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THE UTILIZATION OF POULTRY BREAST MUSCLE OF DIFFERENT QUALITY CLASSES

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Tiivistelmä - Referat– Abstract

The literature review dealt with the principles and methods for the evaluation of the quality of raw meat and meat product in different aspects. The factors influencing the quality of meat products were also involved.

A new type of muscular dystrophy in broiler *Musculus pectoralis,* wooden breast, has been found in broilers. The dystrophy results in fibrinogenesis and thus local hardening in the muscle, but poses no health risk in human consumption. The aim of the study was to explore the maximal percentage of wooden breast that can be used in the meat products without causing a perceived quality defect. In the preliminary tests, wooden breast was incorporated with normal meat in different percentages to make sausage and chicken nuggets. Different methods of comminuting were also applied in the processing of wooden breast. The quality of the products was evaluated through the measuring in different aspects. Comparison was made between normal products and products containing wooden breast, so that a maximal addition percentage of wooden breast was obtained. The results of the preliminary test were later verified in the pilot plant.

The addition of wooden breast increased the shear force and binding strength of the sausage and finely chopped chicken nuggets but resulted little change on the shear force and binding strength of the ground chicken nuggets. The pH, redness, and yellowness of all types of products declined with the wooden breast treatment. Lightness of the products was increased by wooden breast. Through the verification in the pilot plant, sausage and two types of chicken nuggets allow the addition of wooden breast to replace at least 15% and 30% of the lean meat in the recipe, respectively. Due to the low incidence of the dystrophy, that high additions will not be necessary in the practice.

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Preface

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Two years' study in the University of Helsinki will be an unforgettable memory in my whole life. Thank all the teachers and academic staffs I met there. Thank for the support from my parents to let me have the chance to study abroad.

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1 INTRODUCTION AND AIMS

Wooden Breast is a phenomenon occasionally found in broiler chicken showing macroscopically pale and hardened beast muscles. White strips occur on the surface of the breast muscles, which are considered to be caused by muscle damage characterized by degeneration of muscle fibers. The abnormal hardness of wooden breast muscles can be perceived by hand. Due to the visual defect and the difference in hardness, wooden breast is usually rejected to be sold as raw meat products and also rejected to be used in the processing of other meat products. Generally, wooden breast is only used in animal feed, which brings economic losses to slaughter-house and meat industry. Although with undesirable appearance and hardness, wooden breast involves no health hazard. Therefore, wooden breast is possible to be utilized in meat industry and a method for the utilization is needed to be developed.

Modern processing technologies increase the possibilities of the use of less acceptable meat cuts in the meat products. Representatively, restructuring and emulsifying are the two most commonly used methods to produce meat products with low-value meat cuts. Comminuting is usually the first step in the processing of many meat products, in which meat particle size has been reduced. The size reduction caused by comminuting contributes to the release of myofibrillar proteins and the further interactions between them. The binding of meat proteins during cooking forms gel through the formation of a three-dimensional network. The formation of the three-dimensional network in cooked products allows the increasing presence and addition of non-meat ingredients (Acton 1972). For example, meats with high fat content or with high content of connective tissue have been used to produce sausages (Ranken 2000). Even low-value ingredients such as meat fat and skin have been added into the processing of sausage (Biswas et al. 2007) to increase the profit of meat industry. Moreover, these processing technologies also enable the utilization of low-quality meats, such as pale, soft, and exudative (PSE) meat and loose structure meat. The incorporation of PSE meat within a percentage of 50% by comminuting into normal meat produced restructured meat products whose quality showed no significant difference from those made from normal meat (Schilling et al. 2003). Meanwhile, varieties of additives have been reported to be used in the processing to enhance the functionality of myofibrillar and subsequently increase the quality of the restructured products made from low-quality meats. Therefore, the possibilities of the utilization of meat with lower quality but without health hazard are present in meat industry with proper processing technologies incorporating the low-quality meat into normal meat in an acceptable range.

As an important starting stage in the processing of meat products, comminuting contributes to the variations in the products quality. Firstly, the technological methods of comminuting cause variations in the quality of meat products. Boles and Shand (1998) compared slicing, flaking, and grinding in the processing of restructured beef and found significant differences in the fat content, moisture content, raw bind strength, and juiciness. The variations in appearance, shear force, cooking loss, and consumer acceptability caused by different comminuting methods have also been reported (Berry 1980; Costello et al. 1981; Noble et al. 1985). Secondly, the degree of comminuting, producing different particle sizes, also causes variations in the quality of meat products. Stronger comminuting generating smaller meat particles usually improves the quality of meat products due to the better extraction of meat proteins (Acton 1972; Gurikar et al. 2012). On the other hand, comminuting is vital for the utilization of low-quality meat since it enables the incorporation of low-quality meat into normal meat through the reduction of meat particle size.

This study aimed to develop the technologies to utilize wooden breast in meat products in order to minimize the economic losses of meat industry. Firstly, this study aimed to find out the maximal proportion of wooden breast used in different meat products without causing significant perceived defection on the quality of meat products. Secondly, effects of different comminuting methods on the utilization of wooden breast in meat products were aimed to be studied.

2 LITERATURE REVIEW

2.1 Evaluation of the quality of raw poultry meat

2.1.1 pH

pH is an important parameter for the evaluation of the quality of meat as it influences the texture, appearance, and water-holding capacity of the meat. The interaction between pH and temperature after slaughter has been reported to have significant impact on the tenderness of meat by affecting the activities of the proteolytic enzymes (Dransfield 1995). Hannula and Puolanne (2004) found that when the temperature is low, higher pH results in tougher meat. pH of meat also influences the water-holding capacity of meat by affecting the protein net charges which causes a repulsion that increases the binding of water (Hamm 1972). In addition, denaturation of myofibrillar proteins caused by pH also affects the water-holding capacity of meat (Richardson and Mead 1999). Besides, the pH decline *post mortem* affects the color of meat (Govindarajan 1973). The color characteristics of meat have also long been known to be influenced by the *post mortem* pH of meat. Therefore, pH is an important characteristic of meat affecting and reflecting other properties of meat.

Both early *post mortem* pH and ultimate pH are measured as the general properties of poultry meat. The early *post mortem* is usually measured at 15 to 90 minutes *post mortem* (Soares et al. 2003; Wilhelm et al. 2010). The ultimate pH is commonly measured 24 h *post mortem* (Soares et al. 2003; Daigle et al. 2005; Zhu et al. 2011). Generally, two methods for the measurement of pH are used in the studies of meat science. One method is that pH is measured directly with a contact pH meter system equipped with a probe or electrode. Another indirect method is also used, in which the pH of meat is measured from the homogenates of meat with a pH meter coupled with a glass electrode after adding sodium iodoacetate into the homogenates to stop the glycolysis and thus the pH fall of the meat (Mothershaw et al. 2009; Zhu et al. 2011).

2.1.2 Color

The appearance of meat is usually regarded as the most important property of the meat contributing to the meat quality because it is critical for the initial selection and further the sensory evaluation. Therefore, the color of meat is associated closely with the acceptance of meat and meat products. The preference of the color of poultry meat varies in different regions. However, extreme darkness or paleness are often regarded as undesirable color and bring problems on the selection of meat (Richardson and Mead 1999).

Conventional methods of the measuring include the visual assessment and chemical-spectrophotometric and direct pigment analysis. However, drawbacks are present in these methods. Visual assessment is relatively inaccurate and cannot reflect the meat color on an objective level. Analysis of pigment in meat is regarded as an objective way to assess the color characteristics of meat. This method of the evaluation of meat color involves assumption that the amount of pigment is linearly associated with the color of meat. However, in fact the correlation between quantity of meat pigment and meat color may not be strictly linear. Therefore, the pigment analysis may not reflect the color of meat directly (Richardson and Mead 1999). In a few decades, the reflectance colorimetry has been being increasingly used in the measurement of meat color. Meat color can be determined by chroma meters based on a Commission International de l'Eclairage (CIE) L*a*b* system. With this method, the color of poultry breast has been evaluated from the data of the lightness (L*), redness (a*), and yellowness (b*) of the meat. The characteristics of meat is usually obtained from at least three replicate measurements on the different locations of the surface of the muscles at 24 h *post mortem* at room temperature (Soares et al. 2003; Wattanachant et al. 2005a; Mothershaw et al. 2009).

2.1.3 Texture

The texture of meat is associated closely with the sensory properties of meat. Generally, consumers prefer tender meat rather than tough meat. The tenderness of meat is determined by several factors in the meat, including the sarcomere length of the muscle, amount of connective tissue, and the degree of ageing (Greaser, 1986).

Shear force

In the objective instrumental measurements of meat tenderness, either the Warner-Bratzler method or Allo-Kramer method has been applied on the texture analyzer by equipping the analyzer with a specific apparatus. Warner-Bratzler method uses a single blade to shear a meat sample. The maximum shear force is recorded in kilogram to indicate the tenderness of the meat (Bratzler 1954). In Allo-Kramer method, multiple blades are used to compress and then shear the meat pieces. The shear force is recorded in N/g of sample weight. Allo-Kramer method has been reported to be applied in the measuring of the shear force value of poultry meat (Bouton et al. 1975). In the measurement, the raw poultry meat is first cooked, and then cut into proper size and weighted. The blade made parallel to the fibres rather than across them. The shear forces were recorded by the computer (Cavitt et al. 2004; Wattanachant et al. 2005a; Mothershaw et al. 2009; Eadmusik et al. 2011).

Subjective panel evaluation

Sensory evaluation is often accompanied with instrumental test in the description of the meat tenderness. Correlation between the results of sensory evaluations of broiler breast and the objective shear forces of them has been reported by Lyon and Lyon (1990). In the sensory tests of raw poultry meat, the samples are usually packed in plastic bags and then cooked in water bath. The hardness, cohesiveness, and the overall customer acceptability of the cooked meat are evaluated by a group of panelist (Cavitt et al. 2004; Rababah et al. 2005) as a reference for the instrumental analysis for the texture of the raw poultry meat.

Sarcomere length

Lewis et al. (1977) claimed the sarcomere length of muscle has negative correlation with the shear force of bovine *longissimus* muscle, which means longer sarcomere length produces higher tenderness of meat. This theory was verified by many later studies and the principle of the adverse effect of muscle shortening on the tenderness has been found. Therefore, the sarcomere length is being used as a predictor for the tenderness of meat in many studies (Richardson and Mead 1999).

Conventional method for the measuring of sarcomere length is the oil-immersion, phase-contrast microscopy of unstained tissue, in which the space between Z-line can be measured with eye-piece measuring devices (Cross et al. 1980). The meat is first homogenized and the slides of meat homogenate are made. Sarcomere length is measured by observing the slide under a microscope equipped with degree scale on the eyepiece.

Laser diffraction method is an effective way to measure the sarcomere length and has been used in many researches. In this method, the muscle sections act as transmission gratings when placed under the laser with a wavelength of 632.8 nm. Laser passed through the muscle fibers and the diffraction patterns are formed on the screen. The distance between the diffraction bands is proportional to the sarcomere length of the muscle. After a series of calculation, the sarcomere length of the muscle can be obtained (Cross et al. 1980).

Connective tissue

The content and heat-stability of connective tissue in the muscle has correlation with the tenderness of the meat (Smith and Judge, 1991), with greater amount of connective tissue results in tougher meat. The cross-links between collagen in the connective tissue are what contribute to the toughness of meat (Light et al. 1985). Therefore, the connective tissue content in the muscle indirectly reflects the tenderness of meat and is used as a factor in the prediction of meat texture (Swatland et al. 1998).

The measurement of connective tissue content is based on the analysis of amount of hydroxyprolines because collagen contains around 12.5% of hydroxyprolines and only minor amount of hydroxyprolines exists in other components in the muscle tissue. Generally, to measure the content of hydroxyprolines, the muscle tissue needs to be digested in the condition of strong acid and a temperature over 100 ℃ for more than 24h so that hydroxyprolines are liberated from protein structure. The soluble collagen content and insoluble collagen content can be measured separately. After homogenized in the buffer solution, the muscle sample is centrifuged. The supernatants containing soluble collagen and the pellet containing insoluble collagen can be digested and analyzed separately for the determination of the content of soluble and insoluble collagen. The hydroxyproline content is generally analyzed through the methods of Bergman and Loxley (1963), in which the samples are oxidized with chloramime-T. After the addition of 4-dimethylaminobenzaldehyde, a red-purple color is developed which can be measured spectrophotometrically at 560 nm reflecting the concentration of hydroxyproline according to the standard curve prepared. Then the connective tissue content can be calculated by multiplying the hydroxyproline concentration with a coefficient of 8.

2.1.4 Water-holding capacity

The water-holding capacity is an important property for meat and related straightly to the meat quality. Myofibrillar proteins is essential to the ability of meat to hold water in the area between the filaments and its highly affected rate and extent of the *post mortem* pH-fall trigger mechanisms (Offer and Cousins 1992). The importance of the water-holding capacity of meat displays in two aspects. Firstly, meat is sold by weight, which means greater loss of water produces more economic loss. Secondly, the water holding capacity influences the appearance and the eating quality of meat (Pedersen et al. 2003). The water-holding capacity of meat can be reflected in several ways, including drip loss, expressible water, and cooking loss.

Drip loss

The measuring methods of the drip loss of poultry are similar to that of pork and beef. After slaughtering, the muscle sample is usually weighed and sealed in a polyethylene package and placed in 4 ℃ cooler until 24 h *post mortem*. During the storage, water leaks from meat. However, myofibrillar proteins enable the binding of water and prevent the leaking. When the bag is opened, the exudate on the surface of muscles is removed. The drip loss is the weight loss during this process, expressed as a percentage of initial weight (Honikel 1998). In some other studies, the muscle sample was preserved in the 4 ℃ cooler for a longer time (Eadmusik et al. 2011). Drip loss reflects the water-holding capacity by being negatively correlated to the water-holding capacity.

Expressible water

Filter paper method has been reported to be used in the measuring of expressible water of poultry breast meat. In this method, meat sample is collected from the center of breast fillet at 24 h *post mortem*. To evaluate the water-holding capacity, meat sample is placed between two filter papers and an amount of weight is added on it to compress the meat for 5 min. Due to the compression, water in the meat expresses to the filter water. The amount of water expressing to the filter paper is indicated by the areas of the purge on the filter paper, which can be measured by the image analyzer. Meanwhile, the area of the meat is also measured. The expressible water is presented as the difference between the purge and the area of the meat (Grau and Hamm 1952).

