rectangles) of chunked and formed, restructured pork formulated with 0 % PSE and 100 % RFN raw material.
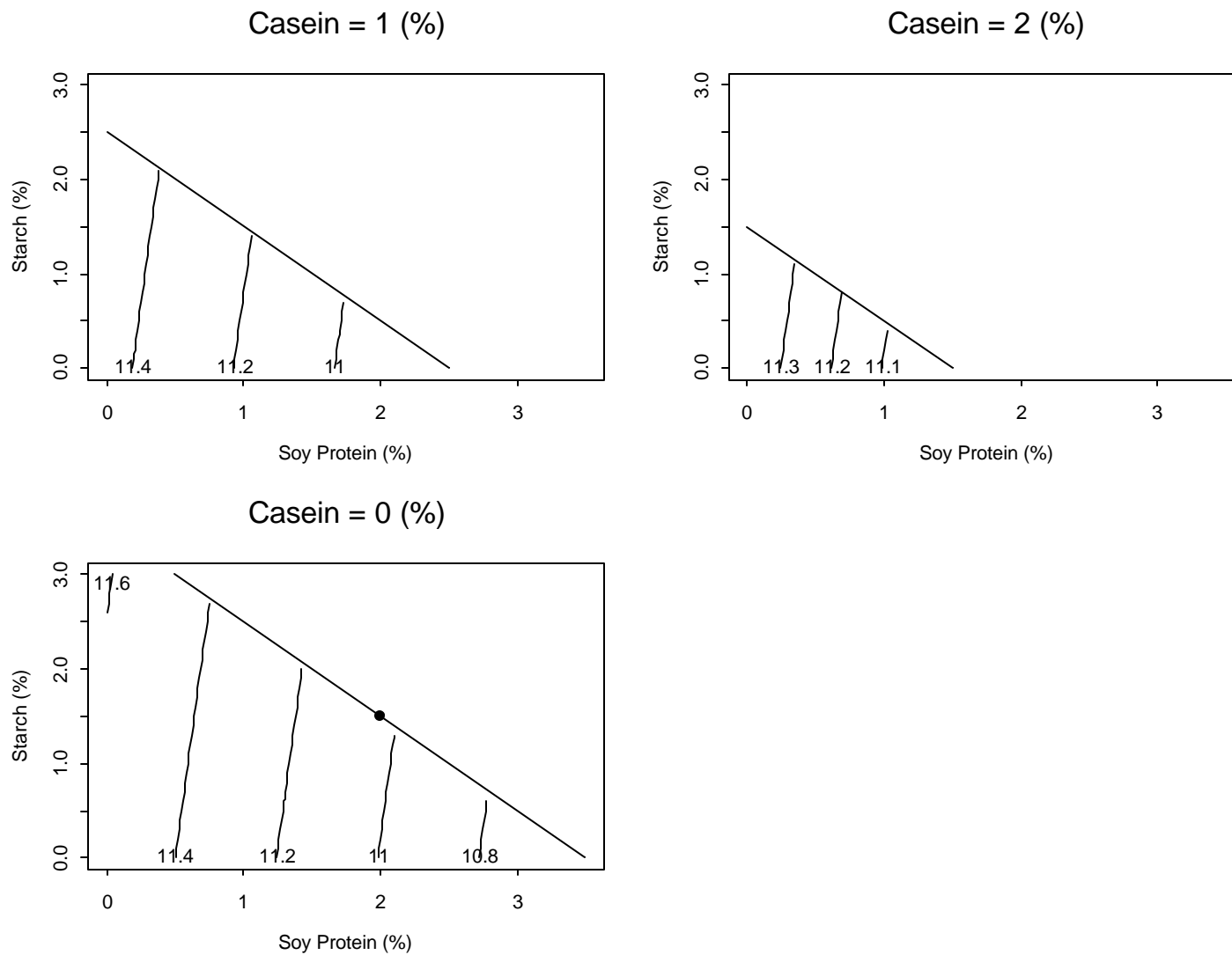
Figure 3.3 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage cooking loss (values reported within rectangles) of chunked and formed, restructured pork formulated with 25 % PSE and 75 % RFN raw material.
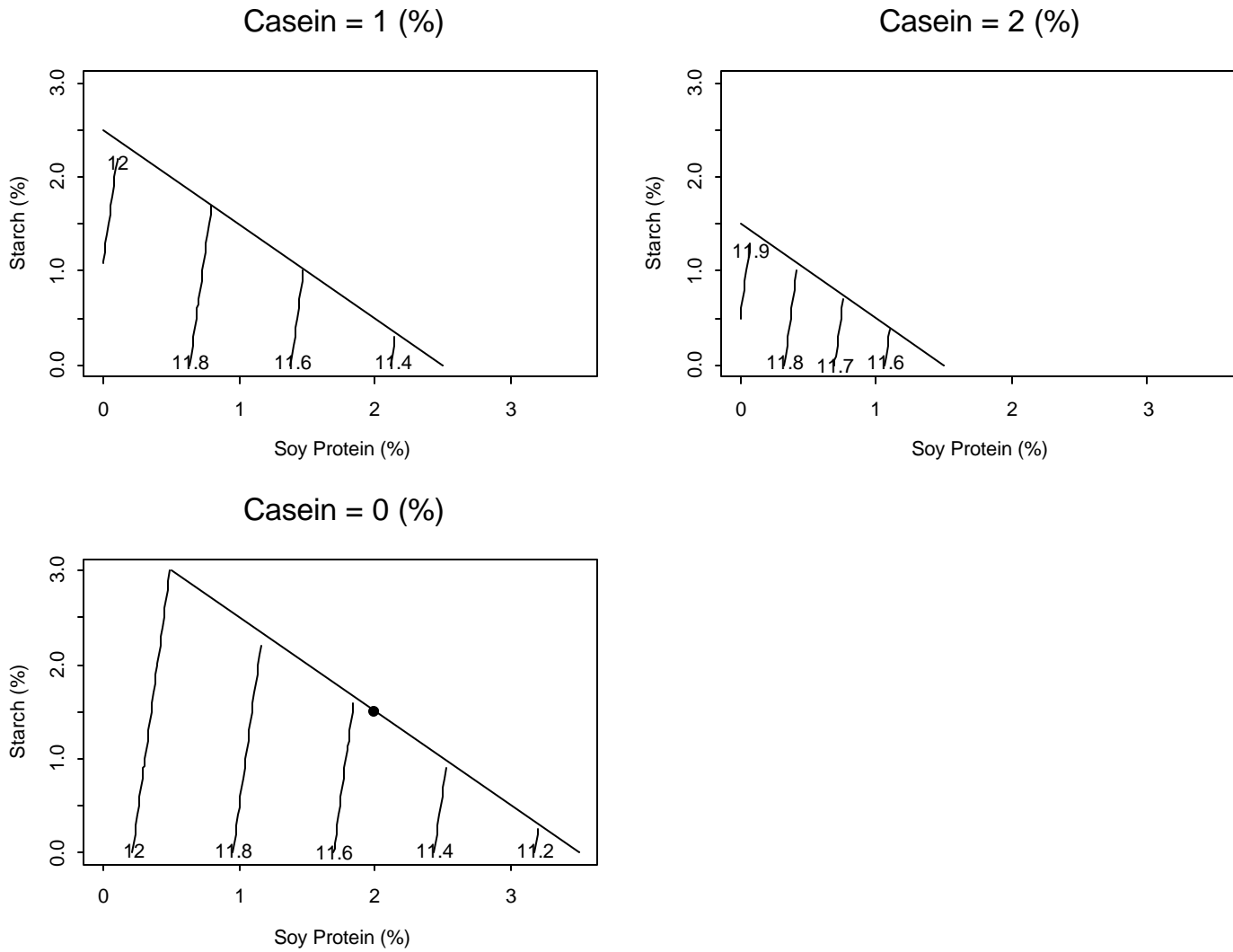
Figure 3.4 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage cooking loss (values reported within rectangles) of chunked and formed, restructured pork formulated with 50 % PSE and 50 % RFN raw material.
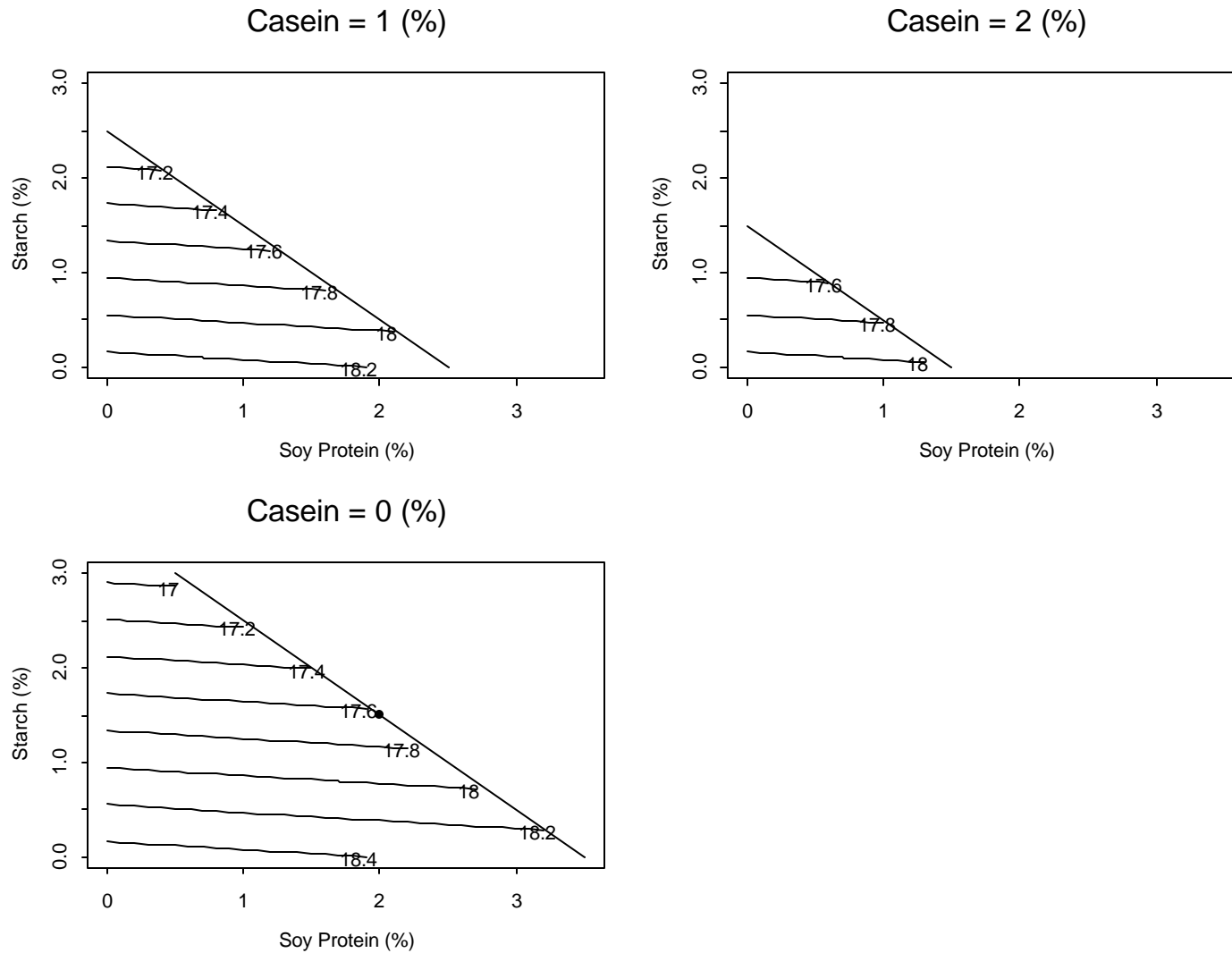
Figure 3.5 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage expressible moisture (values reported within rectangles) of chunked and formed, restructured pork formulated with 0 % PSE and 100 % RFN raw material.

Figure 3.6 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage expressible moisture (values reported within rectangles) of chunked and formed, restructured pork formulated with 25 % PSE and 75 % RFN raw material.
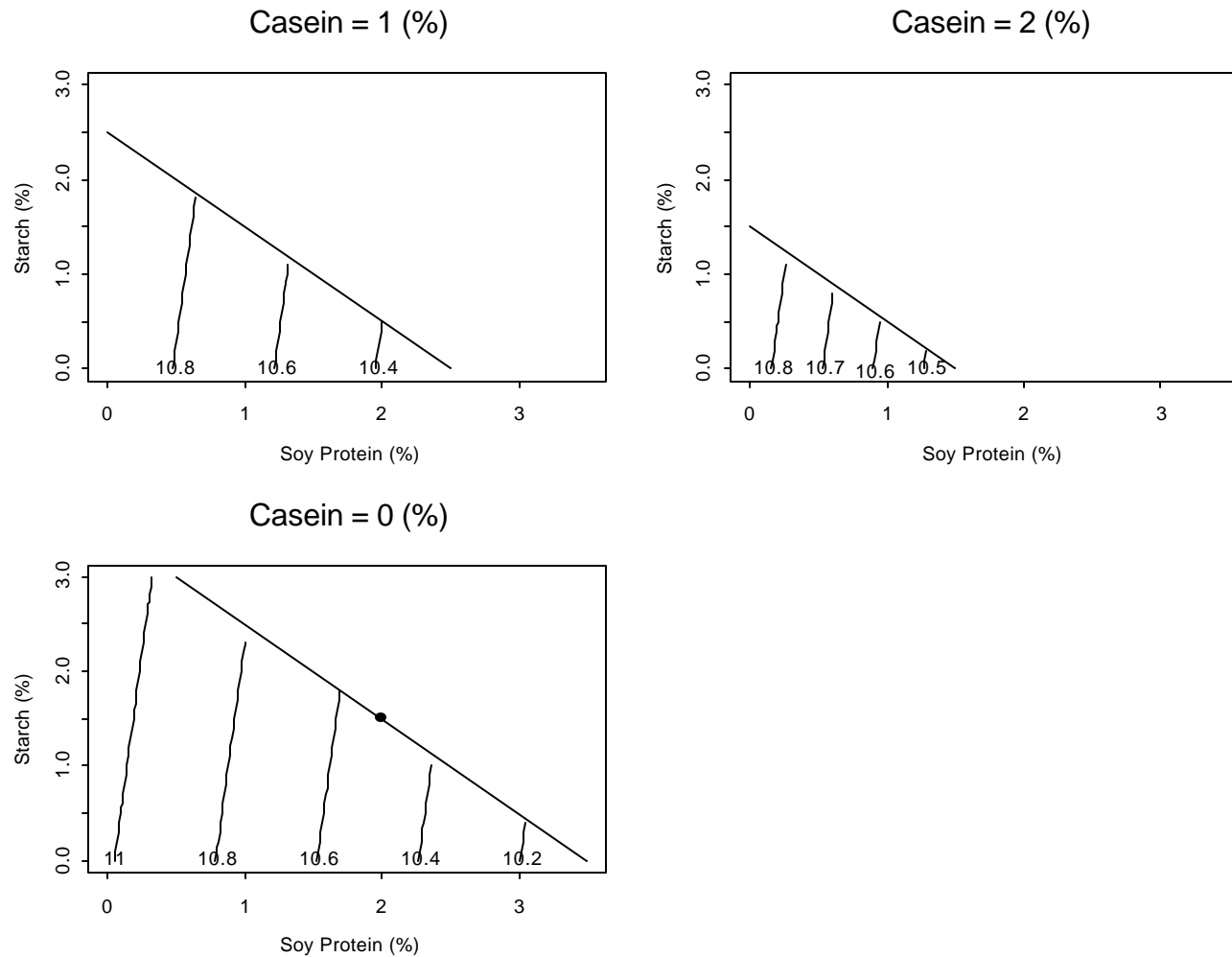
Figure 3.7 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage expressible moisture (values reported within rectangles) of chunked and formed, restructured pork formulated with 50 % PSE and 50 % RFN raw material.

Chapter 4
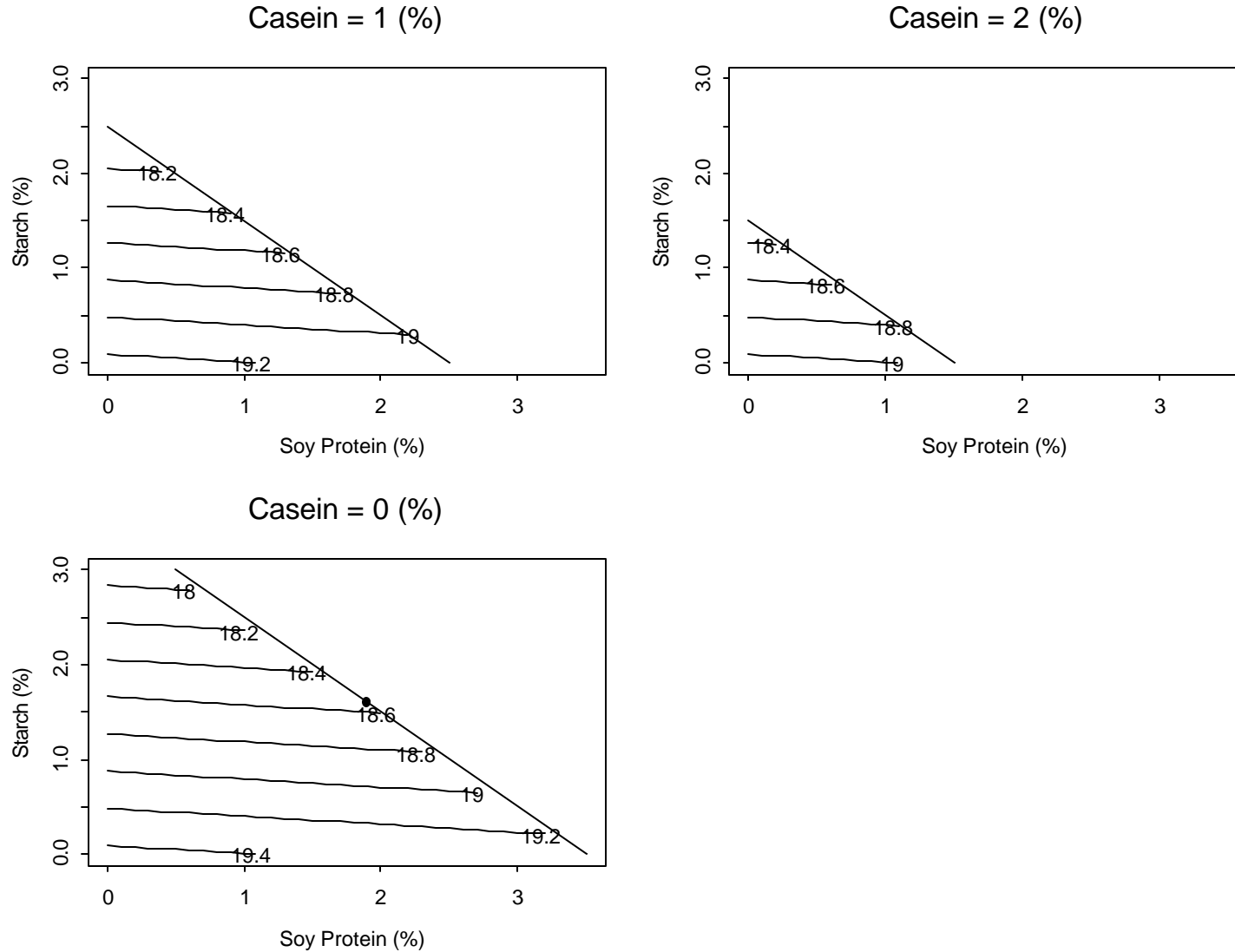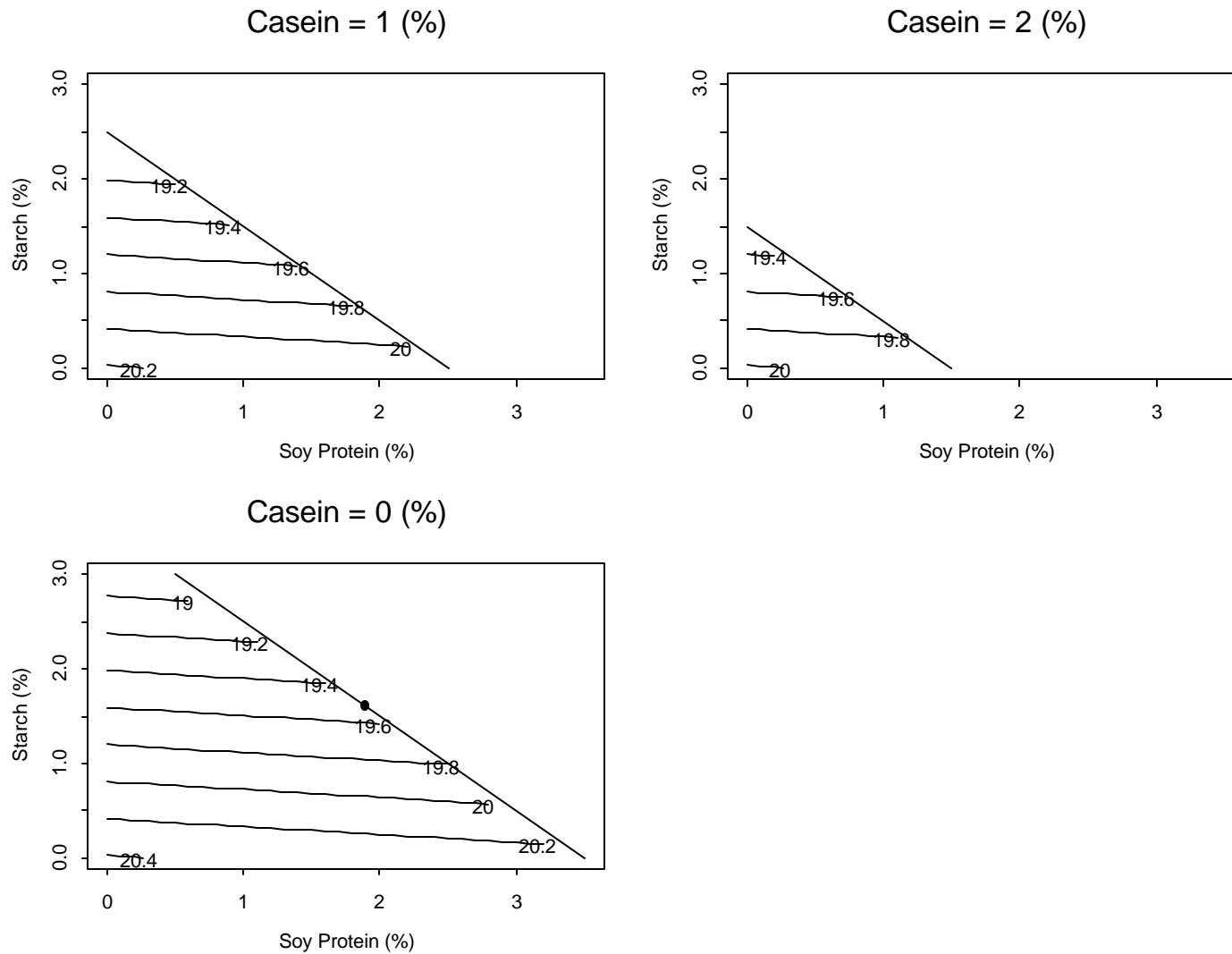## Use of Response Surface Modeling to Evaluate the Effects of
Non-meat Adjuncts and Combinations of PSE and RFN Pork on Cooked
Color in the Production of Boneless Cured Pork

4.1 Abstract

Response Surface Methodology was utilized to determine the effects of soy protein concentrate (SPC), sodium caseinate (SC), and modified food starch (MFS) on CIE L*, a*, and b* values. Chunked and formed, boneless cured pork was produced from combinations of pale, soft, and exudative (PSE) and red, firm, and non-exudative (RFN) *semimembranosus* muscle. Five PSE and RFN combinations were replicated three times for each of fifteen adjunct combinations providing 75 treatments per replication. Utilization of SPC decreased (p<0.01) cooked redness and increased (p<0.001) cooked yellowness. MFS and SC increased (p<0.05) cooked redness and decreased (p<0.01) cooked lightness. As raw CIE L* decreased and raw pH increased, lightness and yellowness decreased (p<0.05). Product formulations using SC and MFS demonstrate the potential to improve cooked color in PSE and RFN pork. This research also demonstrated that diluting RFN pork with no more than 25 % PSE pork allows the formation of a high quality boneless deli ham roll with acceptable color.

4.2 Introduction

Young (1996) stated that appearance of pork is the most essential attribute to the consumer when making purchasing decisions, and that customers will not buy a pale, soft, and watery product. Selection for leaner pork has been responsible for the genetic defect termed Porcine Stress Syndrome (PSS) that either leads to death or yields porcine muscle with a very light color, soft texture, and watery tissue (Briskey & Wismer-Pedersen, 1961). This defect is attributable to the homozygous recessive form of the halothane gene (nn) (Fuji et al., 1991). The NPPC (2000) stated that consumers will not accept fatter pork. Therefore, the industry is challenged with the task of maintaining leanness while simultaneously reducing paleness.

Breeding for heavily muscled animals promotes structural irregularities such as a high white to red muscle fiber ratio (Bandman, 1985). These structural irregularities cause pigs to be very stress susceptible. Increased stress susceptibility leads to a high incidence of pale, watery pork (Solomon et al., 1998). For this reason, selection to eliminate the halothane gene from the

genetic pool may not eradicate the incidence of low quality pork known as Pale, Soft, and Exudative (PSE) as opposed to normal Red, Firm, and Non exudative (RFN) pork.

Genetic selection and pre-slaughter stress cause rapid postmortem glycolysis that results in increased lactic acid production and decreased pH (Briskey & Wismer-Pedersen, 1961). High muscle temperature coupled with acidic pH (Camou & Sebranek, 1990) causes myofibrillar protein denaturation exceeding what is observed in normal muscle (Briskey & Wismer-Pedersen, 1961; Charpentier, 1969; Goutefongea, 1971; Bowker et al., 2000) leading to the production of pork that is soft and exudative. Kauffman and Marsh (1987) stated that myoglobin is either denatured or adsorbed on to myofibrillar proteins during their denaturation. Because of this protein denaturation/adsorption, there is an increase in paleness that is detrimental to product quality (Kauffman and Marsh 1987). Different degrees of denaturation within ham muscles leads to two-toning (Pearson and Gillett, 1996), a defect where both pale and normal color exist in different sections of the same muscle. This non-uniformity in color can be minimized through curing, but incorporation of too high of a percentage of pale or two-toned meat makes the product aesthetically undesirable.

Two ways to reduce PSE pork are to couple breeding for less heavy muscled animals with eliminating the halothane gene from breeding stock, and to reduce the exposure of pigs to short-term stress prior to slaughter. Though these options exist, the presence of a high incidence of pale meat in the industry warrants addressing the optimal utilization of PSE pork. Presently, PSE pork has poor consumer appeal and is normally blended into sausage formulations. A current challenge exists to add value to PSE pork. One possible approach is through investigating the possibility of PSE pork incorporation into the production of restructured products. To increase the feasibility of this approach, color needs to be enhanced from the raw material to the finished product so that there is uniformity, acceptable redness, and decreased lightness and yellowness.

No acceptable values for cooked color have been reported for restructured pork formulated with PSE raw material. But pork that is considered pale in color is synonymous with high CIE L* and low CIE a* values indicating a light color that is lacking redness. Zhu and Brewer (1998) found that PSE pork is lighter than RFN and DFD, and has lower a* values that decrease more rapidly over time. These scientists indicated that PSE pork was also more yellow than RFN at initial storage. Through sensory and instrumental analysis, these authors concluded

that the CIE L* value was the best single instrumental indicator of sensory redness. Brewer and McKeith (1999) reported that purchase intent paralleled overall acceptability. These authors demonstrated that color, wet/dry appearance, and overall acceptability all contributed to purchase intent. Pink PSE samples received high intent to purchase scores. These results infer that consumers only perceive very pale PSE pork as poor in quality. Therefore, consumers would perceive very light pale, cured pork as detrimental in quality.

Two areas need to be explored to resolve the optimal utilization of PSE meat in the production of boneless cured pork. First, it will not be possible to manufacture a satisfactory product from 100 % PSE pork due to myoglobin denaturation/adsorption and two toning. To formulate an acceptable restructured product, the concentration of RFN pork that should be added to PSE pork and non-meat adjuncts must be established. Second, the incorporation of non-meat adjuncts to improve the color of PSE pork through protein functionality enhancement should be explored.

Motzer et al. (1998) has explored previously the effects of combining PSE and RFN pork and beneficial adjuncts in the formulation of restructured ham. These researchers evaluated the effectiveness of water binders and an alkaline phosphate in improving color as well as increasing the protein binding and water-holding capabilities of processed hams made with differing amounts of PSE pork. Their results revealed that the combination of normal and PSE pork and the addition of binders enhanced color of restructured ham slices when compared to that made from only PSE meat. It was concluded that modified food starch and isolated soy protein demonstrated the greatest potential to decrease lightness and that restructured ham could be formulated using a percentage of PSE pork as raw material. This research suggests the questions that follow. How much RFN pork needs to be added to PSE pork to make a product that is acceptable in CIE L* and CIE b* values? What will happen if non-meat adjuncts such as starch, milk protein, and soy protein are combined in the processing of a restructured product?

