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Spray drying technology for the production and processing of microencapsulated omega-3 fish oil with egg powder

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SPRAY DRYING TECHNOLOGY FOR THE PRODUCTION AND PROCESSING OF MICROENCAPSULATED OMEGA-3 FISH OIL WITH EGG POWDER

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Dedicated to

GOD

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NOMENCLATURE

A	cross sectional area of the inlet or outlet air pipe, m^2
AH_{aa}	absolute humidity of inlet ambient air, kg water/kg dry air
AH_{ao}	absolute humidity of outlet air, kg water/kg dry solids
c_{aa}	specific heat of inlet ambient dry air, kJ/[kg K]
c_p	specific heat of inlet ambient air, kJ/[kg K]
c_v	specific heat of water vapor, kJ/[kg K]
E_{va}	evaporation rate calculated from the moisture uptake by the dry air, kg water/h
E_{vp}	evaporation rate calculated based on the moisture content of the cantaloupe juice mixture, powder, kg water/h
K	consistency index, Pa.s
m_{aa}	dry air mass flow rate of inlet ambient air, kg dry air/h
m_{ao}	dry air mass flow rate of outlet air, kg dry air/h
m_d	dust flow rate, kg dry solids/h
m_e	cantaloupe juice mixture flow rate, kg dry solids/h
mP	estimated powder production rate, kg dry solids/h
n	flow behavior index
p_v	saturation pressure of water vapor, kPa
p_w	partial pressure exerted by water vapor, kPa
Q	estimated energy required to spray dry cantaloupe juice mixtures, kJ/kg
RH	relative humidity, %
S	solids present in the food sample, %
T	temperature, °C
T_{aa}	temperature of inlet ambient air, K
T_{ad}	temperature of inlet drying air, K
T_e	temperature of cantaloupe juice mixture, °C
T_d	temperature of cantaloupe juice dust, °C
T_p	temperature of cantaloupe juice powder, °C
ΔT	temperature difference between inlet ambient air and heated air, K
v	average velocity, m/s
V	volumetric flow rate, m^3/s
V'	specific volume, m^3/kg dry air
w_d	moisture content (dry basis) of dust, kg water/kg dry solids
w_e	moisture content (dry basis) of cantaloupe juice mixture, kg water/kg dry solids
w_p	moisture content (dry basis) of product, kg water/kg dry solids

ABBREVIATIONS

ALA	α-linolenic acid
BCCA	branched-chain amino acids
CVD	cardiovascular deseases
DHA	docosahexaenoic acid
DEW	DEW spray dried either at 130, 140, or 150°C
DEW-130	E-EW spray dried at 130°C
DEW-140	E-EW spray dried at 140°C
DEW-150	E-EW spray dried at 150°C
EAA	essential amino acids
E-EW	mixture containing liquid egg white and distilled water
E-MO-EW	emulsion containing refined menhaden oil and liquid egg white
E-SO-EW	emulsion containing purified salmon oil and liquid egg white
EPA	eicosapentaenoic acid
EW	liquid egg white
FFA	free fatty acids
MO	refined menhaden oil
MO-EW	E-MO-EW spray dried either at 130, 140, or 150°C
MO-EW-130	E-MO-EW spray dried at 130°C
MO-EW-140	E-MO-EW spray dried at 140°C
MO-EW-150	E-MO-EW spray dried at 150°C
O_S	surface oil
O_T	total lipid content
O_E	encapsulated oil
PUFA	polyunsaturated fatty acids
PV	peroxides value
pI	isoelectric point
SO	purified salmon oil
T_d	denaturation temperature
TBARS	thiobarbituric acid-reactive substances
SEM	scanning electron microscopy
SO-EW	E-SO-EW spray dried either at 130, 140, or 150°C
SO-EW-130	E-SO-EW spray dried at 130°C
SO-EW-140	E-SO-EW spray dried at 140°C
SO-EW-150	E-SO-EW spray dried at 150°C

ABSTRACT

Protein with essential amino acids is required for recovering, repairing, and building muscles after intensive exercise. A powder produced with egg white (EW) (high quality protein) and fish oil (menhaden (*Brevoortia patronus*) (MO) oil or salmon oil (SO)) with high DHA and EPA content should be particularly beneficial for athletes. The objective of this study was to develop microencapsulated omega-3 fatty acids fortified EW powders. Two stable emulsions were prepared with 3.43% (MO) or (SO), 56.21% EW, and 40.36% water (E-MO-EW and E-SO-EW). An EW with water solution (without fish oil) (E-EW) was prepared as a control. Two emulsions (E-MO-EW; E-SO-EW) and E-EW solution were separately spray dried at 130, 140, and 150 ^{o}C inlet air temperatures producing three microencapsulated menhaden oil fortified EW powders, three microencapsulated salmon oil fortified EW powders, and three egg white powders (dried E-EW). Physical and chemical properties of E-EW, E-MO-EW and E-SO-EW were determined and the energy used to spray dry them was estimated. The powders were analyzed for color, fatty acids methyl esters (FAME), protein, fat, moisture, ash, amino acid profile, minerals, microstructure and particle size. Microencapsulated efficiency (ME) was estimated only for microencapsulated fish oil fortified EW powders. Triplicate experiments were conducted and data statistically analyzed (α=0.05). The actual production rate of powders ranged from 0.056 to 0.060 (kg dry solids/h). More energy was used to spray dry E-EW, E-MO-EW, and E-SO-EW at 150°C than at 130 and 140^{o}C inlet air temperature. The inlet air temperature did not affect the EPA or DHA content of MO and SO or the microencapsulation efficiency. The protein content of the oil fortified powders was lower than that of the dried E-EW powders. Leucine was the main essential amino acid found in all the powders. Most of the powders' particles ranged in size from 20 to 30 μm. The study demonstrated that high quality egg white protein with omega-3

can be produced by microencapsulation. Oil fortified egg white powders could provide benefits for athletes who do high intensity exercise. This study also identifies opportunities for development of microencapsulated omega-3 fatty acids fortified egg white powders.