Cooking loss

Cook loss is determined by calculating the weight loss during cooking. The meat sample is sealed in polyethylene packages and then cooked at in water bath to reach a core temperature of around 75 °C (Zhu et al. 2011). However, difference in cooking time was presented in various studies (Eadmusik et al. 2011, Sheard et al. 2012). After cooking, the package is cooled at 4 °C for 16 h. The meat is moved out from the bag and the water on the surface is removed by filter paper. The cooking loss is expressed as the percentage of the loss on weight during cooking in the initial weight of meat.

Centrifugation methods

A centrifugation method to assess the water-holding capacity avoiding mincing and heating was described by Bouton et al. (1971). In this method, a weighed muscle sample is centrifuged at 36000 rpm for 1 h in stainless steel tubes. The juice released from the meat is decanted off as quickly as possible in order to avoid re-absorption of water. After centrifugation, the water on the surface of meat is dried. Then the meat is reweighed to determine liquid loss. The residue of water in the meat is the part binding to the meat due to the function of myofibrillar proteins. Then the residue is dried in the tube at 105 ºC, to determine the total water content of the sample. The water-holding capacity of meat can be expressed as released or bound water as a percentage of total water.

2.1.5 Protein extractability

The protein extractability reflects the quantity and functionality of proteins in the meat. The extractability of myofibrillar proteins and sarcoplasmic proteins are often used to evaluate the meat quality because it has correlation with water-holding capacity, meat texture, and palatability of processed meat products (Rathgeber et al. 1999a). The myofibrillar protein extractability has particularly significant influence on the meat quality because myofibrillar proteins are essential in the binding of water. Rathgeber et al. (1999b) found the extractability of both sarcoplasmic and myofibrillar proteins are reduced in a high early *post mortem* temperature and thus the PSE meat occurs.

The method of Rathgeber et al. (1999b) is often used for the determining of the protein extractability of meat. The measurement can be divided into two steps, the extraction and the quantifying. In this method, meat samples are first homogenized in the buffer. Low-ionic-strength phosphate buffer is used to dissolve sarcoplasmic proteins and high-ionic-strength phosphate buffer is used to dissolve both sarcoplasmic and myofibrillar proteins, followed by a re-homogenization and ice water bath. Filtration or centrifugation is applied to separate the extracted proteins from other components. Processed by filtration, the extracted protein is retained in the filtrate. After centrifugation, the extracted protein is retained in the supernatant. The protein concentrations in filtrate and supernatant can be analyzed through various methods, including Lowry’s method (Lowry et al. 1951), BCA protein assay kit method, and Kjeldahl’s method. The results are presented as percentages of extracted protein to total protein.

2.1.6 Microstructure

The microstructure of meat helps the prediction of meat quality (Carroll et al. 1976).

Through observing the morphology of meat structure, the characteristics of myofibrillar proteins, muscle cytoskeleton, and intramuscular connective tissue can be obtained. The characteristics of meat microstructure are closely related to the meat tenderness, and can be used for the prediction of meat tenderness.

Scanning electron microscopy (SEM) is commonly used in the studies for the observation of meat microstructure (Palka and Daun 1999; Guarnieri et al. 2004; Wattanachant et al. 2005b; Wilhelm et al. 2010). Palka and Daun (1999) created a method in which the *post mortem* meat samples are fixed in 2.5% glutaraldehyde in 0.1 M carbohydrate buffer pH 7.3 for 2 h at room temperature. Then the specimens are rinsed in distilled water and ethanol solution with gradient concentration. Fragments are taken from the meat and were mounted on holders with silver cement and coated twice with AuPd. Afterwards, they are observed under SEM. Muscle fiber areas and sarcomere lengths are measured through image analysis.

Guarnieri et al. (2004) observed the microstructure of meat in a slightly different way. After fixing in a glutaraldehyde solution, the meat sample was washed in phosphate buffer fixed in 1% osmium tetroxide in phosphate buffer for 2 h. Before observing under SEM, the sample was dehydrated in acetone, and embedded in Araldite resin.

2.2 Category and quality of processed meat products

2.2.1 Typical poultry products

Processed poultry products can be basically categorized into two sorts, formed products and emulsified products. Formed products are processed by reducing the particle size of meat and combining the meat with a ground or emulsified binder and chilled brine. The emulsified products are manufactured by chopping meat to form an emulsion-like batter with fat and water and then stuffed in casing and cooked (Keeton 2001).

<u>Formed poultry products</u>

Formed product is a type of meat product in which meat is comminuted and bind together to form a meat pieces to form a cohesive mass that resembles an intact muscle. Formed products can be classified into two types, sectioned-and-formed products and restructured products (Keeton 2001). The main difference of these two kinds of products is on the particle size. Pearson and Gillett (1996) defined the meat products manufacture from intact meat pieces combining by binders as sectioned-and-formed products. And the restructured product is defined as meat products that using comminuted meat generated by size reduction such as grinding, chopping, flaking, slicing, and dicing to be cross-linked by binders (Pearson and Gillett 1996). Different from sectioned-and-formed products, small bits and pieces of meat can be used as ingredients in restructured meat products (Barbut 2002). Therefore, restructured products usually have smaller particle size than sectioned products but section products present a texture more like "whole-muscle" than restructured products. However, in many publications, the definition of restructured product was used as a wider concept, referring to the products in which meat is disassembled and reformed into new type. Typical formed poultry products include poultry rolls, poultry roasts, chicken patties, chicken nuggets, turkey bacon, and turkey ham.

The processing of formed meat products includes the extraction of myofibrillar proteins and the formation of protein gel during cooking (Raharjo et al. 1994). The size reduction process involved in the manufacturing contributes to the release of myofibrillar proteins and the interaction between them (Berry et al. 1987). With this characteristic in processing, formed of restructured meat products allow the use of cheaper or less good cuts of meat in order to save the cost. The addition of non-meat ingredients is also commonly involved in the processing to product value-added products.

Emulsified poultry products

Emulsified product is another important part of poultry meat products. Typical examples are chicken frankfurters, bologna, and poultry loaf. Instead of whole muscle piece, mechanically deboned poultry or turkey are usually used in manufacturing. Meat is finely chopped during which the proteins attach on the surface of fat particles to form a stable "emulsion" (Allais 2010). The emulsification establishes the stability of the products because it determines the characteristic structure of the batter by preventing the fat and moisture separation from the product during cooking. Typical sensory properties on appearance, texture flavor are formed due to the emulsification during cooking. Emulsification can also be regarded as a means to produce "value-added" meat and to utilize relatively low-value meat such as the less acceptable parts of carcass containing high content of fat or connective tissue.

2.2.2 Utilization of low-quality meat in meat products

Processing technologies makes it possible for the utilization of less acceptable meat in the meat products. The quality of meat ingredient in some meat products such as comminuted products and restructured products is not under strict demand. As a result, it opens the possibility for the incorporation of low-quality meat into normal meat in products. For example, meat with high fat content and meat with high connective tissue which presented a higher toughness than normal meat are usually utilized in comminuted product such as sausage (Ranken 2000). Desmond and Troy (2001) used low-value beef cuts containing high content of connective tissue treated by lactic and citric acid to manufacture frankfurter. Even low–cost ingredients such as chicken skin and fat were added into chicken sausage to reduce the cost of the product (Biswaset al. 2007). The processing of restructured meat products also increases the possibility of the use of less uniform and less tender meat, which is considered not in good quality (Huffman et al. 1984). With processing technologies, some meat defecting in appearance, texture, and protein functionality are also utilized in meat products, for example, loose structured meat and Pale, soft, exudative (PSE) meat.

Loose structure meat was found in porcine *M. semimembranosus* (Voutila et al. 2005). The meat presents a problem that the bundles of the muscle can be easily pulled away by hand and therefore reduces the sliceability of meat products such as ham. Despite the adverse effects it brings to the quality to the products, it was used as the ingredients in processing (Hugenschmidt et al. 2007). After further processing, it may have potential to be used in lower value products.

In contrast, the use of PSE meat has more application. PSE meat displays low protein functionality, defects in appearance and low eating quality. Therefore, it cannot be sold directly as raw meat product. However, by incorporating with normal meat, PSE meat can be acceptable in the processed meat product. Schilling et al. (2003a) demonstrated the possibility of the utilization of a percentage of PSE meat between 0 and 50% in boneless ham. Moreover, some processing technologies have been reported to be capable to improve the functionality of PSE meat and increase the possibility of the use of PSE meat. Woelfel and Sams (2001) found that marination in alkaline brine can improve the functionality of protein in PSE meat in the processing of marinated broiler fillet. The technology of marination was also used by Alvarado and Sams (2003) in the processing of marinated broiler fillet from PSE meat to reduce the adverse effects raised by PSE meat on the quality of product. Ionizing irradiation has been reported to improve the color of PSE and DFD pork loin and thus increase the utilization of these low-quality meats (Nam et al. 2002). Reducing the particle of meat into smaller size increased the acceptability of the deli ham roll with 25% PSE meat as ingredient (Schilling et al. 2003b). Other than processing technologies, a variety of adjuncts were applied to increase the use of PSE meat in the products and increase the quality of the products made from PSE meat. Addition of pork collagen (Schilling et al. 2003a), soybean protein, modified food starch (Motzer et al. 1998; Schilling et al. 2004a; Wilbourn et al. 2007) sodium caseinate, and carrageenan (Prabhu and Sebranek 1997; Schilling et al. 2004a) were able to increase the quality of ham restructured from PSE meat and normal meat in different aspects and in different degrees. Daigle et al. (2005) incorporated turkey collagen, soy protein concentrate, carrageenan in the processing of chunked and formed deli poultry roll made from PSE-like turkey breast to make the products more acceptable. PSE meat has been also reported to be used to make pork sausage by incorporating with mechanically deboned turkey meat (Li and Wick, 2001) and preblending by high ionic strength brine containing polyphosphate (Torley et al. 2000).

Therefore, by applying some processing technologies or additives, low-quality meat is utilizable in the meat products by incorporating with normal within an acceptable proportion. Restructured and emulsified products are good ways to use the low-quality because it allows the incorporation and mixing of different source of meat. Comminuting methods make the incorporation more easily and increase the possibility of the utilization.

2.2.3 Factors influencing the quality of meat products

Effect of comminuting methods

Comminuting is usually the first step in the processing of meat products, for instance, formed products and emulsified products. In the comminuting process, particle size of the meat is reduced. Comminuting increases the release and surface area of the myofibrillar proteins in muscle tissues and therefore influences the functionality of the proteins (Berry 1987). Small meat particles bind together or form the emulsion to form the final structure of the meat products after cooking. Various comminuting methods are used in the processing of formed and emulsified meat products, including chopping, slicing, dicing, sectioning, chunking, flaking, and fiberizing. Generally, some comminuting methods are used for the processing of specific products. For example, chunking and sectioning are used in the manufacture of restructured roasts, rolls, steaks, and nuggets, while flaking, grinding, and slicing are used in the manufacture of steaks, chops, and patties, chopping is used in the manufacture of emulsified products such as frankfurter and bologna. Comminution opens the possibilities of the incorporation of meats from different sources and further enables the utilization of meats from less desirable carcass components and even low-quality meats.

Different comminutions bring variations to the quality of meat products, which is possibly attributed to the differences in the particle size and particle shape by various comminuting methods. Among the comminuting methods, slicing, flaking, grinding, and chopping are the most commonly used methods in the industry.

In slicing, meat is processed into meat slices of uniform thickness. In grinding, meat is compressed by rotating feeding augers, and then goes through the cutting system and extrudes through the holes in the grinding plates to be reduced into smaller particles (Ranken 2000). In flaking, meat is cut in a shaving-like manner into flakes. Compared to grinding, flaking avoids the mechanical squeezing of the muscle fibers in a conventional grinder. As a result, more moisture is retained in the meat. The meat particles obtained in flaking contain a large surface area, which promotes the restructured products a whole muscle-like texture (Barbut 2002). Chopping enables the formation of finely comminuted meat batters made up of very small lean and fat particles. Protein particles cover the surface of the fat particles and form the so-called emulsification (Ranken 2000).

Many comparisons have been done on the qualities of meat products processed through these comminuting methods in order to study the different effects of those methods on the meat and meat products. The meat products made through different comminuting methods varies in the aspects of chemical composition, water-holding capacity, bind strength, texture, appearance, and sensory properties.

Impact of different comminuting methods on the chemical composition of meat products has been reported. Boles and Shand (1998) compared the characteristics of restructured beef made through slicing, grinding, and flaking and found that meat products made by slicing had higher fat contents and lower moisture contents than those made from grinding and flaking. They claimed that the reason for this phenomenon is that larger meat particle size generated in slicing results in less consistent samples for the analysis. Berry (1980) found that cooked beef patties processed by chopping contain higher fat contents and lower moisture contents than the patties processed by grinding. However, some studies suggesting the absence of the impact of comminuting methods on the chemical composition of meat products are also present. No significant difference in the fat and moisture contents in the restructured pork products made from grinding and flaking has been reported (Chesney and Mandigo 1972; Chesney et al. 1978). Likewise, Costello et al. (1981) stated that no significant difference between the moisture and fat contents of the restructure beef steaks processed by flaking and grinding is present.

Variations on the water-holding capacity of meat products processed by different comminuting methods have also been reported. The cooking losses and drip losses of meat products are influenced by the particle size reduction methods. Berry (1980) suggested that chopping produces higher cooking losses than grinding in the manufacture of restructured beef patties. Randall and Larmond (1977) claimed that ground patties have more total drip than flaked patties due to the differences in extractability of the proteins which contribute to improved water-holding capacity of meats, but no significant differences in the thaw loss and cooking loss were found in their study. Conflicting findings also exist claiming no variation on the water-holding capacity of meat products is caused by the comminuting methods. Costello et al. (1981) and Boles and Shand (1998) compared slicing, flaking, and grinding in the processing of restructured beef and found no significant differences in the cooking yield among those products. Raharjo et al. (1995) compared the restructured products made from the beef comminuted through chunking, fiberizing, tenderizing, slicing, and chunking-slicing and found that no significant difference was present in the cooking loss and purge loss of the products. In addition, no significant difference was found in the water holding capacity of restructured pork products in the comparison between grinding and flaking (Chesney and Mandigo 1972; Chesney et al. 1978).