Soy protein concentrate (SPC), modified food starch (MFS), and sodium caseinate (SC) are utilized in the meat industry to improve protein functionality in processed meats (Pearson and Gillett, 1996). SPC enhances water binding and gel formation (Hermansson, 1986), and MFS increases water binding and protein-protein binding in processed products (Pearson and Gillett, 1996). SC has a highly amphiphilic structure, high solubility, and high heat stability that enhance water binding, emulsification, gel formation, and other functional characteristics

(Swaisgood, 1996). These adjuncts are widely used to improve myofibrillar protein functionality, but no published research has been reported that addresses how the combination of these adjuncts would affect the color of a restructured product made formulated with a percentage of PSE pork. SPC and SC are yellow in color, providing potential for increased yellowness and paleness in processed products, which is detrimental to product quality.   No standards have been set for acceptable cooked color values described as CIE L*, a*, and b*. CIE L*, a*, and b* are measurements of lightness, redness, and yellowness, respectively. Large values for each measurement infer lighter, redder, and more yellow values. Since no baselines have been set for these values in processed products, treatments formulated with 100 % RFN samples were used as baseline values. Determination of the utility of the non-meat adjuncts for improvement of the acceptability 25 % PSE+75 % RFN and 50 % PSE+ 50 % RFN ham rolls to approach the quality of ham rolls made with 100 % RFN pork was performed.

Since sources report that over 70 % of pork is exudative and between 10 and 30 % is pale (Kauffman et al., 1992, McKeith et al., 1994), the acceptability of these raw materials must be improved. Thus, the functional properties of PSE pork should be improved so that it can be formulated into products that could improve its value and increase its usability in processed meats. Improved consumer acceptability would enhance the value of pork with increased income to the meat industry.

4.3 Materials and Methods

4.3.1 Porcine Raw Materials

Both RFN pork and PSE pork were selected based on visual color such that the following treatment combinations could be processed: 100 % PSE, 75% PSE +25 % RFN, 50 % PSE+ 50 % RFN, 25 % PSE +75 % RFN, and 100 % RFN. Porcine *semimembranosus* and *adductor* muscles were obtained from a pork packing plant in Virginia. All samples were selected from National Pork Development (NPD) pork carcasses harvested from market age pigs that weighed 110-125 kg. RFN samples were identified as having a CIE L* < 50 and PSE samples were identified as having a CIE L* > 53.

4.3.2 Sample Processing

The brine solution was formulated consisting of added water (18 % meat weight basis (MWB)), sodium chloride (2 % MWB)), sodium tripolyphosphate (0.5 % MWB), dextrose (1 % MWB), sodium nitrite (156 ppm), and sodium erythorbate (0.042 % MWB). Ice was added to reduce the brine temperature to 4-6° C. Soy protein concentrate (SP, Promine DS, Central Soya, Fort Wayne, IN), sodium caseinate (SC, Alanate 191, New Zealand Milk Products Inc. Santa Rosa, CA), and modified food starch (MFS, Pure-Gel B990, Grain Process Corporation, Muscatine, IA) were added to the brine in appropriate treatments based on the MWB. S*emimembranosus* and adductor muscles were then hand diced into 2.5 cm by 2.5 cm cubes and 1.36 kg of this raw material was utilized in the formulation of each treatment. Ten percent of the meat in each treatment was ground with a food processor (Model HC3000, Black & Decker, Shelton, CT) to increase bind. The brine for each treatment was poured onto the meat samples after placing them inside a vacuum tumbler (Model Inject Star MC 20/40/60/80-226, Inject Star of the Americas, Brookfield, CT). The samples and brine were then tumbled under vacuum for 1.5 hr at 4° C, stopping every 15 min for a rest period of 10 min to enhance brine absorption. Each ham treatment was stuffed into the casings (Model Reg Fib CSG 5*25 Light PS, Viskase, Chicago, IL) manually, and a Tipper Tie (Model PRA65L, Tipper Tie, Apex, NC) was used to seal the casings. The samples were stored for approximately 16 hrs (4° C). The next day, the product was processed in a smokehouse (Model 1000, Alkar, Lodi, Wisconsin) to an internal temperature of 69 ^{o} C. The smokehouse schedule was 1 hr for 54 ^{o}C dry bulb and no wet bulb, 2 hr for 66 ^{o}C dry bulb and 47 ^{o}C wet bulb, 1 hr for 71 ^{o}C dry bulb and 57 ^{o}C wet bulb, and approximately 1 hr 15 min for 88 ^{o}C dry bulb and 74 ^{o}C wet bulb. The boneless hams were immediately cold showered for 15 min (10 ^{o}C <) and then stored at 4 ^{o}C for 16 hr prior to slicing of the products. Ham rolls were sliced into 12.7 mm thick slices, packaged aerobically, and stored (4° C) for cooked color measurements to be performed within 72 hr.

4.3.3 Moisture Analysis, Protein Analysis, and pH

Percentage moisture was measured (39.1.02, AOAC, 1995) in triplicate for each muscle using a drying oven (Model OV-490A-2, Blue, Blue Island, IL). The pH of each *semimembranosus/adductor* muscle was taken in triplicate. pH was determined by removing three 2-g samples from three similar anatomical locations on each of the muscles and homogenized (Virtishear Model.225318, The Virtis Company, Inc., Gardener, NY) for 1 min in

20 mL of distilled deionized water. pH was measured for the individual samples with a calibrated pH meter (Model AR25, Fisher Scientific, Pittsburgh, PA) and a pH electrode (Model 13-620-298, Fisher Scientific, Pittsburgh, PA). Percentage Moisture (39.1.02, AOAC, 1995) was measured in triplicate for each muscle using a drying oven (Model OV-490A-2, Blue, Blue Island, IL). Percentage protein was measured (39.1.02, AOAC, 1995) in duplicate using a Kjeldahl extraction apparatus (Model Rapid Still II, Labconco Corp., Kansas City, MO). All of these chemical analyses were repeated for each treatment of processed ham rolls.

4.3.4 Instrumental Color Determination

Two randomly selected ham slices from each treatment were used to evaluate cooked color. Four measurements were be taken for each slice, and CIE L*a*b* values were determined using a chroma meter (Model CR-200, Minolta Camera Co., Ltd., Osaka Japan). The chroma meter was calibrated using a standard Minolta calibration plate (white plate, No. 20933026; CIE L* 97.91, a* -0.70, b* +2.44) each time prior to testing.

4.3.5 Statistical Analysis

The experimental design is a constrained modified simplex mixture (Figure 4.1) with 15 combinations of 3 factors (MFS, SC, SP) crossed with 5 treatment combinations of PSE and RFN (Table 4.1). Each of these combinations was replicated 3 times. Treatment combinations of SC, SP, and MFS were incorporated within legal levels as defined by the USDA (9CFR, 318 and 319) chosen by Design Expert (Design-Expert 5, Stat Ease Inc., Minneapolis, MN) to optimize the design so that the maximum amount of information about adjunct effect on cooked color could be obtained. This experimental design allows the fitting of a second order model to test main, interaction, and quadratic effects for all factors of interest as well as makes it possible to estimate a combination of factors to optimize a variety of responses. Percentage raw moisture and protein, raw pH, and raw color were also included in the regression model as main effects to provide as much information about the model as possible. Analysis with the statistical package SAS (Version 8.12, 2001, SAS, Cary, NC) was conducted to determine the cooked color at various percentages of PSE pork.

4.4 Results and Discussion

4.4.1 Cooked Color Models

 For each of CIE L*, CIE a*, and CIE b*, no interaction (p>0.05) existed between PSE and sodium caseinate, modified food starch, or soy protein concentrate. This lack of interaction deemed it appropriate to utilize models for data collected from all levels of PSE instead of creating different models for each level. These models were statistically significant (p<0.05) and were successful in explaining lightness, redness, and yellowness (eqns. 1,2, and 3), and partial F tests were performed to determine if quadratic terms and covariates were needed in the model to help explain cooked color. Quadratic terms were not needed (p>0.05) in the models but covariate terms (raw CIE L*, raw CIE a**,** raw CIE b*, raw pH, raw moisture, and raw protein percentage) did add (p<0.05) significant information to the three models (SAS, 1999). The final models were selected as linear models with covariates added. The R^2 for the models were 0.47,0.36, and 0.63 for CIE L*, a*, and b* respectively, suggesting that there was high variation among experimental units in each quality classification. This variation is undesirable for experimental purposes, but this design was necessary since the industry would formulate a chunked and formed product similarly, and one research goal was to provide a product that the industry could utilize.

 Three (MFS, SC, and raw CIE L*), five (MFS, SC, SPC, raw CIE L*, and CIE a*) and, three (SPC, raw CIE L*, and raw pH) independent variables were significant (p<0.05) in explaining lightness, redness, and yellowness, respectively. All terms were included in the models since there was so much unexplained variation in the model due to variability in the raw material (Myers and Montgomery, 1995). The models take the form of the following multiple linear regression model:

$y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + B_7X_7 + B_8X_8 + B_9X_9 + B_{10}X_{10} + \varepsilon.$ The explanation of these terms is included in Table 4.2. The assumptions of the model are that the $E(\varepsilon) = 0$**,** Var $(\varepsilon) = $ constant, and that ε_i's are independent of each other and follow a normal distribution. These assumptions allow appropriate tests to be performed to determine if the variables are statistically significant (p<0.05). Under these assumptions, the B hats are the maximum likelihood estimators, and the models for cooking loss and expressible moisture are estimable.

4.4.3 Cooked CIE L* Values

Equation 1: CIE L* = 63.5 + 0.52*PSE - **0.43*MFS** - 0.095*SPC - **0.50*SC** + 0.33*moisture
+ 0.18* prot + **2.33*CIE L*** - 0.53* CIE a* - 0.90*CIE b* - 1.25 *pH raw

SC and MFS decreased (p<0.01) CIE L* value, indicating improved color. Cooked CIE
L* increased (p<0.05) as the CIE L* values of the raw material increased. Cooked CIE L* was
not affected (p>0.05) by the factor percentage of PSE pork incorporated into the product, but this
can be attributed to the factors of raw material CIE L* and % PSE contributing similar
information to the model in explaining cooked CIE L* values. MFS and SC's ability to decrease
lightness may be due to their ability to improve water holding capacity, thus tightening the
structure and causing more reflection. This theory is not applicable to SPC since its yellow color
may increase the lightness of the product. Motzer et al. (1998) reported differences (p<0.05)
between cooked 0, 50, and 100 % PSE products with CIE L* values of 62.24, 64.7, and 66.57,
respectively. Figure 1 reveals that the optimal adjunct combination for CIE L* is 2 % sodium
caseinate (SC) and 1.5 % modified food starch (MFS) incorporation resulting in a CIE L* value
of 59.3. Similarly, Motzer et al. (1998) reported that 2 % MFS or 1.5 % isolated soy protein
(ISP) incorporation decreased (p<0.05) CIE L* values in hams from 65.52 to 63.76 and 64.43,
respectively that were water cooked in bags. Their results differ from our data in that SPC did
not decrease (P>0.05) CIE L* in our experiment and because they did not incorporate SC into
any formulations. These differences can be attributable to the utilization of different soy
proteins, surface area of raw material, and cookery method.

Figures 4.2, 4.3, and 4.4 were produced for 0, 25 and 50 % PSE treatments with
covariates held constant at their means to demonstrate how CIE L* values are affected by MFS,
SPC, and SC incorporation. Utilization of 25 % PSE pork increased CIE L* by 1.4 to 60.7
(Figures 4.2,4.3), suggesting that lightness would not be a problem when 0 to 25 % PSE pork is
incorporated into the product. These results will vary depending on the type of processed
product being formulated and the severity of the PSE condition in the raw material. The
minimum values of 60.7 (Figure 4.3) for 25 % PSE incorporation is lower than the (Figure 4.2)
value that was obtained for the 0 % PSE treatment (60.8) with no adjuncts incorporated. The
prediction value (60.8) is used as the baseline to what an acceptable boneless deli ham is since it
is known that 100 % RFN pork with no adjuncts formulates a high quality product. The 50 %

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PSE treatment is minimized at 62.1 (Figure 3), 1.3 units higher than the control with no adjuncts. These results demonstrate the potential of starch and casein to decrease lightness with products formulated with 25 % PSE to values similar to 100 % RFN treatments with no adjuncts.

Results demonstrated that utilization of 25 or 50 % PSE in the experimental restructured product did increase CIE L* values. However, it may still be practical to produce these products since the increase in CIE L* value does not outweigh the changes in value that could be induced through using this low value raw material. All samples that measured under 63 in CIE L* values were aesthetically pleasing. This statement is supported by the observation that samples greater than 63 were visually pale, yellowish, were exudative, and had cracked texture. Results also infer that utilizing 25 % PSE pork would produce a product that is acceptable in lightness at almost all adjunct combinations. Therefore, whatever adjunct combination provides the greatest yields with acceptable color (1.5 % MFS and 2 % SPC, Chapter 3) should be utilized when no more than 25 % PSE pork is incorporated into the product.

4.4.3. Cooked CIE a* Value

Equation 2: CIE a* = 15.2 + 0.18*PSE + **0.14*MFS** - **0.22*SPC** + **0.17*SC** - 0.31*moisture
              -0.27* prot **-0.98*CIE L*** + **0.51*CIE a*** + 0.16*CIE b* + 0.27 *pH raw

SC, MFS, and raw CIE a* value increased (p<0.05) redness, indicating improved color. Cooked CIE a* decreased (p<0.01) as SPC inclusion and CIE L* values of the raw material increased (p<0.05). Cooked CIE a* values were not affected (p>0.05) by the factor percentage of PSE pork incorporated into the product, but this can be attributed to CIE L* and CIE a* of the raw material and % PSE contributing similar information to the model in the explanation of cooked CIE a* values (Zhu and Brewer, 1999). MFS and SC's ability to increase redness may be due to their ability to improve water holding capacity, thus tightening the structure and causing more reflection. This theory would not work for SPC since its yellow color could lessen the redness of the product. Motzer et al. (1998) reported differences (p<0.05) between 0 and 50 and 0 and 100 % PSE, but no differences between 0 and 50 % treatments. 0, 50, and 100 % treatments had CIE a* values of 11.79, 11.67, and 11.19, respectively. Their data imply that redness, which is correlated with cured color, is not greatly affected by % PSE incorporation.

Figures 4.5, 4.6, and 4.7 were produced for 0, 25 and 50 % PSE treatments with covariates held constant at their means to demonstrate how CIE a* values are affected by MFS, SPC, and SC incorporation. Figure 4.5 reveals that the optimal adjunct combination for CIE a*

is 2 % sodium caseinate (SC) and 1.5 % modified food starch (MFS) incorporation resulting in a CIE a* of 16.5. This blend is the same combination that provided optimal CIE L* values in the experiment. Motzer et al. (1998) reported that incorporation of MFS and ISP, or any other adjunct did not affect (p>0.05) CIE a* values. Differences in results between experiments could be due to different cookery method, raw material surface size, and statistical sample size.

Utilization of 25 % PSE pork decreased CIE a* from 16.5 to 16.2 (Figures 4.5, 4.6), suggesting that redness would not be a problem when 0 to 25 % PSE pork is incorporated into the product. The maximum value of 16.2 (Figure 4.6) for 25 % PSE incorporation is higher than the values (Figure 4.5) that were obtained for the 0 % PSE treatment (15.7) with no adjuncts incorporated. The prediction value (15.7) is used as the baseline to what a very acceptable boneless deli ham is since it is known that 100 % RFN pork with no adjuncts formulates a high quality product. The 50 % PSE treatment is maximized at 15.9 (Figure 4.7), 0.2 units higher than the control with no adjuncts. These results demonstrate the potential of starch and casein to increase redness with products formulated with 25 % and 50 % PSE to values similar to 100 % RFN treatments with no adjuncts.

4.4.4 Cooked CIE b* Value

Equation 3: CIE b* = 5.64 + 0.085*PSE - 0.0098*MFS + **0.40*SPC-** 0.026*SC + 0.12*moisture
-0.054* prot + **0.73*CIE L** * - 0.14*CIE a* + 0.13*CIE b** - 0.64 *pH raw**

SPC increased (p<0.0001) yellowness, an attribute that is detrimental to product quality. Cooked CIE b* values increased as pH decreased (p<0.01) and CIE L* values of the raw material increased (p<0.01). Similarly to cooked CIE L* value, cooked CIE b* value was not affected (p>0.05) by percentage of PSE pork incorporated into the product, but this observation can be attributable to CIE L* of the raw material and percentage PSE contributing similar information to the model in the explanation of cooked CIE b* values (Zhu and Brewer, 1999). Motzer et al. (1998) reported increased yellowness (p<0.05) as percentage of PSE incorporated increased from 0 to 50, to 100 % with values of 4.97, 6.07, and 6.59, respectively. Their data implies that yellowness is affected by percentage PSE incorporation. SPC's increase in yellowness may be due to its yellow color, but results from Motzer et al. (1998) in pork and Brewer et al. (1992) in ground beef report no difference in yellowness in samples treated with and without isolated soy protein or soy protein concentrate.

Figures 4.8, 4.9, and 4.10 were produced for 0, 25 and 50 % PSE treatments with covariates held constant at their means to demonstrate how CIE b* values are affected by MFS, SPC, and SC incorporation. Figure 4.8 reveals that the optimal adjunct combination for CIE b* is no SPC inclusion with any other adjunct combination between MFS and SC with a CIE b* value of 4.6. Motzer et al. (1998) reported that incorporation of MFS and ISP, or any other adjunct did not affect (p>0.05) yellowness. Similar to earlier comparisons made, differences in results between experiments could be due to different cookery method and utilization of a soy protein with a higher carbohydrate and lower protein concentration (Ashbridge, 1995), as well as different statistical sample size.

Utilization of 25 % PSE pork increased CIE b* from 4.6 to 5.1 (Figures 4.8, 4.9), suggesting that yellowness would not be prominent when 0 to 25 % PSE pork is incorporated into the product. The minimum value of 5.1 (Figure 4.9) for 25 % PSE incorporation is higher than the (Figure 4.8) value that was obtained for the 0 % PSE treatment (4.6) with no adjuncts incorporated. The 50 % PSE treatment is minimized at 5.6 (Figure 9), 1 unit higher than the control with no adjuncts. These results reveal the effect of PSE meat and SPC on yellowness. When values started to exceed 6, the product appeared very yellow and pale. This statement is supported by the observation that samples greater than 6 were generally visually pale, yellowish, exudative, and had cracked texture. These results demonstrate that 50 % PSE pork can be incorporated into a product without affecting yellowness too negatively, but that no more than 25 % PSE should not be incorporated with SPC to prevent an undesirable appearance.

Since results infer that utilizing 25 % PSE pork would produce a product that is acceptable in lightness (CIE L* value) at any adjunct combination, whatever adjunct combination provides the greatest yields should be utilized when no more than 25 % PSE pork is incorporated into the product (1.5 % MFS and 2 % SC, Chapter 3).

4.4.5 Product Acceptability

It is not practical to formulate products with 50 % PSE because the raw material increases product paleness and SPC increases yellowness. But 25 % PSE pork would be practical, and some values between 25 and 50 % could also be used. Although, our data demonstrates the practicality of utilizing 25 % PSE pork at any adjunct combination, it is impractical to incorporate 50 % PSE into products due to paleness, poor cohesiveness (Chapter 5), and non-uniformity of color.

4.5 Conclusions

Utilization of 2 % sodium caseinate (SC) and 1.5 % modified food starch (MFS) in product formulation gives optimal results for improving color at all levels of % PSE incorporation. The CIE L* value is lower than the 100 % RFN treatment with no adjuncts added to the formulation at 60.8, but the CIE b* value is larger at 4.8. This observation demonstrates that it is economically favorable to incorporate PSE pork into chunked and formed products at 25 %. This research demonstrates that though MFS and SC incorporation improves color, it is practical to utilize whatever adjuncts provide the best overall protein functionality (1.5 % MFS and 2 % SC, Chapter 3, 5) as long as no more than 25 % of PSE meat is incorporated in the product.

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Table 4.1 - Ingredient combinations[a] of meat adjuncts used in the processing of restructured ham roll.

Treatment Combination #	Ingredients		
	Modified Food Starch	Soy Protein	Sodium Caseinate
1	0 %	3.5 %	0 %
2	0 %	0 %	0 %
3	3 %	0 %	0.5 %
4	0 %	1.5 %	2 %
5	0 %	0 %	2 %
6	2 %	0 %	0 %
7	2 %	1.5 %	0 %
8	0 %	2 %	0 %
9	1.5 %	0 %	2 %
10	1.33 %	0.7 %	0.81 %
11	0.67 %	2.1 %	0.42 %
12	0.67 %	0.35 %	0.42 %
13	0.5 %	0.5 %	2 %
14	0 %	1.25 %	1 %
15	1.5 %	1.16 %	0 %

[a] All combinations were used for each treatment combination of red, firm, and non-exudative (RFN) and pale, soft, and exudative (PSE) meat.

Table 4.2: Explanation of the terms in the multiple linear regression (response surface) model associated with cooking loss and expressible moisture.

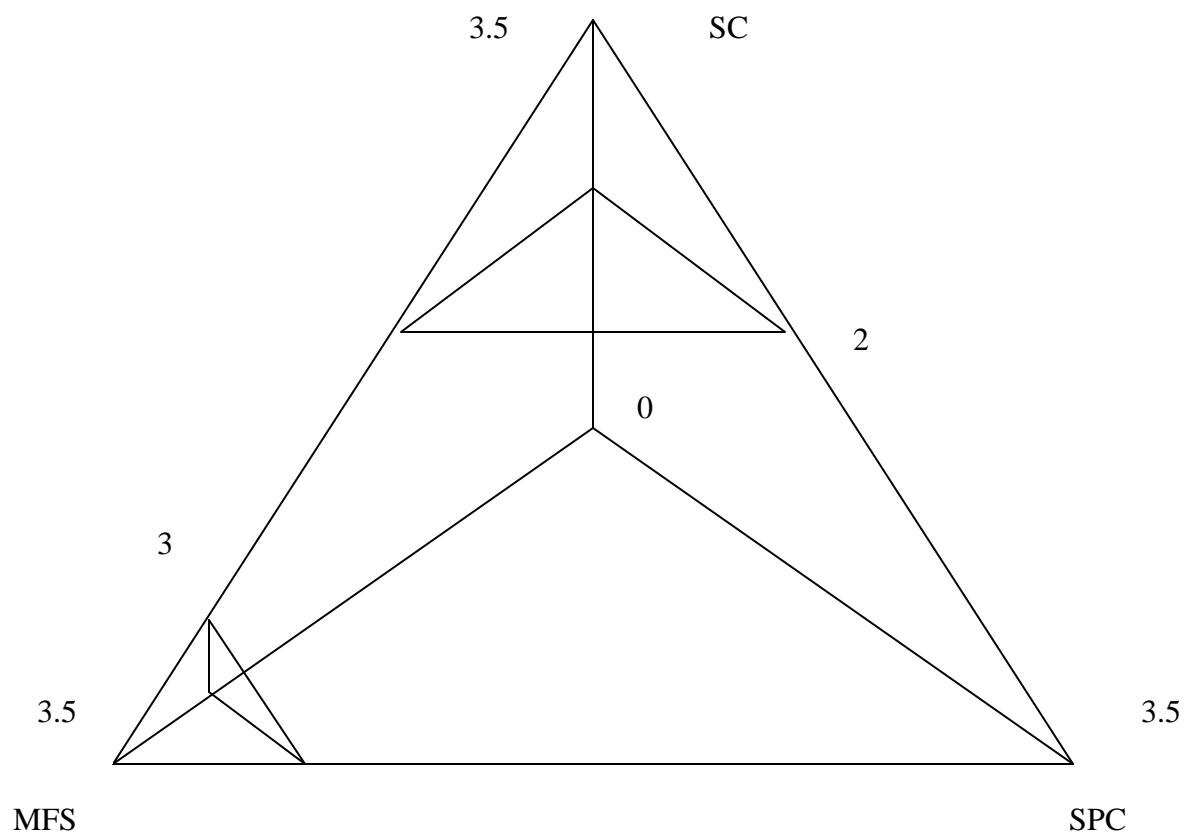| Variable	Definition
B_0 = Intercept	The predicted value of the response when no adjuncts are added and all covariates are at their means
B_1	The amount that the response is predicted to change when PSE is changed from 0 to 1 in the product and all other variables remain constant
B_2	The amount that the response is predicted to change per additional 1 % MFS incorporation into the product when all other variables remain constant
B_3	The amount that the response is predicted to change per additional 1 % SPC incorporation into the product when all other variables remain constant
B_4	The amount that the response is predicted to change per additional 1 % SC incorporation into the product when all other variables remain constant
B_5	The amount that the response is predicted to change per 1 unit change in the moisture value on a standardized –1 to 1 scale when all other variables remain constant
B_6	The amount that the response is predicted to change per 1 unit change in the protein value on a standardized –1 to 1 scale when all other variables remain constant
B_7	The amount that the response is predicted to change per 1 unit change in the CIE L* value on a standardized –1 to 1 scale when all other variables remain constant
B_8	The amount that the response is predicted to change per 1 unit change in the CIE a* value on a standardized –1 to 1 scale when all other variables remain constant
B_9	The amount that the response is predicted to change per 1 unit change in the CIE b* value on a standardized –1 to 1 scale when all other variables remain constant
B_{10}	The amount that the response is predicted to change per 1 unit change in the pH value on a standardized –1 to 1 scale when all other variables remain constant
X_1	% PSE incorporated into product on 0 to 1 scale
X_2	MFS incorporated into product on 0 to 3 scale
X_3	SPC incorporated into product on 0 to 3.5 scale
X_4	SPC incorporated into product on 0 to 2 scale
X_5	Percentage moisture on a –1 to 1 standardized scale
X_6	Percentage protein on a –1 to 1 standardized scale
X_7	CIE L * value on a –1 to 1 standardized scale
X_8	CIE a * value on a –1 to 1 standardized scale
X_9	CIE b * value on a –1 to 1 standardized scale
X_{10}	pH on a –1 to 1 standardized scale