CHAPTER 1: INTRODUCTION

The American table egg production had a value of approximately 4.24 billion dollars in 2009. Iowa, Ohio, Pennsylvania, Indiana and California are the most productive states of table eggs in the United States (USDA, 2010b). The consumption per capita of table egg has decreased in the USA during the last years due to lifestyle changes and health concerns (Stadelman, 1999). Table eggs are an excellent source of high-quality protein, vitamins and minerals. An average large egg provides around 6.25 g of high-quality protein, 5 g of fat and 200 mg of cholesterol (Weggemans *et al.*,2001). Eggs contain all essential amino acids (EAA) including leucine. Leucine is an EAA that contributes to muscles' ability to use energy and aids in post-exercise muscle recovery from dynamic and resistance exercises; it was found that a diet rich in leucine would be advantageous to men and women undergoing resistance exercise due to the complementary effect between leucine and glucose utilization by muscles. Even more, leucine is a critical element in regulating muscle protein synthesis and may be the key amino acid defining the increased need for EAA to optimize skeletal muscles mass (Layman & Rodriguez, 2009).

Positive effects on human heath have been attributed to the consumption of omega-3 polyunsaturated fatty acids (ω-3 PUFA) (Riediger, 2009; Simopoulos, 1999). Alfa linolenic acid (ALA) (C18:3), eicosapentaenoic acid (EPA) (C20:5) and docosahexaenoic acid (DHA) (C22:6) are the main ω-3 PUFA (Clandinin *et al.*,1994). Dietary omega-3 PUFA enhances aerobic metabolic process in athletes; therefore, improving their ability to effectively burn fat as an energy substrate. Menhaden and salmon fish oils are good sources of EPA and DHA. Due to their high polyunsaturated fatty acid content, menhaden and salmon fish oils are susceptible to oxidative deterioration; this has limited the use of fish oil in food products because of flavor degradation by oxidation.

Omega-3 PUFA-fortified eggs are produced through the manipulation of the hen's diet with some limitations (Ferrier, *et al.,* 1995); these eggs contain up to three times the amount the ω-3 PUFA present in conventional eggs. However, a conventional egg is not a rich source of ω-3 PUFA; therefore, even a three-fold increase is considered small (Kassis *et.al.,* 2010).

Microencapsulation is a technology that has been used to transform fish oil into powder by surrounded the tiny fish oil droplets with a wall material resulting in small granules that have powder like flow characteristics. Moreover, microencapsulation can help to overcome the main problems of food fortification with ω-3 fish oil, which are the unpleasant "fishy" flavor and the oxidation of polyunsaturated fatty acids that has negative influence on food acceptability (Kolanowaski *et al.,* 1999).

Spray drying is a common technology used to produce microencapsulated food ingredients. Preparation of stable emulsions, atomization of the emulsions, and dehydration of the atomized particles are the major basic steps involved in producing microencapsulated fish oils. The critical elements of a spray drying system are atomizer, air flow, and spray drying chamber (Patel *et al.,* 2009).

Nowadays, there is a huge interest among athletes in increasing endurance or promote muscle size and strength by the optimal type of nutrition The combination of fish oil and eggs in a single food product may be important to active individuals who routinely consume eggs and fish oil as part of a varied, and balanced diet.

Considerable information regarding to spray dried food powders have been reported in the last few years; however, scientific literature related to the microencapsulation of fish oil with egg white proteins using spray technology is limited. Hence, the objectives of this study were to: (1) develop a spray dried microencapsulated fish oil with egg white powder for athletes, (2)

evaluate the nutritional components and physical properties of ω-3 PUFA-fortified egg white powder, and (3) evaluate the spray drying conditions to produce ω-3 PUFA-fortified egg white powder.

CHAPTER 2: LITERATURE REVIEW

2.1 Hen Eggs

Eggs are an excellent source of nutrients including high quality protein, vitamins and minerals. They are, after all, designed to support life. They are consumed globally and their production represents an important segment of the world food industry. In the U.S., eggs are considered to be a staple food in most American households (USDA, 2009a).

2.1.1 Global Egg Production

A hen's egg production is divided into two categories: hatching eggs and table eggs. Hatching eggs are those eggs intended, if incubated, to develop into chicks; meanwhile, table eggs are those sold as food products for human consumption (AEB, 1999). In 2009, the worldwide egg production was 67.4 million metric tons, of which China produced about 41%, followed by the United States of America (USA) (8%), India (5%), Japan (4%), and Mexico (4%) (FAO, 2010).

2.1.2 U.S. Egg Production

In 2009, the U.S. table egg production totaled 77.75 billion eggs with a value of approximately 4.24 billion dollars. The US table egg production has trended upward in recent years. During 2009 the U.S. table egg production was 26% higher than in 1988 (USDA, 2010b). The Fig. 2.1 shows the total egg production in the U.S. since 1999 to 2009. Currently, the top ten egg-producing states are: 1. Iowa, 2. Ohio, 3. Pennsylvania, 4. Indiana, 5. California, 6. Texas, 7. Georgia, 8. North Carolina, 9. Arkansas and 10. Michigan (Fig. 2.2).