Comminuting methods influence the appearance of the meat products, from the aspects of color and the visual characteristics. Costello et al. (1981) demonstrated that flaked restructured beef steaks have the highest overall appearance among the products processed by flaking, slicing, grinding, and from intact muscle. Flaking produces finer visual texture, less visible fat, and redder color to the beef steaks compared to slicing. Huffman and Cordray (1982) suggested that flaking improves color acceptability than other comminuting methods whereas Raharjo et al. (1995) claimed that no significant difference is present among the color of the restructured beef steaks processed by chunking, fiberizing, tenderizing, slicing, and chunking-slicing.

The bind strength reflects the interaction between meat proteins in the meat products and is also affected by the comminuting methods. Boles and Shand (1998) found that slicing results in a higher raw bind of the restructured beef steaks than grinding and flaking do due to larger particle size generated in slicing. Acton (1972) suggested that chicken loaves processed from ground meat have higher binding strength than those made from meat strips or meat cubes. Raharjo et al. (1995) stated that slicing produces the products with lower cook bind compared to chunking.

Comminuting methods also cause the variations in the textures of meat products, evaluated by either instrumental tests or sensory tests. In the instrumental tests, the variations of shear force of the meat products reflect the impact of comminuting methods on the textures of meat products. Berry (1980) claimed that chopped beef patties have lower shear force values than ground beef patties, which means chopped products are more tender than ground products. Costello et al. (1981) compared the shear forces of beef steaks made from sliced, flaked, ground meat and intact muscle and found that flaking and grinding produce steaks with higher tenderness compared to steaks processed from sliced meat and intact muscle. Shear force has been considered by researchers negatively correlated with tenderness of products. However, there is conflicting theory on the significance of shear forces of the products. Chesney et al. (1978) claimed that shear value reflect the binding strength rather than an objective measure of tenderness and considered that higher shear value of the meat products is more desirable. There are also findings suggesting that comminution contributes no effect on the tenderness of meat products. Noble et al. (1985) demonstrated that slicing produces lower tenderness to meat products than grinding and flaking. Comparison between grinding and flaking in the manufacture of restructured pork product indicated that no significant variation is brought by these two kind of comminuting methods (Chesney et al. 1978). Booren et al. (1981) found little significant difference in the shear values between the products processed by sectioning and flaking.

The results of the evaluation on the tenderness of meat products by the panelists or consumers through sensory evaluation are also influenced by the comminuting methods. Berry (1980) found chopped beef patties receive higher scores in tenderness than patties made from ground beef. Costello et al. (1981) demonstrated flaking in the processing produces higher tenderness to the products than slicing according to evaluation in the sensory tests. Their results obtained in the sensory evaluations on the tenderness of meat products correspond to the results obtained in the instrumental measurements. In addition, Randall and Larmond (1977) suggested that hamburger patties made by grinding are more tender than the those made by flaking, which is attributed to the better binding and cohesive properties of flake-cut patties.

Sensory properties are direct factors influencing the acceptability of the meat products. Comparisons have been done on the sensory properties on the meat products processed by various comminuting methods in order to study the sensory characteristics contributed by comminution. As an important comminuting method commonly used in the meat industry, grinding has been compared with other methods including chopping, flaking, and slicing on the contribution to the sensory properties of the meat products. Meat products processed by grinding has been reported to have less tenderness, less juiciness, and more detected connective tissues than chopped products because chopping can reduce the particle size more efficiently (Berry 1980). Furthermore, ground products have been reported to have higher juiciness than sliced and flaked products (Randall and Larmond 1977; Boles and Shand 1998), and less cohesiveness than flaked products (Chesney et al. 1978). Flaking has been reported to bring higher score in the flavor and the overall acceptability of the products due to the greater release of flavor components in flaking (Randall and Larmond 1977; Chesney et al. 1978).

Effects of meat particle size

Through comminuting, the particle size of meats is reduced. The reduction of particle size plays an important role in the formation of the structures of meat products and has been reported to have important influence on the qualities of meat products. Acton (1972) claimed that the smaller the meat particle size, the higher extractability of myofibrillar proteins, due to the degree of cell disruption and breakage-release of meat proteins. Extraction of proteins has been suggested to be associated closely to the quality of meat products (Gurikar et al. 2012). Moreover, with the decrease of meat particle size, meat proteins gain a larger surface area (Durland et al. 1982), which produces changes in protein extraction and increases exposure and contact of meat constituents with added non-meat ingredients (Cofrades et al. 2004). As a result, the water-holding capacity, texture, appearance, bind strength, and sensory properties of meat products are influence by meat proteins. Therefore, the particle size of meat has essential influence on the quality and characteristics of the meat products (Berry et al. 1987). The particle size of meat can be controlled by changing the opening size of the plate in the comminuting equipment according to the requirement of the meat products. Smaller opening size of the comminuting equipment produces smaller meat particles.

Little influence of the meat particle size on the chemical composition has been reported. Different meat particle size produced in slicing (Boles and Shand 1998), grinding (Suman and Sharma 2003; Cofrades et al. 2004), and flaking (Chesney et al. 1978) has been reported to have no effect on the moisture, protein, and ash contents of the restructured meat products. However, fat contents of the meat products have been reported to be affected by the meat particle size in some studies. Sen and Karim (2003) stated that the grinding size affects the fat content in the restructured mutton steaks. Berry et al. (1999) found larger grind size of meat produces higher fat retention in cold-processed beef patties but lower fat retention in hot-processed beef patties.

The decrease of meat particle size improves the water-holding capacity of meat products, displayed as lower purge losses and cooking losses. Gurikar et al. (2012) suggested that smaller chunk size of meats used in the processing of restructured pork blocks results in higher cook yields of the products. Chesney et al. (1978) reported restructured pork processed from smaller meat particles obtained in grinding, flaking, and slicing have lower cooking losses compared with those processed from larger meat particles. McDermott et al. (1999) found that smaller meat pieces used in the processing of re-formed pigmeat shoulder products decrease the cooking losses of the products. The reason for the improvement that particle size reduction contributes to the water-holding capacity is that smaller particles results in a lager total surface area of the meat proteins, which enables more binding of water (Cofrades et al. 2004). On the other hand, stronger comminution which produces smaller particle size improves the extraction of meat proteins and therefore increases the water-binding (Gurikar et al. 2012).

The impact of meat particle size on the appearance of meat products displays on the visual or physical appearance rather than on the color. Cofrades et al. (2004) the decrease of grind size in the processing of restructured beef causes no variation in the color of the products. Durland et al. (1982) claimed that coarsely ground restructured beef steaks look too fatty and have decreased acceptability due to larger fat particle size of the products whereas finely grinding eliminates the undesirable fat spot from the restructured beef steaks and look more acceptable.

The bind strength of the meat products is affected by the meat particle size. Devatkal et al. (2011) demonstrated that smaller particle size produced by chopping promotes better emulsification due to the improved protein extractions. As a result, the chicken nuggets have better binding properties and gel strengths. Previously, Acton (1972) also explained this principle that finer grind size produced stronger binding of particles. Boles and Shand (1998) reported the interaction between particle size and comminuting methods on the cook binding of restructured beef steaks. For products processed by slicing and grinding, smaller particle size caused higher cook bind strength of the steaks. However, for flaked products, the cook bind declined with the decrease of particle size.

The influence of the meat particle size on the shear values of meat products has been reported in many studies. There are different conclusions on this issue. In some studies, the shear values of meat products was reported to decline with the decrease of the meat particle size or with the increase of the degree of comminution. Such phenomena have been reported on the meat products produced with chunking (Gurikar et al. 2012), grinding (Cross et al. 1980; Suman and Sharma 2003), and flaking (Durland et al. 1982; Berry et al. 1987). However, conflicting theories claimed that lager meat particle produces higher tenderness of the meat products. Sen and Karim (2003) found restructured mutton steaks processed from smaller meat particles have higher shear forces than those made from larger particles.

The tenderness of meat product evaluated in sensory tests has also been reported to have correlation with the meat particle size or the degree of comminution used in the processing. McDermott et al. (1999) found smaller particle size contributes to higher tenderness of re-formed porcine shoulder products. Panel tenderness of restructured products by both grinding (Chesney et al. 1978; Cross et al. 1980; Durland et al. 1982) and flaking (Chesney et al. 1978; Durland et al. 1982) has been found to increase with the decrease of meat particle size.

In addition to the size of meat particles, the shape of meat particles has also been found to have influence on the textures of meat products. Berry et al. (1987) compared the shear forces of beef and pork steaks produced with meat particles minced with same opening size but with different thickness and claimed that both thickness and width of the flaked meat particles, not just size alone, can influence the textures of restructured meats. The results indicated that thin meat particle contributes to higher tenderness to the meat products.

The particle size also causes variation in other sensory properties of meat products. Detected connective tissue is a property relevant directly to the meat particle size. Products made with higher degrees of comminution contain less detectable connective tissue (Cross et al. 1980; Berry et al. 1987; Boles and Shand 1998). Other sensory properties such as gumminess, chewiness, cohesiveness, juiciness, and springiness have also been reported to have correlation with meat particle size. Gurikar et al. (2012) suggested that smaller particle size produces restructured pork blocks with lower gumminess, chewiness and cohesiveness, higher springiness. Corresponding conclusion has been reported by Cardello et al. (1983) that hardness, chewiness, and cohesiveness of meat products increases with flake size. Berry et al. (1987) also claimed that restructure beef and pork steaks made from smaller meat particles have less cohesiveness and less chewiness than steaks made from lager particles. Juiciness of meat products has been reported to increase with the decrease of particle size (Chesney et al. 1978; Suman and Sharma 2003). Products made from smaller particles have also been reported to have better overall acceptability (Suman and Sharma 2003; Gurikar et al. 2012).

Effects of binders on the quality of meat products

Meat to meat binding is achieved in the processing of meat products through the formation of gels. Instead of conventional hot binding systems based on the effect of the salt, phosphate, and mechanical action on the extraction of myofibrillar proteins (Schmidt and Trout 1984), cold-set binders are being increasingly used in the meat industry. Cold-set binders increase the functionality of meat proteins through the interaction with those proteins. As a result, cross-linking forms between meat pieces to give a whole-muscle texture to the meat products. The binding of meat pieces is associated closely to the quality of meat products, including water-holding capacity, texture, color, and acceptability (Ensor et al. 1989). Therefore, the use of binders in the processing essentially influences the quality of meat products.

The cold-set binders being commonly used include transglutaminase, Fibrimex®, and seaweed. Transglutaminase acts directly on meat surface to produce a solid meat mass by the formation of cross-linking between meat proteins. The addition of transglutaminase in the processing has been reported to improve the texture and the water-holding capacity of restructured poultry product (Cofrades et al. 2011). Fibrimex® is a bovine blood protein used as a binding system developed in The Netherlands and commercially produced in Canada by FNA Foods Inc. (Calgary, AB). The function of Fibrimex® is based on the blood clotting action between fibrinogen, thrombin and transglutaminase. Alginate is a polysaccharide extracted from brown seaweed and is used as binder in meat products. When calcium ions are involved in alginate solution, a heat-resistant gel is formed (Means and Schmidt 1987). Sea Spaghetti is another kind of seaweed reported to have the potential to be used as meat binders in restructured poultry steaks decreasing the purge losses and cooking losses and improving the texture of the products (Cofrades et al. 2011). Besides, plant and animal proteins are also added into meat products as binders. Freeze-dried mackerel muscle proteins have been reported to be able to increase of the binding strengths of restructured pork products (Chung et al. 2000).

Binders have been reported to have different degrees of influence on various aspects of the quality of meat product. Comparison between the effects of different binders has been studied. Boles and Shand (1998) stated restructured beef steaks made from alginate have significantly higher raw bind values compared to that made from Fibrimex® whereas Fibrimex® brings less cooking losses to the products. Farouk et al. (2005) demonstrated that restructured beef rolls in which alginate was added in have higher pH values than those processed by transglutaminase due to the presence of sodium and calcium ions in alginate. Transglutaminase contributes higher binding strengths and better water-holding capacity to the products than alginate does. Combination of binders may result in a better improvement of the quality of meat products. Cofrades et al. (2011) claimed good positive effects of the combination of transglutaminase and sea Spaghetti on the qualities of restructured poultry steaks. Therefore, binders may bring different influences to the qualities of meat products. The selection of binders should be based on the requirements for the qualities of products and the characteristics of the raw meat ingredients.

2.3 Evaluation of the quality of meat products

2.3.1 pH

The addition of meat binders and other non-meat ingredients may impact the pH of meat products. The pH of meat products has also been reported to be affected by the methods of comminuting (Boles and Shand 1998). Therefore, pH is usually measured on the cooked products as a general property for the meat product.

The method from AOAC (1995) or its modified version is commonly used in the measuring of restructured and emulsified meat products. pH is measured on the homogenate of meat product blended with distilled water with a pH meter combined with glass electrode (Cofrades et al. 2004; Sudheer et al. 2011). Other than this method, the direct measuring by inserting the electrode into the product is also used. Perlo et al. (2006) used pH equipped with a puncture electrode to measure the pH of raw and cooked chicken nugget.

2.3.2 Chemical composition

Different processing procedures affect the chemical composition of meat products. To evaluate the quality of meat products, proximate chemical analysis is usually done. The contents of moisture, fat, protein, and ash are analyzed to study the effects of processing technologies.

The standard methods of the analysis of moisture, protein, fat, and ash content from AOAC (1995) are widely used in the proximate analysis of chemical composition of meat products. According to the methods, the moisture, protein, fat, and ash content are determined by using hot air oven, Kjeldahl assembly, Soxhlet apparatus and muffle furnace, respectively.

2.3.3 Texture

Texture is one of the most important characteristics of meat products because it is directly associated with the eating quality. Different processing technologies and ingredients contribute to the variations in the texture of meat products. Similar as the evaluation of raw meats, shear force is also used for the evaluation of tenderness of meat products. Both the analyzers applying Warner-Bratzler method or Allo-Kramer method have been reported to be used in the measurement of the shear forces of restructured poultry meat products such as poultry rolls, chicken nuggets (Prinyawiwatkul et al. 1997), chicken steaks (Cofrades et al. 2011), and emulsified products such as chicken frankfurters (Tan et al. 2001).