Figure 4.1 - Modified Simplex Design Structure for the Response Surface Design Utilized. This is the region where predictions can be estimated based on inclusion of modified food starch (MFS), soy protein concentrate (SPC), and sodium caseinate (SC).
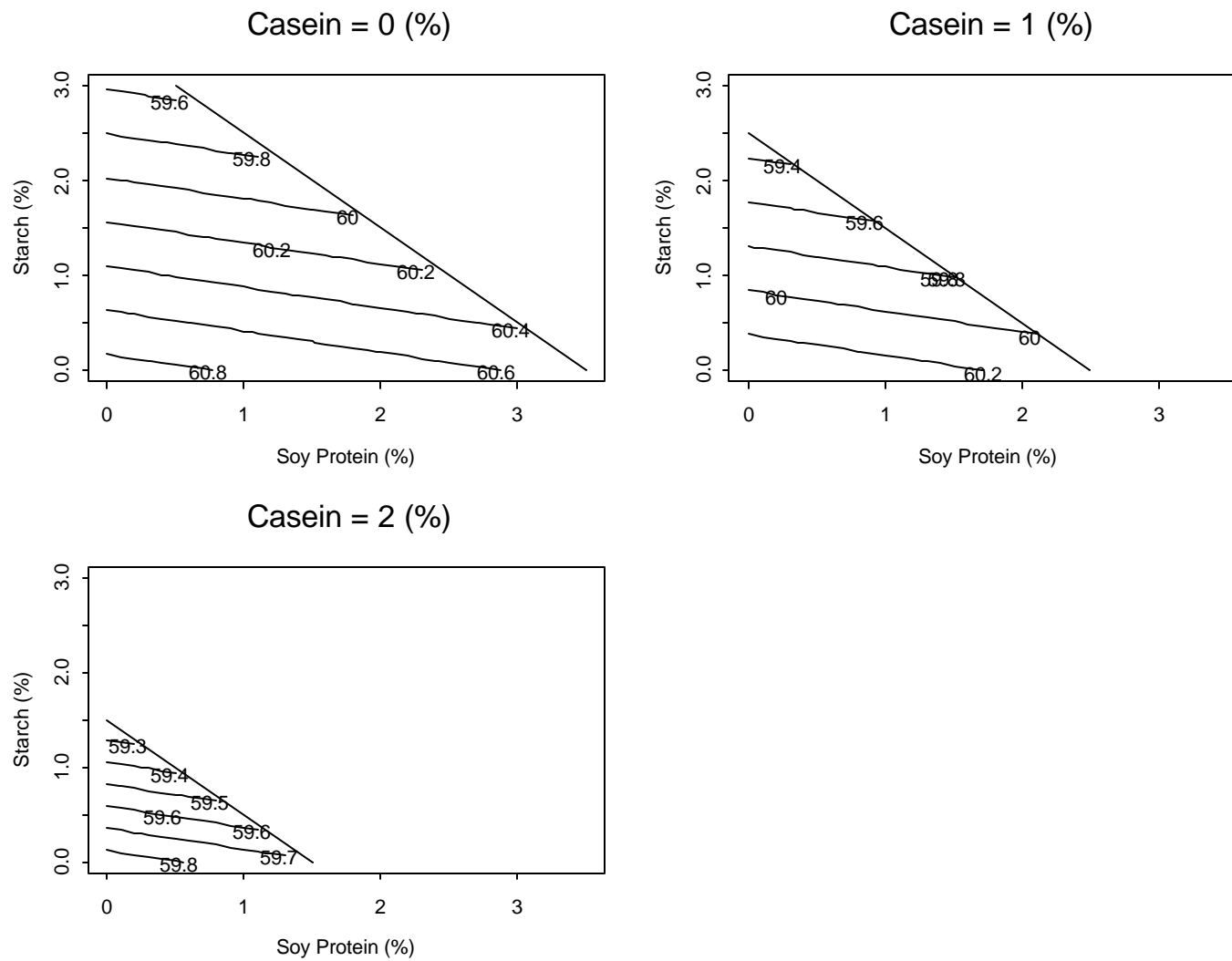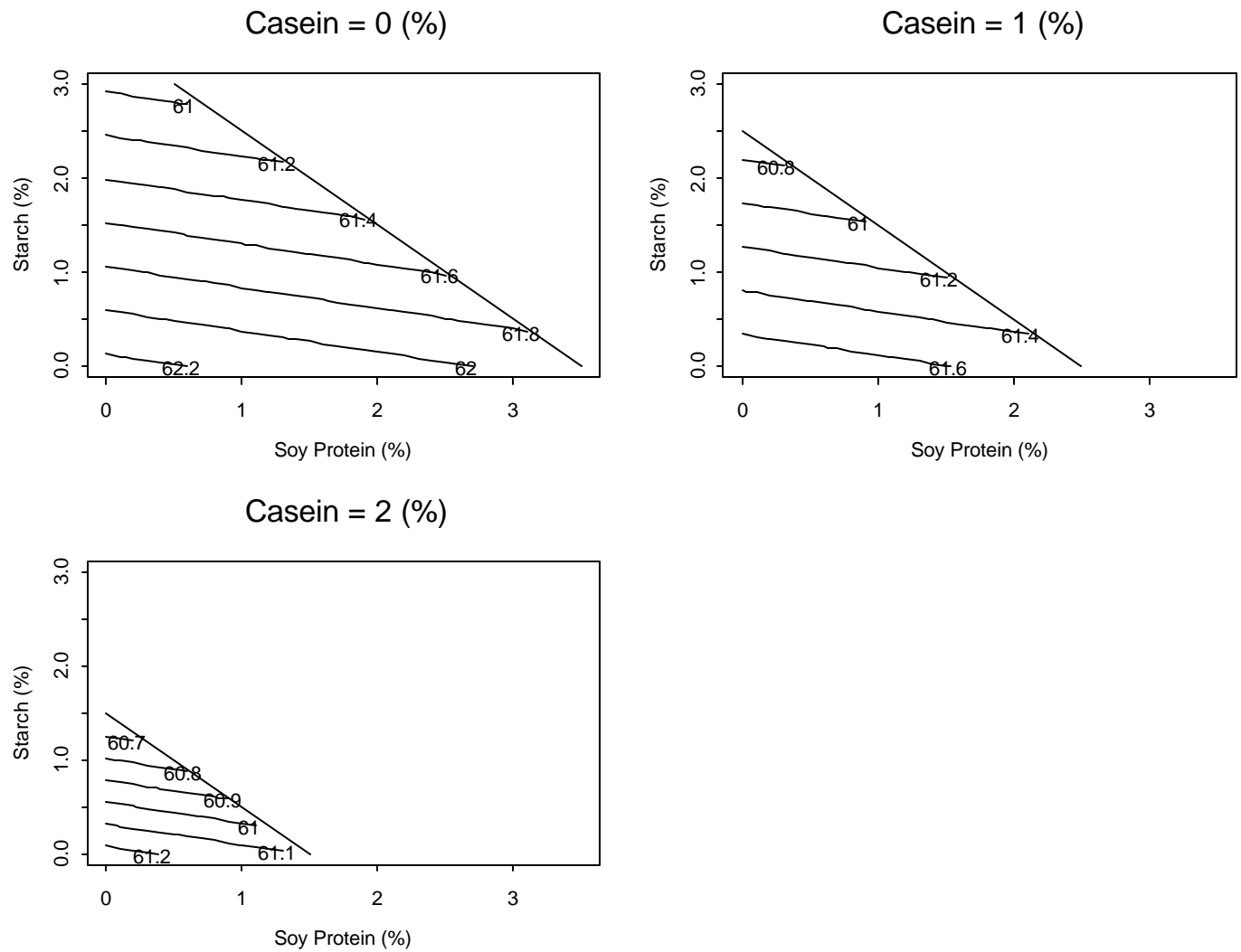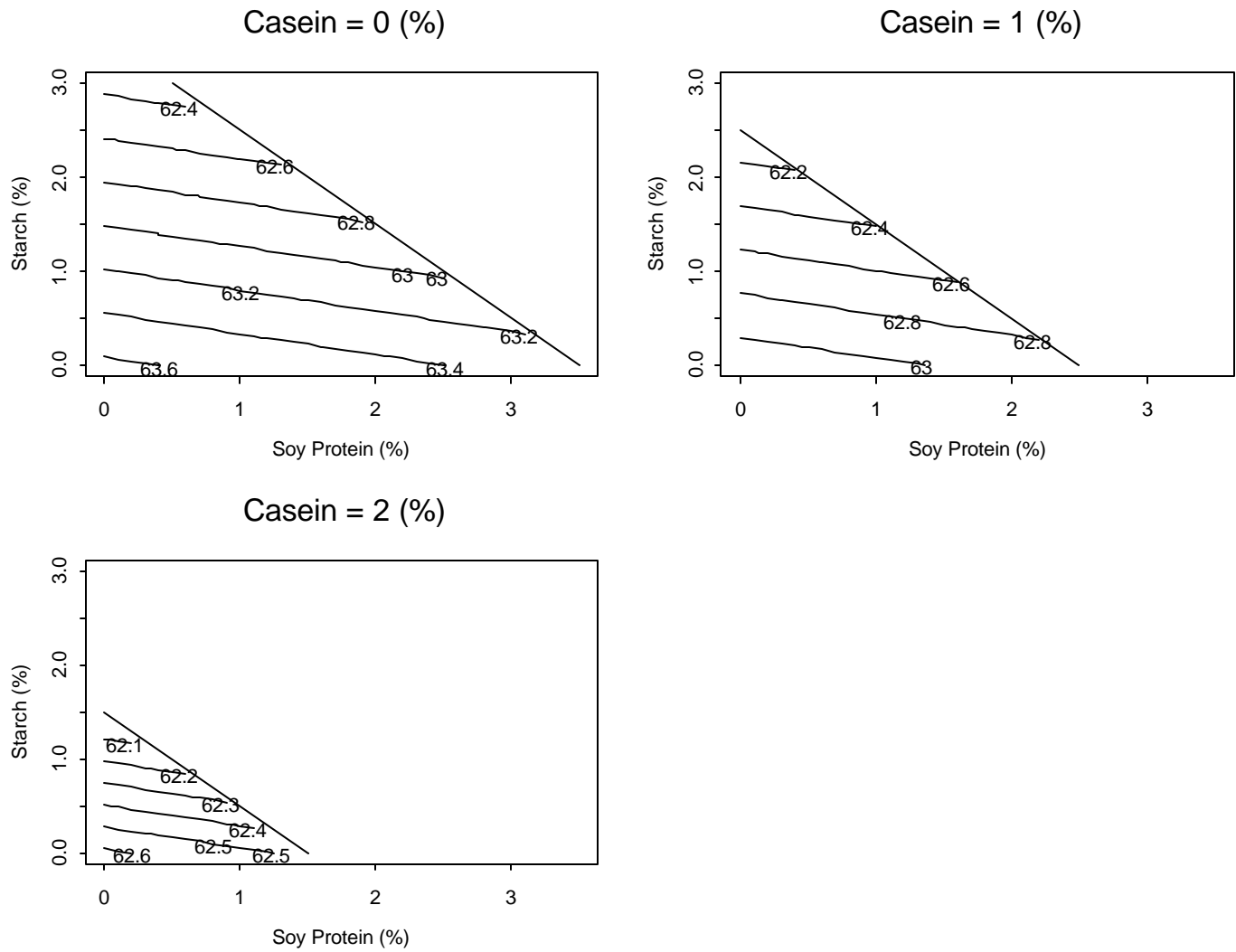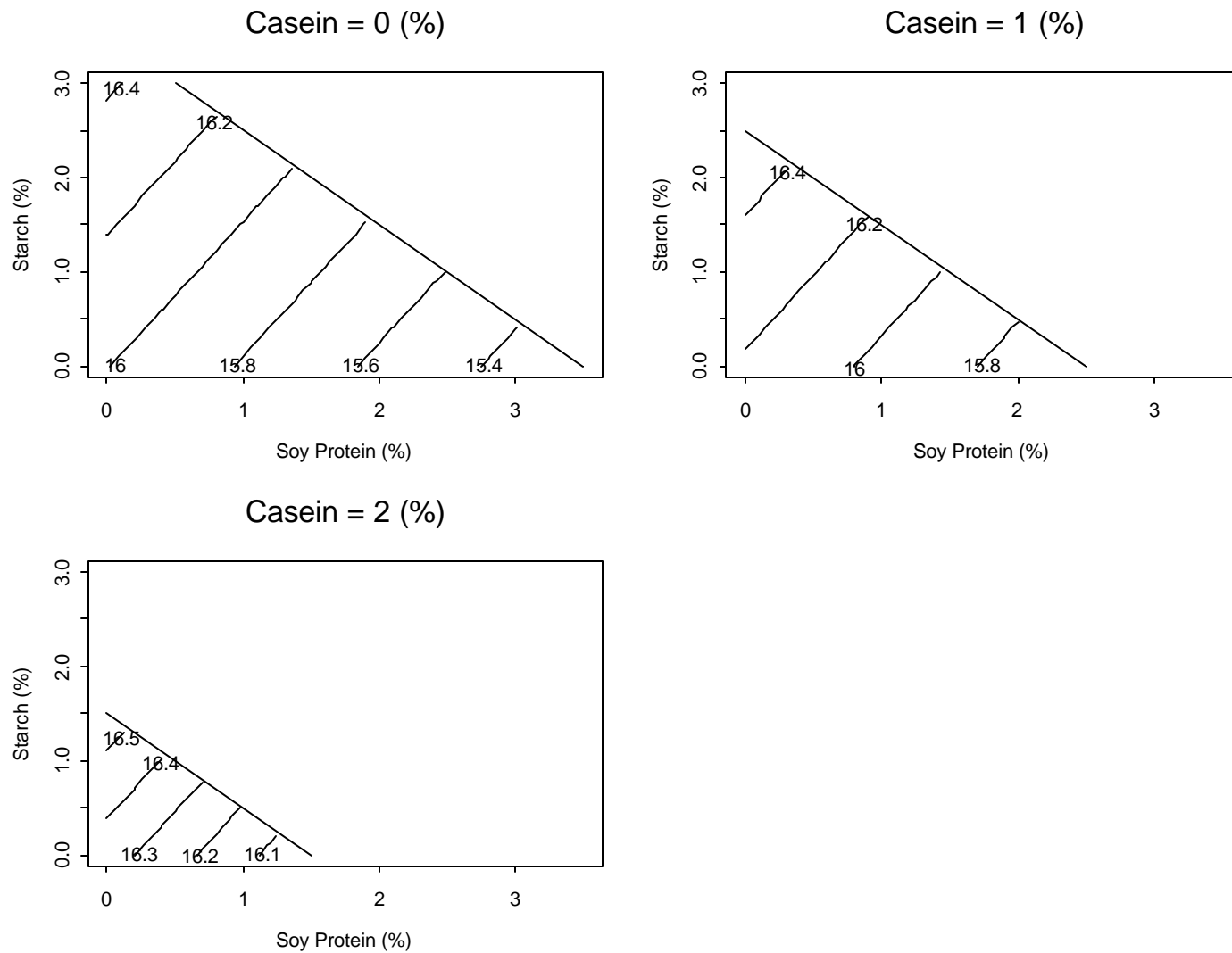
Figure 4.2 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE L* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % RFN raw material.

Figure 4.3 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE L* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 25 % PSE and 75 % RFN raw material.
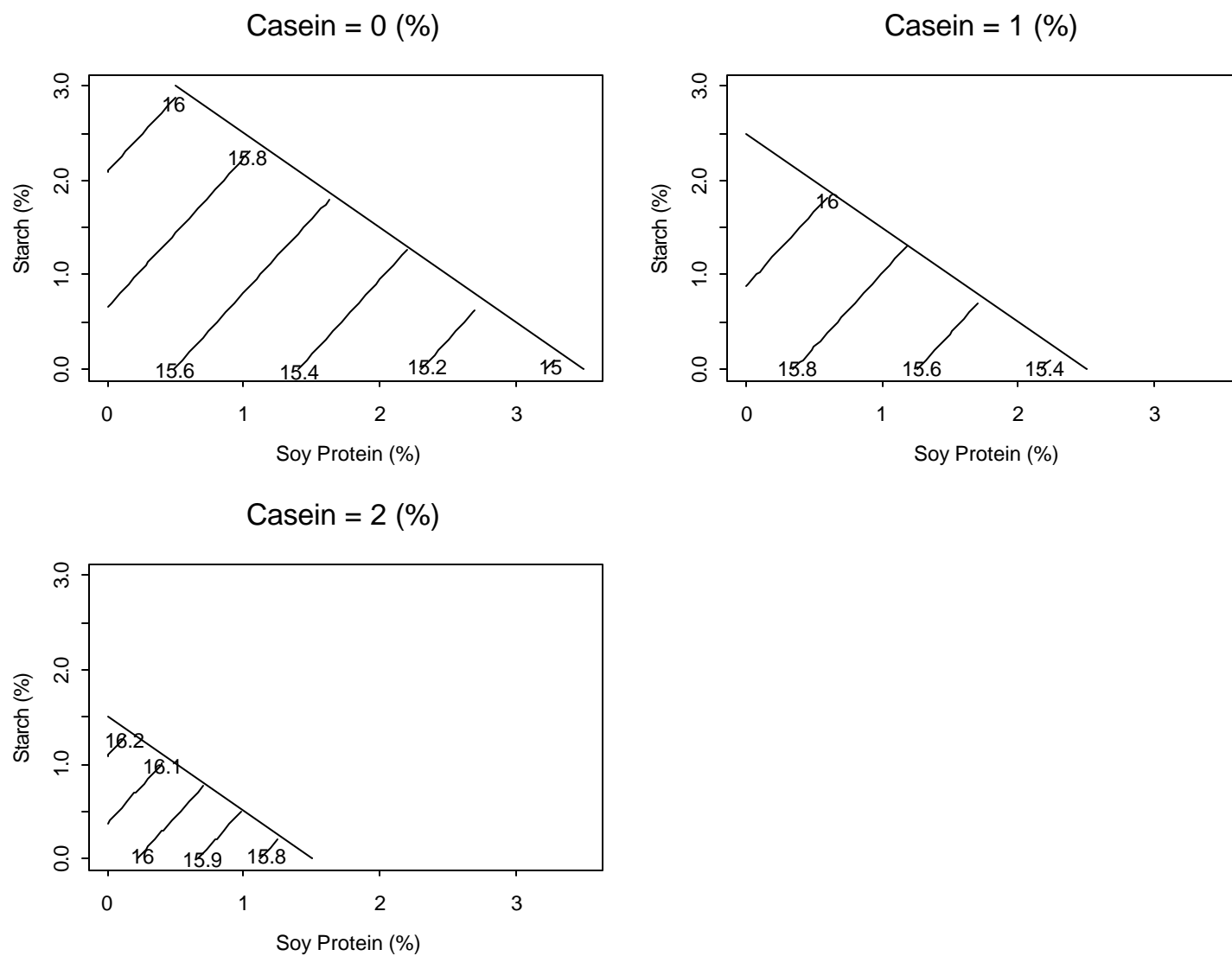
Figure 4.4 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE L* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 50 % PSE and 50 % RFN raw material.
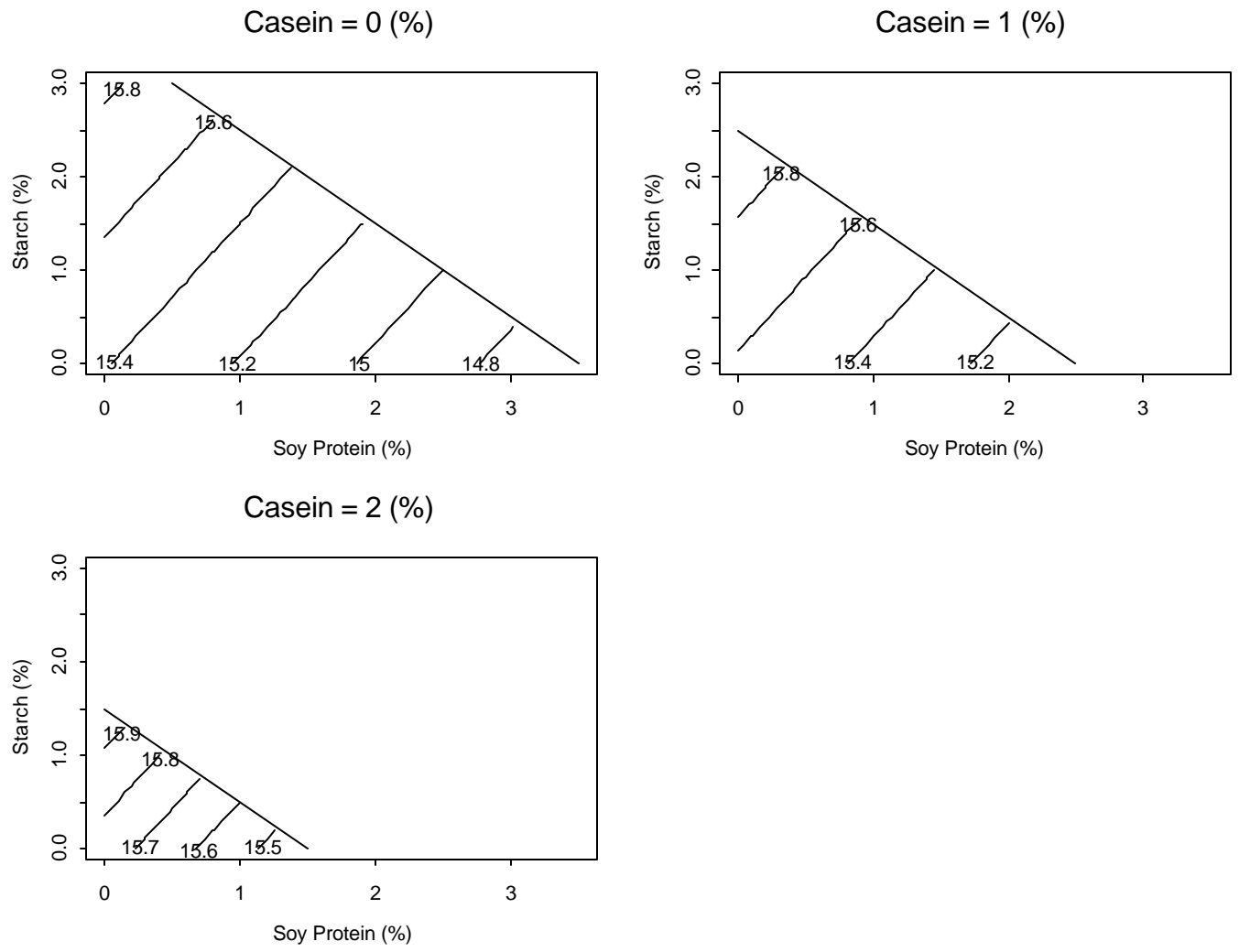
Figure 4.5 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE a* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 100% RFN raw material.

Figure 4.6 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE a* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 25 % PSE and 75% RFN raw material.
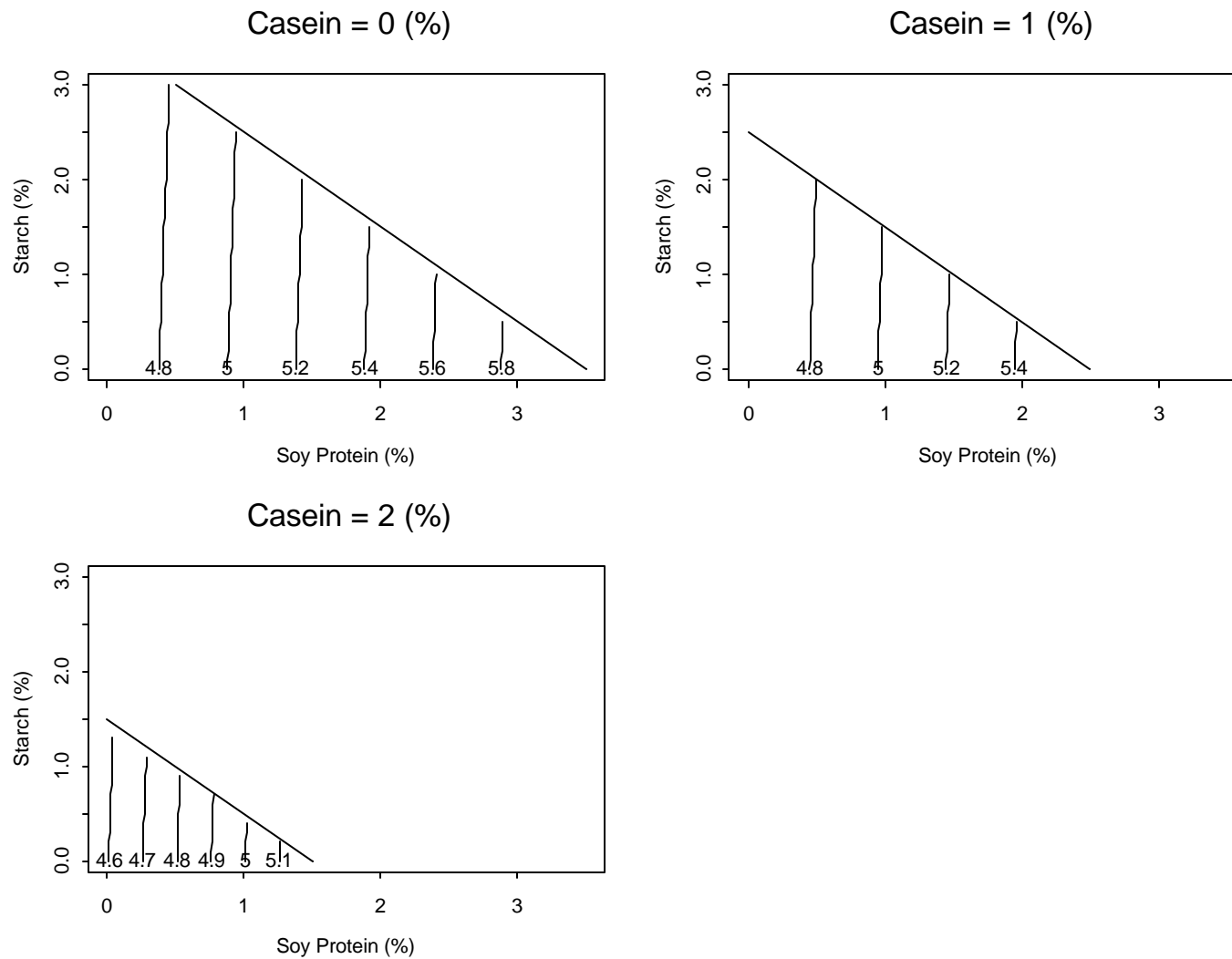
Figure 4.7 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE a* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 50 % PSE and 50% RFN raw material.

Figure 4.8 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE b* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 100% RFN raw material.
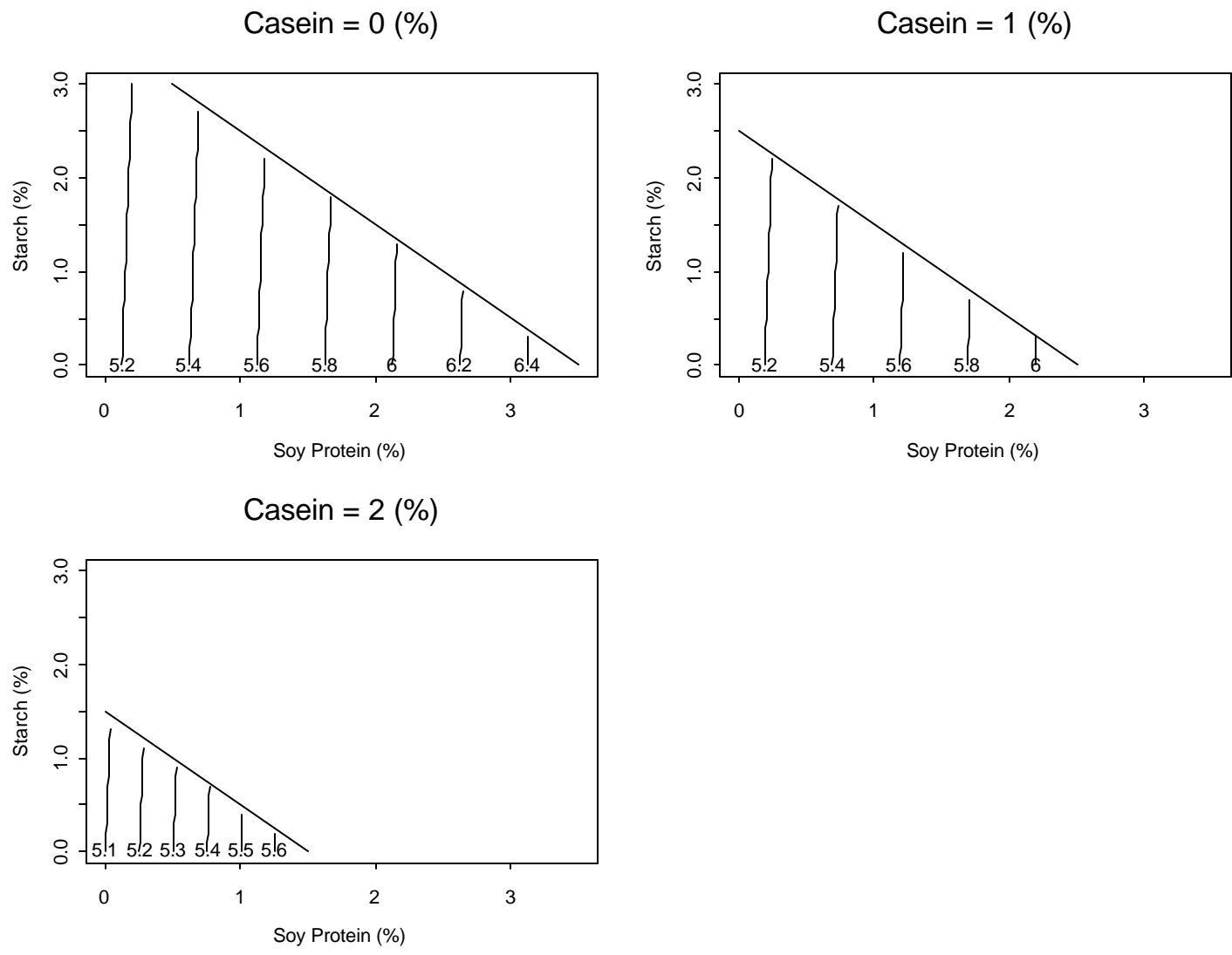
Figure 4.9 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE b* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 25 % PSE and 75% RFN raw material.
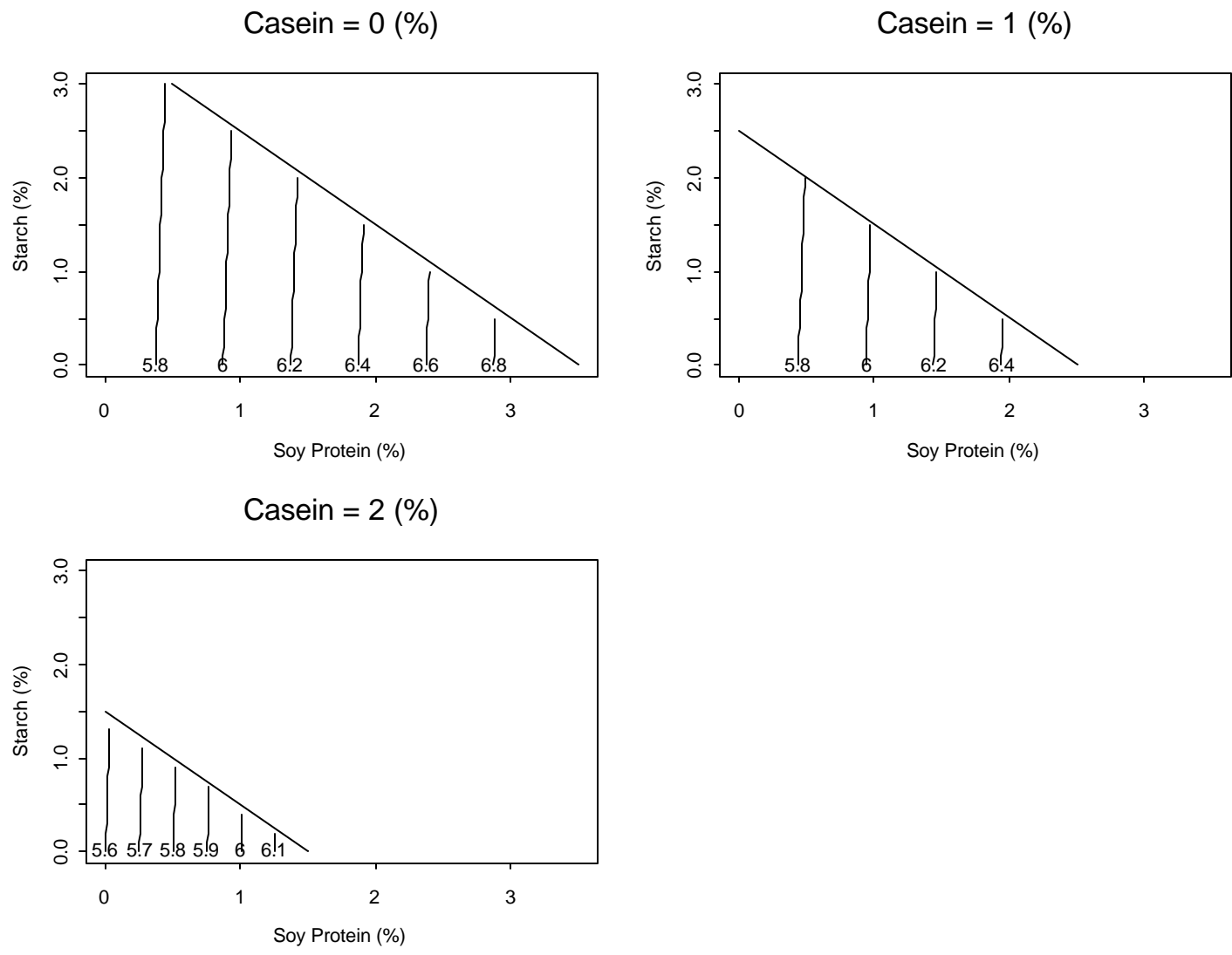
Figure 4.10 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE b* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 50 % PSE and 50% RFN raw material.