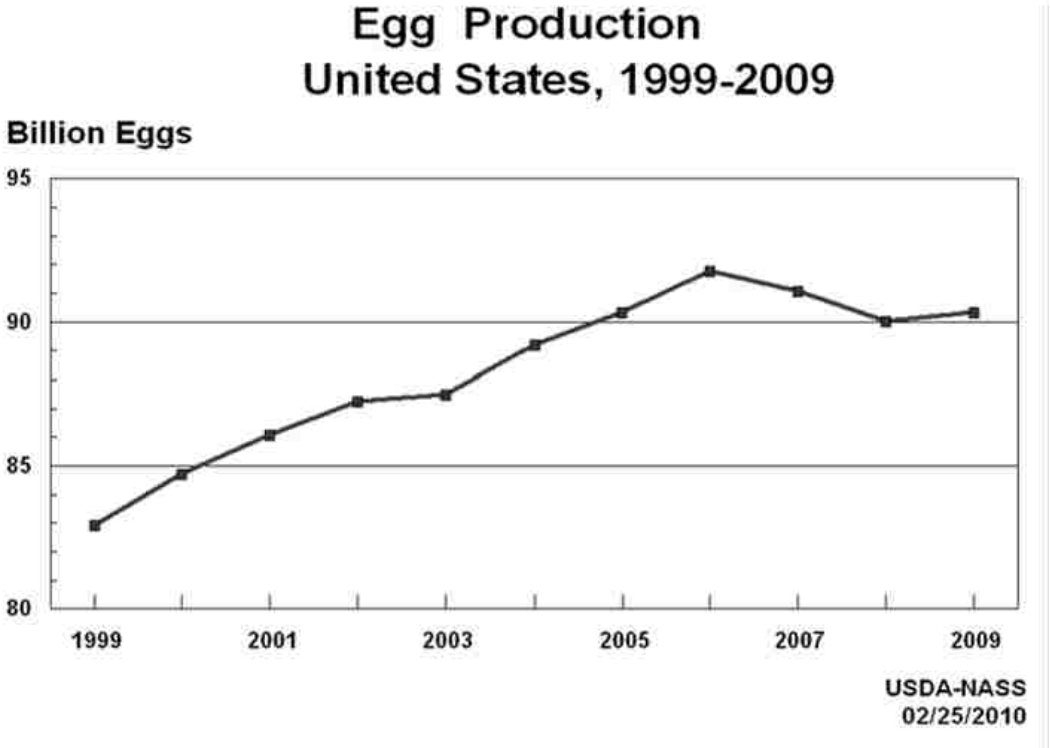

Figure 2.1 U.S. egg production from 1999 to 2009 (USDA, 2010b)

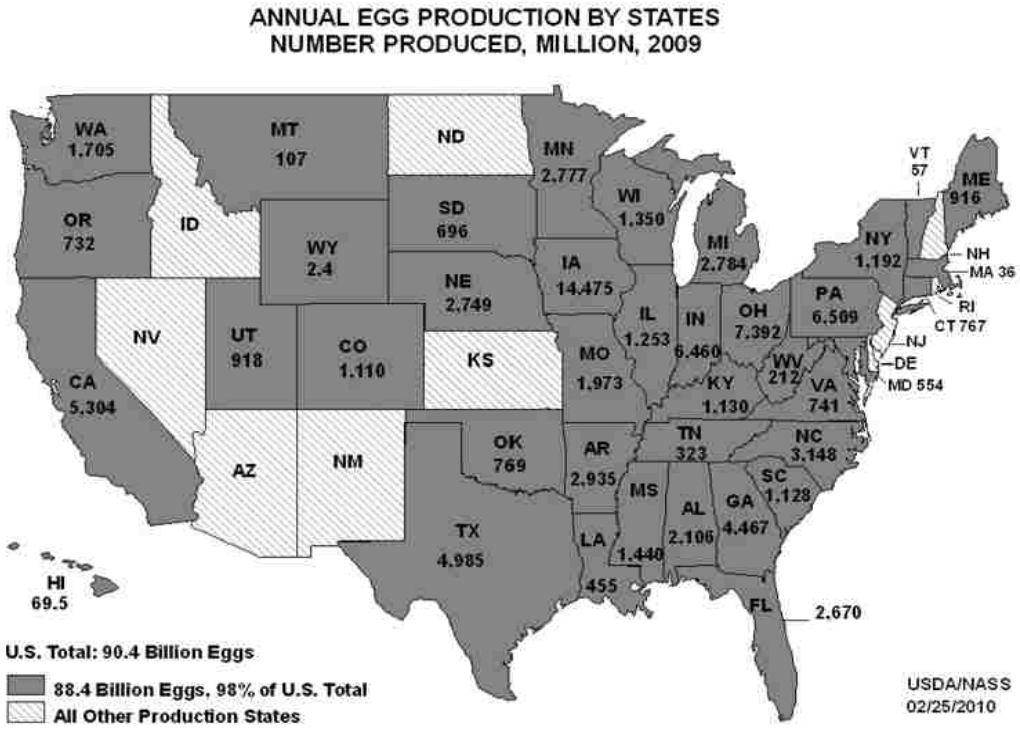

Figure 2.2 2009 U.S. egg production by states (millions of units) (USDA, 2010b)

2.1.3 U.S. Per Capita Egg Consumption

According to the American Egg Board –AEB (1999), egg consumption in the U.S. is frequently reported in terms of per capita consumption (total egg production divided by the total population). Per capita consumption does not equal demand. The high point for per capita egg consumption was reported in 1945, with 402 eggs consumed per person compared to 243.6 eggs consumed per person in 2008 (USDA, 2010a). It can be seen that in the last 40 years, the U.S. per capita consumption of eggs has decreased (Fig. 2.3). This may have resulted from the effect of lifestyle changes (more families moving from rural areas to cities and more women working), and health concerns (Stadelman, 1999).