Besides the results evaluated by the shear force tests, other parameters which reflect the texture are also determined objectively, including firmness, springiness, cohesiveness, gumminess, and chewiness. Texture profile analysis (TPA) is applied to obtain the data about those parameters indicating the texture of the meat products. The measurement is done with a texture analyzer as described by Bourne (1978). The data is collected by the analyzer when the uniform sized test samples are compressed by a probe through two cycle sequence. In the analyzing of instrument, the firmness of the sample is defined as the maximum force required to compress the samples. Springiness is defined as the ability of the samples to recover to their original shapes after the deforming force was removed. Cohesiveness is defined as the longest extents to which the samples could be deformed prior to rupture. The gumminess is recorded as the forces to disintegrate semisolid meat samples for swallowing and is calculated by multiplying the firmness and cohesiveness.

The work to masticate the samples for swallowing is described as chewiness. This method has been reported to be used in evaluation of the texture in various meat products, including chicken steaks (Cofrades et al. 2011), restructure pork blocks (Gurikar et al. 2012), restructured beef (Cofrades et al. 2004), and chicken nuggets (Devatkal et al. 2011).

2.3.4 Water-holding capacity

The measurement of the water-holding capacity of poultry products uses very similar methods as the evaluation of the water-holding capacity of raw poultry meat. Measuring of cooking loss (yield), purge loss, and expressible water are all applied to reflect the water-holding capacity of meat products.

Cooking loss and cooking yield are the most common ways used in studies to reflect the water-holding capacity. Meat products are cooked and weighed in the same way as raw meat. Cooking loss is defined as the percentage of the difference between the weights of meat products before and after cooking in the weight of meat products before cooking. The smaller the cooking loss is, the better the water-holding capacity of meat products is. Cooking yield is calculated as the percentage of the weight of cooked meat products in the weight of raw product, which is positively correlated to the water-holding capacity of the products.

Purge (drip) loss of meat products is measured in the same way as the measuring of raw meat to reflect the water-holding capacity of meat products. Meat products are sealed in package and stored in 4 ℃. The purge loss is defined as the percentage of the difference between the initial weight and final weight of the products in the initial weight of product.

The water-holding capacity is also indicated by the expressible water of the meat products. The meat product is sliced into pieces and compressed by the weight in a similar way as the measuring of raw meat. A method carried out by Instron Universal Testing machine for the determination of turkey product was described by Schilling et al. (2004b), in which the product slices were compressed by Instron Universal Testing machine with a fixed height and the weight losses of the slices were recorded.

2.3.5 Binding strength

Field et al. (1984) defined the binding strength as the force in kg necessary for a polished steel ball on the Instron Universal Testing Machine to burst through the center of a slice of meat products. During years many researchers measured the binding strength of meat products based on this method, and some modification was also made on this method. In the meat products, such as restructured products, the meat particles adhere to each other due to the interactions between the proteins. The ability of meat particles adhering to each other is expressed as the bind strength. The binding strength reflects the quality and quantity of the protein-protein bind formed in the meat products. The binding strength is influenced by the functionality of the proteins in meat, the function of binders added into the product, and also the processing technologies. In the processing of restructured meat products, the products are expected to have a higher binding strength to achieve a better quality. Both the raw binding strength and cook binding strength are measured to reflect the binding capacity of proteins. When cold-set binders are used, protein-protein binding is able to form without cooking. During the cooking, more cross-links form to increase the bind strength.

Kuraishi et al. (1997) described a method to measure the gel strengths of restructured meat products. The gel strength is defined as the maximum force (N) required to cut the gel placed horizontally on the platform into two pieces with a blade set with knife equipped on a texturometer. This property of meat product is also related to the functionality of meat proteins, which further influences the formation of cross-links in the three-dimensional network of proteins in the meat products. Therefore, the gel strength can also be regarded as a parameter reflecting the texture of meat products and the functionality of meat proteins.

2.3.6 Color

Color is a vital property of meat products because it is one of the factors that determine the acceptance of the products to consumers. The color of meat products are measured according to the same principle and system as the measurement of the color of raw meat. Both the internal and external color of meat products have been reported to be measured. The selection of the location of measuring depends on the type of the products. For poultry roll, the internal color is measured (Daigle et al. 2005). However, the assessment of the color of chicken patties is only done on the outer surface. For chicken nuggets, both the internal and external color is measured. For frankfurters, only the internal color is measured. The measurements of color are generally done on cooked products. Sometimes both the color of raw product and cooked product are measured to study the influences which are brought by cooking to the appearance of the meat products (Moraes et al. 2011).

2.3.7 Sensory evaluation

Through the sensory evaluation, the acceptability of the meat products can be obtained, which is associated directly to the potential of the product in the market. Category scales are usually used in the evaluation of acceptability of the products. The acceptability of products is evaluated into different scales.

Besides the overall acceptability, panelists can also be asked for the evaluation of the sensory characteristics in specific aspects through tasting or observing, such as color, flavor, hardness, chewiness, cohesiveness, juiciness, appearance. The category scales are generally applied in this part of evaluation.

3 MATERIALS AND METHODS

Meat and fat samples for the laboratory tests were provided by the HK Company and Atria Company in Finland prior to the start of laboratory works. In the preliminary tests in the laboratory, only meat from HK Company was used. Both the meat from HK Company and Atria Company were used in the pilot plant test. Meat ingredients included poultry mechanically deboned meat (MDM), poultry trimmings (thigh meat), normal breast muscle, and wooden breast muscle (WB). The fat used in the products was pork fat. Meat and fat samples for laboratory products were homogenized and then stored at -20 ℃. Before used, meat and fat were thawed overnight at 4 ℃. Meat and fat samples for pilot plant products were delivered from the slaughter-house one day before processing and stored at 4 ℃.

3.1 Formulation and preparation of products

3.1.1 Laboratory sausage formulation and preparation

Formulation of laboratory sausage

The laboratory sausages were prepared using an appropriate recipe to study the effects of the replacement of meat of normal quality by WB on the quality parameters in the water-holding capacity, texture, and color of the sausages. The meat used in the preparation was from HK Company. The original recipe was made of 72% meat in which MDM and poultry trimmings took up the half respectively, 25% water, 2.6% salt, 0.4% phosphate (57.8% $P_2O_5^-$, MPMaustepalvelu OY, Finland), and 100 ppm nitrite (in 10% nitrite solution, MPMaustepalvelu OY, Finland). Through calculation, appropriate amount of WB was added to the recipe to replace a part of meat ingredients. Pork fat was added with WB to keep the fat content the same as the original recipe. As a result, 12.5%, 25%, 37.5%, 50%, and 100% of the lean meat mass in the recipes were replaced by WB (Appendix 1). And the fat contents of the sausages were kept at 13.54%.

Preparation of laboratory sausage

The ingredients were weighed in advance the preparation of sausages. After weighing, 10% nitrite solution was added to the meat immediately in a table model chopper (1094 Homogenizer, Tecator, France). The meat was mixed shortly for several seconds with half amount of the weighed salt. Then the pork fat was added and mixed with the mass in the chopper, followed by a mixing with the rest of the weighed salt and all the phosphate. Half of the water content was added as the form of ice into the chopper to keep the temperature of batter to at a low level. Water was added to the batter step by step during the continuous mixing. The batter was chopped until the temperature reached 20 ℃ and then stuffed manually into hydrated cellulose casing and tied with threads. Raw sausages were kept at room temperature for equilibrium for 30 minutes and then cooked in 75 ℃ water bath for 30 minutes. After cooking, sausages were cooled in ice and then stored at 4 ℃. Triplicates were made in the preparation of samples from each recipe.

3.1.2 Laboratory chicken nuggets formulation and preparation

Formulation of laboratory chicken nuggets

The control chicken nuggets were prepared according to a recipe of 20% poultry trimmings, 20% MDM, 29% normal breast muscle, 23% water, 5% whole egg liquid (Rainbow, Suomen Osuuskauppojen Keskuskunta, Finland), 2% soy protein isolate (Solae EX 37, Protein 90%, MPMaustepalvelu OY, Finland), 1% salt, 0.2%, and phosphate (58% $P_2O_5^-$). The fat content of the recipe was 7.5%. The meat used in the preparation was from HK Company. In a same way as the sausages were prepared, WB and pork fat was added to the recipe to replace a part of the meat ingredients to make the WB to take up 12.5%, 25%, 37.5%, 50%, and 100% of the lean mass in the recipe (Appendix 2).

Preparation of laboratory chicken nuggets

In the preparation of laboratory finely chopped chicken nuggets, the weighed pre-chopped meat ingredients, soy protein isolate, salt, and phosphate were mixed together in the table model chopper (1094 Homogenizer, Tecator, France) for 3 minutes. During the mixing, ice was added stepwise into the chopper. Then the batter was mixed with weighed whole egg liquid for 1 more minute in the chopper. The batter was formed to nuggets of around 80g in weight manually and coated with bread crumbs (Risetti Oy, Finland). The products were baked in hot-air oven through dry-air heating at 180 ℃ for 20 minutes. Then the nuggets were sealed in plastic bags and cooled in ice before the storage at 4 ℃. Triplicates were made in the preparation of samples from each recipe.

In the preparation of laboratory ground chicken nuggets, the normal breast muscle, WB muscle, and pork fat were ground in a table model grinder (LM-5, Koneteollisuus Oy, Finland) respectively with a 3mm plate. The ground breast muscle was mixed manually with ground pork fat, MDM, and poultry trimmings, following by once more grinding of the mixture in the grinder with same plate. Then the meat batter was mixed with weighed water, whole egg liquid, soy protein isolate, salt, and phosphate by hand until a homogenous consistency was obtained. The batter was formed to nuggets of around 80g in weight manually and coated with bread crumb. The products were baked in hot-air oven through dry-air heating at 180 ℃ for 20 minutes. Then the nuggets were sealed in plastic bags and cooled in ice before the storage at 4 ℃. Triplicates were made in the preparation of samples from each recipe.

3.1.3 Pilot plant sausage formulation and preparation

Formulation of pilot plant sausage

The preparation of pilot plant products was repeated twice. Meat from HK Company and Atria Company were tested respectively in the two replicates. The pilot plant sausages were prepared in a recipe slightly adjusted based on the recipe of laboratory sausages (Appendix 3a and 3b). Because of the differences in the composition of meat from different sources, adjustment on the recipes in the two replicates had to be done. Due to the lower fat content of the meat from Atria Company, their meat was added in an appropriate proportion with more pork fat to make the fat and lean meat content at the same level as the products from HK meat. Based on the results from laboratory test, WB was added to replace 15% and 30% of the lean meat in the recipe.

Preparation of pilot plant sausage

In the preparation of pilot plant sausages, the meat ingredients were put into a bowl chopper (Type SKU-63878A, Seydelmann Maschienenfabrik, Stuttgart, Germany) and mixed shortly at a low speed. 10% nitrite solution, spices mix (95002564/B, MPMaustepalvelu OY, Finland), salt, and phosphate were added to the meat as it continued to be mixed. Afterwards, pork fat was added into the chopper, followed by the addition of ascorbate (E301, MPMaustepalvelu OY, Finland) and a stepwise addition of water. The chopping continued until the temperature of batter attained 20 ℃. Then the batter was stuffed into hydrated cellulose casing through a vacuum stuffer (Handtmann VF50, Albert Handtmann Maschienenfabrik, Biberach/Riss, Germany) and cased. The cooking of sausages started from a condition of 60 ℃, RH=98% for 9 minutes, followed by cooking in changed condition of 65 ℃ to 68 ℃, RH=0% for 7 to 14 minutes. Then the smoking was applied at RH=0 for 6 minutes, and then at RH of 55% for 8 minutes when the temperature reached 70 ℃. Then the temperature was lifted to 75 ℃ and the sausages were kept in this temperature for 100 minutes at a RH of 100%. Cooked sausages were showered with chilled water for 30 minutes and then stored at 4 ℃. Duplicates were made in the preparation of samples from each recipe.

3.1.4 Pilot plant chicken nuggets formulation and preparation

Formulation of pilot plant chicken nuggets

In the preparation of pilot plant nuggets, again both of the meat from HK Company and Atria Company were tested respectively in the two replicates. The control pilot plant nuggets were prepared in a recipe slightly adjusted based on the recipe of laboratory chicken nuggets (Appendix 4a and 4b). The products from different meat sources was made to contain same amount of lean meat, fat (7.5%), and other ingredients in the same way as the sausages were made. WB was added to replace 30% of the total lean meat content in the recipes.

Preparation of pilot plant chicken nuggets

In the preparation of pilot plant coarsely chopped chicken nuggets, the WB and normal breast muscle were coarsely chopped in the bowl chopper for 2 rounds. Then they were mixed with poultry trimmings, MDM, water, spices mix, whole egg liquid, soy protein isolate, salt, phosphate and ascorbate manually until a homogenous batter was obtained. The batter was formed to nuggets of around 60g in weight manually and coated with bread crumb. The products were baked in hot-air oven through dry-air heating at 180 ℃ for 20 minutes. Then the nuggets were cooled in ice before the storage at 4 ℃. Duplicates were made in the preparation of samples from each recipe.

In the preparation of pilot plant ground chicken nuggets, the WB muscle and normal breast muscle were ground in a grinder (KT42, Koneteollisuus Oy, Finland) with a 3 mm plate. The ground breast meat was mixed with poultry trimmings, MDM, water, spices mix, whole egg liquid, soy protein isolate, salt, phosphate and ascorbate manually until a homogenous batter was obtained. The batter was formed to nuggets of around 60g in weight manually and coated with bread crumb. The products were baked in hot-air oven through dry-air baking at 180 ℃ for 20 minutes. Then the nuggets were cooled in ice before the storage at 4 ℃. Duplicates were made in the preparation of samples from each recipe.

3.2 pH

After 24 hours' storage at 4 ℃, the pH values of products were measured with a pH meter (Knick Portamess, Type 913 pH, Germany) equipped with a XEROLYT® polymer electrolyte by inserting the electrolyte into the core of the products. The pH values were measured at 3 different sausages or 3 different nuggets from each batch.