Chapter 5
Use of Response Surface Modeling to Evaluate the Effects of Non-meat Adjuncts and Combinations of PSE and RFN Pork on Texture in the Production of Boneless Cured Pork

5.1 Abstract

Combinations of pale, soft, and exudative (PSE) and red, firm, and non-exudative (RFN) *semimembranosus* muscle were utilized to manufacture chunked and formed, cured pork. Response Surface Methodology was utilized to investigate the effects of soy protein concentrate (SPC), sodium caseinate (SC), and modified food starch (MFS) on bind and texture profile analysis. Fifteen adjunct formulations for five PSE and RFN combinations provided 75 treatments for each of three replications. As Raw CIE L* Values increased, protein-protein bind decreased ($p<0.05$). MFS, SC, and SPC decreased ($p<0.05$) cohesiveness. MFS and SC decreased ($p<0.05$) chewiness, and MFS decreased ($p<0.05$) hardness. Utilizing these adjuncts demonstrated that MFS improved texture in PSE and RFN pork. SPC and SC did not improve texture, even though these adjuncts are generally used to enhance protein functionality in processed meats. This research also demonstrated that diluting RFN pork with no more than 25 % PSE pork permits the formation of a high quality boneless deli ham roll.

5.2 Introduction

Genetic selection and pre-slaughter stress cause rapid postmortem glycolysis in pigs that results in increased lactic acid production and decreased pH. Decreased pH combined with high muscle temperature (Camou & Sebranek, 1990) causes protein denaturation which exceeds that observed in normal muscle (Briskey & Wismer-Pedersen, 1961; Charpentier, 1969; Goutefongea, 1971; Bowker et al., 2000) leading to the production of pale, soft, and exudative (PSE) pork. Because of this protein denaturation, cured products formulated with PSE meat exhibit poor cohesiveness (Solomon et al., 1998), hardness, springiness, and chewiness.

Cohesiveness correlates with sliceability in processed products (Solomon et al., 1998). If sliceability is poor, the product either exhibits cracking or falls apart during slicing. Hardness correlates with protein-protein bind and juiciness, and springiness is how well a product physically springs back after its first compression (Bourne 1978). Chewiness is the product of hardness, springiness, and cohesiveness and is a measurement of the ability of the product to stay

intact during mastication. Protein-protein bind is a measurement of how well the meat proteins function together in the product.

Since sources report that 10-30 % of the pork being produced has the PSE quality defect and up to 60 % of pork being produced is Red Soft and Exudative (RSE) (Kauffman et al., 1992, McKeith et al., 1994), the acceptability of these raw materials must be improved. Two variables need to be considered to determine the optimal utilization of PSE pork in restructured products. First, the addition of non-meat adjuncts that improve the water-holding capacity of PSE pork must be evaluated for their effects on texture. Secondly, a viable solution is not apparent to permit the manufacture of a satisfactory product from 100 % PSE pork. To formulate an acceptable restructured product, the concentration of RFN pork that should be added to PSE pork at different levels of non-meat adjunct incorporation must be established.

Motzer et al. (1998) have previously explored the effects of combining PSE and RFN pork and beneficial adjuncts in the formulation of restructured ham. These researchers evaluated the effectiveness of water binders and an alkaline phosphate in increasing the protein binding and water-holding capabilities of processed hams made with differing amounts of PSE pork. Their results revealed that the combination of normal and PSE pork and the addition of binders enhanced water-holding capacity and bind of restructured ham slices when compared to that made from only PSE meat. It was concluded that modified food starch demonstrated the greatest potential to improve water holding capacity and that restructured ham could be produced successfully with a percentage of PSE pork. This research was designed to answer the questions that follow. How much RFN pork needs to be added to PSE pork to produce an acceptable product? What will happen to the texture and protein-protein bind strength if non-meat adjuncts such as starch, milk protein, and soy protein are combined in the processing of a restructured product?

Sodium caseinate, soy protein concentrate, and modified food starch are adjuncts that have demonstrated water-binding ability in restructured products formulated with percentages of normal and PSE pork (Pearson and Gillett 1996; Motzer et al., 1998). These ingredients are utilized in the industry to improve protein functionality (Pearson and Gillett (1996). Since utilization of PSE pork in processed products causes poor texture, the coupling of these non-meat adjuncts with PSE raw material must be evaluated to determine the effects that these adjunct combinations exhibit on texture. Determination of the effect of non-meat adjuncts on the texture

of 25 % PSE+75 % RFN and 50 % PSE+ 50 % RFN ham rolls in comparison to ham rolls made with 100 % RFN pork was performed.

We have not identified any published research that addresses how the combination of these adjuncts would affect the texture and bind of a restructured product made from PSE pork. Motzer et al. (1998), Brewer et al. (1984) and Field et al. (1984) reported that restructured products formulated from either RFN pork or lamb had bind values between 2.3 and 2.8 kg for different treatments, respectively. These results infer that any sample greater than 2.3 kg would be acceptable in bind for the procedure we incorporated to measure bind strength (kg). In this research, acceptable texture profile analysis values should be similar to 100 % RFN treatments with no adjuncts incorporated.

This research is vital to the pork industry because the acceptability of PSE pork needs to be enhanced. Thus, the functional properties of PSE pork should be enhanced so that it can be incorporated in products containing pork to upgrade its value and increase its use in high value processed meats. Incorporation of PSE meat with non-meat adjuncts into boneless cured pork could add value, but the percentages that they can be incorporated at without negatively affecting texture should be determined.

5.3 Materials and Methods

5.3.1 Porcine Raw Materials

All samples utilized in the study were s*emimembranosus* and *adductor* muscles obtained from National Pork Development (NPD) pork carcasses that were harvested from market age hogs (110-125 kg). The following treatments were formulated: 100 % PSE, 75% PSE +25 % RFN, 50 % PSE+ 50 % RFN, 25 % PSE +75 % RFN, and 100 % RFN. RFN samples were recognized as having a CIE L* Value < 50 and PSE samples were identified as having a CIE L* Value > 53 posterior to selection based on visual color at a pork processing plant in Virginia.

5.3.2 Sample Processing

Raw material was manually cut into 2.5 cm by 2.5 cm cubes and 1.36 kg of these muscles was included in the formulation of each treatment. The brine solution was formulated consisting of added water (18 % Meat Weight Basis (MWB)), sodium chloride (2 % MWB)), sodium tripolyphosphate (0.5 % MWB), dextrose (1 % MWB), sodium nitrite (156 ppm), and sodium

erythorbate (0.042 % MWB). The brine temperature was reduced to 4-6° C through the addition of ice. Modified food starch (MFS, Pure-Gel B990, Grain Process Corporation, Muscatine, IA), soy protein concentrate (SPC, Promine DS, Central Soya, Fort Wayne, IN), and sodium caseinate (SC, Alanate 191, New Zealand Milk Products Inc. Santa Rosa, CA) were blended into the curing solution in appropriate treatments that were based on the MWB. Ten percent of the raw material for each treatment was ground with a food processor (Model HC3000, Black & Decker, Shelton, CT) to improve protein extraction and bind. Each treatment was placed in a vacuum tumbler (Model Inject Star MC 20/40/60/80-226, Inject Star of the Americas, Brookfield, CT), and the brine for each treatment was poured onto the chunked pork. The samples and brine were then tumbled under vacuum for 1.5 hr at 4° C, stopping every 15 min for a rest period of 10 min to improve brine absorption. Each treatment was hand stuffed into the casings (Model Reg Fib CSG 5*25 Light PS, Viskase, Chicago, IL), and a Tipper Tie (Model PRA65L, Tipper Tie, Apex, NC) was used to seal the casings. The treatments were set in a plastic lug (3502 58961, Koch Equipment LLC, Kansas City, MO) for approximately 16 hrs (4° C). The next day, the product was heat processed in a smokehouse (Model 1000, Alkar, Lodi, Wisconsin) to an internal temperature of 69 ^{o} C. The smokehouse schedule was 1 hr for 54 ^{o}C dry bulb and no wet bulb, 2 hr for 66 ^{o}C dry bulb and 47 ^{o}C wet bulb, 1 hr for 71 ^{o}C dry bulb and 57 ^{o}C wet bulb, and approximately 1 hr 15 min for 88 ^{o}C dry bulb and 74 ^{o}C wet bulb. The boneless cured pork was immediately cold showered for 15 min (10 ^{o}C <) and then stored in plastic lugs, at 4 ^{o}C for 16 hr prior to slicing. Boneless ham rolls were then sliced into 12.7 mm thick sections, packaged aerobically, and stored (4° C) for bind and texture measurements to be performed within 72 hr.

5.3.3. Protein and Moisture Analysis and pH

Percentage protein was measured (39.1.02, AOAC, 1995) in duplicate using a Kjeldahl extraction apparatus (Model Rapid Still II, Labconco Corp., Kansas City, MO). All of these chemical analyses were repeated for each treatment of processed ham rolls. Percentage Moisture (39.1.02, AOAC, 1995) was measured in triplicate for each muscle using a drying oven (Model OV-490A-2, Blue, Blue Island, IL).

The pH of each *semimembranosus/adductor* muscle was taken in triplicate. pH was determined by removing three 2-g samples from three similar anatomical locations on each of the muscles and homogenized (Virtishear Model.225318, The Virtis Company, Inc., Gardener, NY) for 1 min in 20 mL of distilled deionized water. pH was measured for the individual samples

with a calibrated pH meter (Model AR25, Fisher Scientific, Pittsburgh, PA) and a pH electrode (Model 13-620-298, Fisher Scientific, Pittsburgh, PA).

5.3.4 Bind

Bind strength was evaluated using a procedure modified from Field et al. (1984) incorporating the Instron Universal Testing Machine (Model 1011, Instron Corp., Canton, MA). Three 12.7 mm slices were randomly selected from each treatment to make determinations. A 25.0 mm diameter steel ball (chrome alloy grade 25) was attached to a rod and then attached to the Instron using a chuck. Nails were placed manually through each sample into the 1.6 mm holes drilled on the top of a plexiglass stand used to secure ham slices in place during testing. Nail holes were drilled 0.5 mm apart in 1 mm deep holes around a circle with a nail diameter of 4.5 mm and an inside diameter of 4.0 mm. The plexiglass stand was placed on the flat, circular surface of the Instron. The slice was then aligned so that the steel ball would penetrate the middle of the meat slice. The steel ball was positioned directly above the meat slice, and bind was reported as the peak force (kg) necessary for the polished steel ball to burst through a slice of restructured ham roll. The Instron was set at a speed of 100 mm/min.

5.3.5. Texture Profile Analysis

Texture Profile Analysis (Bourne, 1978) was performed using an Instron Universal Testing Machine (Model 1011, Instron Corp., Canton, MA) to determine total energy, hardness, springiness, cohesiveness, and chewiness. Texture analyses were performed on samples stored (4^0 C) horizontally in plastic lugs for less than three days. Samples were allowed to equilibrate to room temperature (22^0 C) prior to testing. Four cores (19 mm diameter) were taken from each 12.7 mm slice and 2 slices were tested per treatment. Cores were axially compressed to a height of 3.2 mm (75% compression) to determine total energy and hardness. Separate Cores were then compressed twice to 50% to determine springiness, cohesiveness, and chewiness. The Instron was programmed for a load range of 10 kg (20% of 50 kg compression load cell) with a crosshead speed of 100 mm/min and a chart speed of 200 mm/min.

5.3.6 Statistical Analysis

The experimental design is a constrained modified simplex mixture (Figure 5.1) with 15 combinations of 3 factors (MFS, SC, SP) crossed with the 5 treatment combinations of PSE and RFN (Table 1). Each of these formulations was replicated 3 times. Treatment combinations of SC, SP, and MFS were incorporated within legal levels as defined by the USDA (9 CFR, 318

and 319) that were chosen by Design Expert (Design-Expert 5, Stat Ease Inc., Minneapolis, MN) to optimize the design so that the maximum amount of information about their effect on protein-protein bind and texture. These treatment combinations were chosen by Design Expert to fill the design space. This type of Response Surface Design permits the fitting of a second order model that analyzes main, interaction, and quadratic effects for all factors of interest as well as makes it possible to estimate a combination of factors to optimize textural characteristics and protein-protein bind. Percentage raw moisture and protein, raw pH, and raw color were also incorporated into the regression model as main effects to provide as much information about the responses of interest as possible. Analysis with the statistical package SAS (Version 8.12, 2001, SAS, Cary, NC) was performed to reveal the protein-protein bind and textural characteristics at various PSE pork formulations. Type III Sums of Squares were used to test all effects unless specified otherwise.

5.4 Results and Discussion

5.4.1 Texture Models

No interaction ($p > 0.05$) existed between PSE and sodium caseinate, modified food starch, or soy protein concentrate. This lack of interaction deemed it appropriate to utilize the models for data collected from all levels of PSE instead of creating different models for each level. These models were statistically significant ($p < 0.05$) in explaining protein-protein bind and textural characteristics (eqns. 1,2,3, and 4), and partial F tests were performed to determine if quadratic terms and covariates were needed in the models to help explain texture. Quadratic terms were not needed ($p > 0.05$) in the models but covariate terms (raw CIE L*, raw CIE a*, raw CIE b*, raw pH, raw moisture, and raw protein percentage) did add ($p < 0.05$) significant information to the models (SAS, 1999). The final models were selected as linear models with covariates added. The R^2 for the models are 0.47, 0.36, 0.24, and 0.27 for bind, hardness, cohesiveness, and chewiness, respectively. This information suggests that there was high variation among experimental units in each quality classification. This variation is undesirable for experimental purposes, but this design was necessary because the industry would formulate a chunked and formed product similarly, and one research goal was to provide a product that the industry could utilize.

Three (raw CIE L*, % PSE, and raw moisture %), one (MFS), four (MFS, SPC, SC, and raw moisture %), and three (MFS, SC, and raw pH) independent variables were significant ($p<0.05$) in explaining bind, hardness, cohesiveness, and chewiness, respectively. All terms were included in the models since there was so much unexplained variation in the model due to variability in the raw material (Myers and Montgomery, 1995). The models take the form of the following multiple linear regression model:

$y = B_0+B_1X_1+B_2X_2+B_3X_3+B_4X_4+B_5X_5+B_6X_6+B_7X_7+B_8X_8+B_9X_9+B_{10}X_{10} + \varepsilon$. The explanation of these terms is included in Table 4.2. The assumptions of the model are that the $E(\varepsilon) = 0$, Var $(\varepsilon) = $ constant, and that ε_i's are independent of each other and follow a normal distribution. These assumptions allow appropriate tests to be performed to determine if the variables are statistically significant ($p<0.05$). Under these assumptions, the B hats are the maximum likelihood estimators, and the models for cooking loss and expressible moisture are estimable.

5.4.2 Protein-Protein Bind

Equation 1:
Protein-protein bind = 2.44 - **0.48*PSE** - 0.048*MFS – 0.011*SPC - 0.029*SC + **0.21*moisture**
                       - 0.10*prot - **0.48*CIE L*** - 0.27*CIE a* + 0.10*CIE b* + 1.1 *pH raw

No variables affected ($p>0.05$) bind strength based on Type III Sums of Squares. Type III Sums of Squares are used to test the effect of each factor assuming that it is the last term added to the model. Based on Type I Sums of Squares, bind decreased ($p<0.05$) as CIE L* of the raw material and percent PSE increased, and bind increased ($p<0.05$) as raw product moisture increased. Type I Sums of Squares test each effect based on the order that they are added to the model. SPC, MFS, and SC did not affect ($p>0.05$) bind based on either type of Sums of Squares.

Figures 5.2, 5.3 and 5.4 were produced for 0, 25 and 50 % treatments with covariates held constant at their means to demonstrate how bind value is affected by MFS, SPC, and SC incorporation. If covariate terms were significant ($p<0.05$), they were held constant at their mean for each specific PSE level. Figure 5.2 reveals that the optimal adjunct combination for bind is no adjunct incorporation resulting in a bind value of 2.76 kg. The lowest adjunct combination was recorded at 3 % starch inclusion at 2.62 kg. This graph verifies that adjunct incorporation does not affect bind within each PSE incorporation level. These results are similar to Motzer et al. (1998), who reported no difference in bind strength between controls and

samples formulated with modified food starch or isolated soy protein 2.62, 2.93, and 2.97 kg, respectively. These researchers did report that k-carageenan improved (p<0.05) bind strength resulting in a bind value of 3.21 kg.

Utilization of 25 % PSE pork decreased bind strength by 0.3 kg to 2.46 kg (Figure 5.3). This reduction in bind value is significant, but it also is a value which infers that the product still maintains acceptable protein-protein binding. Motzer et al. (1998), Brewer et al. (1984) and Field et al. (1984) reported that restructured products formulated from either RFN pork or lamb had bind values between 2.3 and 2.8 kg for different treatments, respectively. These results infer that any sample greater than 2.3 kg would be acceptable in bind. This condition can be verified by the observation in our study that samples with bind values greater than 2.2 kg generally held together well. The lowest value for 25 % was predicted for 3.0 % starch inclusion at 2.34 kg. All prediction values for the 50 % PSE treatments were greater than 2.0 kg (Figure 3), but this result is misleading since some of the treatments demonstrated excellent bind, but others exhibited cracking of the texture, a phenomenon that correlates with poor cohesiveness (Solomon et al., 1998). In general, treatments formulated with 75 and 100 % PSE meat exhibited cracking, and a large amount of variation in texture existed in samples from 50, 75, and 100 % PSE treatments that was not apparent in 0 and 25 % PSE treatments. Cracking occurs due to either not enough functional protein or use of too much water in products. It is caused by proteins inability to bind to each other because they are unable to bind the water present in the product. To prevent cracking, incorporation of less added water or less PSE meat could be utilized. Results demonstrate that the utilization of 0 or 25 % PSE in the experimental restructured product had acceptable bind at any adjunct level combination. Therefore, it is practical to incorporate PSE raw material into these products since the decreased bind strength does not outweigh the gains in profit that could be induced through using this low value raw material.

Though, our data demonstrates the practicality of utilizing 25 % PSE, it is impractical to incorporate 50 % PSE into products since it caused poor bind and cohesiveness. Values between 25 and 50 % PSE could potentially be utilized in formulation of chunked and formed, boneless cured pork. However, no research has been conducted to determine the exact percentage of PSE pork that would be acceptable in a product. Therefore, further experimentation would need to be designed and performed to determine usable values.

5.4.3 Texture Profile Analysis

Equation 2:
Hardness = 20.16 – 3.02*PSE - **1.07*MFS** – 0.044*SPC - 0.53*SC + 0.52*moisture+
0.67* prot + 5.1CIE L* +0.017 CIE a* - 0.33*CIE b* +0.19*pH raw

Equation 3
Cohesiveness = 0.402 + 0.019*PSE - **0.017*MFS** – **0.011*SPC** - **0.014*SC** + **0.26*moisture** -
0.009* prot - 0.056*CIE L*-0.008*CIE a* + 0.0036*CIE b* -0.016*pH raw

Equation 4
Chewiness = 6.30 - 1.06*PSE - **0.56*MFS** – 0.13*SPC - **0.34*SC** + 0.37*moisture+
0.035* prot + 0.49*CIE L*-0.28*CIE a* + 0.31*CIE b* **- 0.68*pH raw**

Modified food starch decreased (p<0.01) textural hardness in restructured boneless ham, but no other variables (p>0.05) were effective. These results are similar to Motzer et al., (1998). These authors reported that the incorporation of MFS into water cooked, restructured hams caused decreased hardness. The ability of MFS to entrap water and form hydrogen bonds with water makes it an excellent water binder. This ability to bind water increases moisture content, indirectly resulting in decreased hardness. Decreased hardness may be a desirable characteristic, depending on the initial hardness of the control treatment, since hardness correlates with juiciness. This implies greater water retention, which infers improved yields.

Predictions displayed in Figures 5.5 and 5.6 demonstrate the effects that MFS and % PSE exhibit on hardness values. As MFS inclusion increased, hardness predictions decreased from 16 to 13 kg force. As PSE level increased in levels of 25 %, predictions for hardness increased by 1 kg to 17 and 14 kg, respectively. These results reveal that too much PSE pork incorporation can increase hardness to an unacceptable level. This result is logical since the incorporation of PSE raw material decreases moisture content, which would cause hardness. Utilization of MFS could counteract some of the negative effects of PSE on instrumental hardness, improving acceptability.

MFS (p<0.01), SC, and SPC all decreased (p<0.05) cohesiveness, and as raw moisture increased (p<0.05), cohesiveness increased. There was little difference in cohesiveness values for different PSE levels (Figures 5.7 and 5.8). However, 3 % MFS inclusion caused predictive values to decrease from 0.42 to 0.38 and 0.37, respectively. These results are similar to those of

Motzer et al. (1998) who reported no differences in cohesiveness between PSE and RFN pork and the ability of MFS to decrease cohesiveness.

The lack of difference between levels of PSE meat is misleading. Cracking of the texture occurred in some 50 %, several 75 %, and almost all of 100 % PSE treatments. The reason this observation is misleading is because cracking (Figure 5.9) is an example of poor cohesiveness in a processed meat product (Solomon et al., 1998), and the regression model did not find different predictive values for cohesiveness when comparing samples exhibiting cracking and those that did not.

Inclusion of MFS and SC decreased ($p<0.01$) chewiness, and as raw product pH decreased, chewiness increased. Chewiness predictive values dropped from greater than 5.5 to less than 4.5 as MFS and SC incorporation was maximized (Figure 5.10). The same trend occurred for all incorporation levels of PSE raw material. These results mimic those of Motzer et al. (1998), who reported chewiness values of 3-5 for PSE and RFN pork and values less than 3 for samples including MFS.

Texture results demonstrate the potential that MFS addition to restructured hams has in improving texture through decreasing hardness, chewiness, and cohesiveness. However, the similar values between levels of PSE for these textural characteristics is misleading since it was evident that samples with greater than 25 % PSE incorporated demonstrated poor cohesiveness.

5.5 Conclusions

Utilization of modified food starch (MFS) in product formulation appears to give optimal results for improving the texture profile analysis characteristics of restructured pork. All adjuncts can be incorporated into formulations without significantly diminishing bind strength if no more than 25 % PSE meat is utilized. Since texture characteristics were not negatively affected by SC and SPC inclusion, and since MFS provided potential for improving textural characteristics. Adjunct combinations that maximize cooking and chill yields at PSE levels less than 25 % PSE incorporation should be used (Chapter 3).

5.6 References

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Table 5.1 - Ingredient combinations[a] of meat adjuncts used in the processing of restructured ham roll.

Treatment Combination #	Modified Food Starch	Soy Protein	Sodium Caseinate
		Ingredients	
1	0 %	3.5 %	0 %
2	0 %	0 %	0 %
3	3 %	0 %	0.5 %
4	0 %	1.5 %	2 %
5	0 %	0 %	2 %
6	2 %	0 %	0 %
7	2 %	1.5 %	0 %
8	0 %	2 %	0 %
9	1.5 %	0 %	2 %
10	1.33 %	0.7 %	0.81 %
11	0.67 %	2.1 %	0.42 %
12	0.67 %	0.35 %	0.42 %
13	0.5 %	0.5 %	2 %
14	0 %	1.25 %	1 %
15	1.5 %	1.16 %	0 %

[a] All combinations were used for each treatment combination of RFN and PSE meat.

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Table 5.2: Explanation of the terms in the multiple linear regression (response surface) model associated with cooking loss and expressible moisture.

Variable	Definition
B_0 = Intercept	The predicted value of the response when no adjuncts are added and all covariates are at their means
B_1	The amount that the response is predicted to change when PSE is changed from 0 to 1 in the product and all other variables remain constant
B_2	The amount that the response is predicted to change per additional 1 % MFS incorporation into the product when all other variables remain constant
B_3	The amount that the response is predicted to change per additional 1 % SPC incorporation into the product when all other variables remain constant
B_4	The amount that the response is predicted to change per additional 1 % SC incorporation into the product when all other variables remain constant
B_5	The amount that the response is predicted to change per 1 unit change in the moisture value on a standardized –1 to 1 scale when all other variables remain constant
B_6	The amount that the response is predicted to change per 1 unit change in the protein value on a standardized –1 to 1 scale when all other variables remain constant
B_7	The amount that the response is predicted to change per 1 unit change in the CIE L* value on a standardized –1 to 1 scale when all other variables remain constant
B_8	The amount that the response is predicted to change per 1 unit change in the CIE a* value on a standardized –1 to 1 scale when all other variables remain constant
B_9	The amount that the response is predicted to change per 1 unit change in the CIE b* value on a standardized –1 to 1 scale when all other variables remain constant
B_{10}	The amount that the response is predicted to change per 1 unit change in the pH value on a standardized –1 to 1 scale when all other variables remain constant
X_1	% PSE incorporated into product on 0 to 1 scale
X_2	MFS incorporated into product on 0 to 3 scale
X_3	SPC incorporated into product on 0 to 3.5 scale
X_4	SPC incorporated into product on 0 to 2 scale
X_5	Percentage moisture on a –1 to 1 standardized scale
X_6	Percentage protein on a –1 to 1 standardized scale
X_7	CIE L * value on a –1 to 1 standardized scale
X_8	CIE a * value on a –1 to 1 standardized scale
X_9	CIE b * value on a –1 to 1 standardized scale
X_{10}	pH on a –1 to 1 standardized scale

Figure 5.1 - Modified Simplex Design Structure for the Response Surface Design Utilized. This is the region where predictions can be estimated based on inclusion of modified food starch (MFS), soy protein concentrate (SPC), and sodium caseinate (SC).
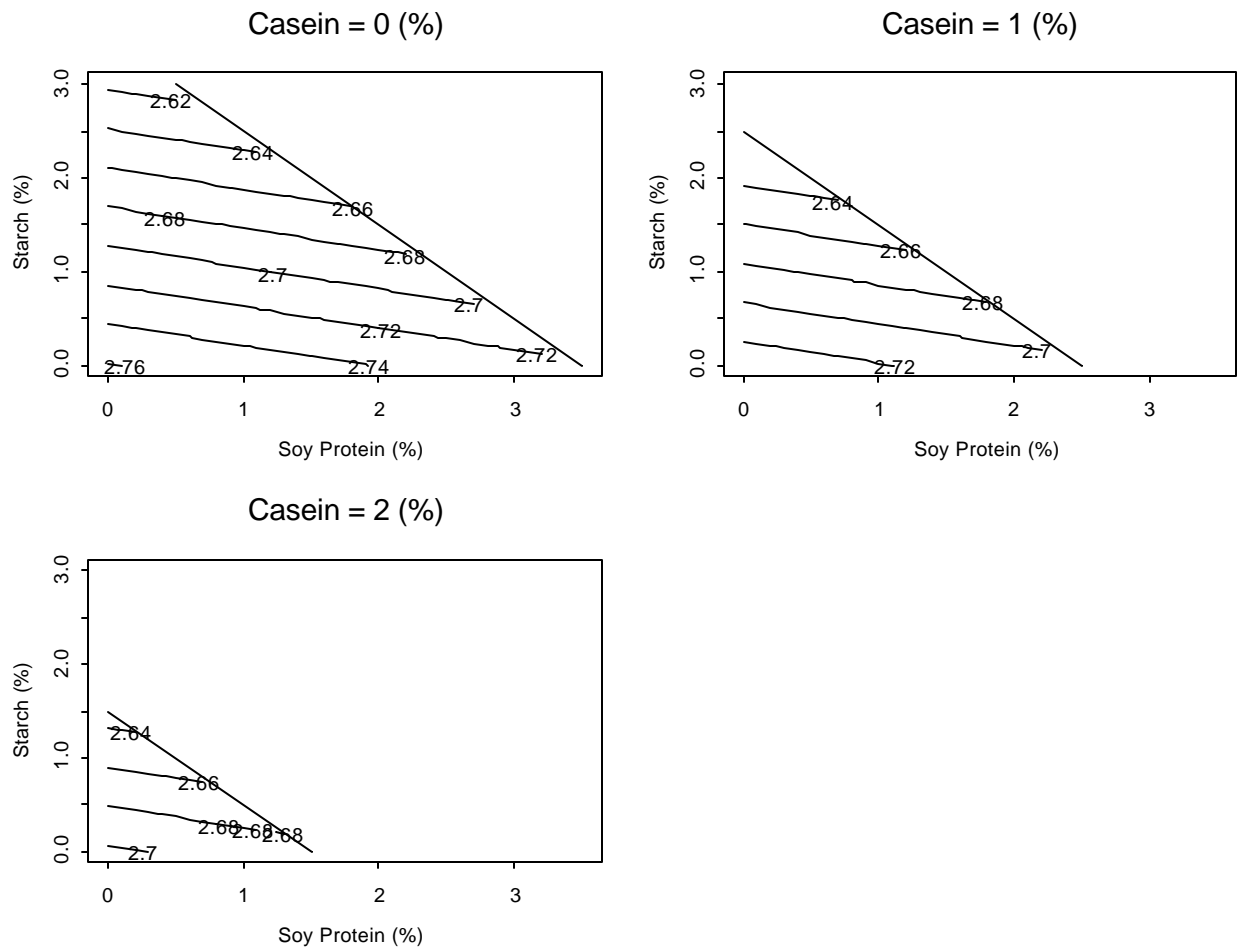
Casein = 0 (%)

Starch (%)

3.0 2.0 1.0 0.0

2.62
2.64
2.66
2.68
2.68
2.7
2.7
2.72
2.72
2.76 2.74

0   1   2   3
Soy Protein (%)

Casein = 1 (%)

Starch (%)

3.0 2.0 1.0 0.0

2.64
2.66
2.68
2.7
2.72

0   1   2   3
Soy Protein (%)

Casein = 2 (%)

Starch (%)

3.0 2.0 1.0 0.0

2.64
2.66
2.68 2.68 2.68
2.7

0   1   2   3
Soy Protein (%)

