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PHYSICOCHEMICAL AND SENSORY PROPERTIES OF SURIMI-LIKE MATERIAL FROM DUCK MEAT AND ITS APPLICATION IN BURGER

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PHYSICOCHEMICAL AND SENSORY PROPERTIES OF SURIMI-LIKE MATERIAL FROM DUCK MEAT AND ITS APPLICATION IN BURGER

by

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All praise is due to Allah, who has sent down upon His Servant (Muhammad) the Book and has not made therein any deviance. O Allah, send your greetings (Salawat) and blessings on Muhammad and Muhammad's family, the same way as You sent Your Salawat and blessings on Ibrahim and Ibrahim’s family. You are indeed worthy of all praise, full of glory.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	Meaning
CB	Chicken burger
DB	Duck burger
DSLM	Surimi-like material from duck meat
MDCM	Mechanically deboned chicken meat
NaCl	Sodium chloride
$NaHCO_3$	Sodium bicarbonate
PCA	Principal component analysis
QDA	Quantitative descriptive analysis
SEM	Scanning electron microscopy
SL	Burger made from DSLM with polydextrose added
SLM	Surimi-like material
SS	Burger made from DSLM with sucrose-sorbitol added
TPA	Texture profile analysis
WHC	Water holding capacity

SIFAT FIZIKOKIMIA DAN SENSORI BAHAN SEAKAN SURIMI DARIPADA DAGING ITIK DAN KEGUNAANNYA DALAM BURGER

ABSTRAK

Kajian ini dijalankan untuk menentukan: kesan dua kitaran basuhan (dua dan tiga kali basuhan) dan empat jenis larutan basuhan (air paip, NaCl, $NaHCO_3$, dan larutan penampan natrium fosfat) pada komposisi, sifat fungsian, dan struktur mikro bahan seakan surimi yang diperbuat daripada daging itik (DSLM); aktiviti krioprotektif (perlindungan krio) daripada empat jenis krioprotektan kurang manis (polidekstros, trehalos, laktitol, dan palatinit), dibandingkan dengan campuran krioprotektan komersial (sukros-sorbitol) dan kawalan pada DSLM semasa penyimpanan sejuk-beku serta terdedah pada kitaran beku-cair; dan sifat-sifat fizikokimia, tekstur, dan sensori burger yang diperbuat daripada DSLM (yang ditambah dengan polidekstros dan campuran sukros-sorbitol) serta perbandingan dengan burger yang diperbuat daripada daging ayam dan itik. Basuhan sebanyak tiga kali pada daging itik adalah mencukupi untuk mengeluarkan komponen yang tidak dikehendaki dalam bahan seakan surimi seperti lemak dan protein sarkoplasmik, untuk memekatkan protein miofibrilar, untuk membentuk struktur gel yang padat dan tumpat setelah dimasak. Ini akan menyebabkan sifat-sifat fungsi dan teksturnya mempunyai nilai yang lebih tinggi. Antara larutan basuhan yang dikaji, basuhan dengan air paip secara signifikan menunjukkan nilai kekuatan, kekerasan, kesepaduan dan kekenyalan gel yang tertinggi; peningkatan yang sederhana dalam kapasiti memegang air (water holding capacity, WHC), pH, keterlarutan protein, kecerahan, dan keputihan; serta sedikit lemak yang tertinggal. Penambahan krioprotektan kurang manis pada DSLM menunjukkan aktiviti krioprotektif bagi

protein miofibrilar semasa penyimpanan sejuk-beku selama empat bulan dan terdedah pada kitaran beku-cair, dengan mengekalkan WHC, keterlarutan protein, serta daya pemecahan gel yang lebih tinggi daripada sampel kawalan. Antara krioprotektan kurang manis yang digunakan, polidekstros menunjukkan WHC DSLM yang paling tinggi. Sifat-sifat fizikokimia, tekstur serta sensori burger yang disediakan daripada DSLM menghampiri sifat-sifat burger ayam. Burger yang diperbuat daripada DSLM mempunyai kandungan lemak dan kolesterol yang rendah, tetapi ia juga kurang berair, kurang berminyak, lebih keras, kenyal, dan kurang berbau haiwan serta kurang mempunyai rasa daging jika dibandingkan dengan burger yang diperbuat daripada daging itik yang dibuang tulangnya secara mekanikal.

PHYSICOCHEMICAL AND SENSORY PROPERTIES OF SURIMI-LIKE MATERIAL FROM DUCK MEAT AND ITS APPLICATION IN BURGER

ABSTRACT

This study was carried out to determine: the effect of two numbers of washing cycle (twice and thrice washings) and four types of washing solutions (tap water, NaCl, $NaHCO_3$, and sodium phosphate buffer) on composition, functional properties, and microstructure of surimi-like material made from duck meat (DSLM); the cryoprotective activity of four types of low sweetness cryoprotectants (polydextrose, trehalose, lactitol, and palatinit), compared to commercial blend cryoprotectant (sucrose-sorbitol) and control on DSLM during frozen storage and exposed to freeze-thaw cycles; and the physicochemical, textural and sensory properties burgers made from DSLM (added with polydextrose and sucrose-sorbitol blend) and compared to burgers made from chicken and duck meat. Three times washing on duck meat was sufficient to remove the undesirable components in surimi-like material such as fats and sarcoplasmic proteins, to concentrate the myofibrillar proteins, to form a compact and dense structure of cooked gel which resulted in high values of functional and textural properties. Among the washing solutions tested, washing with tap water achieved the highest gel strength, hardness, cohesiveness, and chewiness significantly; moderate increases in water holding capacity (WHC), pH, protein solubility, lightness, and whiteness; and left a small amount of fat. The addition of low sweetness cryoprotectants on DSLM showed cryoprotective activity for myofibrillar proteins during 4 months frozen storage and exposed by freeze-thaw cycles, by retaining the WHC, protein solubility, and gel

breaking force higher than control sample. Among the low sweetness cryoprotectants used, polydextrose resulted in the highest WHC of DSLM. Physicochemical, textural, and sensory properties of burgers prepared from DSLM approached those of burgers made of chicken. Burgers made from DSLM had lower fat and cholesterol content, but they also were less juicy, less oily, harder, chewier, springier, and had less animalic odor and meaty flavor compared to burgers made from mechanically deboned duck meat.