3.3 Fat content of meat ingredients

Fat contents of poultry trimmings, MDM, WB and normal breast muscle were analyzed using the Gerber method (Krol and Meester 1963). 4.5g homogenized meat sample was weighed into butyrometer tube added with 10ml 1:1 acetic acid and strong perchloric acid reagent. The tubes were placed in the water bath of 95 ℃ and shaked until the sample and additives are dissolved (about 20 minutes). The fat portion is not dissolved but accumulated on the surface. Then reagent was added to make the solution surface on the scale of 25. Thereafter, the tubes were centrifuged for 5 min at1350 rpm in a Gerber centrifuge. After the centrifugation, butyrometer tubes were put back in the water bath of 95 ℃ for 5 to 10 min. The fat column volume was read on the scale of the butyrometer tubes. The measurements were done for four times on each individual sample. The fat contents of the samples were calculated according to the below equation:

$$Fat\,\% = \frac{5\ \times fat\ column\ volume}{sample\ (g)}$$

3.4 Cooking loss

The weights of the casings, threads and the total weight of raw cased-sausages were recorded before cooking. The peeled cooked sausages which were wiped off the excess water on the surface were weighed again after 24 hours' storage at 4 ℃. Three measurements and five measurements were done on each individual laboratory sample and pilot plant sample, respectively. The cooking loss of the sausages was calculated as follows:

$$\text{cooking loss\%} = \frac{W1 - Wc - W2}{W1 - Wc} \times 100$$

Where W1=total weight of raw sausage, Wc=weight of casing and thread, W2=weight of peeled cooked sausage.

The weights of formed raw chicken nuggets were recorded before cooking. After 24 hours' storage after cooking, the cooked nuggets were weighed again. Two measurements and four measurements were done on each individual laboratory sample and pilot plant sample, respectively. The cooking loss of chicken nuggets was calculated as follow:

$$\text{cooking loss\%} = \frac{W1 - W2}{W1} \times 100$$

Where W1=weight of raw chicken nugget, W2=weight of cooked chicken nugget

3.5 Expressible water

The sausage slices were weighed and then placed between two filter papers. Then they were placed between two plastic boards with 300g weight on the top. After 10 minutes, the sausage slices were weighed again. Four measurements were done on each individual sample. The expressible water percentage was calculated as follow:

$$\text{Expressible water\%} = \frac{W1 - W2}{W1} \times 100$$

Where W1=weight of the sausage slice before compression, W2=weight of the sausage slice after compression.

3.6 Centrifuge loss of meat batter

The weights of centrifuge tubes were recorded prior to the sampling. About 30g of meat batter of chicken nuggets was weigh into centrifuge tubes. The tubes were then heated in the water bath at 75 ℃ for 30 minutes during which the meat batters were cooked. The samples were centrifuged immediately after cooking when they were still warm at 5000 rpm for 10 minutes at minimal temperature of 40 ℃ with a rotor pre-warmed at 60 ℃ in a hot-air oven. After centrifuge, the fluid water in the tubes was decanted off as soon as possible to avoid re-absorption of water. Then the tubes were reweighed to determine liquid loss. Tow measurements and three measurements were done on each individual laboratory sample and pilot plant sample, respectively. The percentage centrifuge loss was calculated as follow:

$$\text{Centrifuge loss\%} = \frac{W1 - W2}{W1 - Wt} \times 100$$

Where W1=total weight of batter and tube before cooking, W2=total weight of batter and tube after cooking

3.7 Allo-Kramer shear force

The shear forces of the products were measured by an Instron Device (Instron 4465 H 2237, capacity 50kN, weight 286 LB-130kg; Instron Ltd, UK) with Allo-Kramer methods. The laboratory sausages were cut into slices of 4 cm in diameter and 5 mm in thickness. The pilot plant sausages were cut into pieces of $4 \times 4 \times 0.5$ cm. Pieces of $3 \times 2 \times 0.5$ cm were cut from the center of laboratory and pilot plant chicken nuggets. 10 samples were taken for the products from each batch for the measuring of shear force.

3.8 Binding strength

The binding strengths of the products were measured by a method modified from the method of Field et al. (1984). The binding strength was recorded as the maximal force in kg necessary for a probe (1.2 cm in diameter) on Instron Device (Instron 4465 H 2237, capacity 50kN, weight 286 LB-130kg; Instron Ltd, UK) to burst through the center of the sample. The maximal distance the probe inserted into the sample before it broke was recorded as the elongation of the sample. Specimens of cooked sausages were prepared as slices of 6 mm in thickness. The specimens of chicken nuggets were taken from the center of different nuggets, prepared as 4×4×0.6 cm cuts. 10 samples were taken for the products from each batch for the measuring of binding strength.

3.9 Measurement of color

The internal colors of chicken sausages and chicken nuggets were measured with CR-400 Head chromemeter (Konica Minolta, Japan). Lightness (L*), redness (a*), and yellowness (b*) were recorded. The measurements were done for four times on the different positions or different individual samples of the products from each batch.

3.10 Sensory analysis

Sensory evaluations were organized on pilot plant sausages and chicken nuggets. Panelists were recruited from the food science researchers and students in the department. Sausage samples were prepared as slices of 5 mm in thickness. Chicken nuggets were put into the trays directly as sample.

Tasting triangle tests were done between normal sausages and sausages containing 15% WB, between normal sausages and sausages containing 30% WB, between sausages containing 15% WB and sausages containing 30% WB, between normal chopped nuggets and chopped nuggets containing 30% WB, and between normal ground nuggets and ground nuggets containing 30% WB. Panelists were asked to mark the different sample among the 3 samples in each tray. Any differences except the shape and size of the sample were counted. The tasting evaluation of sausages was done in a dark condition in order to exclude the influence of the color of the sausages on the evaluation.

Besides, specific tests on the difference of the color of the sausages were done. Triangle tests were done between normal sausages and sausages containing 15% WB, between normal sausages and sausages containing 30% WB, and between sausages containing 15% WB and sausages containing 30% WB. Panelists were asked to mark the different sample among the three samples in one tray only by observing the color of the sausage slices. The results of the triangle test were analyzed according to the significance table of triangle test.

Meanwhile, the panelists were asked to describe the main differences they felt between samples. The descriptions from those who gave the correct selection of the different sample were collected.

3.11 Statistical analysis

IBM SPSS statistics 21 was used for the statistic analysis in the study. One-way ANOVA analysis was done to analysis the effect of the addition percentage of WB in each kind of laboratory products. Two-way ANOVA was done to analyze the statistics from pilot plant product. By this way, the influence of different meat source was eliminated and the effect of addition percentage of WB was obtained. In both analysis, Duncan's test was used to separate the significant difference ($P<0.05$) between every two treatments.

4 RESULTS

4.1 Fat content and pH value of meat ingredients

The pH values of MDM and Poultry trimmings were apparently higher than the pH of breast muscle (Table 1). The pH of WB was higher than that of the normal breast muscle. Compared to the MDM and poultry trimmings, WB and normal breast contained much less fat, which was ignored in the calculation of recipes. MDM and poultry trimmings from HK and Atria companies showed difference in the fat contents. Therefore, the proportion of each ingredient was needed to be adjusted according to their fat contents in the processing of the products from different meat sources in order that the recipes contained same percentage of fat.

Table 1. Fat content (n=4) and pH (n=3) value of meat ingredients.

Meat Ingredients	pH	Fat content %
MDM (HK)	6.67±0.01	18.9±0.4
Poultry Trimmings (HK)	6.46±0.02	18.8±0.2
WB (HK)	6.16±0.02	<1.0
Normal Breast (HK)	5.84±0.03	2.2±0.2
MDM (Atria)	6.63±0.01	18.1±0.5
Poultry Trimmings (Atria)	6.36±0.03	10.4±0.3
WB (Atria)	6.14±0.02	<1.0
Normal Breast (Atria)	5.92±0.02	2.1±0.1

4.2 Effects of wooden breast addition on the properties of laboratory products

4.2.1 pH of laboratory products

The pH values of the sausages was decreased with the increase of the addition percentage of WB (Table 2) because the pH of WB was apparently lower than the pH of the other main meat ingredients in the sausages, including MDM and poultry trimmings.

The pH of chopped and ground chicken nuggets also dropped with the increase of WB percentage in the recipes (Table 3; Table 4). However, the drops were slower because a part of normal breast meat whose pH value was lower than the pH of WB was also replaced by the WB besides MDM and poultry trimmings.

4.2.2 Shear force of laboratory products

The shear force of laboratory sausages increased steadily with the increasing addition of WB when the addition was within 37.5% (Fig. 1). Once the addition exceeded 37.5%, the increase of the shear force became faster. However, within 25% addition, WB caused no statistically significant difference ($P>0.05$) on the shear force of the sausages.

The addition of WB produced different effects on the two types of laboratory chicken nuggets. As shown in Fig. 2, the shear force of finely chopped chicken nuggets started to increase when the addition was higher than 12.5% ($P<0.05$) and continued to go up with the increase of the percentage of WB. The shear force of ground chicken nuggets was higher than that of finely chopped chicken nuggets when there was no WB added in whereas the addition of WB caused no significant difference.

4.2.3 Binding strength of laboratory products

The binding strength of the sausages increased with the addition of WB (Fig. 3), which means the addition of WB enabled more protein interactions between meat ingredients. However, addition which was lower than 25% caused no significant change ($P>0.05$). As another parameter reflecting the binding strength of the product, the elongation of the sausages, which referred to the maximal distance the probe inserted into the samples before it broke, started to increase when the addition of WB increased to 25%, followed by a slight drop when the addition was increased from 37.5% to 50%, and then continued to increase when the addition percentage became higher.

The binding strength of finely chopped chicken nuggets increased significantly ($P<0.05$) even if only 12.5% of the lean meat in the recipe was replaced by WB (Fig. 4). However, addition of WB produced no effect on the elongation of that product (Fig. 6). No significant difference was found in the binding strengths of ground chicken nuggets with the continuously increasing addition of WB (Fig. 4). The elongations of that product fluctuated with the addition of WB (Fig. 6).

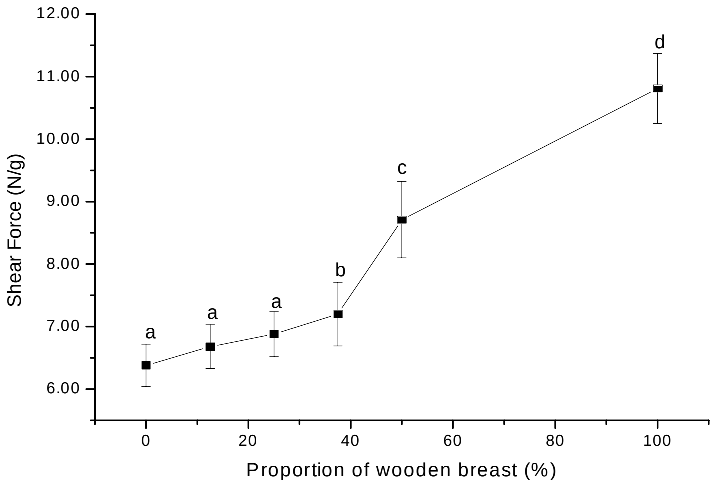

Fig. 1. Shear force of laboratory sausage with different percentage addition of WB (n=10×3). Means with the same letter in the same line are not significantly different (P > 0.05).

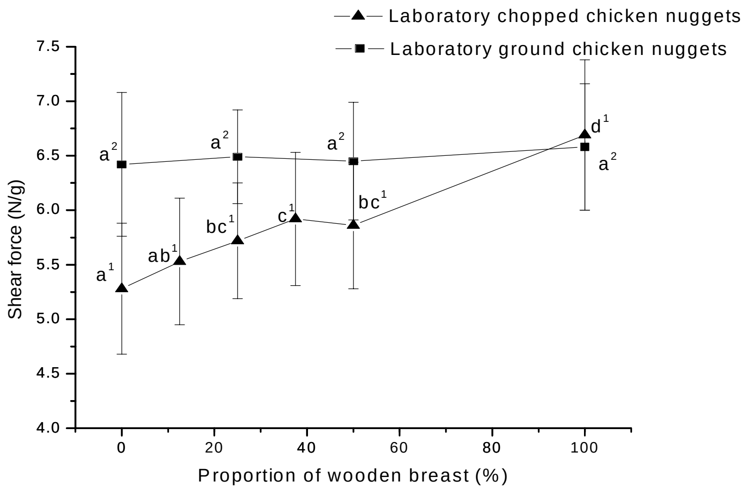

Fig. 2. Shear force of laboratory chicken nuggets with different percentage addition of WB (n=10×3). Means with the same letter in the same line are not significantly different (P > 0.05).

Fig. 3. Binding Strength of laboratory sausage with different percentage addition of WB (n=10×3). Means with the same letter in the same line are not significantly different (P > 0.05).

Fig. 4. Binding Strength of laboratory chicken nuggets with different percentage addition of WB (n=10×3). Means with the same letter in the same line are not significantly different (P > 0.05).

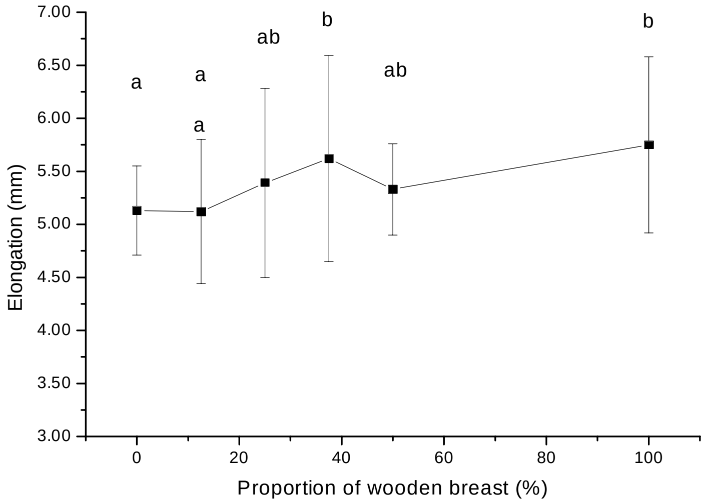

Fig. 5. Elongation of laboratory finely chopped chicken nuggets with different percentage addition of WB (n=10×3). Means with the same letter in the same line are not significantly different (P > 0.05).