Figure 5.2 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on protein-protein bind strength (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 0 % PSE and 100 % RFN raw material.
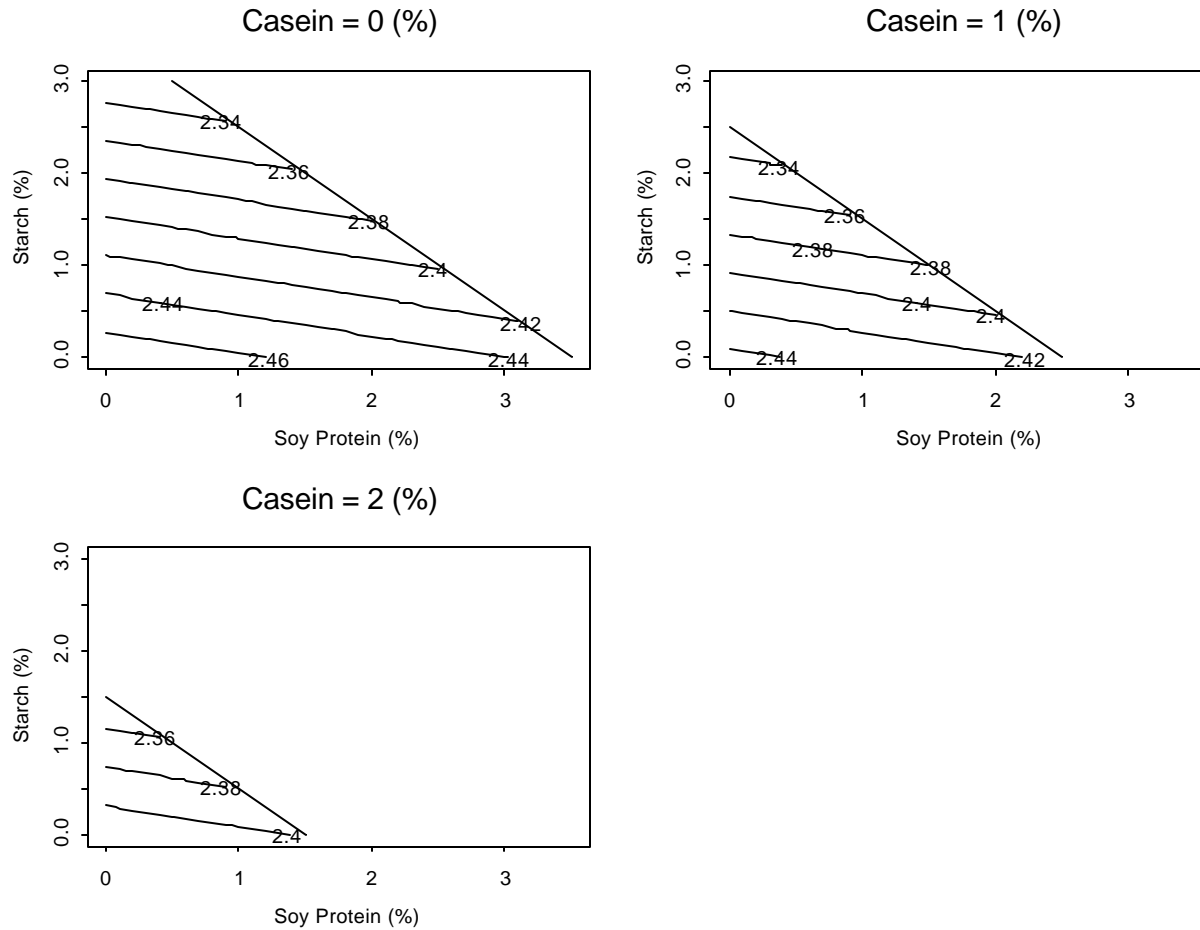
Figure 5.3 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on protein-protein bind strength (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 25 % PSE and 75 % RFN raw material.
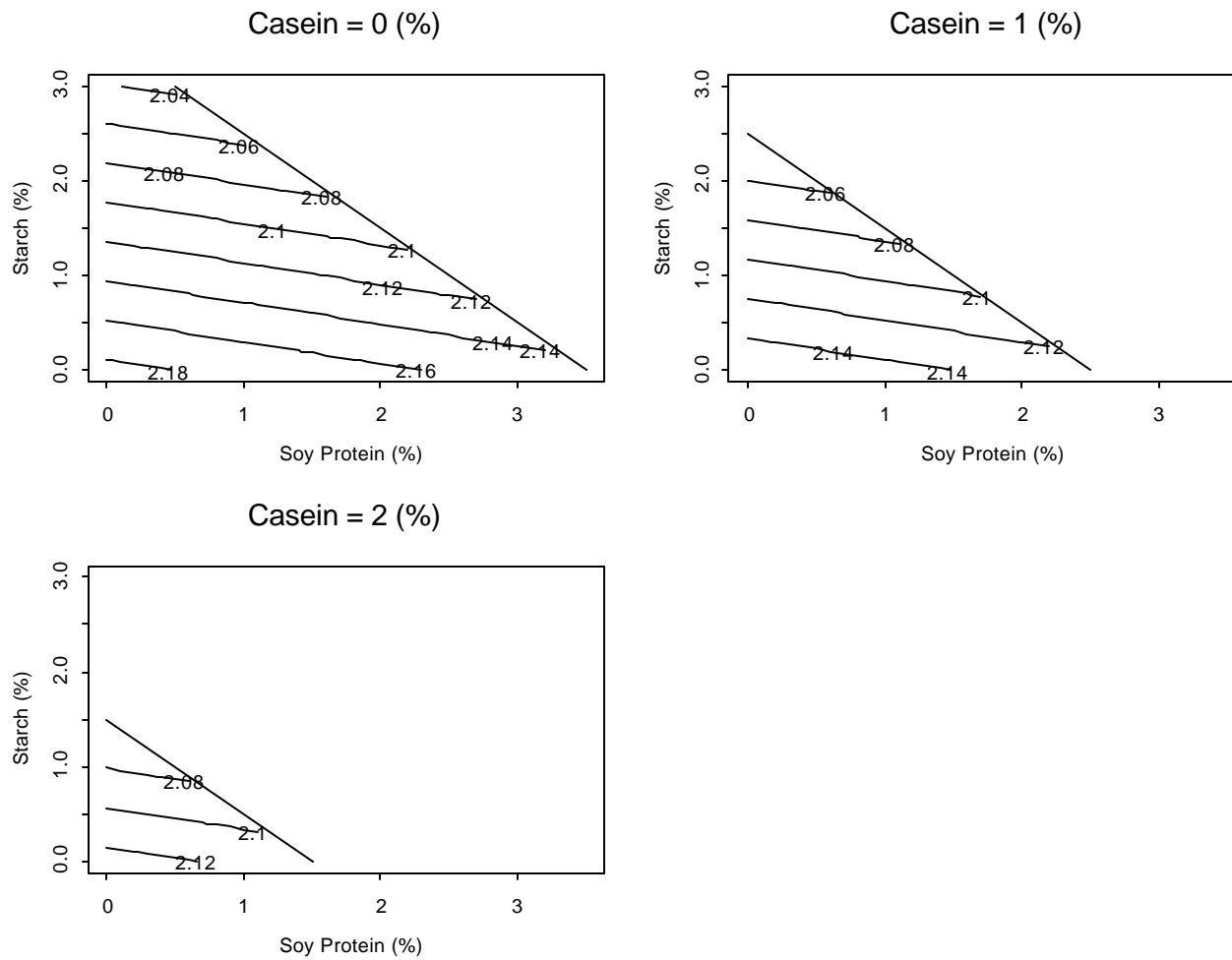
Figure 5.4 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the protein-protein bind strength (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 50 % PSE and 50 % RFN raw material.
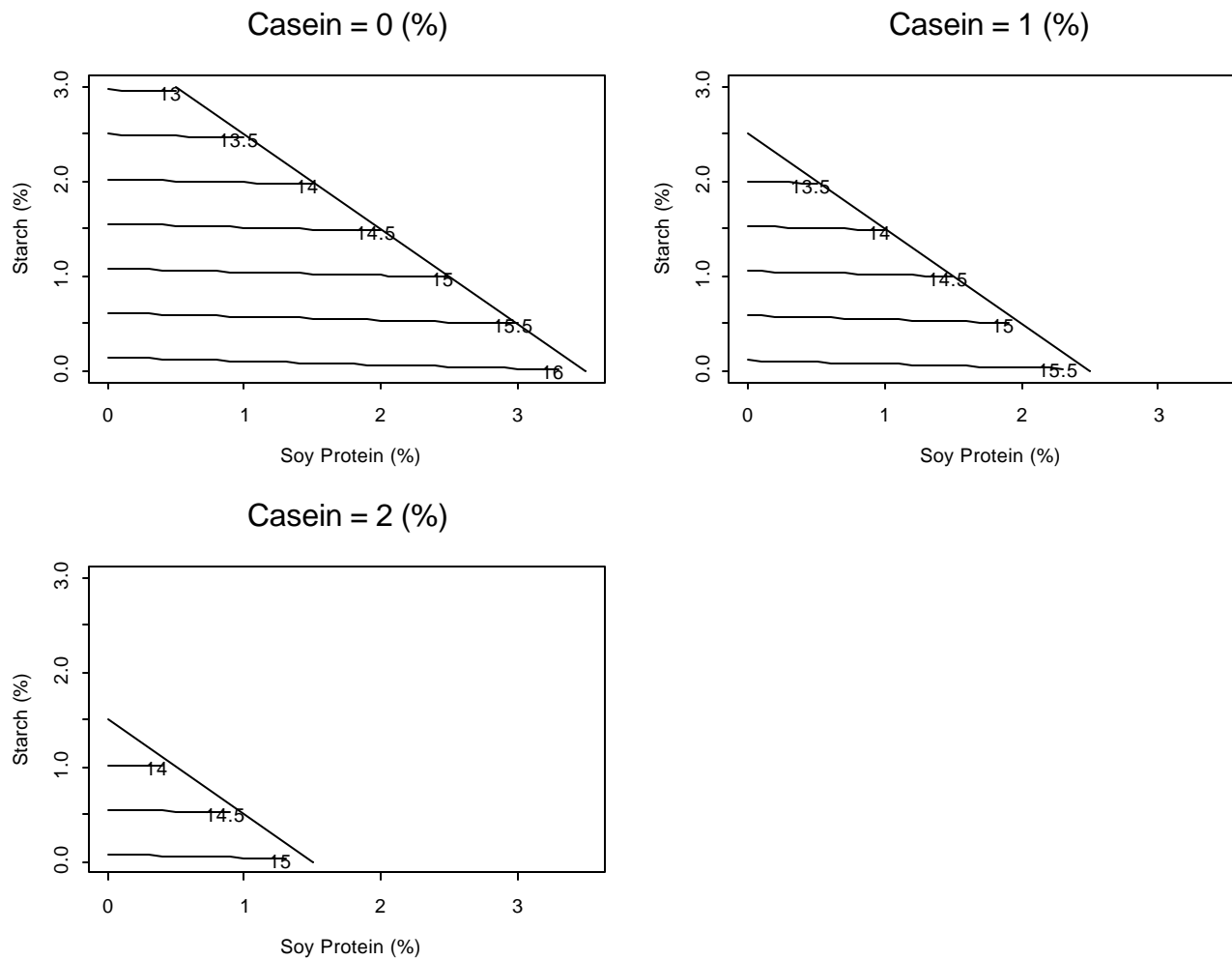
Figure 5.5 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis hardness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 0 % PSE and 100 % RFN raw material.
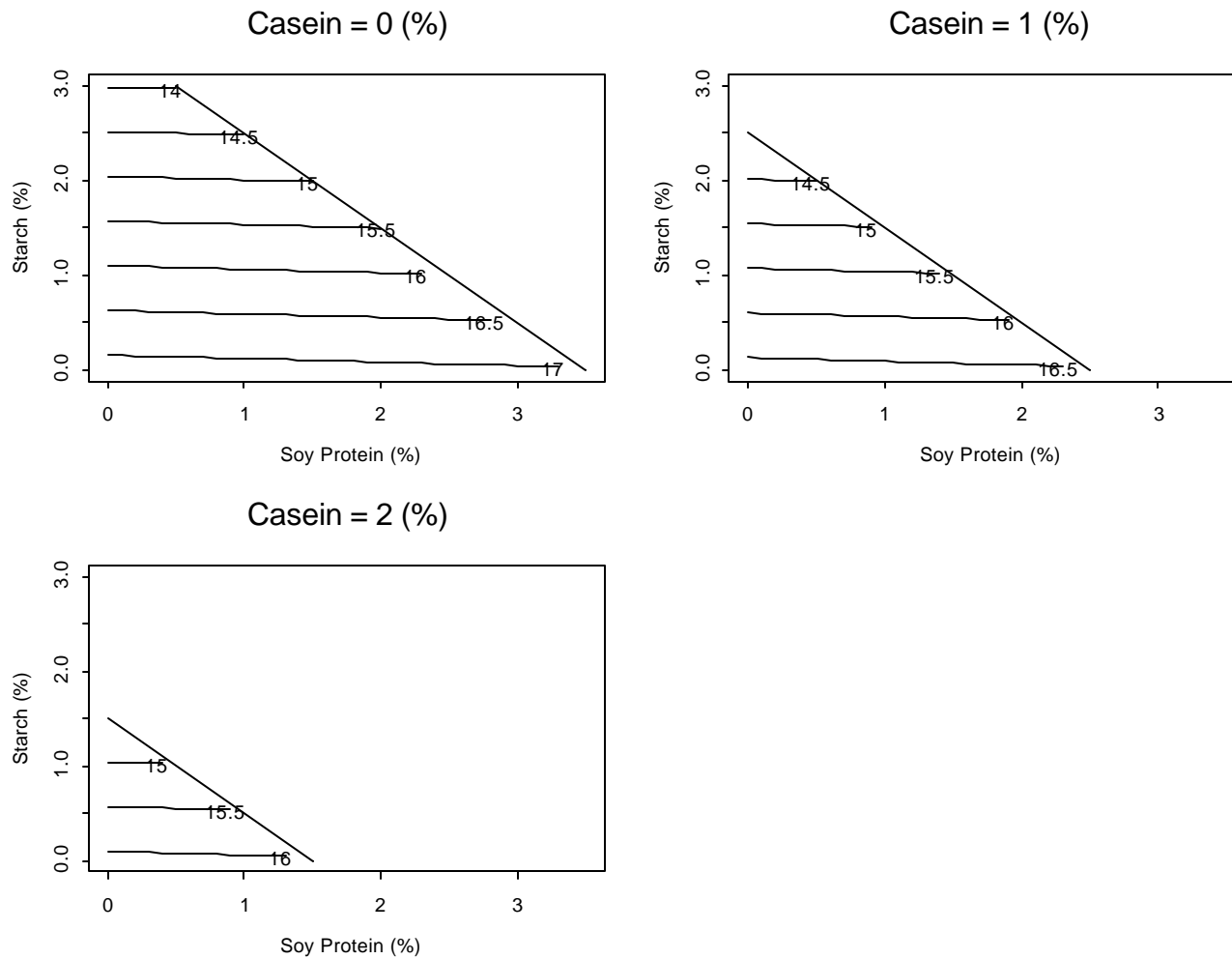
Figure 5.6 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis hardness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 25 % PSE and 75 % RFN raw material.
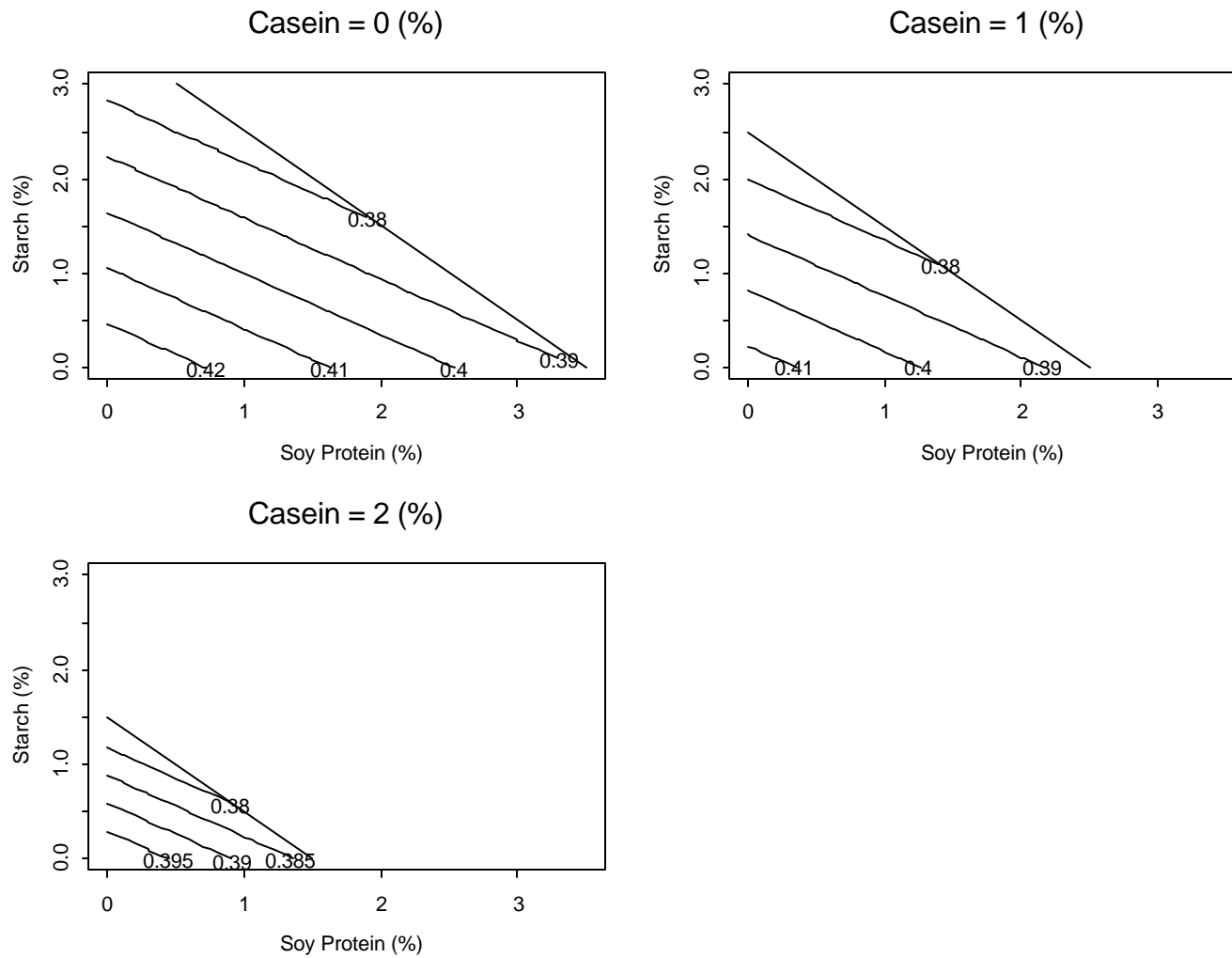
Figure 5.7 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis cohesiveness (values reported within rectangles) of chunked and formed, restructured pork formulated with 0 % PSE and 100 % RFN raw material.
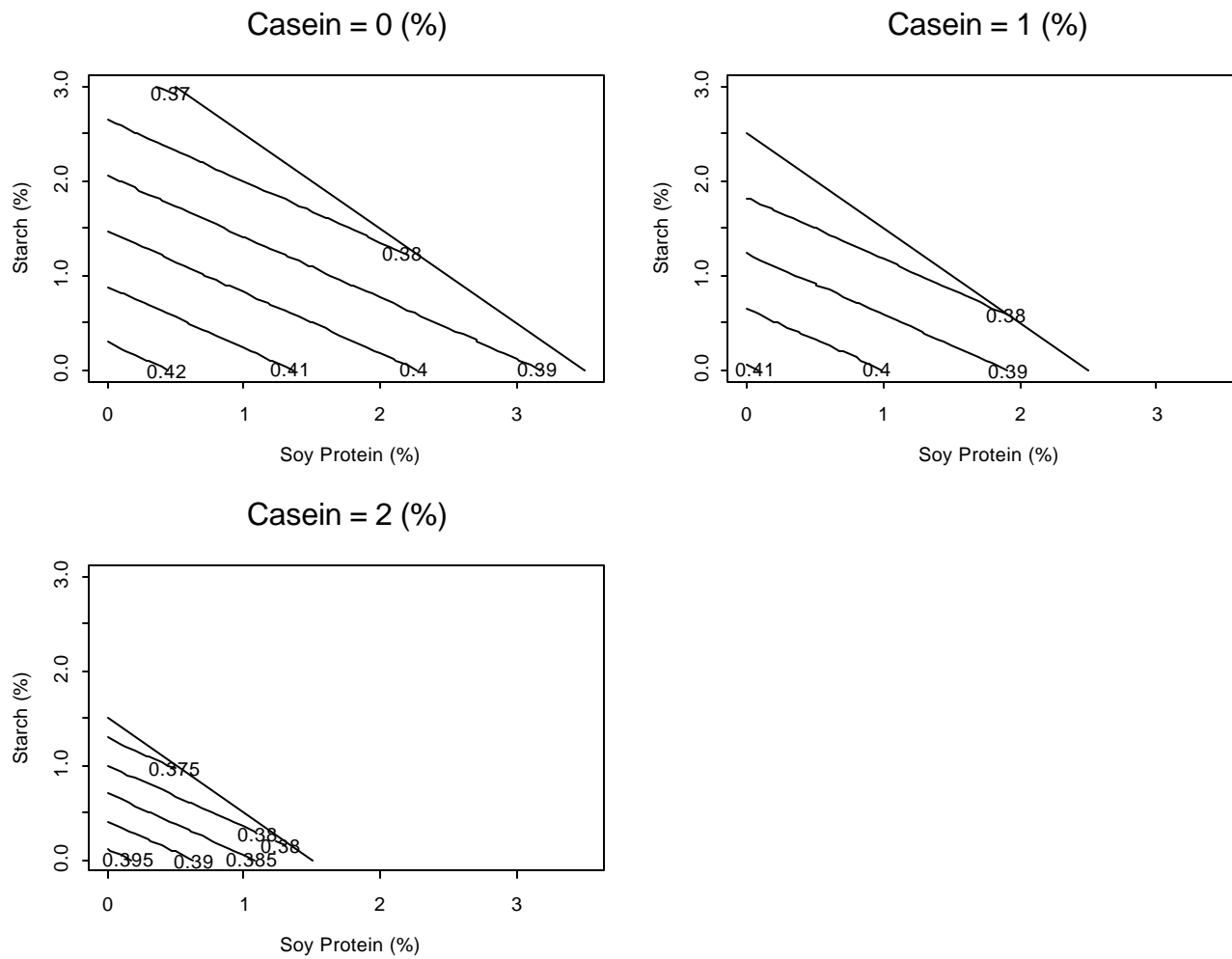
Figure 5.8 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis cohesiveness (values reported within rectangles) of chunked and formed, restructured pork formulated with 25 % PSE and 75 % RFN raw material.

Sample Demonstrating Cracking   Sample Demonstrating Desirable Texture

Figure 5.9 – Example of textural cracking in restructured pork formulated with 75 % PSE and 25 % RFN pork.
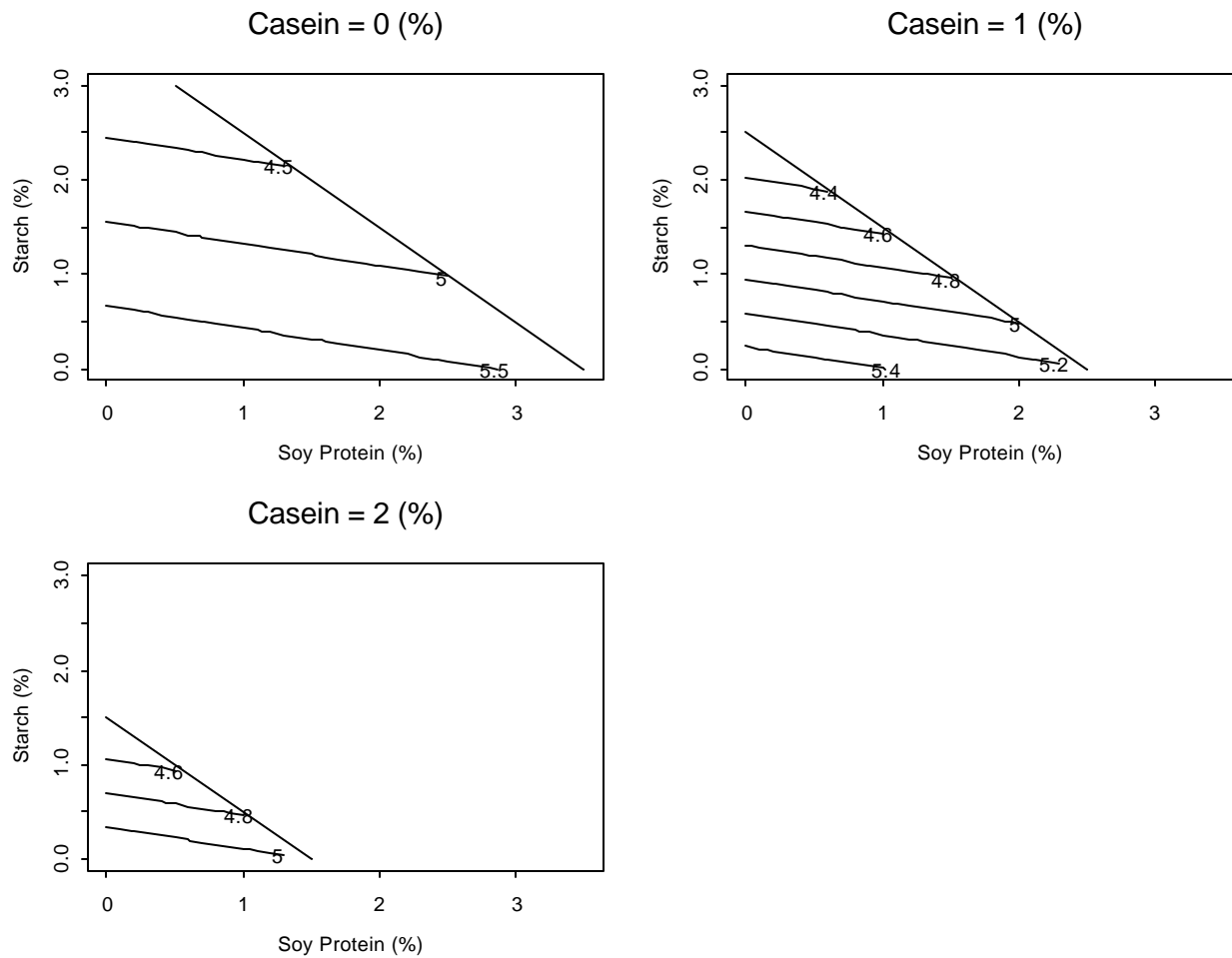
Figure 5.10 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis chewiness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 0 % PSE and 100 % RFN raw material.

Chapter 6
CHEMICAL PROPERTIES OF RESTRUCTURED BONELESS PORK PRODUCED FROM PSE AND RFN PORK UTILIZING MODIFIED FOOD STARCH, SODIUM CASEINATE, AND SOY PROTEIN CONCENTRATE

6.1 Background

Pale, Soft, and Exudative (PSE) pork is a quality classification characterized as being very light colored, soft, and watery. Such meat is classified as low quality pork that is undesirable to consumers due to its poor appearance, texture, and palatability (Pearson and Gillett, 1996). This problem causes several million dollars per year in losses to the pork industry, which include excessive shrinkage, costs of sorting carcasses, customer claims, and the salvage of discounted pork through sausage manufacture. Processed meat products produced from PSE pork demonstrate poor cohesiveness, textural firmness, and cured color formation (Pearson and Gillett, 1996). The ability to produce a restructured, chunked and formed ham through the utilization of PSE pork can add utility to this lower value foodstuff since it could be used in a higher quality product than the sausage items currently being manufactured from this lower value raw material.

6.2 Objective

The objective of this study was to determine the effect of porcine raw material quality, chemical composition of raw material, and use of non-meat adjuncts on the chemical composition of restructured boneless ham rolls. This information is required to be proficient in determining what characteristics in the formulation of a boneless ham roll are important in explaining percentage cooked protein, percentage moisture, and cooked pH.

6.3 Methods

RFN and PSE Porcine *semimembranosus* muscles were sampled every three weeks until 3 replications of 75 treatments of boneless cured pork were produced. CIEL*

values, pH, moisture, and protein were measured for the samples prior to processing. Porcine *semimembranosus* and *adductor* muscles were cut into 2.5 cm by 2.5 cm cubes and 1.36 kg of these muscles were incorporated in the formulation of each treatment. Treatments consisted of 0 % PSE, 25 % PSE, 50 % PSE, 75 % PSE, and 100 % PSE raw material with the percentage difference containing RFN pork. Fifteen combinations of modified food starch (MFS, Pure-Gel B990, Grain Processing Corporation, Muscatine, IA), soy protein (SP, Promine DS, Central Soya, Fort Wayne, IN), and sodium caseinate (SC, EMSER 736, DMV USA, Onalaska, WI) were incorporated for each raw material combination. Ten percent of the meat was reduced in particle size to increase bind. The brine solution was formulated consisting of added water (25 %) Meat Weight Basis (MWB), sodium chloride (2 % MWB)), sodium tripolyphosphate (0.5 % MWB), dextrose (1 % MWB), sodium nitrite (156 ppm), and sodium erythorbate (0.042 % MWB). Ice was added to reduce the brine temperature to 4-6° C. Each treatment was placed in a vacuum tumbler, and the brine for each treatment was poured onto the meat samples. The samples and brine were tumbled under vacuum for 1.5 hr at 4° C. Each ham treatment was stuffed into the casings manually, and clipped to seal the casing. The samples were set in a meat lug for approximately 16 hrs (4° C). The next day, the product was processed in a smokehouse to an internal temperature of 69^0 C.