CHAPTER 1: INTRODUCTION

1.1 Research Background

The production of duck meat has risen steadily in recent years, and has become the third most widely produced poultry meat in the world after chicken and turkey. Furthermore, there has been an increase in demand for duck meat because it is no longer considered a seasonal dish and has become acceptable to eat at any time of year. This has been promoted by modern husbandry techniques that are able to supply greater quantities of duck meat (Dunn, 2008; Hird et al., 2005). Both meat purpose ducks and spent egg-laying ducks are considered as source of duck meat (Abraham and Ravindran, 2009; Sonaiya and Swan, 2004). The availability of duck meat presents an opportunity to expand its use into many further processed meat products.

However, duck meat is less appropriate as further processed meat products compared to chicken and turkey meat (Huda et al., 2010a). Several published reports mentioned about duck meat's susceptibilities. Bhattacharya et al. (2007) reported that sausages made from duck meat had lower cooking yield and emulsion stability. Biswas et al. (2006) reported patties made from duck meat also had lower emulsion stability and cooking yield compared with chicken patties. Ali et al.(2007) confirmed that duck meat had higher cooking loss, darker color, and more rapid declining of shear force during storage compared to chicken meat. Huda et al. (2010b) reported that duck sausage had fewer score on texture and overall acceptability compared to chicken sausage through sensory evaluation. Another result reported by Yang et al. (2009) mentioned that duck sausage without addition of any cereal flours had the

lowest overall acceptability. Therefore this abundant source of meat is necessary to be improved.

There has been a method used to improve meat with low functional properties by making it into surimi-like materials. It requires washing processes of meat in order to remove undesirable components and concentrate myofibrillar proteins which play essential roles in texture properties of processed meat products (Antonomanolaki et al., 1999).

Like the original surimi, the addition of cryoprotectants needs to be done as a protection of proteins during freezing process and frozen storage. The most commonly used cryoprotectant added to surimi is sucrose-sorbitol at concentration 8% (wt/wt) and ratio 1:1. This compound, however, imparts a sweet taste that is undesirable to some consumers (Carvajal et al., 1999). In an effort to replace sucrose, many researchers have studied the use of various types of low sweetness sugars as cryoprotectants (e.g., polydextrose, trehalose, palatinit, and lactitol) (Sych et al., 1990; Sultanbawa and Li-Chan, 1998; Pan et al., 2010). Finally, the application of surimi-like material in a product needs to be evaluated.

The hypothesis of this study is: by processing the duck meat into surimi-like material, myofibrillar proteins will be concentrated, and hence it will improve its functional properties of duck meat and lead to a better application in the processed meat products.

1.2 Objectives

1. To determine the effect of number of washing and washing solutions on composition, functional properties, and microstructure of surimi-like material made from duck meat (DSLM).

2. To analyze the cryoprotective activity of low sweetness cryoprotectants on DSLM during frozen storage and exposed to freeze-thaw cycles.
3. To analyze the physicochemical, textural and sensory properties burgers made from DSLM.

CHAPTER 2: LITERATURE REVIEW

2.1 Duck Meat

The production of duck meat has been dominated by Asian countries, which supply more than 80% of the duck meat produced in the entire world. The People's Republic of China has been the top producer and exporter of both live ducks and duck meat over many years. Although France is the second-largest producer of duck meat, several Asian countries are close behind: Malaysia the third-largest, Thailand, and Vietnam produce approximately as much duck meat as the United States of America. The production of live ducks has also been dominated by Asian countries. The five countries with the largest live duck stocks are China, Vietnam, Indonesia, India and Bangladesh (Food and Agriculture Organization, 2010).

Figure 2.1 shows the increase in world duck meat production and live duck stocks over time. The figure illustrates the threefold increase that occurred between 1987 and 2008 to achieve a total duck meat production of 3.7 million tons per year. The number of live duck stocks dropped in 1998 after reaching a peak at 1997, but have continued to increase since that time. In Malaysia, duck meat production has been doubling from about 55000 tonnes in 1998 to 111000 tonnes in 2008, whereas live ducks stock increasing from 25 million heads in 1998 to 47 million heads in 2008 (Food and Agriculture Organization, 2010).

Ducks, in term of meat source, are classified into three types: 1) Broiler or fryer duckling is young duck of either sex, usually under eight weeks of age which has tender meat, soft bill and windpipe. 2) Roaster duckling is young duck of either sex, usually under 16 weeks of age which has tender meat, a not completely hardened bill, and an easily dented windpipe. 3) Mature or old duck is of either sex,

usually over six months of age with toughened meat, and hardened bill and windpipe (Barbut, 2002). There are particular times for certain duck breeds ready to be slaughtered. Generally, Pekin duck (*Anas platyrhynchos domesticus*) of either sex are slaughtered between seven and eight weeks of age. Whereas Muscovy (*Cairina moschata*) males are slaughtered at 12 weeks of age and its females are at 10 weeks (Rémignon, 2004).