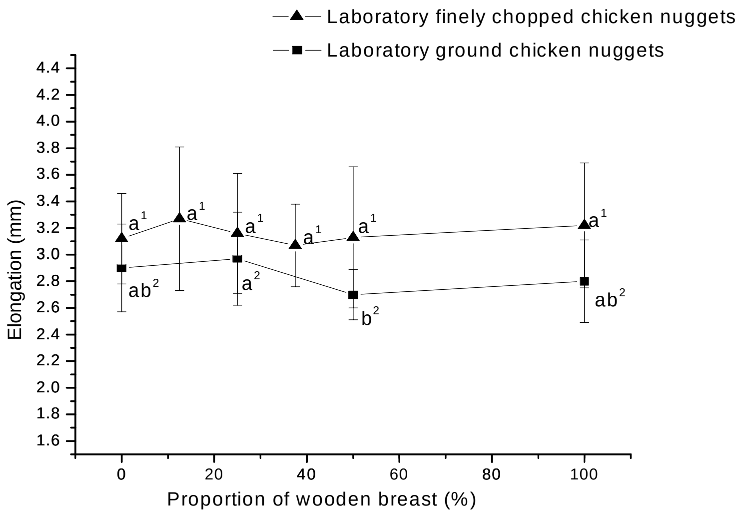

Fig. 6. Elongation of laboratory ground chicken nuggets with different percentage addition of WB (n=10×3). Means with the same letter in the same line are not significantly different (P > 0.05).

4.2.4 Cooking loss of laboratory products

The sausages with 37.5% addition of WB had higher cooking losses (P<0.05) than the products with the other percentages of addition (Table 2). No significant difference (P>0.05) was found among the normal sausages and sausages with 12.5%, 25%, 50%, and 100% addition of WB.

12.5% addition of WB significantly increased the cooking loss of chopped chicken nuggets compared to the products with other the percentages of addition of WB (P<0.05) (Table 3).

The cooking loss of the ground chicken nuggets with the difference percentages of addition of WB showed no significant difference (P>0.05) (Table 4). The differences in the cooking loss showed no apparent trend with the addition of WB. In all types of product, the significant higher cooking losses at some particular WB addition percentage may be caused by errors in the processing of the products or in the measuring of the cooking loss.

Table 2. Cooking loss (n=2×3), expressible water (n=4×3), lightness (L*) (n=4×3), redness (a*) (n=4×3), yellowness (b*) (n=4×3), and pH (n=3×3) of laboratory sausage with different percentage addition of WB.

Proportion of WB	Cooking loss %	Expressible water %	L*	a*	b*	pH
Control	1.7±0.2ab	7.8±1.0a	66.0±0.8a	10.5±0.1a	13.9±0.3a	6.64±0.01a
12.5% WB	1.9±0.7ab	9.0±0.9a	68.0±0.5b	9.9±0.2b	13.7±0.2a	6.54±0.02b
25.0% WB	2.4±1.0ab	8.4±0.4a	69.5±0.6c	9.4±0.2c	13.1±0.3b	6.47±0.05c
37.5% WB	2.7±1.0b	8.1±0.4a	71.0±0.5d	9.0±0.2d	12.9±0.3b	6.43±0.03cd
50.0% WB	1.2±0.2a	7.9±0.7a	71.6±0.9d	8.8±0.3d	12.6±0.4c	6.40±0.01d
100.0% WB	2.0±0.4ab	8.3±1.0a	83.8±1.7e	3.6±0.6e	8.2±0.4d	6.33±0.01e

[a]Means with the same letter in the same column are not significantly different (P > 0.05).

Table 3. Cooking loss (n=2×3), centrifuge loss (n=2×3), lightness (L*) (n=4×3), redness (a*) (n=4×3), yellowness (b*) (n=4×3), and pH (n=3×3) of laboratory finely chopped chicken nuggets with different percentage addition of WB.

Proportion of WB	Cooking loss %	Centrifuge loss %	L*	a*	b*	pH
0%	11.6±0.6a	5.1±1.5a	68.4±0.5a	6.0±0.6a	15.1±0.4a	6.49±0.02a
12.5%	13.6±2.2b	4.9±1.6a	69.2±0.5b	5.2±0.7b	15.0±0.3a	6.47±0.02b
25.0%	11.3±1.1a	4.2±1.0a	70.5±0.7c	5.6±0.3ab	14.4±0.4b	6.46±0.01bc
37.5%	11.5±1.3a	7.0±2.4a	71.6±0.6d	5.2±0.4b	14.1±0.4b	6.45±0.01cd
50.0%	11.0±1.5a	6.2±1.7a	71.6±1.4d	4.7±0.8c	14.4±0.3b	6.44±0.02d
100.0%	11.3±1.8a	6.1±2.2a	80.5±0.9e	1.8±0.3d	13.8±0.5c	6.38±0.02e

[a]Means with the same letter in the same column are not significantly different (P > 0.05).

Table 4. Cooking loss (n=2×3), centrifuge loss (n=2×3), lightness (L*) (n=4×3), redness (a*) (n=4×3), yellowness (b*) (n=4×3), and pH (n=3×3) of laboratory ground chicken nuggets with different percentage addition of WB.

Proportion of WB	Cooking loss %	Centrifuge loss %	L*	a*	b*	pH
0%	15.0±2.2a	9.9±2.3a	62.5±1.0a	6.3±0.6a	14.9±0.6a	6.49±0.02a
25.0%	13.3±1.6a	10.4±1.1ab	66.4±0.5b	6.0±0.4a	14.6±0.4a	6.48±0.00a
50.0%	12.9±3.2a	12.7±2.0b	68.2±1.7c	5.8±0.4a	14.6±0.5a	6.46±0.03ab
100.0%	12.7±2.0a	16.6±2.3c	76.9±1.9d	3.1±0.7b	13.6±0.4b	6.44±0.04b

[a]Means with the same letter in the same column are not significantly different (P > 0.05).

4.2.5 Expressible water of laboratory sausage

Compression produced around 8% loss of the weight of the sausage slices (Table 2). The addition of WB caused no significant change (P>0.05) in the expressible water percentages of the sausages.

4.2.6 Centrifuge loss of laboratory chicken nuggets

The centrifuge loss of the finely chopped chicken nuggets showed little change with the addition of WB (P>0.05) (Table 3). However, when grinding was used as the comminuting method in the processing, the addition of WB higher than 25% increased the centrifuge loss of the products significantly (P<0.05) (Table 4).

4.2.7 Color of laboratory products

In all types of products, the addition of WB increased the lightness and decreased the redness and yellowness. For the sausages and finely chopped chicken nuggets, 12.5% WB treatment was enough to change the lightness and redness significantly (P<0.05). The yellowness of those products started to decrease (P<0.05) when 25% WB was added into the recipe (Table 2; Table 3).

The lightness of the ground chicken nuggets was significantly higher (P<0.05) than the controls when 12.5% WB treatment was applied (Table 4). The redness and yellowness of the ground chicken nuggets did not change significantly (P>0.05) when the addition of within 50%. However, when the product was made totally of WB, the redness and yellowness were different from the controls (P<0.05).

4.3 Effects of wooden breast addition on the properties of pilot plant products

According to the results of laboratory tests, the addition of WB brought influence on the quality of the meat products, mainly on the textural properties and color. However, when WB was added in the recipes at a relatively low level, the addition caused very little changes on the properties of the products. The results showed that in all types of products, an addition of WB within 25% of the lean meat caused ignorable differences in the texture, water-holding capacity and color. Therefore, 30% was selected for the maximal addition percentage of WB in the pilot plant products to verify the results of the laboratory tests.

In the processing of chicken nuggets, addition of WB up to 100% caused no significant difference on the quality of the ground chicken nuggets whereas the properties of finely chopped chicken nuggets changed significantly only by the 25% addition of WB. Therefore, grinding displayed better effects on the utilization of WB than fine chopping. In the pilot plant tests, only coarsely chopped chicken nuggets were prepared instead of finely chopped chicken nuggets.

4.3.1 pH of pilot plant products

The addition of WB slightly lowered the pH of pilot plant sausages (Table 5). Although the differences were statistically significant ($P<0.05$), the pH values of the products containing WB were very close to the pH of control products. On the contrary, the pH values of chicken nuggets were increased slightly ($P<0.05$) by the addition of WB because normal breast muscle replaced by WB had a higher pH than WB (Table 6; Table 7). No significant difference ($P>0.05$) in the pH values of ground chicken nuggets was found between WB-containing products and control group.

4.3.2 Shear force of pilot plant products

The shear force of pilot plant sausages was significantly higher ($P<0.05$) than the normal sausage when 30% of the lean meat in the recipe was replaced by WB (Fig. 7). When the addition was 15%, the shear force of the sausages did not change compared to that of the

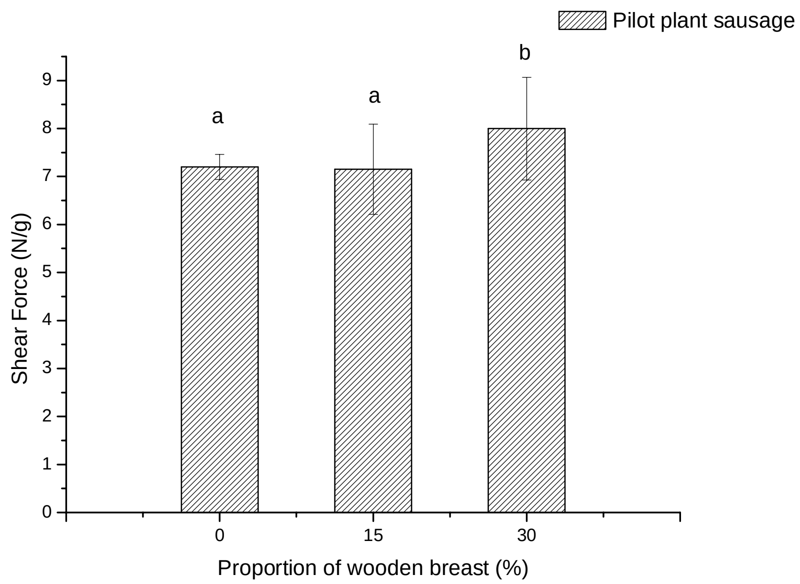

Fig. 7. Shear force of pilot plant sausage with different percentage addition of WB. Means with the same letter are not significantly different ($P > 0.05$).

Fig. 8. Shear force of pilot plant chicken nuggets with different percentage addition of WB. Means with the same letter within same treatment are not significantly different (P > 0.05).

normal sausages (P>0.05). The shear forces of both coarsely chopped chicken nuggets and ground chicken nuggets with 30% of WB displayed no significant difference compared to the control group (P>0.05) (Fig. 8).

4.3.3 Binding strength of pilot plant products

As shown in Fig. 9, the binding strength of sausages with 15% addition of WB stayed at same level with the normal sausages (P>0.05). However, when the addition came up to 30%, the binding strength of the products was significantly higher than the normal ones (P<0.05). The elongation of the sausages showed no significant difference with the addition of WB (P>0.05) (Fig. 11).

The 30% addition of WB caused no significant difference (P>0.05) in the binding strength of coarsely chopped chicken nuggets but produced ground chicken nuggets whose shear force were significantly higher (P<0.05) than the normal products (Fig. 10). There was no significant difference (P>0.05) in the elongation of both types of the chicken nuggets with the addition of WB (Fig. 12).

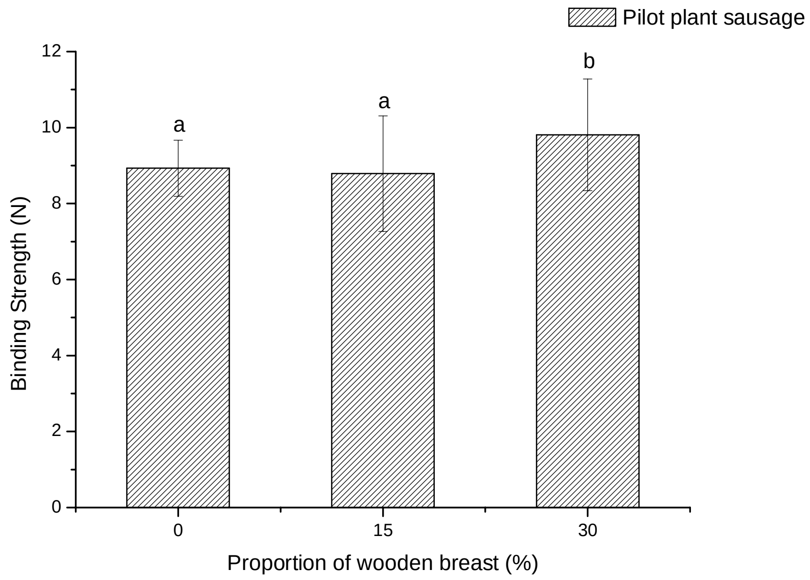

Fig. 9. Binding Strength of pilot plant sausage with different percentage addition of WB. Means with the same letter within same treatment are not significantly different (P > 0.05).

Fig. 10. Binding Strength of pilot plant chicken nuggets with different percentage addition of WB. Means with the same letter within same treatment are not significantly different (P > 0.05).

Fig. 11. Elongation of pilot plant sausage with different percentage addition of WB. Means with the same letter within same treatment are not significantly different (P > 0.05).

Fig. 12. Elongation of pilot plant chicken nuggets with different percentage addition of WB. Means with the same letter within same treatment are not significantly different (P > 0.05).

4.3.4 Cooking loss of pilot plant products

No significant change (P>0.05) was caused by the 15% and 30% additions of WB on the cooking losses of pilot plant sausages (Table 5). The 30% addition of WB caused no significant difference (P>0.05) in the cooking losses of coarsely chopped chicken nuggets compared to the normal products but produced ground chicken nuggets with higher cooking losses than control group (P<0.05) (Table 6; Table 7).

4.3.5 Centrifuge loss of pilot plant chicken nuggets

The 30% addition of WB increased the centrifuge losses of both types of chicken nuggets. The centrifuge losses of coarsely chopped chicken nuggets with 30% addition of WB were significantly higher (P<0.05) than those of the normal products (Table 6). However, the 30% addition of WB showed no statistically significant difference in the centrifuge losses of ground chicken nuggets although the values of the treatment were apparently higher than those of the controls (Table 7).

4.3.6 Color of pilot plant products

The addition of WB caused increases in the lightness and decreases in redness and yellowness of the sausages (P<0.05). Although the differences were statistically significant, 30% addition only changed 3.5% in lightness, 9.2% in redness, and 5.0% in yellowness (Table 5). For the pilot plant chicken nuggets, the 30% addition of WB did not change the color significantly in either types (P>0.05) (Table 6; Table 7).