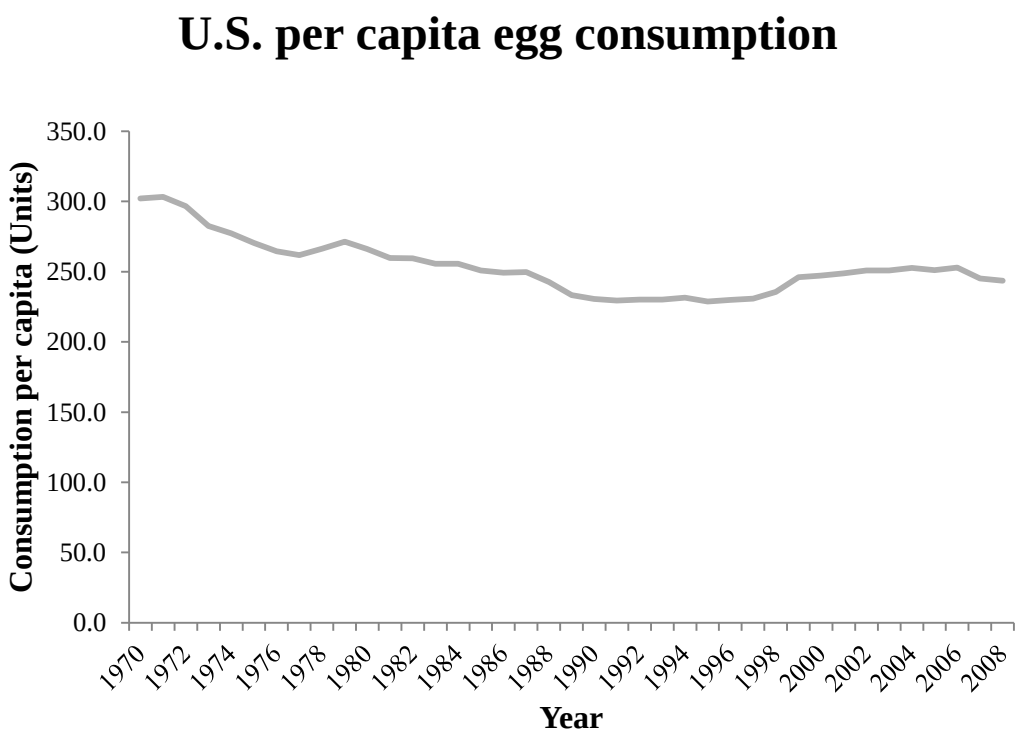

Figure 2.3 U.S. per capita egg consumption (USDA, 2010a)

2.1.4 Egg Nutritional Content

Table eggs are one of best low-price sources of high quality protein. Dietary protein is used by the human body to build and maintain muscles and other body organs, nerves, bones and blood. Protein quality is measured by how efficiently the human body can use it for growth. It has been reported that after mother's milk, eggs contain the highest quality food protein known. The Food and Agriculture Organization of the United Nations (FAO) (1970), rates the biological value of whole egg protein at 93.7 (based on a 100-point scale), followed by cow's milk (84.5), fish (76), beef (74.3), soybeans (72.8), polished rice (64), whole wheat (64), corn (60) and dry beans (58). Proteins are made up of amino acids. Some amino acids are essential to humans because the human body cannot synthesize them. Eggs contain all nine essential amino acids (EAA) including histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. Because the pattern of essential amino acids in egg protein is very similar to the pattern needed by the human body; the egg is often used as a standard of comparison for measuring the protein quality of other foods (AEB, 1999). Additionally, eggs are an excellent source of leucine. Leucine is an EAA that contributes to muscles' ability to use energy and aids in post-exercise muscle recovery; it was found that a diet rich in leucine would be advantageous to men and women undergoing resistance exercise due to the complementary effect between leucine and glucose utilization by muscles (Layman & Rodriguez, 2009).

Eggs provide little to considerable amounts of all vitamins and minerals known to be needed for the human body, except for vitamin C (AEB, 1999). They are also a good source of choline, a nutrient that is essential for normal brain development, folate, and selenium (Herron & Fernandez, 2004). An egg can be divided into two distinct parts: the albumen (egg white), and the yolk. Both the albumen and the yolk provide important nutrients to the human body. An

average large egg provides 6.25 g of high-quality protein (10- 12.5% of the Daily Reference Value for protein), and 5 grams of fat, most of which is unsaturated. Nevertheless, one large egg also contains around 200 mg of cholesterol (Weggemans *et al.*, 2001); which nearly meets the dietary cholesterol intake limit established by the American Heart Association at ≤ 300 mg/d; and they are not a good source of carbohydrates and fiber (AEB, 1999).