6.3.1 pH, Moisture, and Protein Measurements

The pH of each *semimembranosus/adductor* muscle was measured in triplicate. pH was determined by removing three 2-g samples from three similar anatomical locations on each of the muscles and homogenized (Virtishear Model.225318, The Virtis Company, Inc., Gardener, NY) for 1 min in 20 mL of distilled deionized water. pH was measured for the individual samples with a calibrated pH meter (Model AR25, Fisher Scientific, Pittsburgh, PA) and a pH electrode (Model 13-620-298, Fisher Scientific, Pittsburgh, PA).

Percentage Moisture (39.1.02, AOAC, 1995) was measured in triplicate for each muscle using a drying oven (Model OV-490A-2, Blue, Blue Island, IL). Percentage protein (39.1.02, AOAC, 1995) was measured in duplicate using a Kjeldahl extraction

apparatus (Model Rapid Still II, Labconco Corp., Kansas City, MO). All of these chemical analyses were repeated for each treatment of processed ham rolls by the same methods mentioned above.

6.3.2 Statistical Analysis

The experimental set-up is a constrained modified simplex mixture with 15 combinations of 3 factors (MFS, SC, SP) crossed with the 5 treatment combinations of PSE and RFN. Each of these combinations were replicated 3 times. This type of Response Surface Design allows the fitting of a second order model to model main, interaction, and quadratic effects for all effects of interest. It also permits estimation of a combination of factors to optimize a variety of responses. Percentage raw moisture, percentage raw protein, raw pH, and raw color were also included in the regression model as main effects to provide as much explanation of the model as possible. Analysis with the statistical package SAS (Version 8.12, 2001, SAS, Cary, NC) was conducted to determine the chemical composition characteristics at various percentages of PSE pork.

6.4 Results and Discussion

Multiple linear regression demonstrated that MFS, SC, SP, raw moisture percentage and, CIEL* values explain (p<0.05) variation in the cooked moisture response (Equation 1) giving an R^2 of 0.3681 for the model. This R^2 is not extremely large, but it does indicate over a 60 % correlation between the significant variables in the model and the response. MFS, SC, and SP all decreased cooked moisture due to the existence of a higher percentage of solids in the boneless ham roll. Raw moisture had a positive effect on cooked moisture since it provided a greater amount of moisture going into the product. As raw material lightness increased, lower cooked moisture was exhibited. This observation occurred because PSE pork exhibits less moisture due to shrinkage of the myosin heads caused by denaturation, resulting in a lower water holding capacity (Offer and Trinick, 1983).

Cooked pH is explained (p<0.05) by raw material protein percent, lightness, redness, yellowness, and pH (Equation 2). The addition of non-meat adjuncts did not

contribute (p>0.05) to the cooked pH of the boneless ham rolls. The R^2 of this model is 0.71 indicating a superb relationship between the response and the explanatory variables. The partial R^2 provided by L* and raw material pH is 0.64. The other significant variables do not add much in explanation to the model, but they do decrease the C(p) in the model signifying a reduction in bias. Raw pH was the greatest contributor to the cooked pH, but CIEL*,a *,b* of the raw material also influenced the pH of the product. As percentage protein of the raw material increased, the cooked pH was elevated. This observation is puzzling since pale meat usually has a higher protein content than darker meat resulting from lower water holding capacity, and since darker fresh muscle has a higher pH than paler fresh meat (Offer and Trinick, 1983). Cooked pH is explained by variation in raw material and not due to any non-meat adjuncts that are added to the formulation to improve protein functionality characteristics.

The first variable added to the model explaining (p<0.05) the majority of the percentage cooked protein is percentage protein in the raw material (Equation 3). Paleness, yellowness, and redness all explain (p<0.05) percent protein. The R^2 for the model is very low, equaling 0.23, but this result could be due to only taking two measurements per treatment due to high costs, leading to unexplained variation. MFS and % PSE incorporated into the product affect (p<0.10) the percentage cooked protein, but not at the alpha=0.05 level. However, they should be added to the regression model to lower the value of the c(p) statistic. Otherwise, the model will be underspecified, causing it to be biased. The equations incorporated were:

Equation 1:
Cooked Moisture = 71.639 – .268*MFS - .588*SC - .293*SPC +
                  .258*raw moisture - .104 CieL* + .244 ciea*

Equation 2:
Cooked pH = 6.16 +.0633*raw protein - .0294 cieL* - .0386*ciea* + .0329 cieb*
          +.267*pHraw

Equation 3:
Cooked Protein = 23.07 - .227 MFS + 0.43*rawprot - .147*CieL* - .183 ciea* +
                 .542*cieb* + 1.6*%PSE

6.5 Conclusions

Chemical composition and quality of raw material play a larger role than the adjuncts studied in the explanation of the chemical composition of cured, boneless deli-ham rolls. Since raw material composition plays a larger role in the explanation of these characteristics, it is possible that raw material composition can also play more of a role in protein functionality characteristics of this product than the addition of non-meat adjuncts.

6.6 References

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Pearson, A.M. and Gillett, T.A. 1996. Raw Materials. In *Processed Meats.* 3rd Ed. p. 126-143. Chapman and Hall, New York, N.Y.

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Appendix
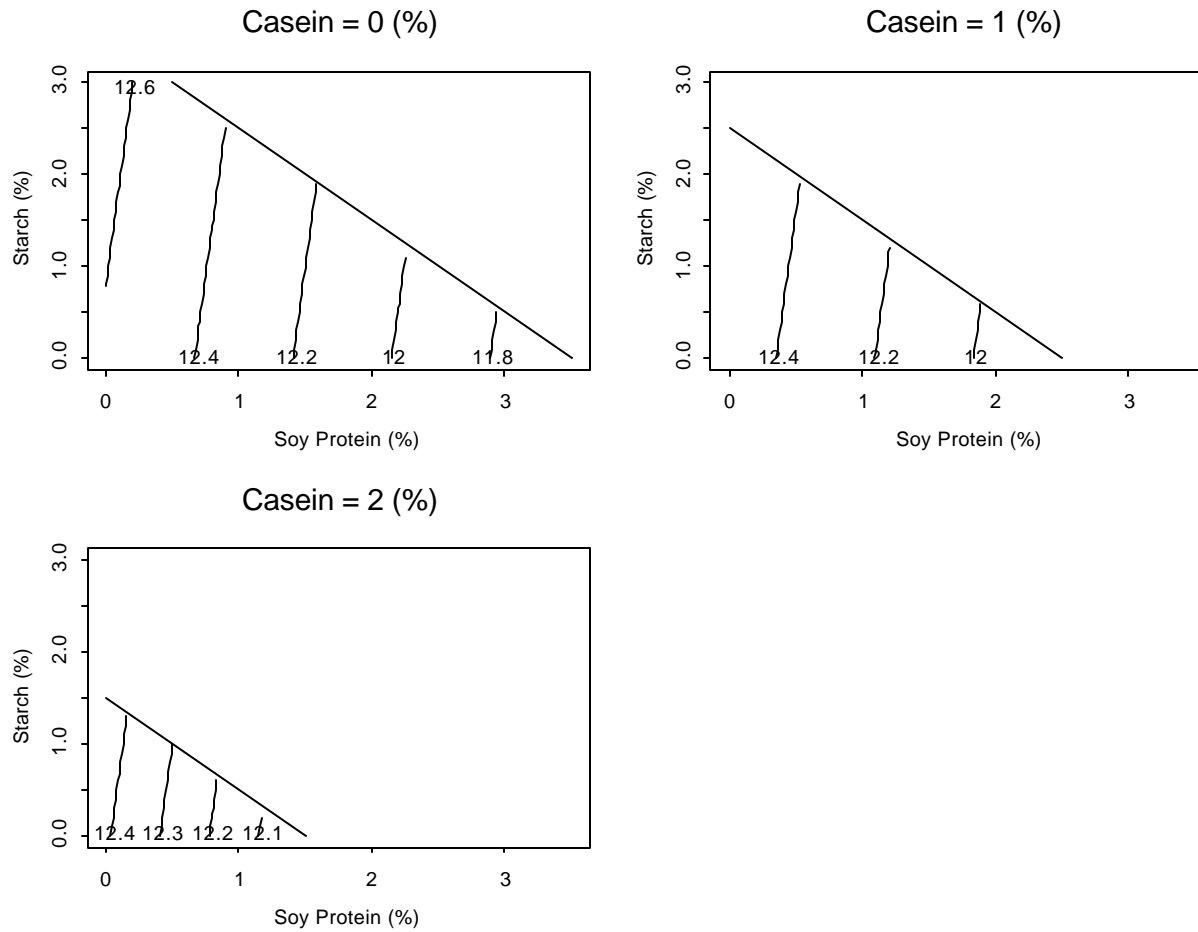
Figure A.1 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage cooking loss (values reported within rectangles) of chunked and formed, restructured pork formulated with 75 % PSE and 25 % RFN raw material.
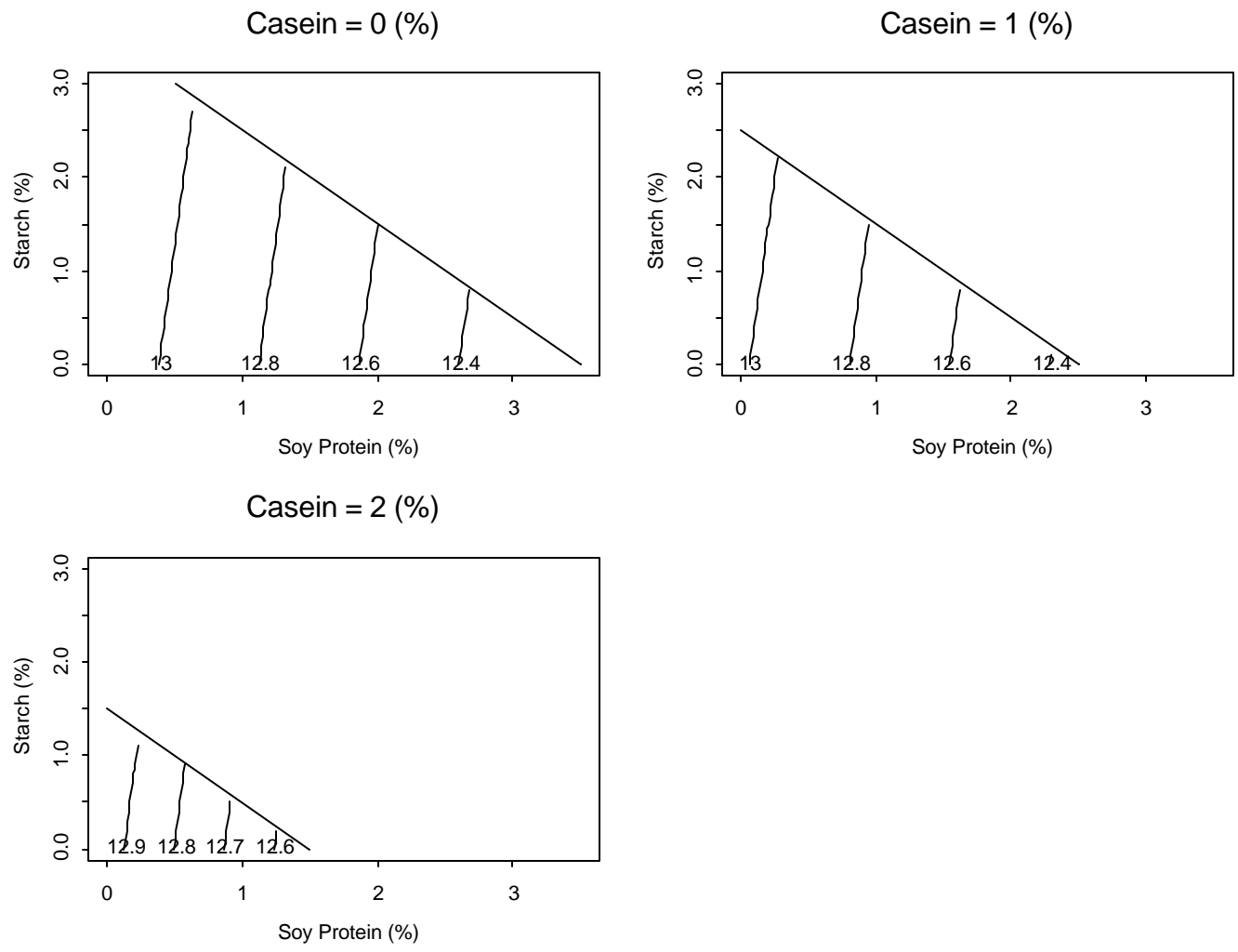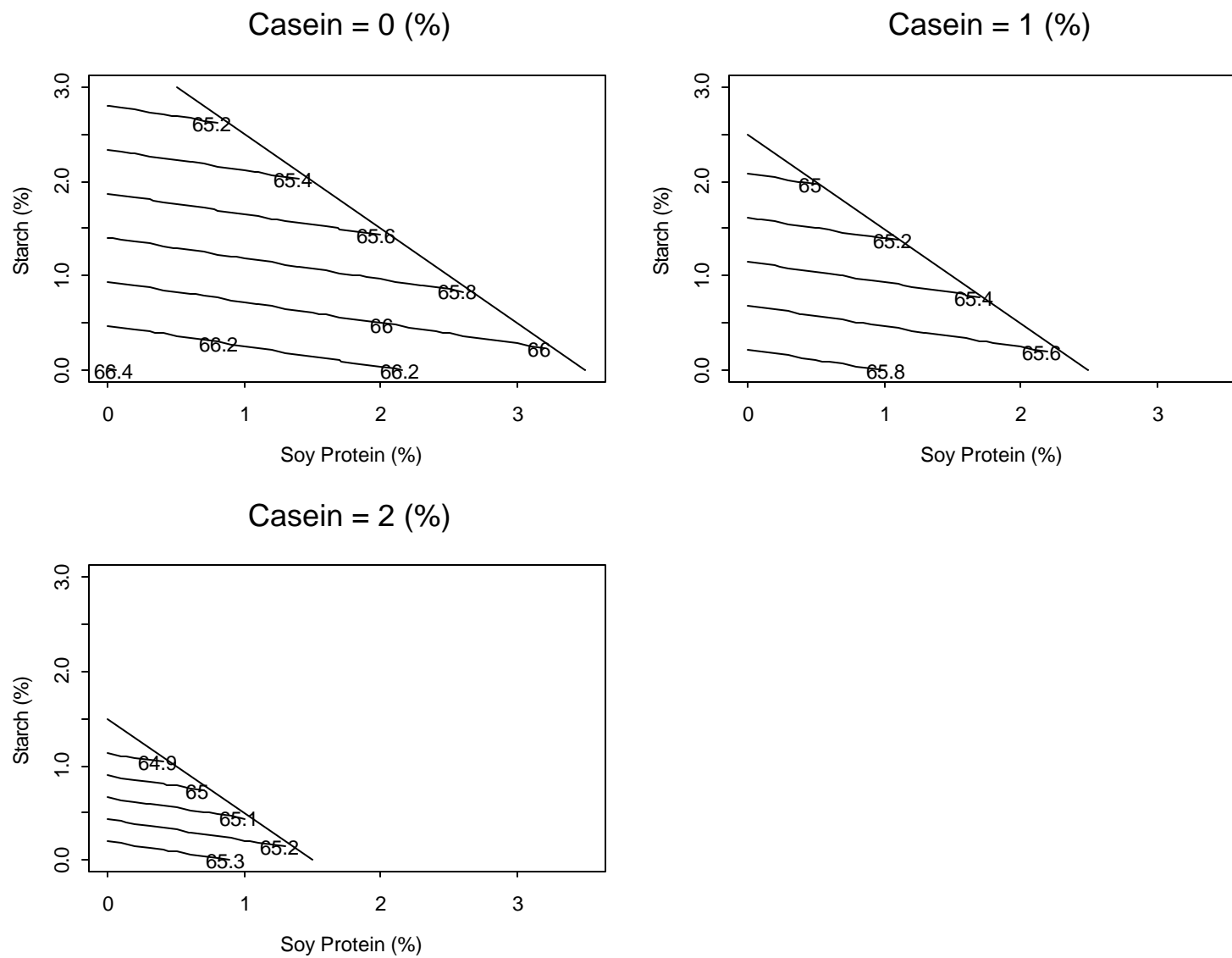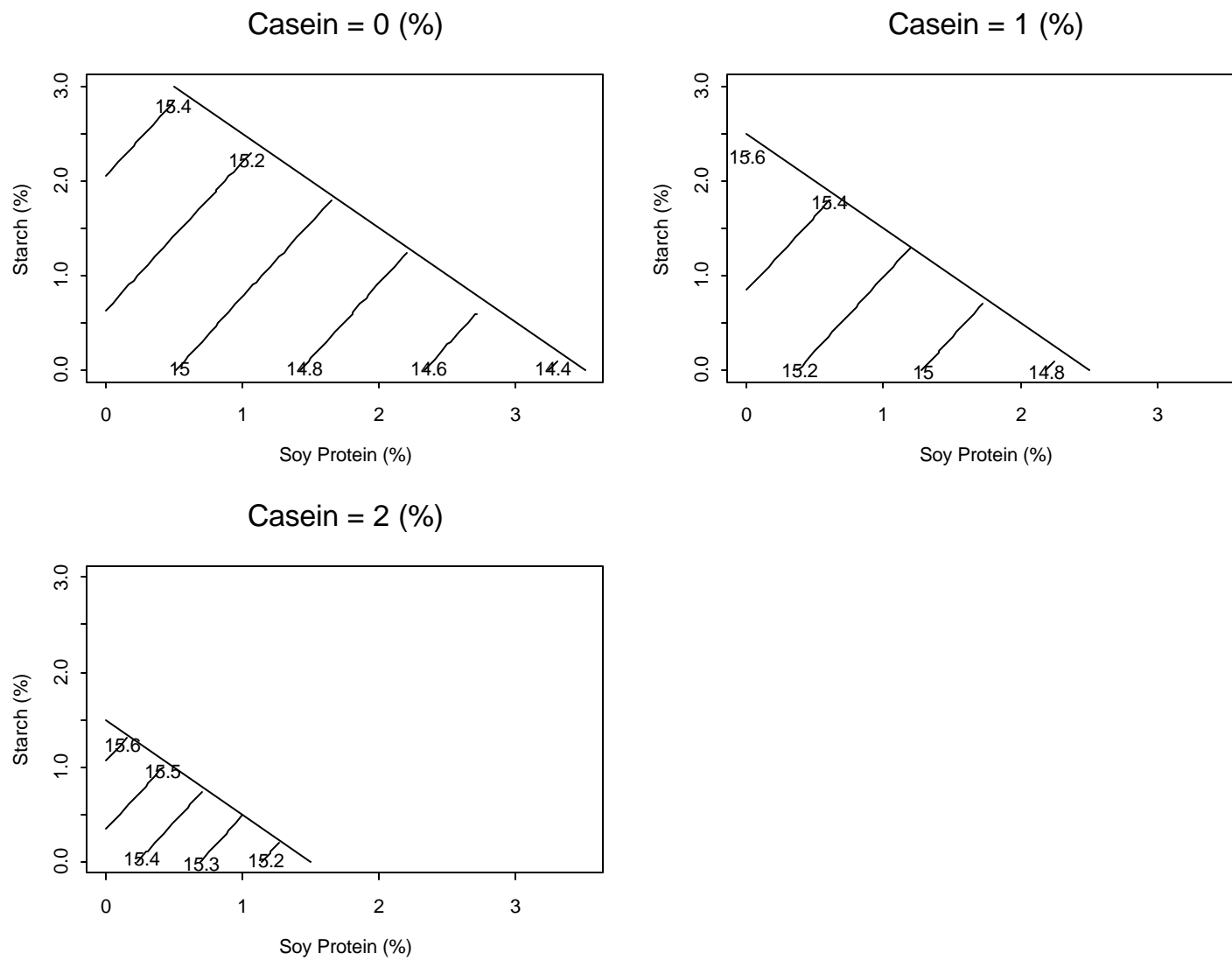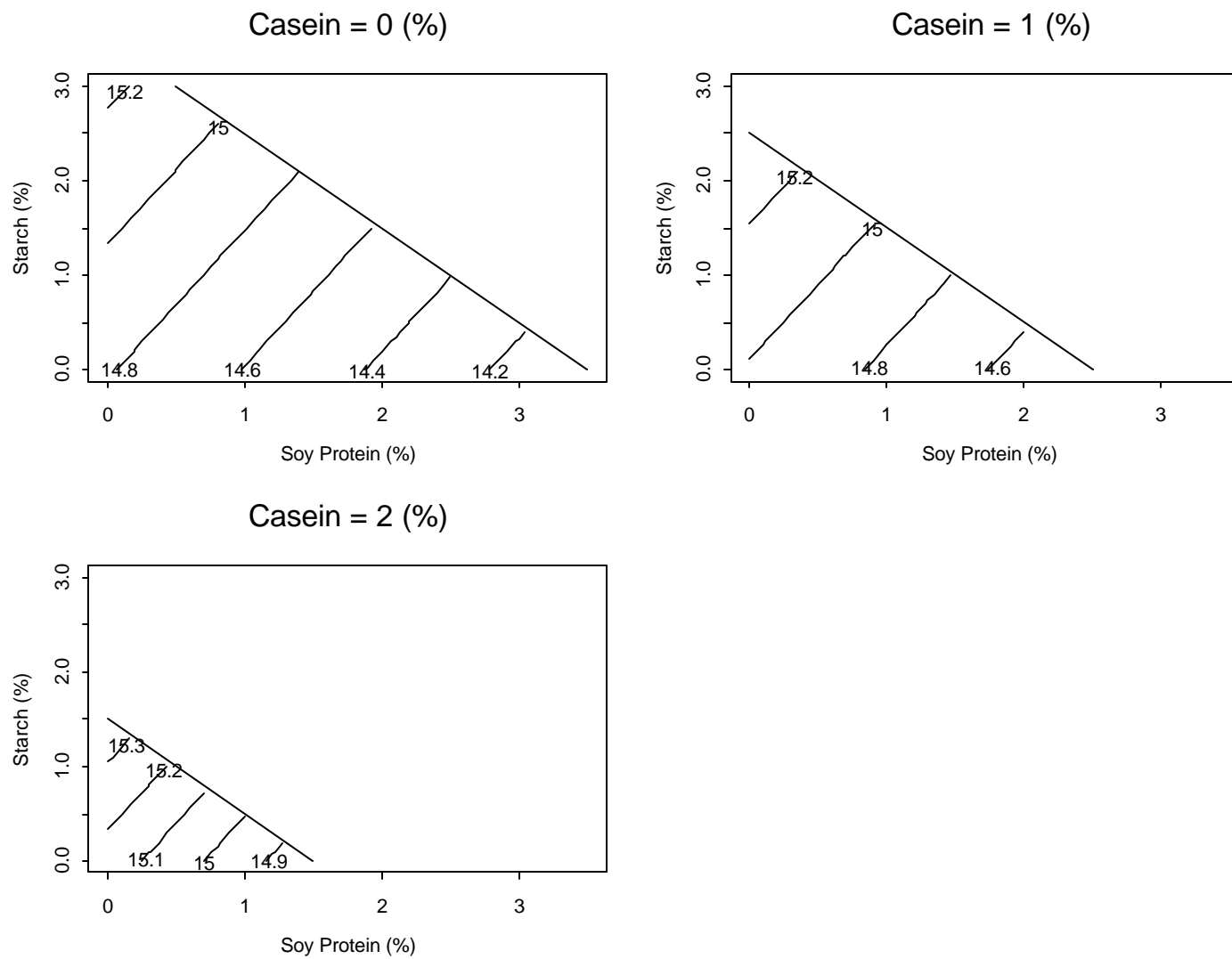
Figure A.2 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage cooking loss (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % PSE and 0 % RFN raw material.
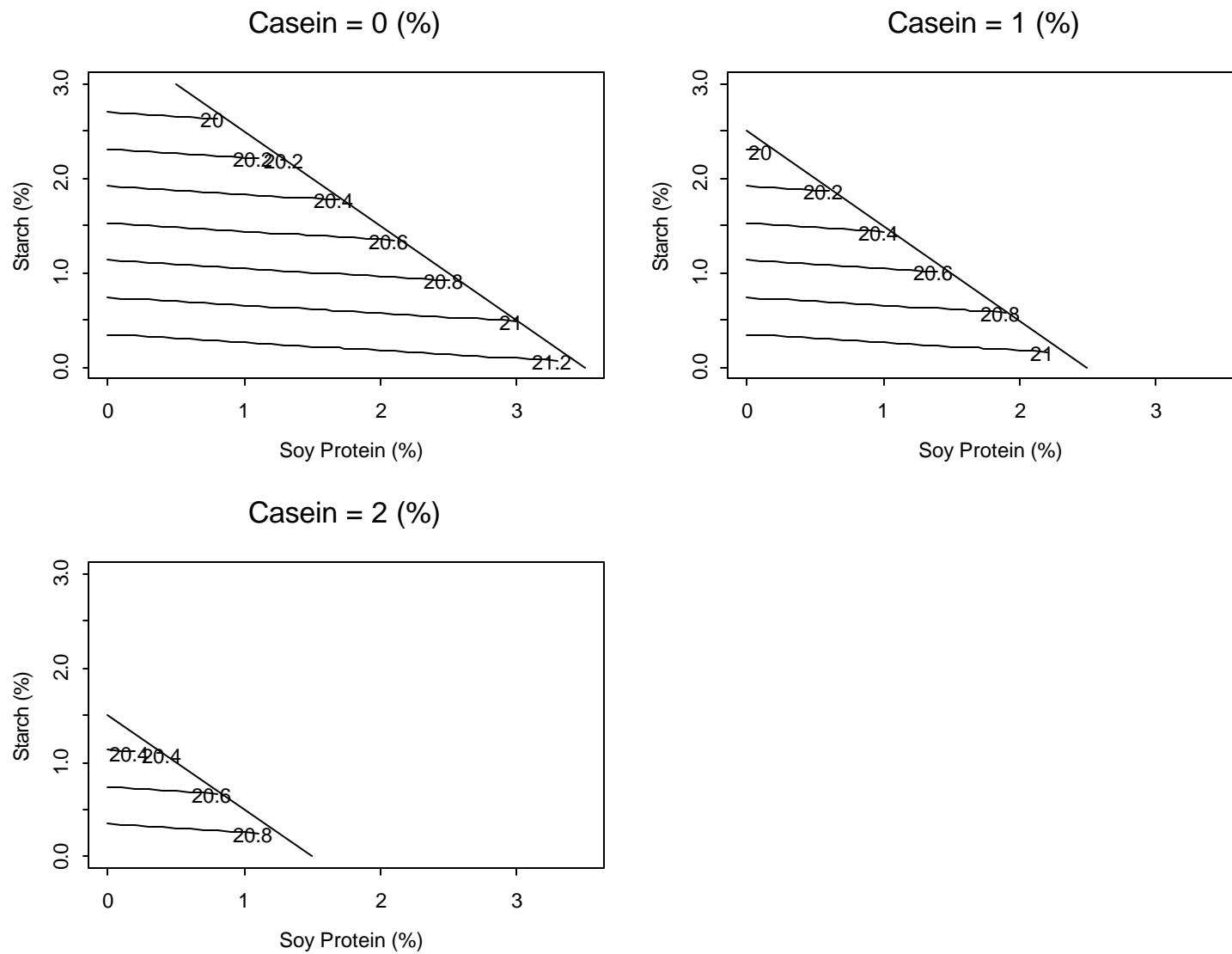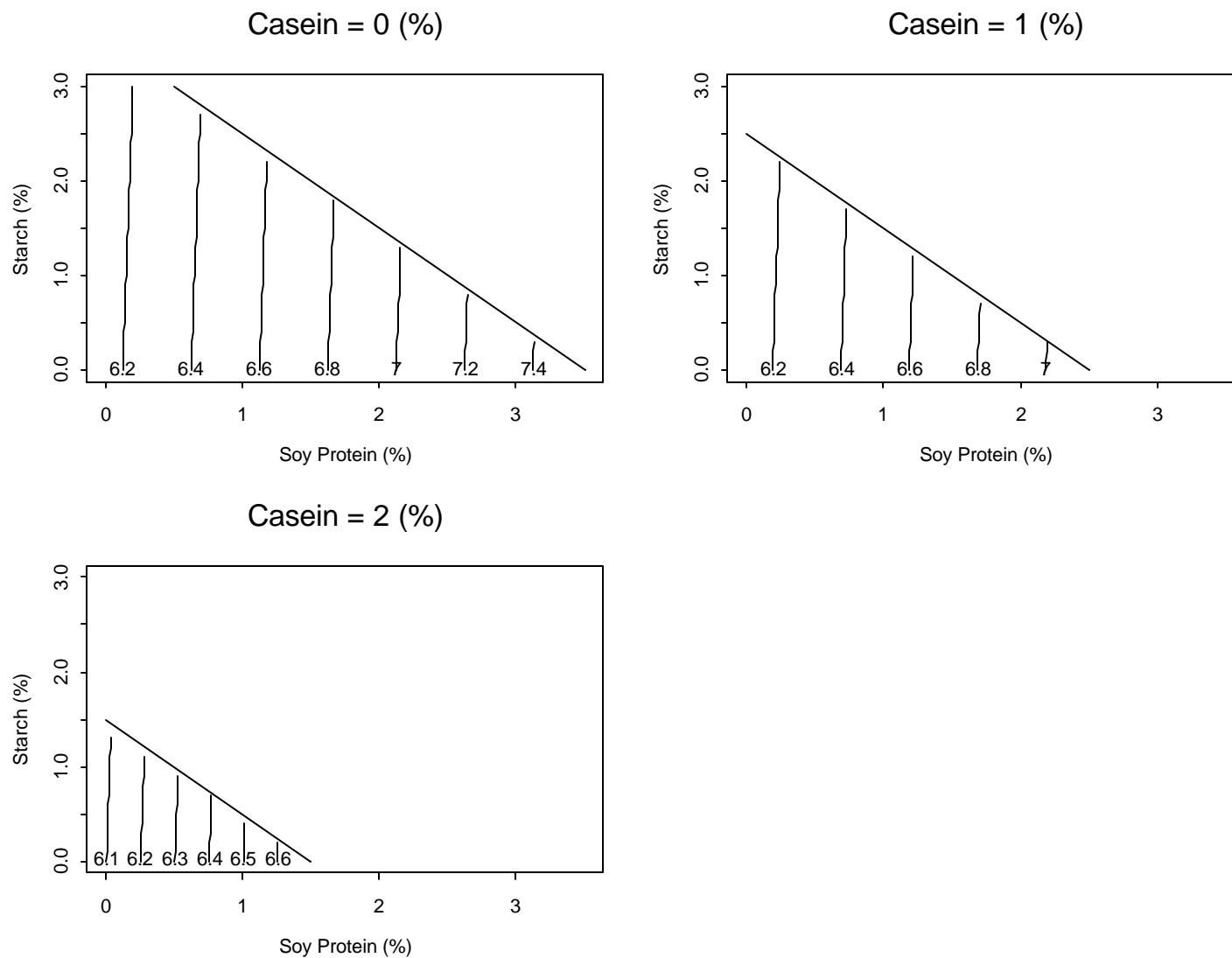
Figure A.3 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage expressible moisture (values reported within rectangles) of chunked and formed, restructured pork formulated with 75 % PSE and 25 % RFN raw material.
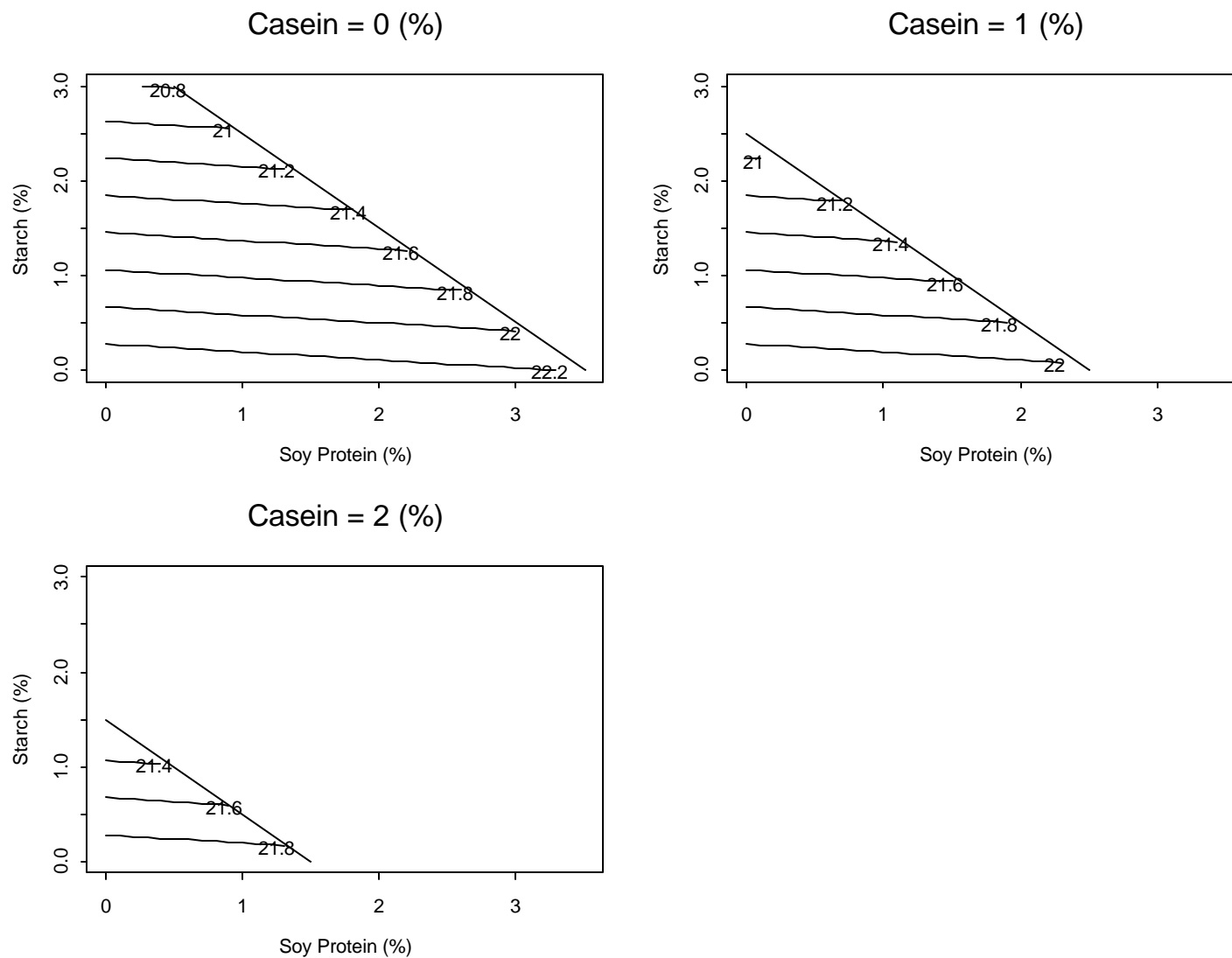
Figure A.4 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the percentage expressible moisture (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % PSE and 0 % RFN raw material.
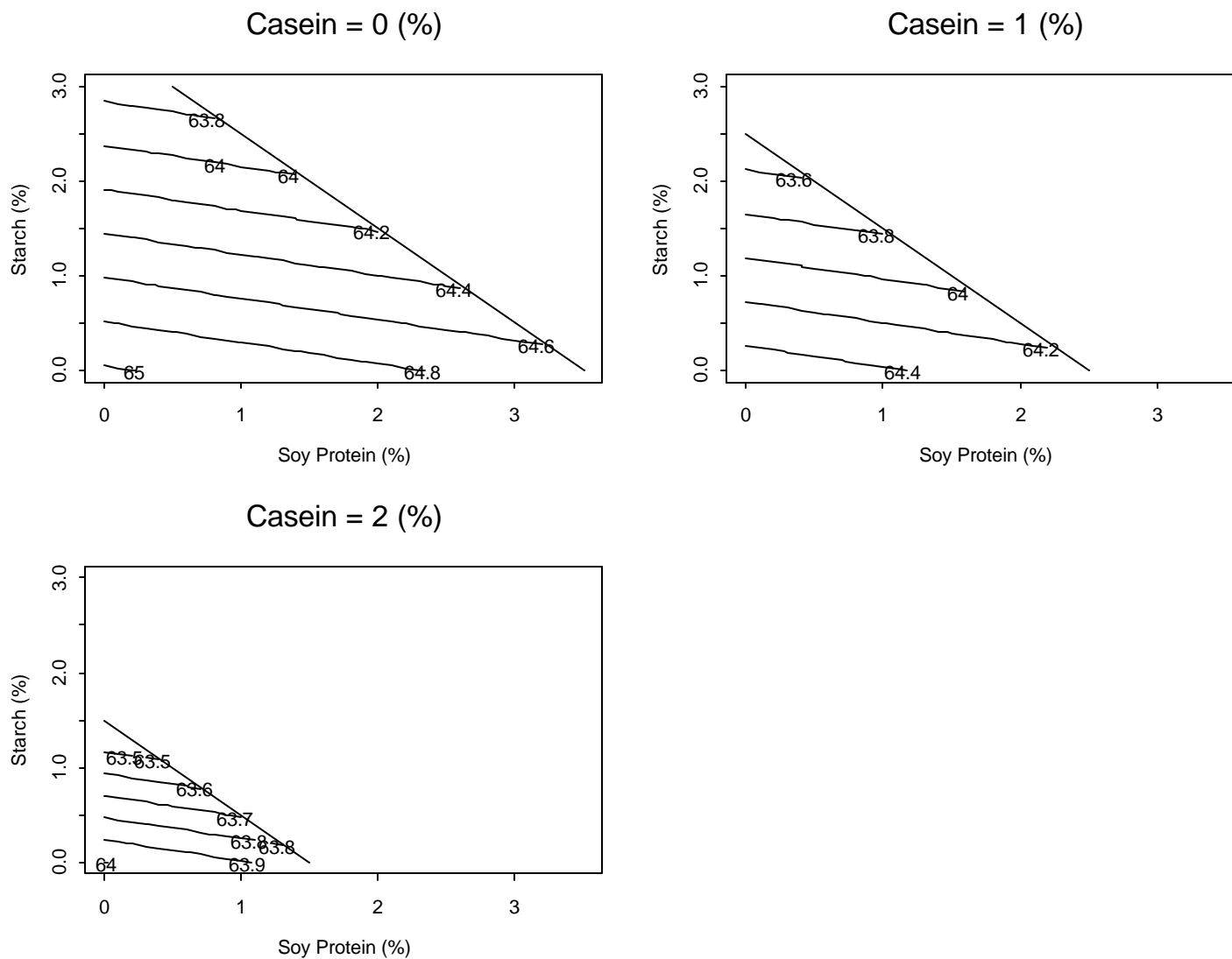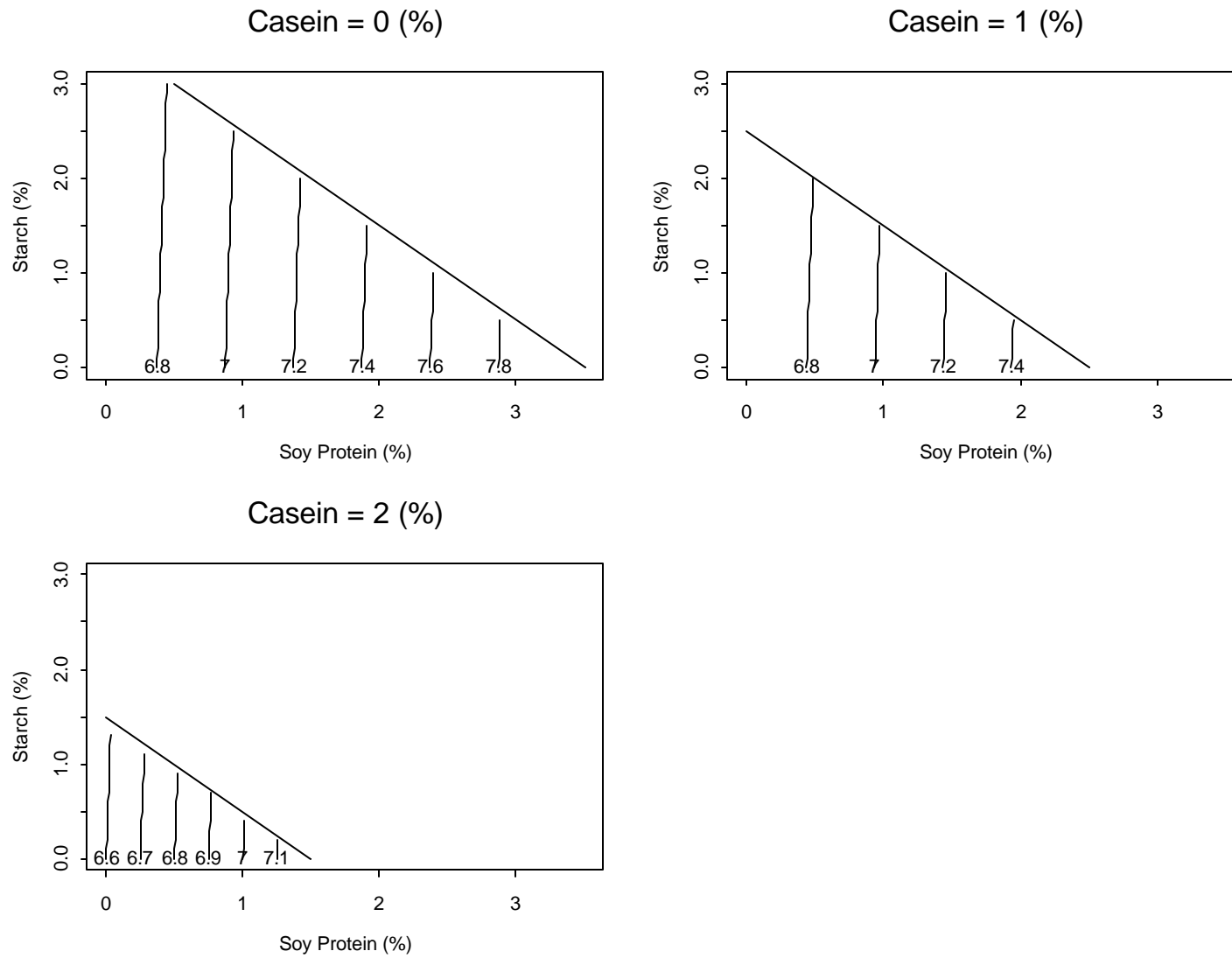
Figure A.5 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE L* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 75 % PSE and 25 % RFN raw material.
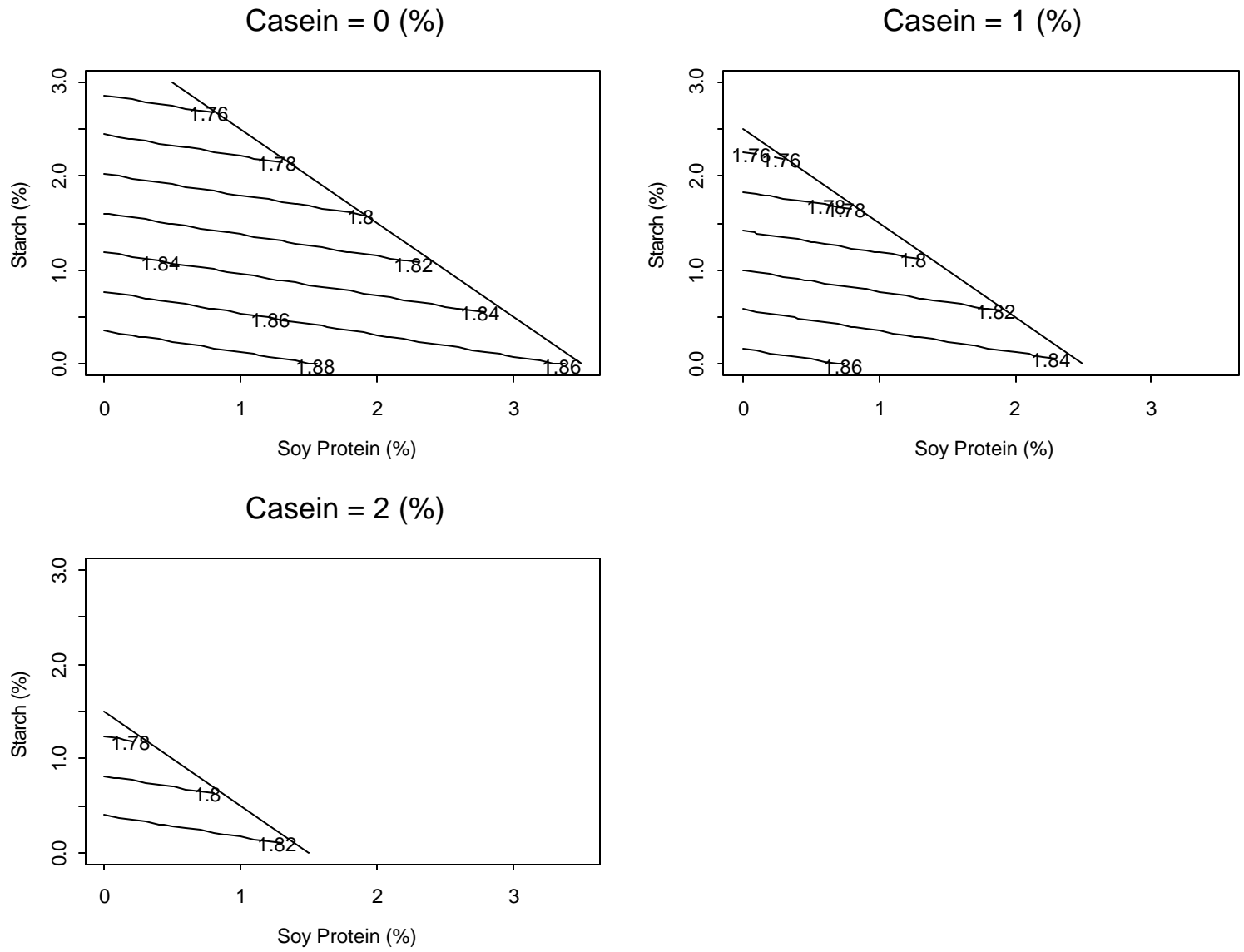
Figure A.6 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE L* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % PSE and 0 % RFN raw material.