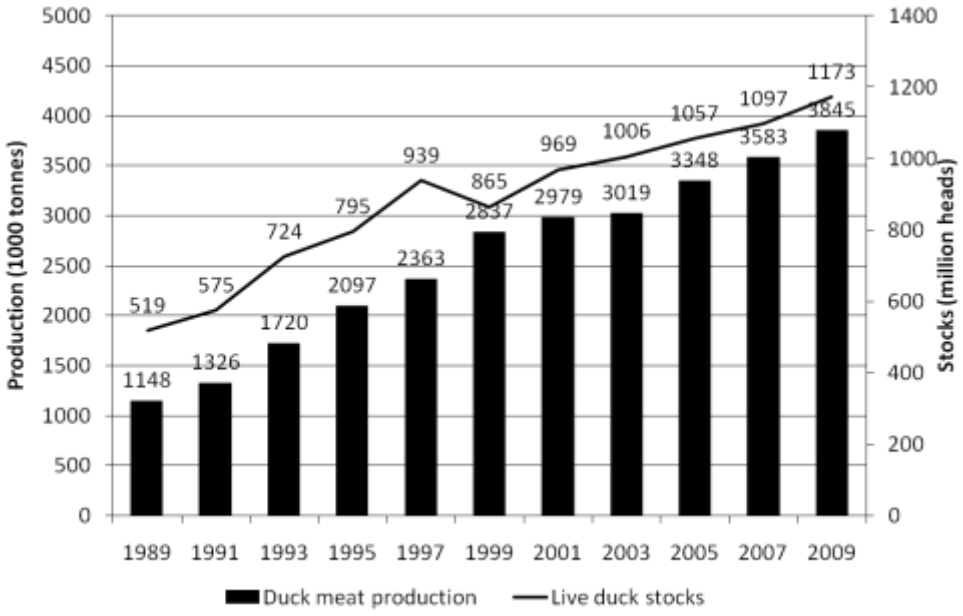

Figure 2.1 World's duck meat production and live duck stocks from 1989 to 2009 (Based on the data of FAOSTAT of the Food and Agriculture Organization, 2010)

Duck meat has a unique combination of red meat and poultry meat characteristics (Baéza, 2006). Like red meat, duck meat has relatively high fat content and levels of intramuscular phospholipids, which play a substantive role in the development of meat flavor (Chartrin et al., 2006). Wang et al. (2009) reported phospholipids accounted 46.69% of duck meat's total lipid, mainly consists of phosphatidyl-ethanolamine and phosphatidyl-choline. Approximately 90% of duck meat fibers are consisting of red muscle fibers (Baéza et al., 1999). Red muscle

fibers had smaller size in diameter, adapted to aerobic (oxidative) metabolism, rich with myoglobin concentration, contained high number of mitochondria with larger size, slow contraction speed (sustained activity), fatigue resistant, and appear redder in color (Barbut, 2002; Dransfield and Sosnicki, 1999).

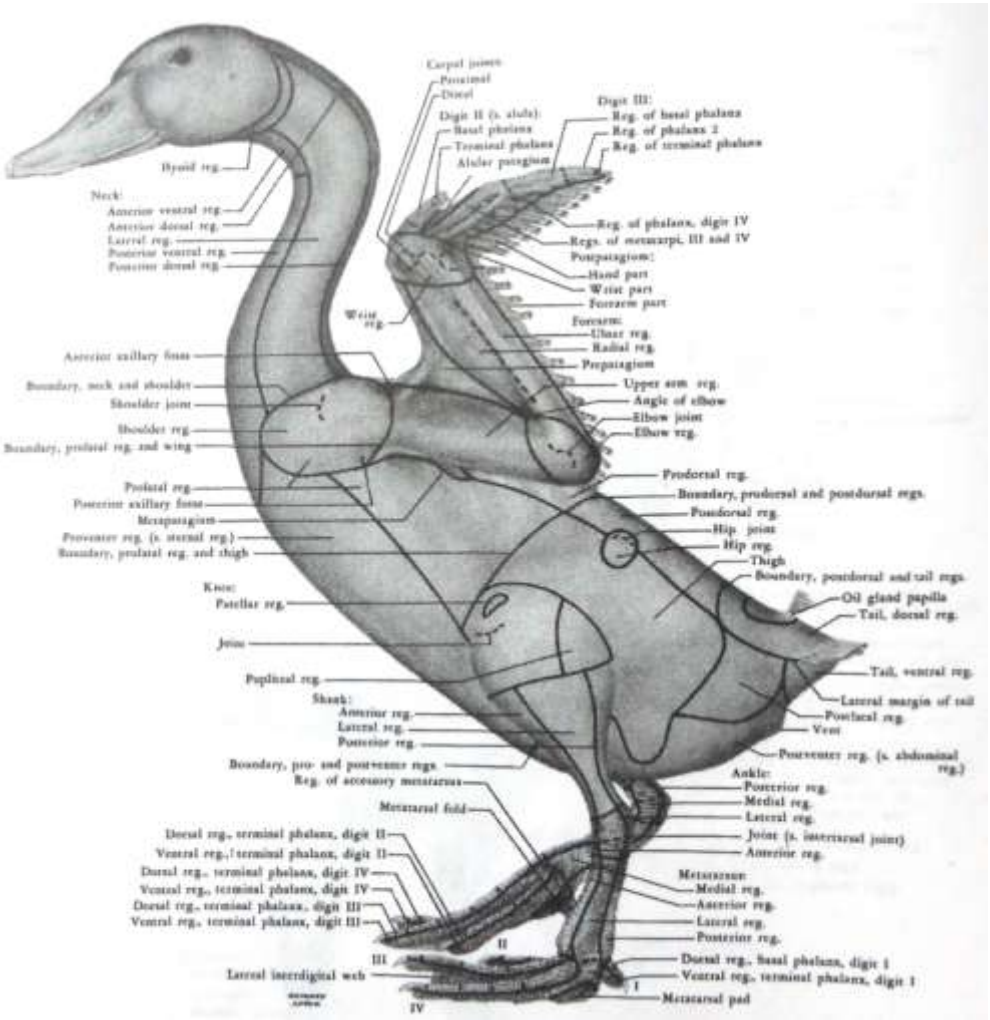

Figure 2.2 Lateral view of Pekin duck. Abbreviations: mar. (Margin); reg. (region); s. (synonym) (Taken from Barbut, 2002; figure number 2.3 on the page 34)

The nutritional composition of duck meat varies depending on the breed and strain of duck. For example, Pekin duck meat contains more fat than Muscovy duck (Wołoszyn et al., 2006). The lateral view of Pekin duck carcass is shown in Figure 2.2. Table 2.1 shows the nutritional composition of duck meat. Duck skin contributes

most of the fat content in duck meat, which is much higher than chicken meat, with approximately equal amount between saturated and unsaturated fatty acid. High levels of iron together with heme pigment makes duck meat appear darker than chicken. Cholesterol of duck meat either with or without skin are obviously higher than chicken.