2.1.4.1 Egg White (EW) Composition

Egg white represents nearly 67% of an egg's liquid weight. Water is the major component of egg white, constituting about 87.8% (w/w); followed by protein, accounting for 9.7 to 10.6% (w/w); and carbohydrates from 0.5 to 0.6 % (w/w). Egg white contains 56% of the egg's total proteins along with the majority of the minerals, riboflavin, chlorine, magnesium, potassium, sodium and sulfur in egg (AEB, 1999). The major egg white proteins are summarized in Table 2.1 Carbohydrates present in egg white are either in free form or combined with protein. Glucose accounts for 98% of the total carbohydrates in egg white. In addition, the amount of lipid in egg white (0.01 %) is negligible (Mine, 1995). An average egg white obtained from a large egg contains approximately 17 calories (AEB, 1999).

Table 2.1 Composition and some physicochemical properties of the major egg white proteins[a]

Protein	Albumen (%, dry mas-basis)	pI	Molecular weight (kDa)	T_d (°C)	Characteristics
Ovalbumin	54.0	4.5	44.5	84.0	Phosphoglycoprotein
Ovotransferrin	12.0	6.1	77.7	61.0	Binds metallic ions
Ovomucoid	11.0	4.1	28.0	77.0	Inhibits trypsin
Ovomucin	3.5	4.5-5.0	$5.5\text{-}8.3 \times 10^3$	ND	Staloprotein; viscous
Lysozyme	3.4	10.7	14.3	75.0	Lyses some bacteria
G2 globulin	4.0	5.5	49.0	92.5	ND
G3 globulin	4.0	5.8	49.0	ND	ND
Avidin	0.1	10.0	68.3	ND	Binds biotin

[a]Compiled from Powrie & Nakai (1985)
pI, Isoelectric point
T_d, Denaturation temperature
ND, Not determined

2.1.4.2 Egg Yolk Composition

The yolk makes up around 33% of the liquid egg weight and contains all the egg's fat and cholesterol and 44% of its protein. A large egg yolk contains around 5 grams of fat; of which 1.6 g are saturated, 1.9 g are monounsaturated and 0.7 g are polyunsaturated fat, providing 6 and 8% of the Daily Reference Values for total fat and saturated fat, respectively (AEB, 1999). All of the cholesterol is located in the yolk of the egg. An average large egg contains around 213 mg of cholesterol. It has been reported that dietary cholesterol increases serum total and LDL-cholesterol concentrations, which are risk factors for cardiovascular disease (CVD) (Howell, *et al.,* 1997). Nevertheless, it has been demonstrated that eating two eggs per day had almost no effect and that four eggs per day had only a slight effect on human serum cholesterol (Ginsberg *et al.,* 1994). Except for niacin and riboflavin, the yolk contains a higher proportion of each of egg's vitamins than does the albumen. All of the egg's vitamin A, D and E are in the yolk. Larger amounts of calcium, copper, iodine, iron, manganese, phosphorus, selenium and zinc are contained in the yolk than in the albumen. Normally, the yolk of a large egg contains 59 calories (AEB, 1999).

2.1.5 Omega-3 Fortified Eggs

Omega-3 polyunsaturated fatty acid (ω-3 PUFA) fortified eggs have been produced through the manipulation of the hens' diets (Ferrier, *et al.,* 1995). As a result, ω-3 PUFA fortified eggs contain up to three times the amount of ω-3 PUFA present in conventional eggs. However, a conventional egg is not a rich source of ω-3 PUFA; therefore, even a three-fold increase is considered small, if it is compared to the recommended daily intake for ω-3 PUFA by the governments of Canada, Scandinavia, and Britain, which is between 1000 and 2000 mg/d. The United States has not yet set a recommended daily intake for ω-3 PUFA (Kassis *et al.,* 2010).

The DHA content of a fortified egg is approximately 150 mg/egg (Anonymous, 2004). Additionally, it has been demonstrated that the incorporation of ω-3 PUFA into quail egg yolks by altering levels of flaxseed in the feed, reduced the total saturated FA content and increased the PUFA levels in some treatment groups without affecting the cholesterol levels. Therefore, even though these nutritionally-enhanced eggs via alteration of hens' diets may contain less saturated fat, their cholesterol remains unchanged (Silva *et al.,* 2009).

2.2 Omega-3 Polyunsaturated Fatty Acids (ω-3 PUFA)

Recently, the role of ω-3 PUFA in human health has increased attention. Several studies have shown positive roles for ω-3 PUFA in infant development, and in combating cancer, coronary heart diseases, hypertension, obesity, type II diabetes; and more recently, various mental illnesses, including depression, attention-deficit hyperactivity disorder and dementia (Riediger, 2009; Simopoulos, 1999). The major ω-3 PUFA are as follows: α-linolenic acid (ALA) (C18:3), eicosapentaenoic acid (EPA) (C20:5) and docosahexaenoic acid (DHA) (C22:6) (Clandinin *et al.,*1994). It has been proposed that the mechanisms for health benefits of ω-3 PUFA are related to the incorporation of the fatty acids into membrane phospholipids, alteration of gene expression, or eicosanoid production. Due to the health properties attributed to the consumption of ω-3 PUFA, several authorities have recently recommended increases in intakes of ω-3 PUFA by the general population (Abayasekara, 1999).