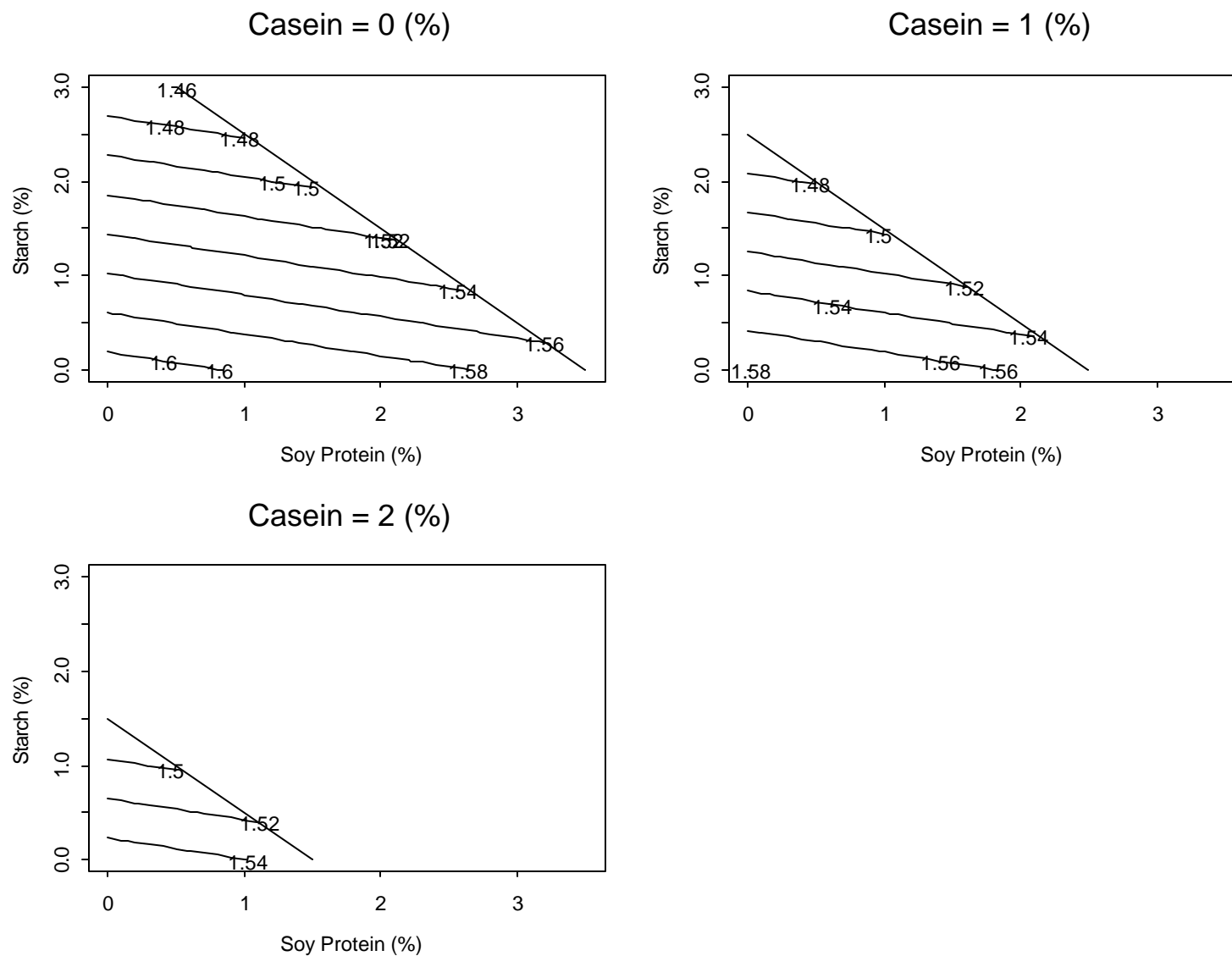Figure A.7 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE a* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 75 % PSE and 25 % RFN raw material.

Figure A.8 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE a* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % PSE and 0 % RFN raw material.

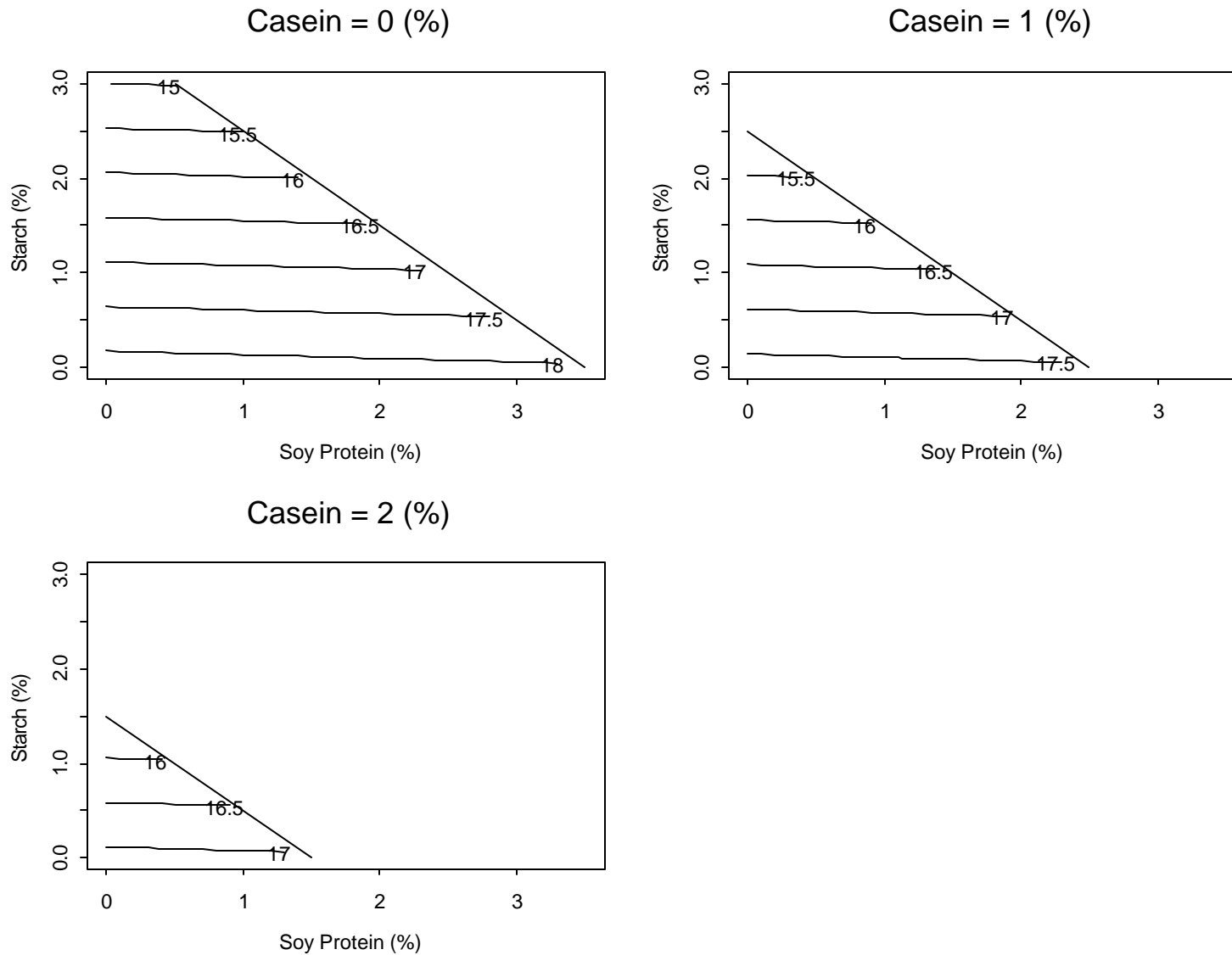Figure A.9 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE b* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 75 % PSE and 25 % RFN raw material.

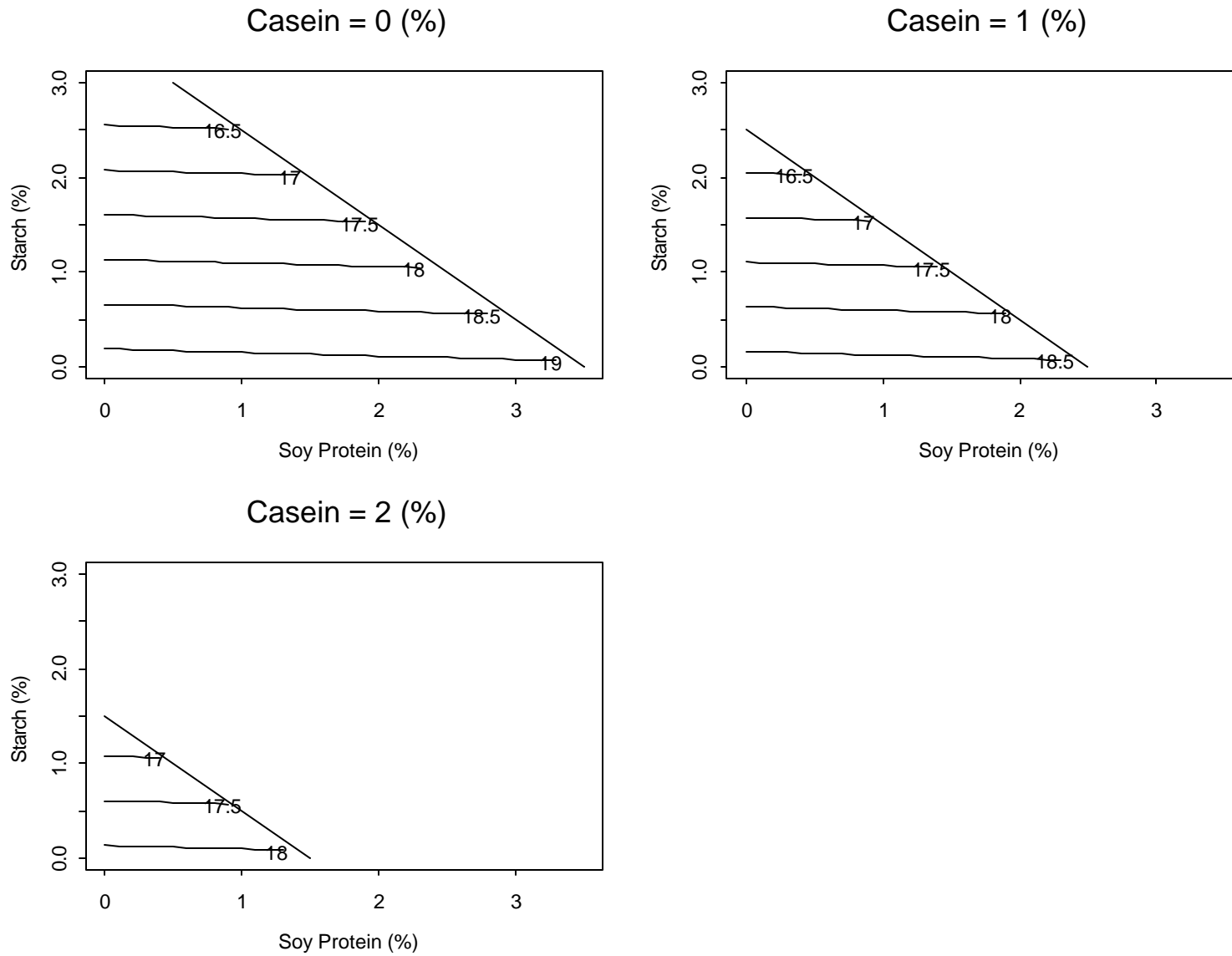Figure A.10 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the CIE b* value (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % PSE and 0 % RFN raw material.

Figure A.11 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the protein-protein bind strength (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 75 % PSE and 25 % RFN raw material.