Table 5. Cooking loss (n=5×2), lightness (L*) (n=4×2), redness (a*) (n=4×2), yellowness (b*) (n=4×2), and pH (n=3×2) of pilot plant sausage with different percentage addition of WB.

Proportion of WB	Cooking loss %	L*	a*	b*	pH
Control	6.3±0.9a	68.8±4.5a	15.2±2.3a	12.1±0.7a	6.53±0.02a
15% WB	6.0±1.0a	70.0±4.7b	14.5±2.3b	11.8±0.8ab	6.52±0.02b
30% WB	6.1±0.9a	71.2±4.1c	13.8±2.3c	11.5±0.7b	6.45±0.02c

[a]Means with the same letter in the same column are not significantly different (P > 0.05).

Table 6. Cooking loss (n=4×2), centrifuge loss (n=3×2), lightness (L*) (n=4×2), redness (a*) (n=4×2), yellowness (b*) (n=4×2), and pH (n=3×2) of pilot plant coarsely chopped chicken nuggets with different percentage addition of WB.

Proportion of WB	Cooking loss %	Centrifuge loss %	L*	a*	b*	pH
Control	16.1±2.3a	13.7±2.0a	61.6±5.0a	9.0±1.7a	15.6±2.6a	6.46±0.03a
30% WB	13.7±3.0a	19.9±4.8b	59.7±5.0a	8.9±1.2a	17.4±2.4a	6.49±0.03b

[a]Means with the same letter in the same column are not significantly different (P > 0.05).

Table 7. Cooking loss (n=4×2), centrifuge loss (n=3×2), lightness (L*) (n=4×2), redness (a*) (n=4×2), yellowness (b*) (n=4×2), and pH (n=3×2) of pilot plant ground chicken nuggets with different percentage addition of WB.

Proportion of WB	Cooking loss %	Centrifuge loss %	L*	a*	b*	pH
Control	16.9±2.8a	17.9±2.6a	60.6±4.1a	8.8±1.5a	16.8±1.9a	6.47±0.02a
30% WB	19.8±2.8b	20.6±1.7a	60.5±4.2a	9.6±1.7a	17.6±4.1a	6.49±0.01a

[a]Means with the same letter in the same column are not significantly different (P > 0.05).

4.3.7 Sensory test

The triangle tests on the products processed from different meat sources showed similar results (Table 8). Difference was detected at tasting by the panelists between the normal sausages and the sausages with 30% addition of WB (P<0.05). The differences were described by the panelists as the normal sausages had a softer texture than the sausages containing WB. Meanwhile, significant differences (P<0.05) were found between the color of normal sausages and sausages with 30% addition of WB, and between the color of sausages with 15% addition of WB and those with 30% addition of WB. The panelists commented that the sausages containing more WB were paler. However, panelists did not detect any difference between normal chicken nuggets and chicken nuggets containing WB (P>0.05).

Table 8. Sensory test result of pilot plant products.

	Significance of Difference	
	Replicate-1 (HK)	Replicate-2 (Atria)
Sausage 0%-15%	No	No
Sausage 0%-30%	Yes	Yes
Sausage 15%-30%	No	No
Sausage color 0%-15%	No	No
Sausage color 0%-30%	Yes	Yes
Sausage color 15%-30%	Yes	Yes
Chicken Nuggets chopping 0%-30%	No	No
Chicken Nuggets grinding 0%-30%	No	No

[a]The evaluation on the tasting and the color of sausage was given by 18 panelists. The evaluation of chicken nuggets was given by 15 panelists.
[b]Yes means the difference between samples was significant (P<0.05). No means the difference between samples was not significant (P>0.05).

5 DISCUSSION

The study on WB is a relatively new area in meat science. At the moment, there is very little research published on this topic. The present study focused on the technological part of the topic, which is one part of the whole project on WB *"Study on the possibilities to reduce the 'Wooden Breast' lesions in broilers".* The study is funded by Finnish poultry industries and leaded by Professor Emeritus Eero Puolanne and the Project Manager and Principal Investigator Dr. Kaisa Immonen. The project also studies other aspects in regard with WB including the determination of chemical compositions, the study on protein oxidation, the study on fat oxidation, the study on the microstructure, and the study on the utilization of WB. The current study aimed to explore the possibilities of the utilization of WB in meat products in order to lower the economic losses in the meat industry. To achieve the utilization, WB was incorporated with normal meats through comminuting technologies as one of the ingredients in the processing. The tests were done on different products, chicken sausage and chicken nugget, which are common products in the market in Finland. On the other hand, different comminuting methods were applied in the processing of chicken nuggets to attain a comparison between the effects of different methods of particle size reduction on the utilization of WB.

The WB was added to the recipes to replace a proportion of normal meat at different percentages. In the preliminary tests in the laboratory, the percentages of addition were made to an extreme situation, from 0% to 100%, so that tendencies of the influences of WB on the products could be obtained. The normal meats used in the recipes of the products were mechanically deboned poultry meat (MDM) and poultry trimmings. Due to the differences in the fat contents between WB and the normal meats, pork fat was added at the meantime with WB into the recipes to keep the fat contents of the products consistent. As a result, WB took up 0%, 12.5%, 25%, 37.5%, 50%, and 100% of the lean meat in the recipes of the products. However, products with the different percentages of WB addition probably still had different protein contents and moisture contents. Considering the essential influences of the fat content on the texture of the products, fat content was made constant prior to other components in the recipe.

The results of the preliminary tests in the laboratory were later verified in the pilot plant, in which the conditions of the processing were closer to that in the industries. According to the results in the preliminary tests, WB treatment within 25% of the lean meat in the recipes produced little difference with the controls in the tests of sausages and chicken nuggets. Therefore, 30% was set as the highest percentage of WB treatment in the pilot plant tests to verify the results of the laboratory tests. Moreover, the results showed that the addition of WB caused almost no difference in the quality of ground chicken nuggets up to the percentage of 100%. Comparing the effects of the two comminuting methods on the utilization of WB in chicken nuggets, finely chopped chicken nuggets were not included in the pilot plant tests. Instead, coarsely chopped chicken nuggets were tested in the pilot plant in which the comminuting is coarser and larger particles were produced.

In the verifications in the pilot plant, nearly the same recipes and procedures as in the laboratory were applied. However, some differences were present between laboratory tests and pilot plant tests. In the processing of laboratory chicken nuggets, WB was added to replace a part of the whole meat mass. Considering the experiment conditions and the practice in meat industry, WB was added to replace a part of normal breast muscle in the processing of pilot plant chicken nuggets because it was easier to apply in the pilot plant and industrial processing. Furthermore, the new procedure in which breast muscle was replaced by another breast muscle was expected to have less influence on the quality of the products and it was more meaningful for the industry to save the economic costs. In addition, the salt contents in the sausages was adjusted from 2.5% in the laboratory tests to 1.5% in the pilot plant tests considering the relevant legislation for the industrial sausage products in the market in Finland.

5.1 Toughness of wooden breast

Easily perceived through testing by hand, raw WB muscle is clearly tougher than normal breast muscle. In addition, another obvious difference between the WB muscle and normal breast muscle is that WB is paler in color. Therefore, WB is easily distinguished from the normal breast and rejected by the manufacturer. According to the previous literature, the toughness of meat is affected by several factors. The content of connective tissue has been considered to have correlation with the tenderness of the meat. The meat containing more connective tissue is tougher (Smith and Judge, 1991). Contrary to the effect of connective tissue, the sarcomere length of the muscle has negative correlation with the toughness of meat (Light et al. 1985). In addition, the degree of proteolysis also has influence on the toughness of meat. Harrison et al. (1970) claimed that longer ageing times increase the tenderness of the pork. The reason was explained by other researchers as proteolysis activities occur during *post mortem*, in which the calpain system functions to degrade the Z-disk in the muscle. With the increasing ageing time, more proteolysis activities take place and make the meat tender (Taylor et al. 1995). Considered from the theory of the occurrence, WB is defined as a kind of regenerative myodegeneration and necrosis with fibrosis. Therefore, the differences in the content of connective tissue were expected to characterize WB as a possible reason for the toughness it has.

To study the chemical composition of WB and compare it with normal breast muscle, a cooperating study was done by another member (Wang) in the group. WB muscle and normal breast muscle from chicken with same age and from same feeding group were analyzed. The results showed that the total collagen content was a little higher in the WB than that in the normal breast muscle (0.53% vs. 0.51%). However, the difference between the collagen content of WB and that of normal breast was very small. When WB was added as a part of ingredients in the products, the difference in the connective tissue content was even smaller. The protein content of WB was 6.7% lower than that of normal breast (20.97% vs. 22.48%). In summary, WB is a complicated phenomenon on the structure of the muscle, and the reason for the toughness of WB is hard to explain based on the studies that have been done so far. More studies need to be done to explain the reason for the toughness and paleness of the meat.

5.2 Influence of wooden breast addition on the quality of laboratory products

The textures of sausages and finely chopped chicken nuggets were influenced apparently by the addition of WB. The binding strengths of those products also increased with the addition. The meat used to process the control products was MDM and poultry thigh meat trimmings. MDM is a kind of meat produced from mechanical process of removing meat from the bone. The extreme stress causes the cell breakages, protein denaturation and extraction of lipids and heme components from the bone marrow (Dawson and Gartner 1983; Pereira et al. 2011). Due to the applicable consistency and relatively low costs, MDM is commonly used as an ingredient of many comminuted meat products (Mielnik et al. 2002). According to the previous studies on the chemical composition of MDM, MDM usually has protein content around 15%, and it is variable due to the location of the meat from the body (Duranti and Cerletti 1980; Archile et al. 1999). Apparently, MDM contains less protein compared to the intact skeletal muscle and it also has been reported to have higher fat and moisture content. The addition of MDM in some emulsified meat products to replace the intact muscles was found to influence the texture of the products. Daros et al. (2005) demonstrated the tensile strength, normalized strength, and compressive strength decrease with the addition of mechanically deboned poultry meat when replacing a part of pork and beef because MDM produces higher moisture contents in the cooked products, which decreases the hardness of the sausages. The decrease in the contents of myofibrillar proteins in the products caused by MDM was given as another reason for the decline in the hardness of the products. Hsu et al. claimed the muscle proteins, especially myofibrillar proteins are partially disrupted in MDM and produce softer texture of the emulsified meatballs. In the present study, although WB had a lower protein content than normal breast, it still contained more protein than MDM. Therefore, the addition of WB actually increased the protein contents in the products and thus increased the meat to meat binding in the comminuted products which was produced through the formation of gels between myofibrillar proteins (Boles and Shand 1998).

The shear forces of the sausages and finely chopped chicken nuggets also increased with the addition of WB. The shear force of meat and meat products is generally considered to be positively correlated to the toughness. However, there was also a different viewpoint claiming that the shear force in some cases is associated with the binding strength of the products rather than the toughness. Chesney et al. (1978) demonstrated that shear values of restructured meat products reflects the binding strength rather than an objective toughness and considered that meat products of higher shear force are more desirable. The results of the current study showed that the both of the shear forces and binding strengths of sausages and finely chopped chicken nuggets increased with the addition of WB in a similar trend. The increase of shear forces caused by the addition of WB was probably to be attributed to the increase of meat protein content which produced more protein-protein binding in the products.

Generally, the connective tissue content also has an essential influence on the textures of the products. The incorporation of collagen has been reported to have influence the textures of the products. Pereira et al. (2011) reported that the addition of collagen increases the firmness of the sausages by retaining more water. Meullenet et al. (1994) found that the incorporation of collagen in the sausages lifts the shear values of the products because of the gelation ability of collagen. The addition of collagen has also been reported to increase the protein-protein binding of ham (Schilling et al. 2005). Schilling et al. (2003) claimed that the influence brought by the addition of collagen to the textures of the products depends on the degree of the comminuting. According to the results of parallel study on the chemical composition of WB (Wang), the difference between the collagen content of WB and that of normal breast was very small. In addition, chopping is a kind of comminuting method generating very fine particles and is effective to disrupt the connective tissue. Therefore, the influence caused by connective tissue on the textures of sausages and finely chopped chicken nuggets was minor compared to the effect of total protein content.

Contrary to sausages and finely chopped chicken nuggets, the shear forces and binding strengths of ground chicken nuggets were not affected significantly (P>0.05) by the addition of WB. The phenomenon was probably generated by the difference in comminuting methods. Chopping is able to comminute myofibrils of the muscle to make very fine particles. In contrast, grinding produces relatively coarser comminuting and generates larger particles. Comminuting methods generating finer particles produce higher protein extractability of myofibrillar proteins due to the higher degree of the cell disruption and thus more breakage-release of meat proteins (Acton 1972). Moreover, the smaller particle size means that the proteins have larger surface area contributing to more interactions and binding between proteins and other added ingredients (Durland et al. 1982; Cofrades et al. 2004). In the present study, when the total protein contents of the products were increased by the addition of WB, chopping enhanced the effects of that increase by reducing the particles into smaller size whereas grinding which produced relatively larger particles was not able to attain the same effect. Therefore, the addition of WB resulted in difference effects on the shear forces and binding strengths of the chopped products and ground products.

The water-holding capacity of the meat is essentially affected by the extractability of myofibrillar proteins (Bendall and Wismer-Pederson 1962; Sayre and Briskey 1963). Theoretically, the increase in total protein contents in the products caused by the addition of WB would decrease the cooking losses of the products. However, the changes of cooking losses in all types of products by WB addition displayed no regular tendency. The loss of the functionality of the meat proteins has been reported to have influence on the quality of meat. For example, the denaturation of myofibrillar proteins and sarcoplasmic proteins has been reported to be responsible to the poor water-holding capacity of pale, soft, and exudative (PSE) meat (Offer 1991). In the current study, it is possible that WB has defects in the myofibrillar or sarcoplasmic proteins due to the histological changes occurring inside the meat and therefore the cooking losses of the products was not influenced by the WB addition. On the other hand, the replicates (2×3) for the measuring of cooking losses might not have been enough, from which the results displayed big fluctuation.