Table 2.1 Nutritional composition of 100 g duck and chicken meat (USDA, 1999)

Nutrient	Duck meat with skin		Duck meat without skin		Chicken meat without skin	
Energy	404	kcal	132	kcal	119	kcal
Moisture	48.5	g	73.77	g	75.46	g
Protein	11.49	g	18.28	g	21.39	g
Fat	39.34	g	5.95	g	3.08	g
Carbohydrate	0	g	0	g	0	g
Ash	0.68	g	1.06	g	0.96	g
Calcium	11	mg	11	mg	12	mg
Phosphorus	139	mg	203	mg	173	mg
Iron	2.4	mg	2.4	mg	0.9	mg
Sodium	63	mg	74	mg	77	mg
Potassium	209	mg	271	mg	229	mg
Vitamin A	168	IU	79	IU	52	IU
Thiamin	0.197	mg	0.36	mg	0.073	mg
Riboflavin	0.21	mg	0.45	mg	0.142	mg
Niacin	3.934	mg	5.300	mg	8.239	mg
Saturated Fatty Acid	13.22	g	2.32	g	0.79	g
Monounsaturated Fatty Acid	18.69	g	1.54	g	0.90	g
Polyunsaturated Fatty Acid	5.08	g	0.75	g	0.75	g
Cholesterol	76	mg	77	mg	70	mg

The fatty acid content of duck meat is dominated by oleic acid ($C_{18:1}$), a monounsaturated fatty acid; palmitic acid (C_{16}), a saturated fatty acid; and linoleic acid ($C_{18:2}$), a polyunsaturated fatty acid. Duck meat is more easily influenced by the animal's diet than is chicken meat. Some researchers have reported that duck feeds may be modified to yield duck meat that contains more unsaturated fatty acid and less saturated fatty acid (El-Deek et al., 1997; Russel et al., 2003). Although this

improves its value for human health, the high concentration of unsaturated fatty acids makes duck meat very susceptible to lipid oxidation.

Duck meat has been recognized with its distinctive ducky odor. It caused duck meat less acceptable by some people (Bhattacharyya et al., 2007). Soncin et al. (2007) reported volatile compounds detected in duck meat are 1-hexanol (alcohol), 3-hydroxybutanone (ketone), 2-pentylfuran (heterocyclic compound), aldehydes, and hexanoic (carboxylic acid). Particularly aldehydes are important component which imparts fatty flavors. And hexanal is one aldehyde that has low odor threshold and responsible for a rancid flavor.

2.2 Mechanically Deboned Poultry Meat

Mechanically deboned, or sometimes recognized as mechanically recovered meat or mechanically separated meat is obtained by separating meat from carcasses using mechanical deboning equipment (Abdullah and Al Najdawi, 2005). Formerly, mechanical deboning is used to acquire meat from residual parts of poultry carcasses such as necks, bones, and skeletal frames. According to Abdullah and Al Najdawi (2005) and Vera et al. (2010), besides residual parts of poultry, the deboning process can be applied to whole carcass. European Commission has made a definition, “mechanically separated meat” means the product obtained by removing meat from flesh-bearing bones after boning or from poultry carcasses, using mechanical means resulting in the loss or modification of the muscle fibre structure (European Union, 2004).

The processes consist of grinding the cut parts or whole carcass coarsely and then forced through fine-mesh screen with high pressure expelled soft muscle tissues together with fluid fat resulting in fine meat paste with pink or dark reddish color,

while the bones, connective tissues and less fluid residues are collected separately (Fletcher, 2004; Stangierski and Kijowski, 2000).

Inevitably, mechanically deboned meat keeps some disadvantage aspects. The mechanical processes of meat separation cause cell breakage, protein denaturation, and increasing in lipids and heme pigments from bone marrow which lead to the change in the chemical, physical, sensory and functional properties of the meat. Hence, mechanically deboned meat has high amount of fats and heme components, and very susceptible to lipid oxidation due to extensive stress and aeration during the machine deboning process and the compositional bone marrow, heme, and lipid. Those lead to undesirable smell, rancid flavor and shorter shelf life (Daros et al., 2005; Mielnik et al., 2002; Ozkececi et al., 2008; Smyth and O'Neill, 1997).

Chemical composition of mechanically deboned poultry meat is fully dependent on species, breed and ages of the animal as well as the proportion of bone and fat in the deboned materials, machine type and settings. Protein content can be varied from 11.4-20.4%, whereas fat are ranging from 7.5-24.7% (Vera et al., 2010). Bones and cartilage tissues are usually remained in mechanically deboned meat which contribute higher amount of mineral content. Sodium, aluminum, potassium and magnesium contents are not significantly different between mechanically deboned and hand deboned poultry meat, whereas calcium, manganese, and zinc are significantly higher in the mechanically deboned poultry meat (Al-Najdawi and Abdullah, 2002; Negrão et al., 2005). In order to maintain bone content in mechanically deboned poultry meat is less than 1%, USDA has set the upper limit for calcium content of mechanically deboned poultry meat must not exceed 0.235% for mature poultry or 0.175% for other poultry (Vera et al., 2010).

The inclusion of bone marrow in mechanical deboning process results in great variation in fatty acid content, higher percentage of cholesterol and phospholipids. The inclusion skin contributes in higher cholesterol content in mechanically deboned poultry meat (Al-Najdawi and Abdullah, 2002). Skin also significantly decreased the emulsification capacity of both mechanically deboned and hand deboned poultry meat due to its high collagen content (Abdullah and Al Najdawi, 2005).

Mechanically deboned meat has been widely used for comminuted meat or emulsion products. Its fine consistency, ability on water retention and emulsification properties makes it suitable for sausages and salami production. Lower price has also became a reason for manufacturers utilizing mechanically deboned meat (Daros et al., 2005). Frozen storage is frequently applied for mechanically deboned meat. The addition of cryoprotectant is used to prevent protein denaturation and loss of functional properties of myofibrillar proteins during frozen storage. Nonetheless, deterioration of some oxidative reactions still occurs that affect the quality adversely. Thus some antioxidants are used to prevent lipid oxidations. The storage life of meat can be extended by using antioxidants, though it can not suppress the development of hydrolytic rancidity (Vera et al., 2010).