2.2.1 Omega-3 Fish Oil

Omega-3 fish oil obtained recognition of its possible health benefits when it was found that traditional Eskimo populations had a low incidence of despite high fat intake. This was attributed to positive aspects of their diet. Deepwater fish that Eskimos consumed were high in ω-3 PUFA (Kromhout *et al.,* 1985). These findings led to an increase in research examining the beneficial

and/or preventive effects of ω-3 PUFA contained in fish on numerous debilitating and common conditions including cardiovascular diseases (CVD), rheumatoid arthritis, and asthma, among others (Riediger, 2009). Omega-3 fish oil is obtained from the extraction of lipids from tissues of appropriate fish species (not all fish contain significant amounts of emega-3 PUFA). Fish do not produce ω-3 PUFA; instead, they accumulate ω-3 PUFA from either consuming microalgae containing ω-3 PUFA or by eating prey fish that accumulated ω-3 PUFA from microalgae. Due to its high polyunsaturated fatty acid content, fish oil is highly susceptible to oxidative deterioration; which has limited the use of fish oil in food products because of flavor degradation by oxidation. Perhaps an even more serious potential problem is that hydroperoxides, the primary product of lipid oxidation, may be toxic (Oarada & Miyazawa, 1990). Menhaden and salmon oils are commercially produced in the U.S. and both fish oils are abundant sources of omega-3 polyunsaturated fatty acids, especially EPA and DHA.

2.2.1.1 Menhaden Oil

Menhaden *(Brevootia tyranuus)* is an abundant fish in U.S. waters, but this fish is rarely consumed in the U.S. as a food product for humans. In 2008, more than 608.45 million Kg of menhaden was harvested in the U.S.; this represented about 16% of the total harvest of all U.S. commercial fisheries (NMFS, 2009). Menhaden is mainly used for oil production, fish meal, fish solubles, and as bait. According to Yin & Sathivel (2010), menhaden oil is a good source of EPA (12.8%-15.4%) and DHA (6.9 – 9.1%). Purified menhaden oil is approved for human consumption (FDA, 2004a). Fish oil produced from menhaden is sold in the U.S., Europe, Canada, and Japan. It is estimated that the production of oil from Gulf of Mexico menhaden was 46,528 metric tons in 2006. Most of Gulf fishmeal/fish oil processing plants are located in Moss Point, Miss.; and in the Louisiana cities of Empire, Abbeville, and Cameron (IFFO.net).

2.2.1.2 Salmon Oil

Alaska produces over 65% of the total wild fish harvested for human consumption in the U.S. Large amounts of salmon byproducts are produced in Alaska every year. It is estimated that around 98,045 metric tons of salmon byproducts were produced out of 363,132 metric tons of salmon harvested in Alaska in 2009 (ADFG, 2010). Salmon heads, skin, and viscera are counted as salmon processing by-products. According to Sathivel (2005), much of the oil in salmon processing by-products is found in the head, which contains approximately 15-18% lipids. Generally, fish by-products including heads are discarded or are mixed and used in the production of fish meal, and fish oil (Bechtel & Oliveira, 2006). Refined salmon oil is approved for human consumption (FDA, 2004b)

2.3 Microencapsulation Technology

According to Rosenberg *et al.* (1985), microencapsulation is a processing method in which small quantities of solid, liquid and gaseous materials are packed into a wall matrix; which forms microcapsules. It has been observed that these microcapsules can release their contents at controlled rates over prolonged periods of time (Champagne & Fustier, 2007). Microencapsulation can also help overcome the main problems of food fortification with ω-3 PUFA, the unpleasant "fishy" flavor of fish oil and the oxidation of polyunsaturated fatty acids that has negative influence on food acceptability (Kolanowaski *et al.,* 1999). The structure formed by the microencapsulating agent around the microencapsulated compound (core) is called a "wall"; this wall protects the core compound from biological degradation and enhances its stability (Figure 2.4). Because of the direct effect of the wall on microencapsulation efficiency, microencapsulation stability, and protection efficiency of the core compound, the selection of the wall material is very important in the microencapsulation process (Perez-Alonso

et al., 2003). The wall material of a microcapsule produced by spray drying has to be highly soluble. It is also desirable that the concentrated solution of the wall material has a low viscosity (Reineccius, 1988). The stability of the microencapsulated substance is influenced by the composition of the wall (Anandaraman & Reeineccius, 1986; Beatus *et al.*,1984; Reineccius, 1994). Choosing a particular wall material depends on many factors such as solubility, viscosity, glass or melting transition, forming and emulsifying properties (Gharsallaoui *et al.,* 2007).

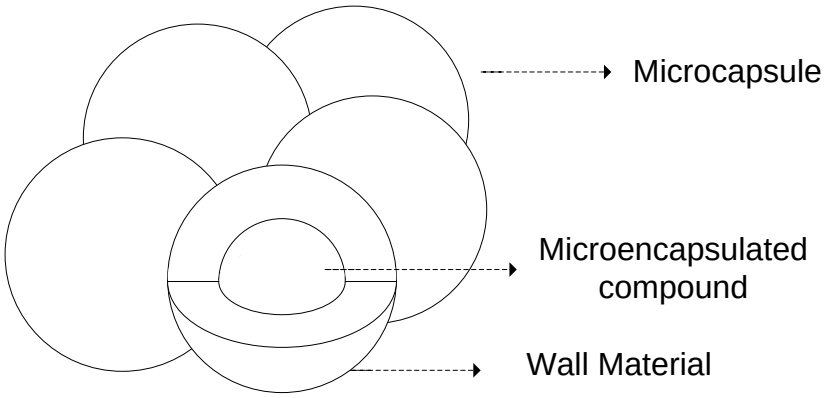

Figure 2.4 Graphic representation of a microencapsulated compound

Carbohydrates, especially sugars like glucose and sucrose and polysaccharides like starch, maltodextrins, pectin, alginate and chitosan, have been successfully used as wall materials (Risch, 1995; Kenyon, 1995). However, carbohydrates cannot be used in wall systems without the presence of a surface-active constituent because they generally have no emulsifying properties (Bangs & Reineccius, 1988). The incorporation of carbohydrates in a wall matrix has been shown to improve the drying properties of the wall by enhancing the formation of a dry crust around the droplets of the microencapsulated compound. High concentrations of low molecular weight sugars may not be suitable for spray drying due to the formation of sticky powders and caramelization (Bayrarn *et al.,* 2005).