The addition of WB induced different effects on the centrifuge losses of chicken nuggets made from diverse comminuting methods. The centrifugation was done right after the batters were cooked. In this way, the batters can be kept at a temperature higher than 40 ℃ during the centrifugation. In the centrifugation, collagens in the batters stayed in a melted form and soluble collagens were able to flow out from the batters with free water. However, the difference between the soluble collagen content of WB and that of normal breast was very small according to the results from the parallel study on the chemical composition of WB (Wang). Therefore, the different effects of WB addition on the centrifuge losses of the chicken nuggets made by diverse comminuting methods are considered not to be caused by the soluble collagen contents in the products. It is possible that WB addition decreases the water-holding capacity of the ground chicken nuggets and produces more centrifuge losses. In contrast, the chopping is able to comminute the meat to very fine particles and form the emulsion in the batter, in which salt soluble proteins adhere on the fat globules. During cooking, a three-dimensional network of proteins containing fat will be formed (Jones and Mandigo 1982) and keeps the water inside the products.

WB breast was clearly paler than the normal breast muscle whereas MDM and poultry trimmings were darker than the breast muscle due to the difference in the fiber types in addition to release of heme group from bone marrow during the mechanical processing. Therefore, the replacements of MDM, poultry trimmings and normal breast muscle by WB naturally decreased the redness and yellowness and increased the lightness of the products. In addition to the essential influence of the color of ingredients, the color of the sausage has been reported to be affected by the fat content. Carballo et al. (1995) stated the reduction of fat content induces to the decrease of the lightness of the sausages because the decreasing fat content causes the reduction of light scattering associated with fat. In the present study, the fat contents in the recipes were controlled at the same level in each treatment. Nonetheless, the fat contents may be different in the cooked products due to the losses of the fat during cooking caused by different fat binding abilities of the products containing different amounts of WB. Pereira et al. (2011) claimed that the addition of collagen produces frankfurters which have higher lightness values because the light scattering is decreased by swelling of collagen fibers under the interaction with water. However, the similar collagen contents in WB and normal breast eliminated the influence of connective tissues on the color. Moreover, even if the influence from collagen contents and fat contents did exist, they were still minor compared to the influence of the addition of WB. After all, the apparent color difference between WB and other meat ingredients was the primary reason for the color difference of the products.

The pH values of the products also decreased with the increasing addition of WB. The mechanical processing also produced MDM a higher pH value than normal skeletal muscle. Therefore, the adding of WB to replace MDM and poultry trimmings decreased the pH of products.

5.3 Verification in the pilot plant

The instrumental measurements of pilot plant products produced similar results as laboratory products. The influences brought by WB on the sausages mainly displayed on the texture and color. The results from laboratory tests showed that the qualities of sausages were not changed much within a WB addition of 25%. Corresponding to this result, when the addition was increased to 30% in the pilot plant tests, the increases of shear forces and binding strengths were significant ($P<0.05$). Although the changes in the color of the sausages were statistically significant ($P<0.05$), the difference was small, which is probably hardly detected by naked eye. Through the sensory tests, panelists found that sausages with 30% was harder in textures than the controls ($P<0.05$), which corresponded to the instrumental measurements. Although the differences were detected, the preferences of the panelists on the texture were unknown. The increase in the hardness is not equal to the reduction in the quality. Chesney et al. (1978) gave the viewpoint that restructured meat products with higher shear forces are more desirable. To evaluate the desirability of the products containing WB, preference tests would be needed. In the present study, the sausages with 30% WB addition were also recognized by the panelists to be lighter in color compared to the controls. However, when the consumers observe only one product in the market in one time, the difference is probably difficult to perceive.

The addition of 30% WB only produced a little difference in the binding strengths of the ground chicken nuggets ($P<0.05$). Other instrumental properties of both coarsely chopped and ground chicken nuggets were not affected ($P>0.05$). In contrast to sausages, same amount of WB treatment (30%) produced smaller influence on the properties of chicken nuggets. The inhomogeneous texture of chicken nuggets (Appendix 5), processed through coarsely comminuting, induced a fluctuation of the results in instrumental measurements, which eliminated the significance of the difference between treatments and controls. Such inhomogeness also made the addition of WB difficult to be detected in the sensory tests. On the other hand, coarse comminuting which produced larger meat particles reduced the effects of the increase in total protein content by the WB addition. The meat proteins in the chicken nuggets had less interactions and binding due to the smaller surface area compared to the activities of proteins in the sausages. Therefore, the textural changes caused by WB addition were smaller in the chicken nuggets than in the sausages. The differences between the color of WB treatment products and the controls was not significant ($p>0.05$). The lack of significance was also more or less contributed by inhomogeneity of the products, which formed inconsistent appearances to the slices of chicken nuggets (Appendix 5). Nevertheless, the color of chicken nuggets is a less important property because the products are coated by bread crumb.

Concluded from results of pilot plant tests, chicken nuggets made through coarse comminuting allowed more utilization of WB in the recipes without causing significant changes in the quality of the products than sausages. However, the desirability of the quality changes brought by WB on the sausage was unknown.

5.4 Applicability of the study

The study indicated the possibilities of the utilization of WB in the processing of meat products. When incorporated with normal meats in relatively low proportions, WB caused no obvious change to the quality of sausages and chicken nuggets, meaning that a small amount of WB to be used in the industrial processing is acceptable. Although higher percentages of WB addition produced quality changes to the products, the desirability of the changes was unknown. Possibly the addition of WB actually improves the quality and desirability of the products and higher amount of WB is acceptable to use in the processing. Therefore, further studies on the acceptability of the WB-containing products would be needed. Nevertheless, the addition of WB in very high percentages is pointless for the industry because WB is a phenomenon occurred at around only in less than 5% of broilers. Moreover, meat products containing a very high percentage of WB may be acceptable in the quality but not acceptable mentally by the consumers.

The study was done practically, wherein the theories were less considered. To apply the WB in meat products more efficiently, more analysis on the chemical compositions of WB would be needed, so that the influence of WB on the quality of the meat products can be better explained and predicted. For example, the measurements of the contents of myofibrillar protein and sarcoplasmic protein of WB and also other ingredients would be helpful to predict the changes of the water-holding capacity of the products. Likewise, the measurements of the chemical compositions of the cooked products would explain the changes in the compositions of batters during cooking and the effects of WB on the compositions of the cooked products.

The utilization of WB can be also tested in more types of products at a similar percentage based on the results of the present study. The comminuting methods may have influence on the maximal percentage of the WB used in the products. The preference tests by the panelists would be needed to obtain an optimal percentage use of WB, which is desirable for the eating quality and minimizes the economic losses to the industry.

6 CONCLUSIONS

The present study indicated that the wooden breast can be used to prepare comminuted meat products without lowering the qualities of the products by mixing with normal meat at a relatively low percentage. Addition of wooden breast as 15% of the lean meat causes no significant change in the qualities of the chicken sausages whereas 30% wooden breast addition changes the qualities of the sausages. Addition of wooden breasts to replace 30% of normal breast in the coarsely chopped chicken nuggets and ground chicken nuggets causes no significant change in quality. The comminuting methods have different effect on the utilization of wooden breast. Coarser comminuting methods are able to reduce the influences of the addition of wooden breast on the quality of meat products. Compared to comminuting methods producing finer particles, coarser comminuting methods enable higher percentages of wooden breast in the meat products.

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APPENDIXES

Appendix 1. Recipes of laboratory sausages (HK).

Addition of wooden breast	0%WB	12.5%WB	25.0%WB	37.5%WB	50%WB	100%WB
Poultry trimmings (18.7% fat)	36.00%	31.50%	27.00%	22.50%	18.00%	
MDM (18.7% fat)	36.00%	31.50%	27.00%	22.50%	18.00%	
WB		7.31%	14.62%	21.92%	29.23%	58.46%
Pork fat		1.69%	3.38%	5.08%	6.77%	13.54%
Water	25.00%	25.00%	25.00%	25.00%	25.00%	25.00%
Salt	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%
Phosphate (58% $P_2O_5^-$)	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%
Nitrite	100ppm	100ppm	100ppm	100ppm	100ppm	100ppm

Appendix 2. Recipes of laboratory chicken nuggets (HK).

Addition of wooden breast	0%WB	12.5%WB	25.0%WB	37.5%WB	50.0%WB	100.0%WB
Poultry trimmings (18.7% fat)	20.00%	17.50%	15.00%	12.50%	10.00%	
MDM (18.7% fat)	20.00%	17.50%	15.00%	12.50%	10.00%	
Normal breast	29.00%	25.38%	21.75%	18.13%	14.50%	
WB		7.71%	15.39%	23.08%	30.76%	61.50%
Pork fat		0.92%	1.86%	2.80%	3.74%	7.50%
Water	23.00%	23.00%	23.00%	23.00%	23.00%	23.00%
Whole egg liquid	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%
Soya powder (EX 37)	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%
Salt	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
Phosphate (58% $P_2O_5^-$)	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%

Appendix 3a. Recipes of pilot plant sausages (HK).

Addition of wooden breast	Control	15%WB	30%WB
Poultry trimmings (18.7% fat)	36.00%	30.60%	25.20%
MDM (18.7% fat)	36.00%	30.60%	25.20%
WB		8.77%	17.54%
Pork fat		2.03%	4.06%
Water/ice 2/1	25.33%	25.33%	25.33%
Salt	1.50%	1.50%	1.50%
Phosphate (58% $P_2O_5^-$)	0.40%	0.40%	0.40%
10% nitrite solution	0.10%	0.10%	0.10%
Ascorbate (E301)	0.07%	0.07%	0.07%
Spices mix (95002564/B)	0.60%	0.60%	0.60%

Appendix 3b. Recipes of pilot plant sausages (Atria).

Addition of wooden breast	Control	15%WB	30%WB
Poultry trimmings (10.0% fat)	32.60%	27.71%	22.82%
MDM (18.0% fat)	36.00%	30.60%	25.20%
WB		8.77%	17.54%
Pork fat	3.40%	4.92%	6.44%
Water/ice 2/1	25.33%	25.33%	25.33%
Salt	1.50%	1.50%	1.50%
Phosphate (58% $P_2O_5^-$)	0.40%	0.40%	0.40%
10% nitrite solution	0.10%	0.10%	0.10%
Ascorbate (E301)	0.07%	0.07%	0.07%
Spices mix (95002564/B)	0.60%	0.60%	0.60%

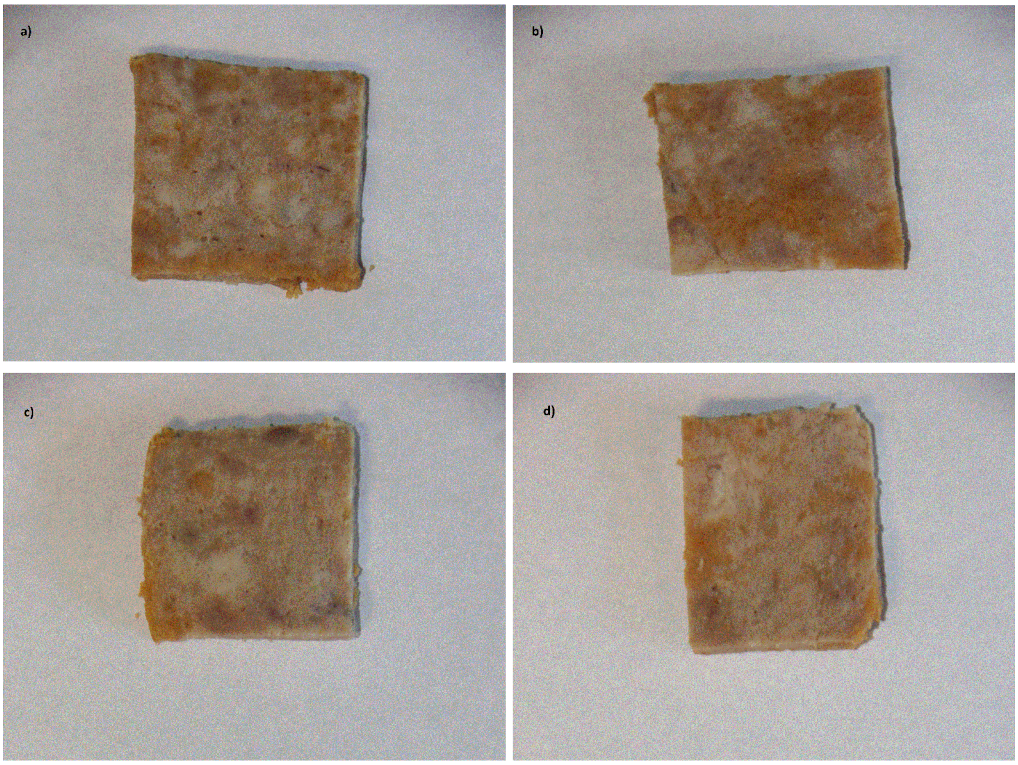
Appendix 4a. Recipes of pilot plant chicken nuggets (HK).

Addition of wooden breast	0% WB	30% WB
Poultry trimmings (18.7% fat)	20.00%	20.00%
MDM (18.7% fat)	20.00%	20.00%
Normal breast	29.00%	8.30%
WB		20.70%
Water	22.37%	22.37%
Whole egg liquid	5.00%	5.00%
Soya powder (EX 37)	2.00%	2.00%
Salt	0.76%	0.76%
Phosphate (58% $P_2O_5^-$)	0.20%	0.20%
Ascorbate (E301)	0.07%	0.07%
Spice mix (95002564/B)	0.60%	0.60%

Appendix 4b. Recipes of pilot plant chicken nuggets (Atria).

Addition of wooden breast	0% WB	30% WB
Poultry trimmings (18.7% fat)	18.11%	18.11%
MDM (18.7% fat)	20.00%	20.00%
Normal breast	29.00%	8.30%
Pork fat	1.89%	1.89%
WB		20.70%
Water	22.37%	22.37%
Whole egg liquid	5.00%	5.00%
Soya powder (EX 37)	2.00%	2.00%
Salt	0.76%	0.76%
Phosphate (58% $P_2O_5^-$)	0.20%	0.20%
Ascorbate (E301)	0.07%	0.07%
Spice mix (95002564/B)	0.60%	0.60%

Appendix 5a. Pictures of chicken nugget slices



a) Slice of control pilot plant chopped chicken nugget. b) Slice of pilot plant chopped chicken nugget with 30% WB addition. c) Slice of control pilot plant ground chicken nugget. d) Slice of pilot plant ground chicken nugget with 30% WB addition.

[a]The clearly lighter parts on the slices were from breast muscle while the darker parts were from MDM and poultry trimming