Meat recovered from bones or carcass parts by mechanical processes is generally considered as poor quality in many countries, consequently it has been subjected to strict regulations concerning use of the product as either binding agent or source of meat. This limitation implied the huge amount of these meats have to be discarded or utilized into pet food (Vera et al., 2010).

2.3 Surimi and Surimi-like Material

2.3.1 Surimi

The term “surimi” was originally used in Japan to refer to a water-washed muscle protein extract produced from fish, usually mechanically recovered fish slurry. This technique has been established for centuries to supply raw materials of traditional Japanese fish gel products, particularly kamaboko. Before 1960, kamaboko industry in Japan used fresh surimi. The frozen Surimi started to expand after 1960, influenced by the invention of Japanese scientists on Alaska Pollock frozen surimi protected from freeze denaturation using cryoprotectant. That invention stimulated Japanese fisher vessels to extend their catches and produce more surimi without bothering the loss of quality while keeping it for longer time. It had also responded by revolutionized of domestic surimi-based food manufacturer which could receive the products year round (Guenneugues and Morrissey, 2005; Park and Lin, 2005; Sonu, 1986).

High quality surimi is mostly made from cold water fish, particularly Alaska Pollock which has white muscle, tends to be uniform in size, and can be captured in large volumes. It is mostly caught in Bering Sea off Alaska and Okhotsk Sea, Northern Pacific. Other cold water fish species spread over the world have also been used for surimi production are Pacific Whiting, Arrowtooth Flounder, Southern Blue Whiting, and Hoki. Over fishing in period of time caused Alaska Pollock became limited hence Japanese fishers looked for alternative fish. Pelagic fish such as mackerel from Japan waters is considerable source for surimi production. Although this fish resulted in dark color surimi, with relatively low gel strength, and strong fishy taste, it can be processed traditionally into low-priced surimi-based product, such as fried fish cakes. Surimi also can be produced from tropical water fish,

practically used in Southeast Asia mainly is threadfin bream, bigeye snapper, croakers, lizardfish, and goat fish. Surimi productions in Southeast Asia are dominated by Thailand, followed by Vietnam, Indonesia, Myanmar, and Malaysia (Bentis et al., 2005; Guenneugues and Morrissey, 2005).

Surimi production in industry commonly consists of several steps: filleting and mincing, washing, dewatering, refining, screw press, blending with cryoprotectant, freezing, and finally frozen storage. Washing process is essential step that removes fats, water-soluble sarcoplasmic proteins (including enzymes and pigments), blood, and metal ions, and increases the concentration of salt-soluble myofibrillar proteins that have useful functional properties with respect to product texture (Park and Lin, 2005; Sultanbawa and Li-Chan, 1998; Yang and Froning, 1992).

Park and Lin (2005) explained during washing processes of minced fish, the main objective is to removes sarcoplasmic proteins. However, the mechanical forces also contribute in the loss of functional myofibrillar proteins. Extensive washing may cause myofibrillar dissolve in water. This is due to the removal of sarcoplasmic proteins and undesirable non-protein nitrogen compounds could be accomplished in early washing cycle. By using fresh water, most of the sarcoplasmic proteins were easily solubilized and removed in the first washing step of four successive washing cycles. In the second step of washing, the residual sarcoplasmic proteins were continuously removed by sacrificing a relatively small amount of myosin heavy chain, actin, troponin, and tropomyosin. In the next washing steps, no significant amounts of sarcoplasmic proteins were found, while the proportion of myofibrillar proteins significantly increased.

The water used in washing process must be refrigerated hence the fish muscle protein can retain its functional properties. Warm (tropical) water fish can tolerate higher water temperature than cold water fish, without losing its protein functional properties. Recommended temperature is 5^{o}C or less. A proper washing process is vital to achieve high quality surimi with high recovery. Insufficient washing process could result in a substantial loss of gel quality during frozen storage. Otherwise, over-washing may cause a substantial loss of fine particles and excessive moisture content. In the early 1990s, it is common to use high volume of wash water in surimi production e.g. 5:1 to 10:1 for water/mince ratios. However, there have been efforts to reduce the cost in water usage therefore now effective washing process can be accomplished with water/mince ratio of 2:1 (Park and Lin, 2005).

An issue on surimi production is the yield after washing process. Decanter centrifuge is an innovation in surimi technology developed in 1990's. The decanter has been applied in surimi processing to replace the conventional screw press, and in order to recover fine insoluble particles from wash water. Decanter surimi process increases yield and result in consistent product quality. The recovery strategy of meat particles using decanter centrifuge is to get fine particles lost through conventional screens and screw press used for dewatering process. When decanter is used, loses in functional proteins can be reduced by 50% compared to using rotary screens and screw press alone. Surimi produced through the decanter is considered as recovery-grade surimi, which poses fairly good color, low amount of impurities, and comparable gel deformation with primary grade surimi that is produced with screw press (Park and Lin, 2005). Nolsøe et al. (2011) reported surimi made from blue whiting fish dewatered by centrifugation method resulted in higher breaking force than surimi dewatered by filtration method.

One important quality of surimi is its ability to form a gel. Gel quality is influenced by the proportion of myofibrillar proteins; generally, an increase in protein concentration will increase gel forming ability. However, the presence of undesirable components remains after the washing process cause unintended effects on surimi quality, e.g., inhomogeneity and granularity (Mizuta et al., 2007). The most popular gel measurement technique in surimi industry is punch (penetration) test to measure the gel strength. The punch test imitates the large deformation to failure involved in mastication. This test commonly used a spherical probe with specific diameter and length to compress the surface of a gel sample at a constant deformation rate until puncture occurs. In industry mostly used modern penetrometers at fixed rate 60 mm/min. The recorded peak force (breaking force) and the depth of penetration (deformation) are used to describe the gel properties. Both are multiplied together to obtain the gel strength using units of gram-centimeters, the value used in Japanese grading standard (Kim et al., 2005).