Proteins have the ability to assemble at interfaces because of their amphiphilic nature. It has been proven that proteins are good wall materials for flavor compounds because of their high

binding activity with flavors (Landy *et al.,* 1995). Whey proteins have been reported to be effective as a wall material for microencapsulation of anhydrous milkfat or volatiles. The combination of whey protein with lactose significantly limits the diffusion of core material through the wall thereby leading to high microencapsulation efficiency (Moreau & Rosenberg, 1993; Rosenberg & Young, 1993). Sodium caseinate is also an effective wall material for microencapsulation of oils. It has strong amphiphilic characteristics and high diffusivity, which provides a better distribution around the enclosed oil surface (Hogan *et al.,* 2001). Maltodextrin, and highly branched cyclic dextrin (BHCD) in combination with sodium caseinate and whey protein isolate have been used as wall materials for the microencapsulation of fish oil; and it was reported that the combination of maltodextrin or HBCD with sodium caseinate improved the oxidative stability of encapsulated fish oil (Kagami *et al.,* 2003). Currently, there is a lack in scientific literature regarding lipid compounds microencapsulated in wall systems containing egg proteins; however, it is believed that egg proteins may be good encapsulating agents due to their emulsifying properties (Mine, 1995).

2.3.1 Spray Drying

Spray drying is a technology used to preserve foods. The core of this technique is spraying a feed material in a liquid state into a hot drying medium (temperature ranging from 100 to 300°C) in which liquid (often water) is evaporated. The final product of a spray drying process is a dried form of powders, granules or agglomerates, depending upon the physical and chemical properties of the feed, the dryer design and operation. Evaporation of water from the droplets is facilitated by heat and vapor transfer through/from the droplets. It is believed that the wet-bulb temperature of the droplets is in the range of 30- 50°C and total duration of drying is only a few seconds (Schuck *et al.,* 2009). Spray dried food powders show high storage stability, good handling

characteristics (for some applications) and minimized transportation weight in comparison with liquid concentrates (Obón *et al.,* 2009). Spray drying is a common method of encapsulation of food ingredients in the food industry. Several studies have demonstrated the efficiency of spray drying to encapsulate food products such as carotenoids, vitamins, minerals, flavors, polyunsaturated oils, enzymes and probiotic microorganisms.

The basic steps in the microencapsulation involves the preparation of a stable emulsion to be processed; homogenization of the emulsion; atomization of the emulsion; and dehydration of the atomized particles (Dziezak, 1988; Shahidi & Han, 1993). A stable emulsion of fine droplets of the core material in the wall solution is critical during microencapsulation (Kenyon & Anderson, 1988). Therefore, the wall materials need to have emulsifying characteristics as well (Sheu & Roserberg, 1995). In addition, it is reported that the rheological properties of the emulsion is a key parameter in the spray drying process; thus, an emulsion with high viscosity causes the formation of large droplets which affects the drying rate (Drusch, 2007).

The spray drying procedure involves: (I) concentration of the feed prior to spray drying; (II) atomization of the feed to create the optimum conditions for evaporation to a dried product having the desired characteristics; (III) droplet–air contact in the chamber, the atomized liquid is brought into contact with hot gas, resulting in the evaporation of +95% of the water contained in the droplets in a matter of a few seconds; (IV) droplet drying, moisture evaporation takes place in two stages, a) during the first stage, there is enough moisture in the drop to replace the liquid evaporated at the surface and the evaporation rate is relatively constant (Keey & Pham, 1976), and b) the second moisture evaporation stage begins when there is no longer enough moisture to maintain saturated conditions at the droplet surface, causing a dried shell to form at the surface. The evaporation rate depends on the diffusion of moisture through the shell, which increases in

thickness as the evaporation proceeds. The final step in a conventional spray drying process is (V) separation; this involves the use of cyclones, bag filters, and/or electrostatic precipitators (Patel *et al.*, 2009). Spray drying is a technology that can be used with both heat-resistant and heat sensitive products, and from which nearly spherical particles can be produced.

According to Patel *et al.* (2009), the critical elements of a spray drying system includes the atomizer, the air flow, and the spray drying chamber.

2.3.1.1 Atomizer

The atomizer is the "heart" of any spray drying system. One of the functions of the atomizer is to disperse the feed material into small droplets, which increases the surface are and allows a well distribution of the feed within the dryer chamber. The atomized droplets must not be large that they produce an incomplete dried product, nor so small that the product recovery is difficult. There are different configurations of atomizers; however, the most common designs are in the form of high-speed rotating disc, two fluid nozzles; airless atomization nozzles; pressure nozzle; an ultrasonic nozzle.

2.3.1.2 Air Flow Patterns

a) Co-current flow design or parallel design; in this configuration, the feed is sprayed into the hot air entering the dryer and both pass through the chamber in the same direction. This exposes sensitive dry product to only the cooler exit air. (Figure 2.5a).

b) Counter-current flow: in this spray dryer configuration, the feed and the air are introduced at opposite ends of the chamber, with the atomizer positioned at the top and the air entering at the bottom (Figure 2.5b) This configuration exposes the product to hot air, and evaporates bound residual water more efficiently than the co-current flow design; it is no recommend for sensitive materials to heat.