Figure A.12 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on the protein-protein bind strength (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % PSE and 0 % RFN raw material.
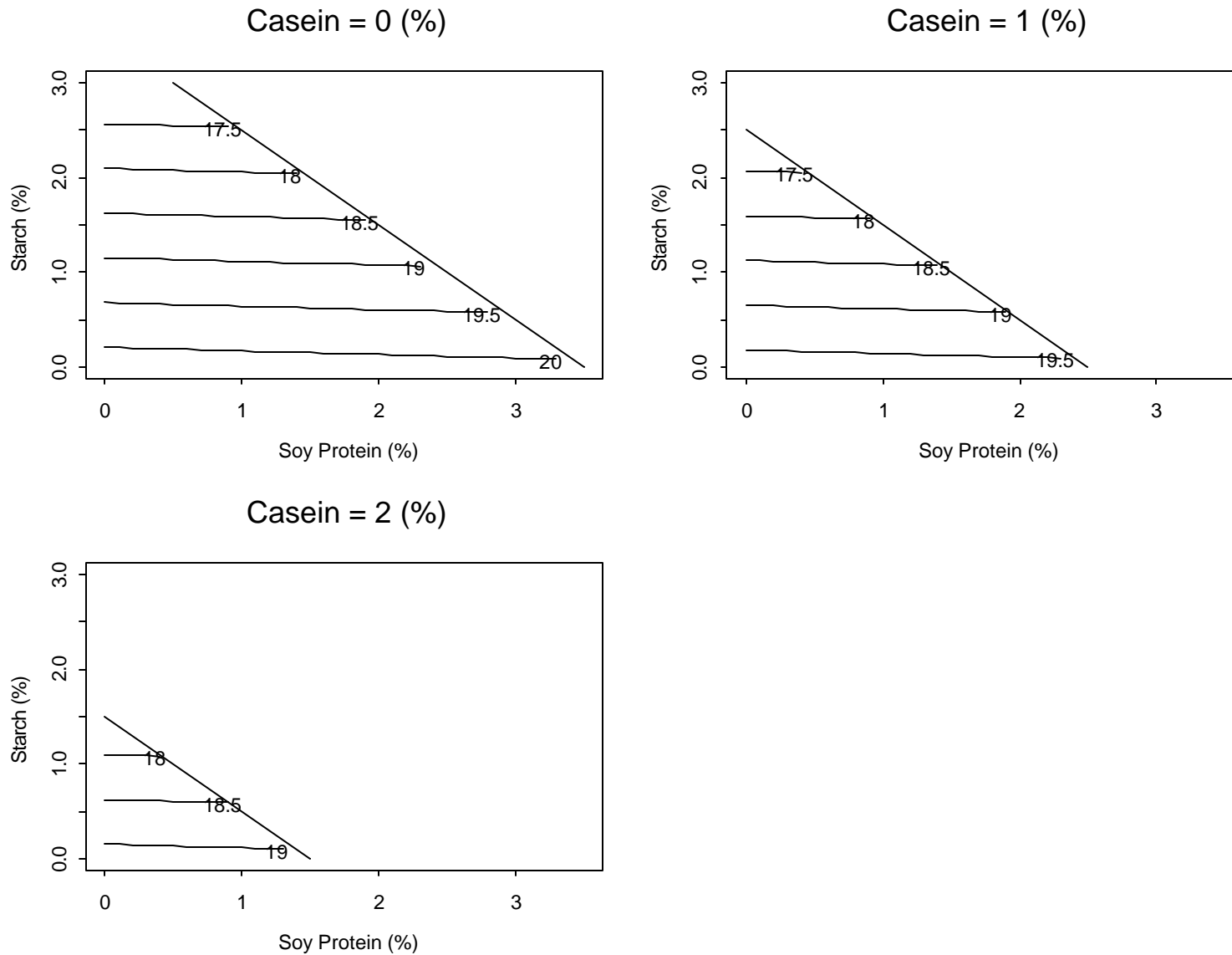
Figure A.13 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis hardness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 50 % PSE and 50 % RFN raw material.
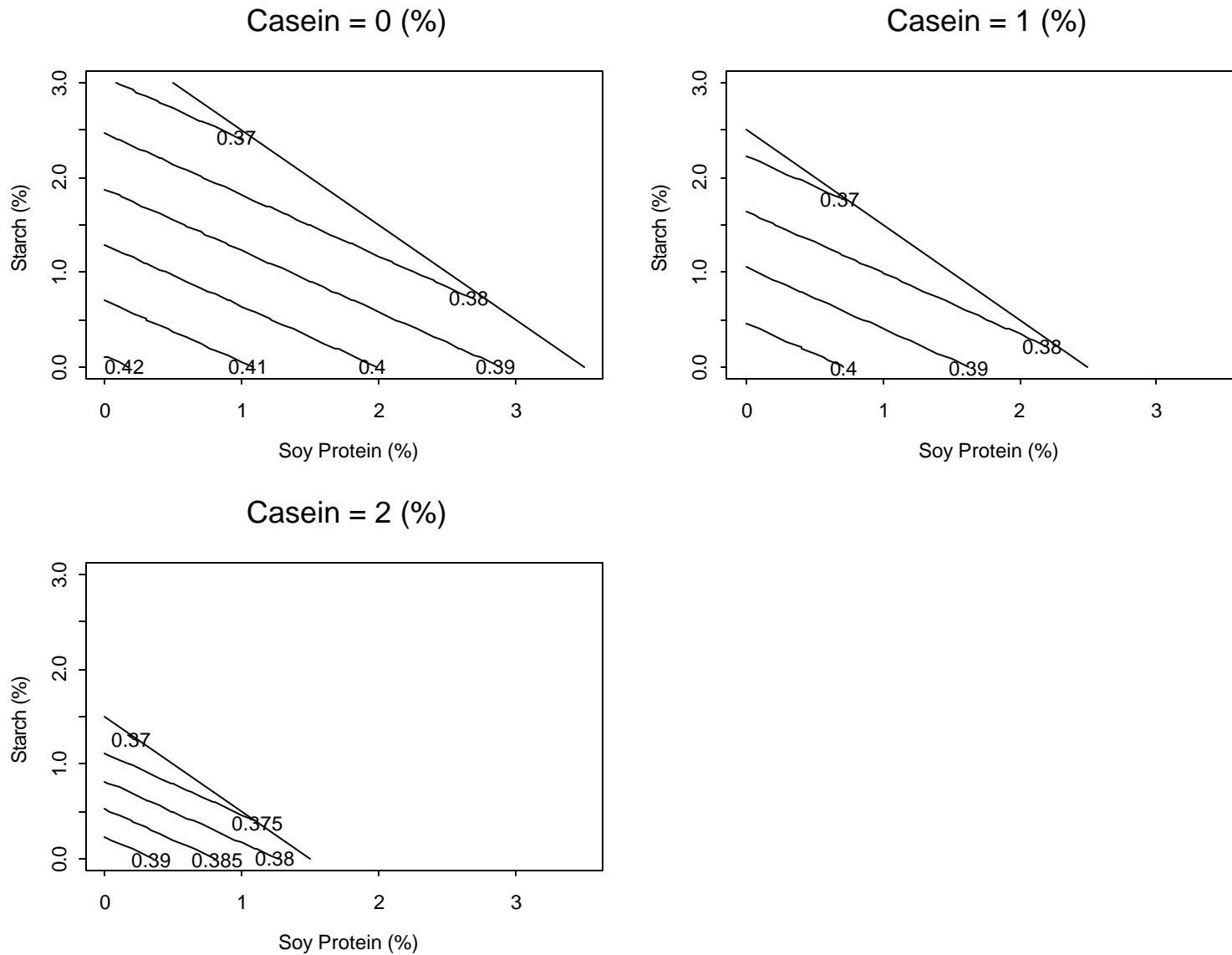
Figure A.14 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis hardness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 75 % PSE and 25 % RFN raw material.

Figure A.15 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis hardness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % PSE and 0 % RFN raw material.
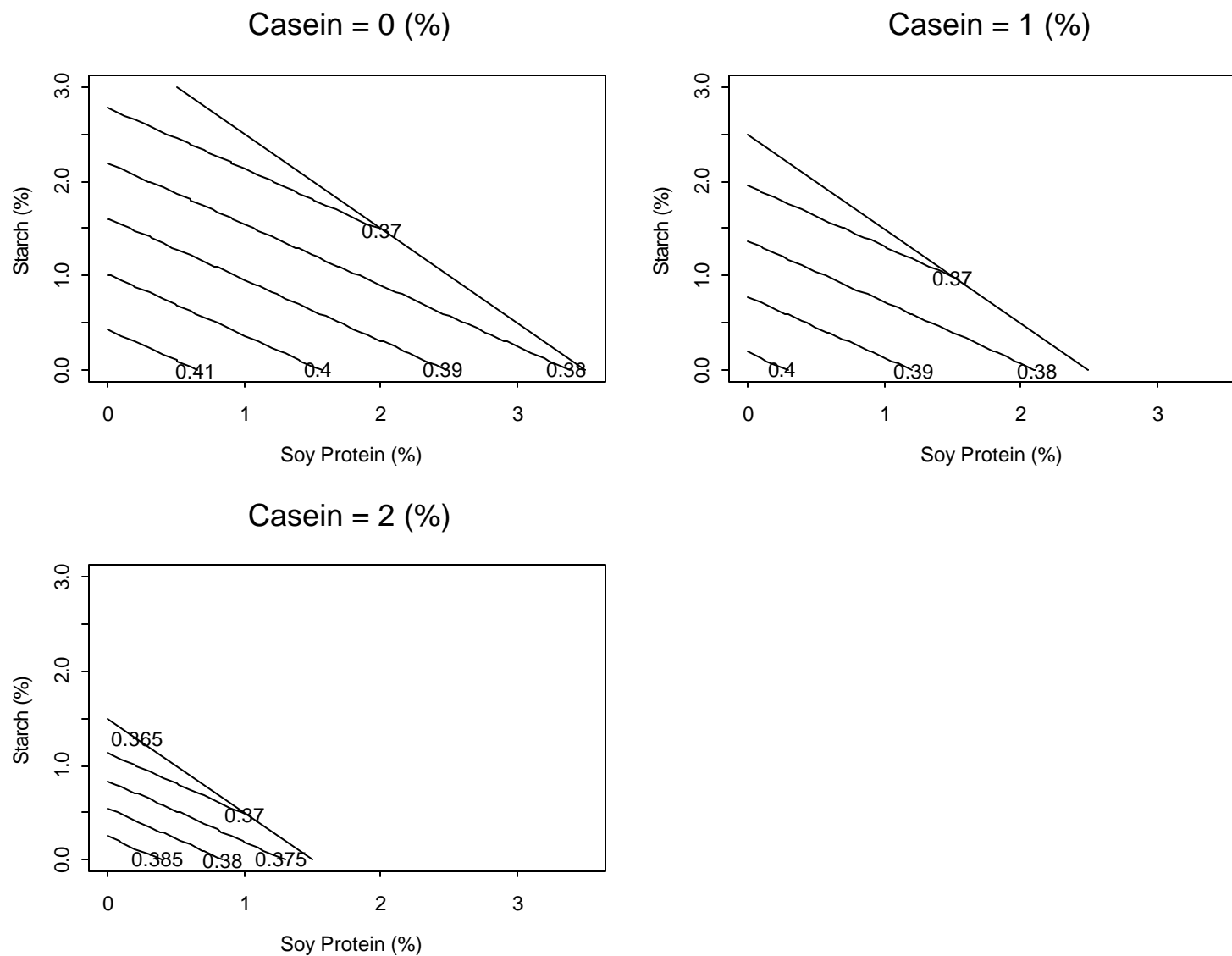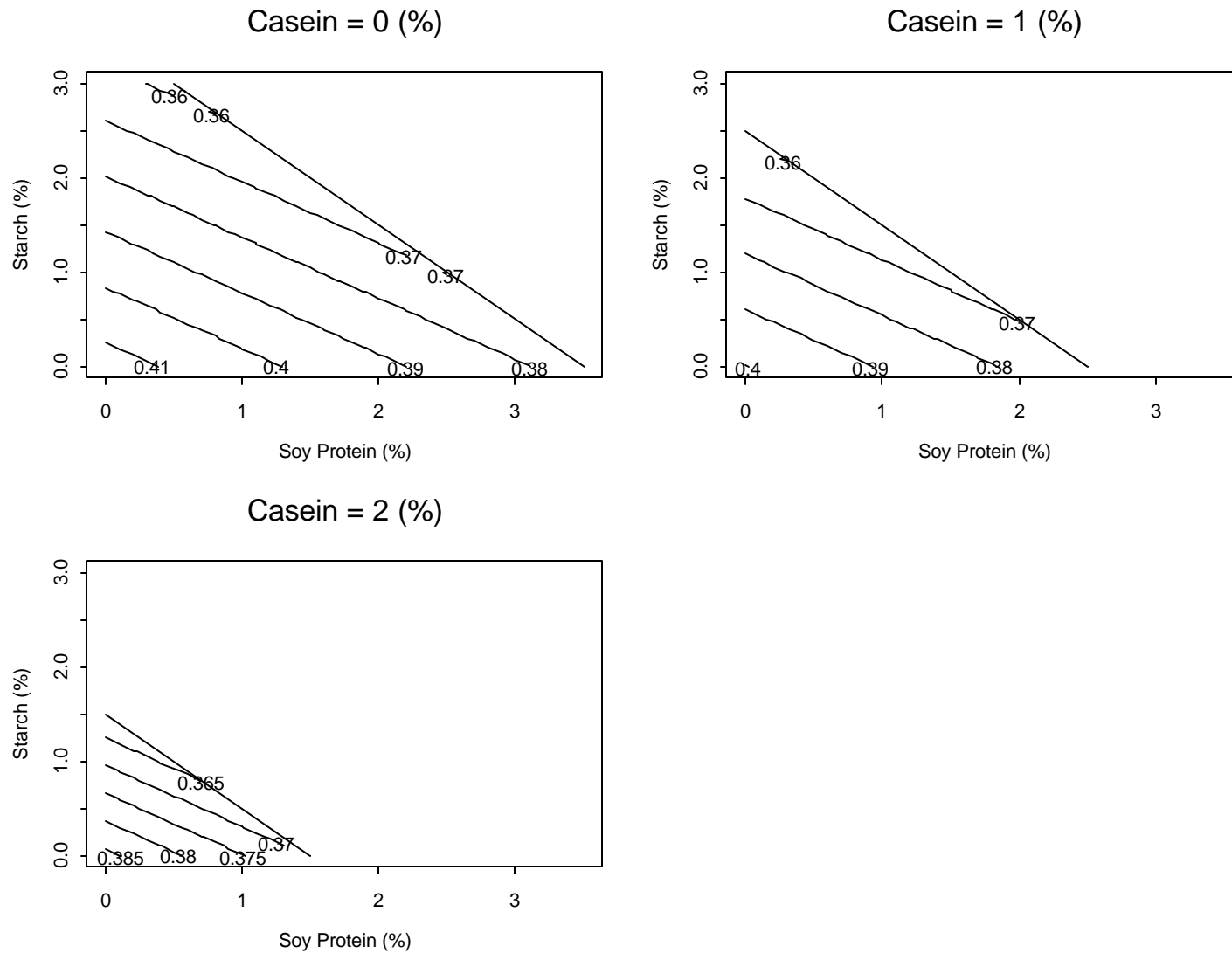
Figure A.16 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis cohesiveness (values reported within rectangles) of chunked and formed, restructured pork formulated with 50 % PSE and 50 % RFN raw material.

Figure A.17 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis cohesiveness (values reported within rectangles) of chunked and formed, restructured pork formulated with 75 % PSE and 25 % RFN raw material.

Figure A.18 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis cohesiveness (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % PSE and 0 % RFN raw material.
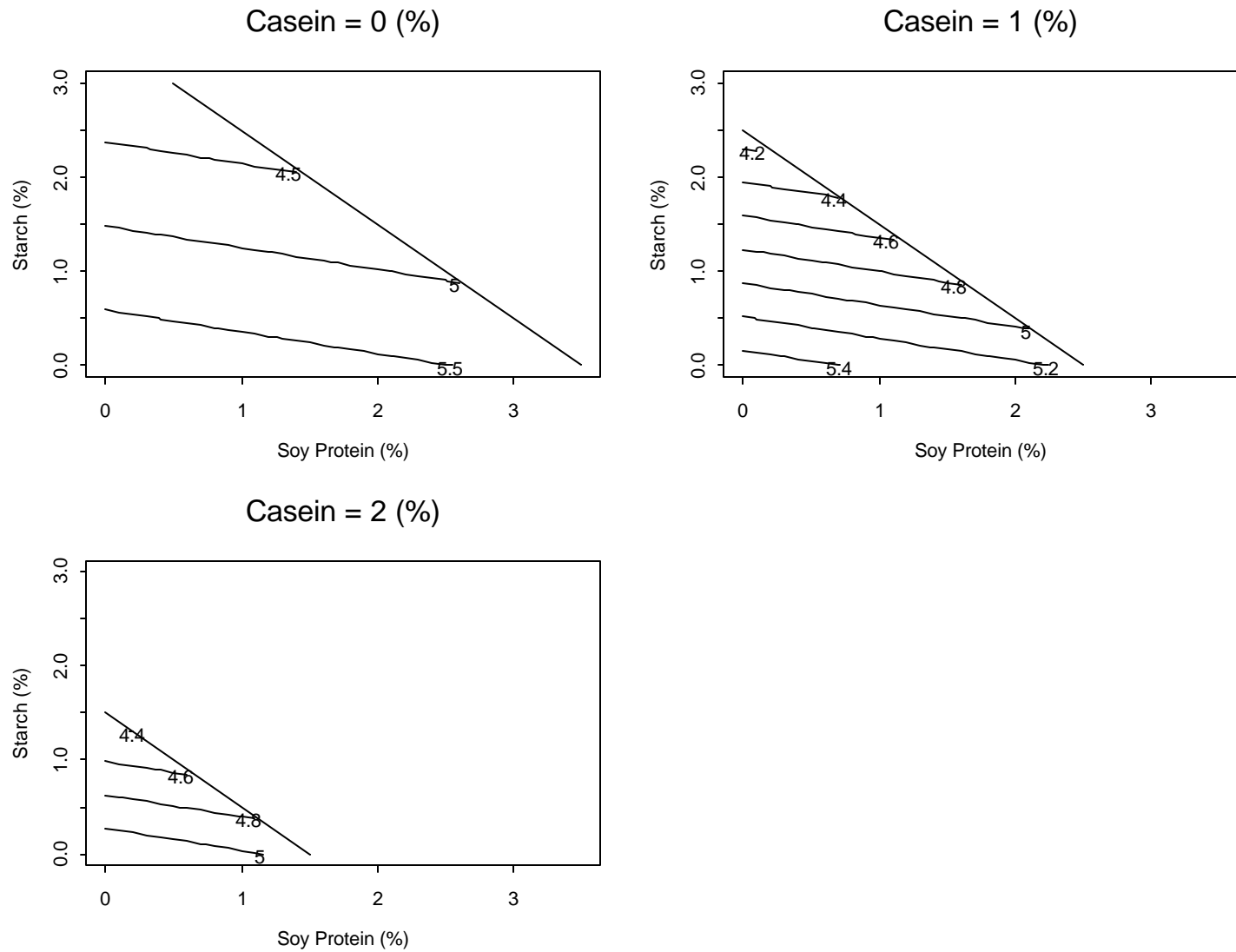
Figure A.19 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis chewiness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 25 % PSE and 75 % RFN raw material.
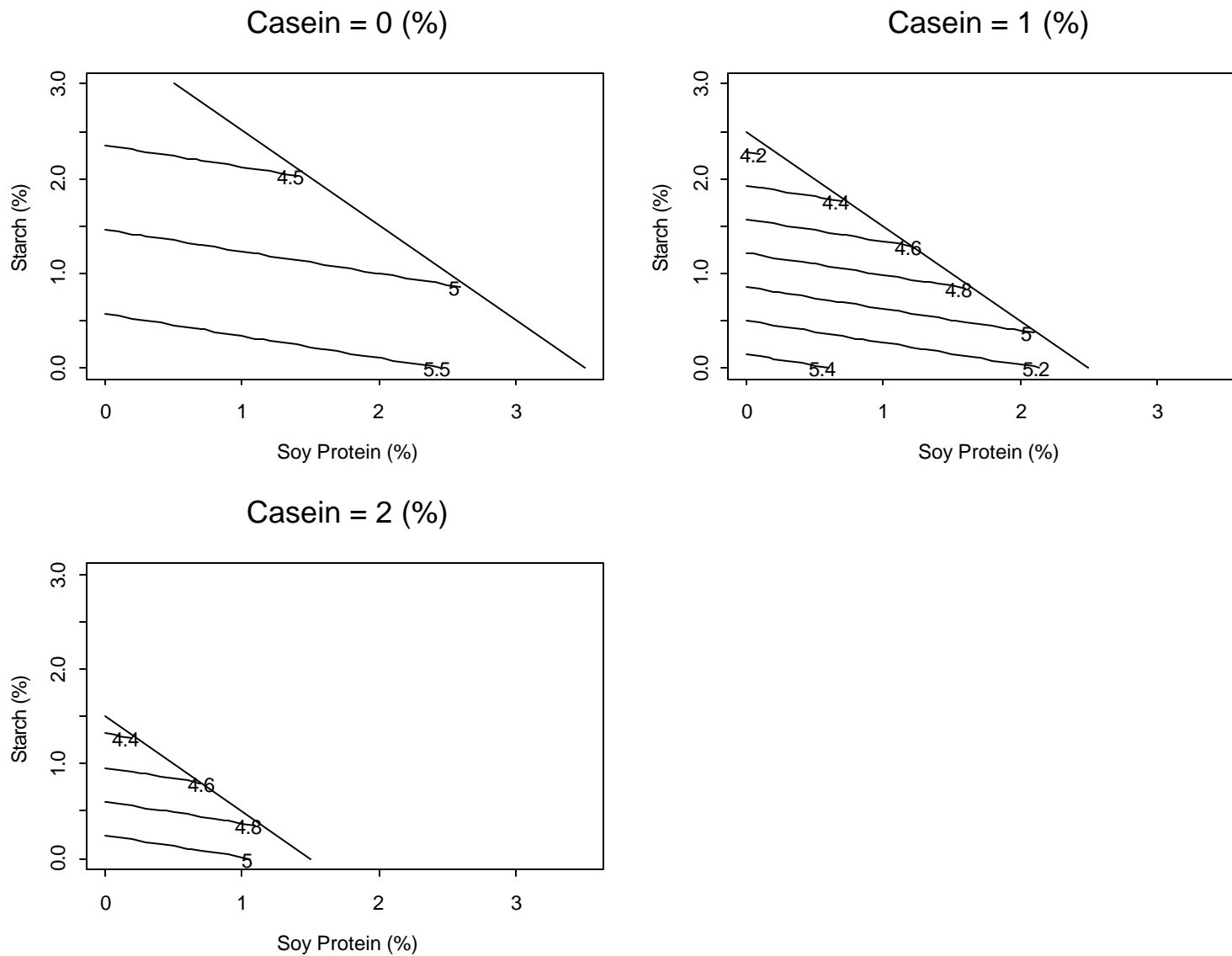
Figure A.20 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis chewiness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 50 % PSE and 50 % RFN raw material.
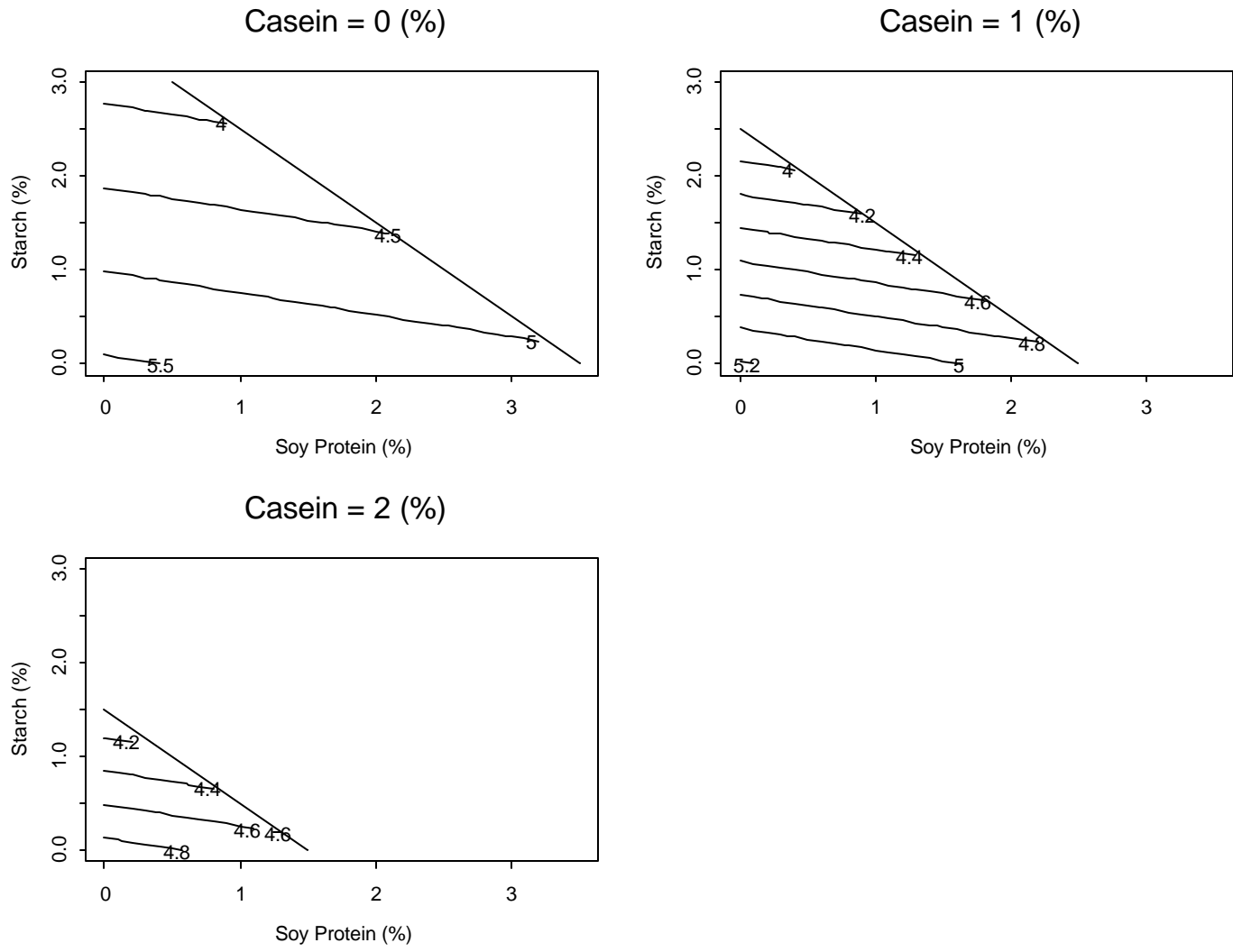
Figure A.21 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis chewiness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 75 % PSE and 25 % RFN raw material.
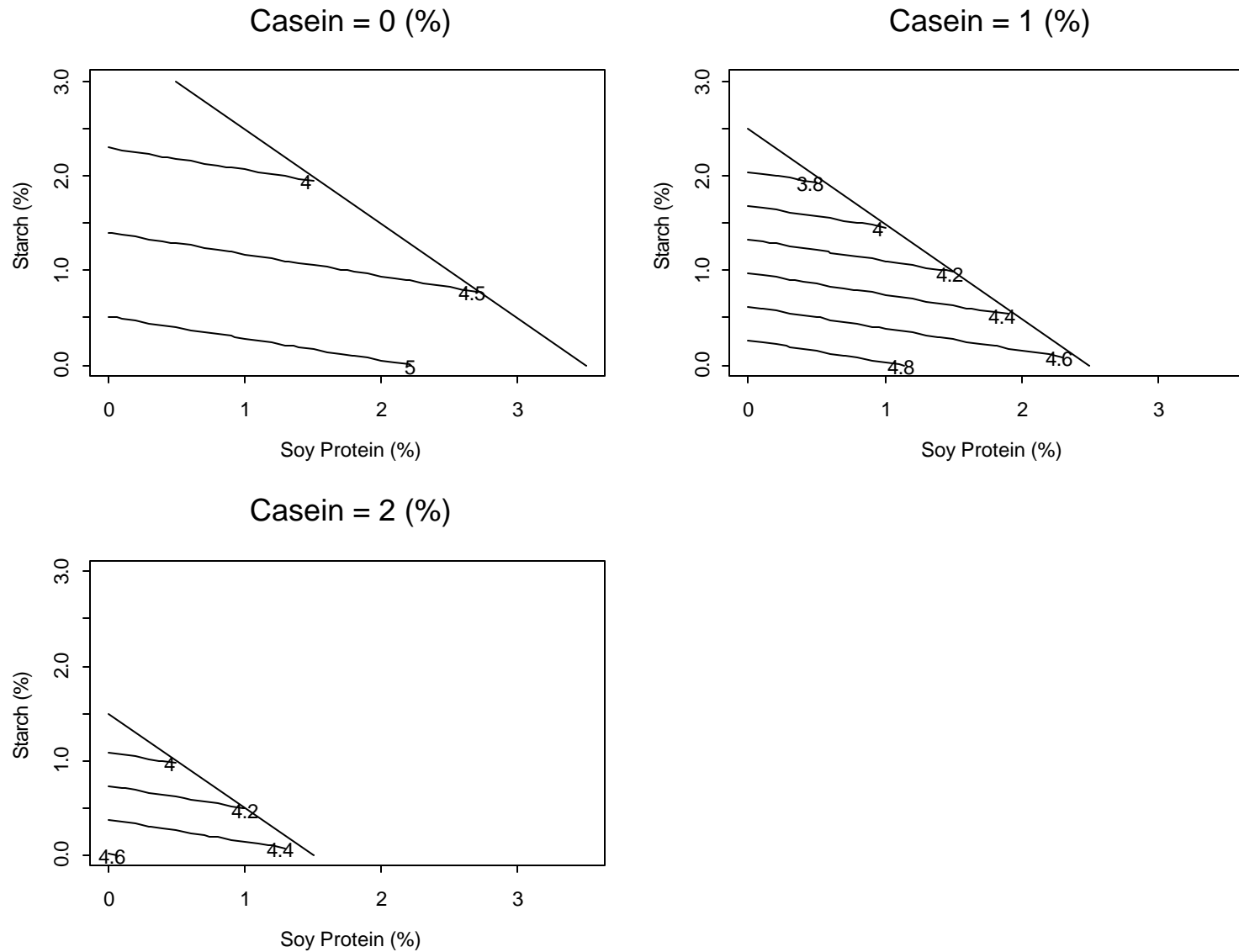
Figure A.22 – Effects of soy protein concentrate, modified food starch, and sodium caseinate on texture profile analysis chewiness (kg) (values reported within rectangles) of chunked and formed, restructured pork formulated with 100 % PSE and 0 % RFN raw material.

Vita

Mark Wesley Schilling was born on October 28th, 1975 in Oak Ridge, Tennessee, the son of Robert M. and Carolyn S. Schilling. He graduated from Oak Ridge High school in June, 1993 and later married Jennifer Knowles on May 29th, 1999.

Wes studied Food Science and Technology at Virginia Polytechnic Institute and State University where he received a Bachelor of Science in May, 1997. He continued his graduate studies where he received his Master of Science in Food Science and Technology and Master of Science in Statistics in the fall of 1999 and spring of 2002, respectively. Future plans are to finish his PhD in Food Science where he researched protein functionality in pale, soft, and exudative pork in the summer of 2002.

Wes is a member of the American Meat Science Association and the Institute of Food Technologists. In September of 2002, he plans to pursue either an academic or industrial career in food science where he can perform research and utilize his statistics background.