Besides to improve gel-forming ability, the washing process is required to produce brighter, whiter surimi. This obviates the need for extra coloring agents during the production process, thus reducing costs (Babji et al., 1995; Mizuta et al., 2007). In Japan, surimi has been processed into numerous products. There are many variations of kamaboko (traditional Japanese fish gel): Itatsuke kamaboko (steamed on a wooden board), chikuwa (grilled on bamboo stick), satsuma-age (deep-fried), hanpen and tsumire (boiled). Further development has brought surimi to be widely utilized for various products which are acceptable in many countries, such as seafood analogues (imitation crab and shrimp), fish balls, fish ham and fish sausages (Boran and Köse, 2007; Konno, 2005; Larkin and Sylvia, 2000; Park and Lin, 2005).

2.3.2 Surimi-like Material (SLM)

Based on the very successful application of surimi in fish industries, there have been considerable efforts to apply this technique (i.e. washing processes to remove undesirable components and to concentrate myofibrillar proteins) using non-fish animal muscle. These products have been called surimi-like material (SLM) or washed meat. As fish surimi was made from underutilized fishes, SLM have generally been produced from low value or unpopular meat sources, such as spent hen and beef heart. However, many studies have investigated the functional properties of SLM made from various meats, including beef heart (Srinivasan and Xiong, 1996; Wang et al., 1997), pork (Jin et al., 2007a), mutton (McCormick et al., 1993), sheep meat (Antonomanolaki et al., 1999), and chicken (Babji et al., 1995; Nowsad et al., 2000a; Yang and Froning, 1992). These animals meat contain more amount of fat than fish flesh, hence either more washing cycles or longer washing time is necessary.

Although similar to surimi production, different meat types make particular modification is needed in the method of SLM production. As shown in Table 2.2, many studies reported at least two washing cycles is required to remove the fat, pigments and other undesirable components. And longer time in washing is necessary for raw materials from red meats. Most of the dewatering process needs centrifugation besides using filter (sieving) and screw press.

Previous studies demonstrated SLM had lower fat content, improved lightness (color) and textural properties compared with unwashed meat. Issue regarding fat content in meats has been concerned as modern consumers prefer lower fat meats (Farhat, 2009; Weiss et al., 2010).

Table 2.2 Previous studies on SLM

Raw material	Washing cycles (times)	Dewatering method	Fat removal (%)	Increasing in Textural properties (%)	Increasing in Lightness (%)
Spent hen meat[a]	2	Centrifuge	79.64	36.62	46.17
Spent hen meat[b]	3	Screw press	30.77-61.54	NA	10.16-14.36
Broiler meat[a]	2	Centrifuge	76.66	33.16	32.93
Sheep meat[c]	3	Filter, centrifuge, and screw press	89.68	33.10	63.48
Mutton, hand and mechanically deboned[d]	4	Filter and centrifuge	94.44-98.79	NA	NA
Chicken breast[e]	2 and 4	Filter and centrifuge	NA	NA	NA
Pork leg[e]	2 and 4	Filter and centrifuge	NA	NA	NA
Mechanically deboned chicken meat[f]	2	Filter and centrifuge	NA	NA	16.39-24.69
Mechanically deboned chicken meat[g]	3	Centrifuge	84.20-87.90	18.54-125	1.19-9.11
Mechanically deboned turkey meat[h]	Single washing, acid precipitation	Centrifuge	91.91-94.72	NA	NA

References: [a]Nowsad et. al. (2000b); [b]Ensoy et. al. (2004); [c]Antonomanolaki et. al. (1999); [d]McCormick et. al. (1993); [e]Jin et. al. (2007a); [f]Babji et. al. (1995); [g]Kijowski and Richardson (1996b); [h]Liang and Hultin (2003).

Nowsad et al. (2000b) reported washing processes in SLM successfully removed more than 79% fat from spent hen meat, increased its gel strength for about 36% higher, and improved its lightness for about 46%. Whereas washed broiler meat had about 76% fat removed, 33% gel strength higher, and 32% lightness improved.

Sheep meat, as reported by Antonomanolaki et al. (1999), which contains 23.74% fat in wet basis or 56.58% in dry basis was obviously reduced its fat content until almost 90% when processed into SLM. High volume of wash water with ratio of meat/water is 1:5, longer stirring and settling time with the total of 20 min per washing cycle were applied, stripping the fat layer, filtered, repeated for three times washing, continued with centrifugation and final dewatering by screw press, led to very high fat removal. The textural properties had resulted in 33% shear force higher, and the color properties had 63% lightness value increased.

McCormick et al. (1993) processed mutton into SLM. Ratio 1:5 for meat/water was used with 10 min of stirring time, continued with filtration, stripping the fat layer, centrifugation, and repeated until four times washing, had caused obvious fat removal. Mechanically deboned mutton lost 94% fat after processed into SLM, while the hand deboned one had 98% fat removed.

Liang and Hultin (2003) developed SLM from mechanically deboned turkey meat by acid and alkaline solubilization. The meat proteins were firstly solubilized in very low or high pH, fat were separated, then the soluble proteins were precipitated by adjusting the pH near to isoelectric point. This method led to a very high fat removal in SLM.

The use of SLM as substitute ingredient has been reported in numerous publications. Perlo et al. (2006) reported that washed chicken meat may be used as a substitute ingredient in chicken nuggets for up to 40% of the meat in the formulation.

Another study showed that spent hen surimi can replace around 40-60% of the meat in sausage formulations (Jin et al., 2007b).

Although SLM can be used in large proportions in product formulations, some research has shown that optimum results can be reached with lower proportions of surimi. Desmond and Kenny (1998) found that the optimum frankfurter formulation contained 7-10% beef heart surimi. Similarly, McCormick et. al. (1993) described preferred results when 5% of restructured roast beef steak formula was replaced with mutton surimi. Jin et. al. (2009) reported optimal results for imitation crab sticks using 5.5-11% spent hen surimi as a substitute ingredient.

2.3.3 Gelation of Meat Proteins

Meat proteins consist of three major groups, based on their water and salt solubility: The first one is sarcoplasmic proteins, which constitute about 25-30% of meat proteins, are water soluble and distributed within the cellular fluid, containing oxygen-carrying molecule, myoglobin, and various enzyme. There are about 100 proteins known to be present in the sarcoplasmic fraction. Those globular proteins have relatively low molecular weight, ranging from 17,000 to 92,500 Dalton. This group of proteins has very low water retention capacity. The second one, myofibrillar proteins are salt soluble, constitute about 55-60% of meat proteins. These proteins mainly contain myosin, actin, troponin, and tropomyosin. Myosin and actin are myofilamentous fibrous protein, building up the thick and thin filaments in myofibrillar structure. Tropomyosin-troponin complex acts as regulatory proteins together with α- and β-actinin, M-protein and C-protein. The third one, stromal proteins are non soluble both in water and salt, mainly containing connective tissue proteins, collagen, and elastin. It constitute about 10-15% of meat proteins.

Connective tissues bind the individual bundle of muscle fibres and bind group of muscles together (Barbut, 2002; Nuñez-González, 2010; Tornberg, 2005).

Gelation of meat protein is thermally irreversible and has essential role to the formation of textural properties on meat products. Gelation is an orderly aggregation of denatured molecules that give rise to a three-dimensional solid network that traps an aqueous solvent consisting of immobilized water within a matrix. Most of gel formation in foods are influenced by heat then followed with cooling process. Heat-induced gelation is a result of sequential events relating protein transformation from suspension to semisolid state. It begins with a conformational change from the native state to pre-gel state by applying heat. This process involved dissociation, denaturation, and deployment with exposed protein functional groups, hence it possible to build various inter-macromolecular links, which result in an orderly continuous network. Partially deployment of polypeptides before the aggregation stage is required to make an orderly, homogenous, strongly expanded, elastic transparent and stable gel. Heat increase the protein-protein interactions, protein molecules deployed, hydrophobic groups increased, water-protein interaction reduced, promoting covalent union of disulphide bridge formation, reinforcing the strength of macromolecular network, and resulting irreversible gels (Zogbi and Benejam, 2010).

The main protein that responsible for texture of processed meat products is myofibrillar protein, particularly myosin and actin. Myosin determines binding quality, while the presence of actin alone does not exhibit any binding. Synergetic action of actin, myosin, and actomyosin complex is resulting rigid gel. Maximum rigidity can be obtained from weight ratio of myosin to actin of about 15:1 (Barbut, 2002).

2.3.4 Cryoprotectants in Surimi

Cryoprotectants have been added into surimi to protect them during freezing process and frozen storage hence the functional properties of myofibrillar proteins can be retained. Low temperature decreases molecular mobility, intramolecular hydrophobic interactions, which stabilize many protein native conformations, became weaker as the temperature decrease, while hydrogen bonds become more important to stabilization at lower temperature. Once the surimi is frozen, ice crystal formation leads to protein molecule aggregation and denaturation. It followed by disruption of cells and dehydration. Ice crystalline structure excludes almost all solutes thus it is nearly pure single component phase. Water molecules can diffuse from smaller ice crystals to larger ones, which grow and increase probability of strain in the biological material due to the presence of ice. Temperature gradients in frozen stored products can produce moisture migration because crystals in low temperature areas grow at the expense of those in higher temperature. Formation and modification of ice crystals lead to a redistribution of water and entering its original sites, which affects to the protein rehydration. Therefore, these modifications or re-crystallizations will result in interruption of the hydrogen bonding system and exposure of hydrophobic or hydrophilic zones, thus leaving unprotected and vulnerable regions. This favors intramolecular interactions, leading to alterations of the three dimensional, or intermolecular structures, which induce protein-protein interactions and finally aggregation (Carvajal et al., 2005).

Overall results will decrease in functional properties of surimi, changes in water holding capacity, protein solubility, and gel forming ability (Howell, 2000; Kijowski and Richardson, 1996a; Xiong et al., 2009). Cryoprotectants slow down the

ice crystal growth rate during freezing and alter crystal shapes, therefore protein molecules are protected (Jin et al., 2010). Low molecular weight carbohydrate cryoprotective additives, such as sugar and sorbitol perturb the cohesive force of water and its surface tension. The preferential hydration of proteins in the present of sugars is due to the ability of sugar to increase the surface tension of water. It has been attributed to stronger or more extensive hydrogen bonding between solute hydroxyl groups and and water molecules. Solutes could affect hydration forces at the protein surface if they were either adsorbed onto protein-water interface with an altered capacity to polarize water and an altered surface mobility, or excluded from the interface then create a barrier between macromolecules (Carvajal et al., 2005).

Numerous compounds have been tested and known to have cryoprotective effectiveness, such as saccharides, polyols, some amino acids and related compounds. Nonetheless, some of them are not possible to be used as cryoprotectant is surimi due to prohibition by food regulation, high cost, or adverse sensory properties (Herrera and Mackie, 2004). In industries, mixture of sucrose-sorbitol (ratio 1:1) combined with sodium tri-polyphosphate is the most commonly used cryoprotectant for surimi. However, this sucrose imparts sweet taste in surimi which is less desirable. Besides, calories level in foods has become an issue among consumers that is preferred to be reduced. As efforts to replace the sucrose, there have been many studies reported various types of low sweetness sugars used as cryoprotectants i.e. sorbitol, polydextrose, trehalose, and lactitol (Carvajal et al., 1999; Pan et al., 2010; Sultanbawa and Li-Chan, 1998). Manley et al. (2005) mentioned typical surimi used 4-5% sorbitol, 4% sugar, and 0.3% sodium polyphosphate as cryoprotectant, whereas surimi from warm water fish contains 6% sugar and 0.3% sodium polyphosphate.

Sorbitol is the first polyols or sugar alcohols widely used in foods. It is produced from starch which is typically by cooking to about 110^{o}C in the presence of a heat stable α-amylase enzyme. The cooking continues to 135^{o}C in order to ensure all the starch is gelatinized. The starch then is hydrolyzed by a combination of saccharifying enzymes results in dextrose. The dextrose is crystallized as monohydrate to increase the purity, redissolved in water and hydrogenated. Relative sweetness of sorbitol is 0.60 compared to sucrose. The molecular weight of sorbitol is about 182 g/mol (Kearsley and Deis, 2006). As cryoprotectant, 4% sorbitol usually mixed with 4% sucrose (Sultanbawa and Li-Chan, 1998).

Lactitol is disaccharide composed of sorbitol and galactose, and a part of sugar alcohols or polyols group. It is produced from lactose by catalytic hydrogenation. A 30-40% lactose solution is used and heated to approximately 100^{o}C. The reaction is occurred in autoclave under hydrogen pressure of 40 bars or more. The hydrogenated solution is filtered and purified by means of ion-exchange resins and activated carbon. The purified lactitol solution is concentrated and crystalyzed. It has 0.40 relative sweetness compared to sucrose. The molecular weight of lactitol monohydrate is 362.34 g/mol (Young, 2006). Lactitol were used as cryoprotectant in surimi at 8% concentration (Herrera and Mackie, 2004).

Trehalose is disaccharide consisting of two glucose moieties linked through their respective anomeric carbon atoms (1,1) by an α-glycosidic bond. It was initially found from natural sources such as bacteria, yeast, fungi, algae, and some higher plants. Commercial trehalose produced from food grade starch, treated in multi step enzyme process involving hydrolysis, to glucose followed by enzymatic synthesis of trehalose by maltooligosyl trehalose synthase and maltooligosyl trehalose trehalohydrolase. Both enzymes are obtained from a strain of *Pseudomonas*

amyloderamosa. Trehalose has 0.45 relative sweetness compared to sucrose (Lindley, 2006; O'Donnell, 2005). The molecular weight of trehalose anhydrous is 342.3 g/mol and trehalose dihydrate is 378.3 g/mol (Jain and Roy, 2009). Zhou et al. (2006) reported trehalose was used as cryoprotectant in surimi at 8% concentration.

Polydextrose is a low-molecular weight randomly bonded polysaccharide of glucose. It is produced from glucose, sorbitol, and citric acid, then under tightly controlled processing condition a randomized glucose polymer is produced. This low-calorie bulking agent has significant use to replace sugar in reduced calorie foods, and is less digestible hence it used as dietary fibre in many countries. Polydextrose has a broad molecular weight from 162 to about 20,000 and it contains zero relative sweetness (Auerbach et al., 2006; Craig et al., 1996; O'Donnell, 2005). Herrera and Mackie (2004) reported polydextrose was used as cryoprotectant in surimi at 8% concentration.

Isomalt or well known with the trade name as palatinit, is a type of sugar alcohol. It is derived from sucrose, consists of two stage manufacturing: firstly, sugar is transformed by enzymatic transglucosidation, then hydrogenated into isomalt. The molecular weight of isomalt is 344.31 g/mol. The relative sweetness of isomalt is in between 0.45 to 0.6 compared to sucrose (Wijers and Sträter, 2001). Sych et al. () reported that palatinit had cryoprotective activity to stabilize cod surimi protein until 12 weeks of frozen storage (Sych et al., 1990).

2.4 Burger Processing

The term “burgers” was originated from the word “hamburger” which presumably is a product that originated from Hamburg. In Europe during the 18th century, there was initial product called “Hamburgh Sausage” which contained

chopped beef, suet, and spices. Since the middle of 19th century in America, a cuisine named "Beefsteak à la Hamburg" or "Hamburg steak", which was actually chopped beef steak, had been introduced. In the early 20th century, hamburger served in two slice of bread called "hamburger sandwich" started to be sold in America. As time goes by, the peak of popularization of hamburger is affected by the rapid growth of fast food restaurant business (Katz, 2003).

The estimated hamburger consumption in America, where it has been an iconic food, is about 5 billion hamburgers per year (Prayson et al., 2008). Hamburgers were originally made from ground beef. Further development on poultry meat processing in around 1970's introduced similar products made from poultries, named turkey burgers and chicken burgers. Nowadays, the burgers are not only sold at the ready-to-eat food stalls and restaurants, but also available through out the markets in the frozen form (Fletcher, 2004). In Malaysia, burgers began to penetrate the market since early 1980's with most of the products were imported. The situation had turned with the emerging of local manufacturers therefore local brands of burgers have overwhelmed markets since 1990's (Babji et al., 2000; Chang, 2005).

Most of European countries regulated that burgers should contain at least 80% meat and 20-30% of fat content. In other circumstances, burgers are also recognized as patties (Al-Mrazeeq et al., 2008; Ranken, 2000). In Malaysia, the government has set a minimum requirement of meat content in manufacturing of any processed meats including burgers, to be not less than 65% (Law of Malaysia, 2009).

Burger is categorized as restructured or formed meat products. It is mainly produced from pieces of meat, trim or flake material which is very fine shavings of meat that retain some fibrous structure. The meat is mixed with salt together with desired flavoring agents, and then formed into patty shapes. This kind of products

have more fibrous structure than emulsified products, e.g. frankfurter and bologna (Fletcher, 2004; Keeton, 2001).

According to Suman and Sharma (2003), particle size of meat, as a result of grinding, would affect the burger texture. The smaller grind size obtained lower hardness and shear force of burger. Trends among the consumers to eat low-fat products have been a concerned to processed meat manufacturers, including burgers. Low-fat burgers are usually containing fat below than 10% (Suman and Sharma, 2003; Troy et al., 1999; Turhan et al., 2009; Weiss et al., 2010).

There are various methods to cook burgers i.e. frying, grilling, griddling, roasting, and deep-fat frying. Dreeling et al. (2000) reported griddled burger is the most acceptable on sensory evaluation, whereas deep-fat frying is least acceptable, and had the highest cooking loss and diameter reduction. However, according to Gisslen (1999) pan frying is the most common cooking method, it imparts aromatic and savory flavor to the burger.

When a frozen burger is placed on the heating surface, it quickly absorbed a large amount of heat due to a broad temperature difference between the burger and heating surface. Consequently, the heating surface temperature dropped significantly in seconds because of limited heating capacity and heating rate of the heater. Ice would melt followed by a fat melting. By a combination of dehydration and browning reaction, the crust formation takes place. Increase in temperature lead to increase in crust thickness. A solid-liquid interface during melting and a liquid-vapor interface during evaporation can be assumed when a frozen burger is cooked by contact. After the initial period, the temperature of the heating surface increased gradually toward the preset temperature. Thin liquid layer formed between the burger and heating surfaces. It is due to the temperature of this layer increased gradually,