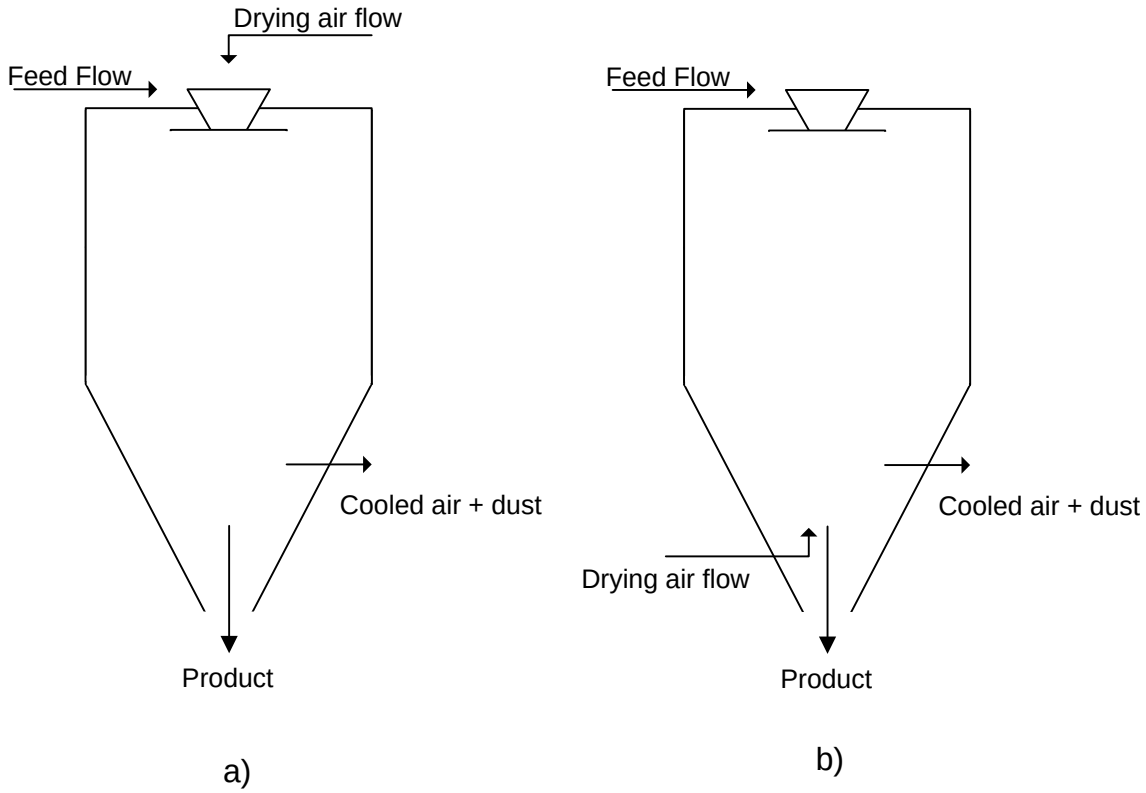

Figure 2.5 Spray dryer configuration. a) Co-current configuration. b) Counter-current configuration.

2.3.1.3 Spray Drying Chamber

Air circulating with the chamber keeps a flow pattern, this prevent the deposition of partially dried product on the wall or atomizer (Ronald, 1997). Air movement and temperature of inlet air influences the type of final product.

In addition to the critical elements of a spray drying system, Patel *et al.* (2009) describes the inlet air temperature, outlet air temperature, viscosity of the feed, solid content of the feed, surface tension of the feed, feed temperature, volatility of the solvent, and nozzle material as critical parameters of spray drying process. Spray drying technology is widely used by the food industry. This is an ideal process where the end-product must comply with precise quality standards regarding particle size distribution, residual moisture content, bulk density and morphology. The production of food powders by spray drying has gained more attention in the recent years due to the versatility and controllability of a spray drying system.

2.4 Effect of Dietary Protein on Athletes' Performance

At rest, immediately after consumption of a meal containing amino acids, the absorptive process of amino acids begins with the delivery of amino acids to muscles, which exceeds the muscles' capacity to assimilate them, resulting in an expansion of the intramuscular amino acid pool, such expansion being less than might be expected (Bergstrom *et al.,* 1990). This may be due to protein synthesis, the inhibition of breakdown, and the stimulation of the branched-chain amino acids (BCAAs) catabolizing enzymes. The BCCAs amino acids include valine, isoleucine and leucine. BCCAs are transaminated, and the synthesis of alanine and glutamine, which are stimulated in the presence of ample pyruvate (from blood glucose), is initiated. The net balance of other nonmetabolized amino acids simply reflects the protein balance (Rennie & Tipton, 2000).

The synthesis of protein decreases and the breakdown increases during the post-absorptive state. The novo-synthetized alanine, glutamine altogether with the dietary leucine are decarboxylated, but only leucine is completely oxidized in the Krebs cycle and it is the only one that gives rise to acetate. Some BCCAs carbon (from valine and isoleucine) may escape muscle as hydroxyl acids, thereafter contributing to gluconeogenesis, which is the generation of glucose from a non-carbohydrate carbon substrate (Brosnan & Letto, 1991). The fates of alanine and glutamine are mainly gluconeogenesis and ureagenesis (Consoli *et al.,* 1990; Nurjhan *et al.,* 1995). At rest, in the post-absorptive state, muscle amino acids may account for 30% of total gluconeogenesis. However, the synthesis of alanine and glutamine increases almost linearly with aerobic exercise; although gut-derived amino acids may contribute substantially as exercise continues (Wasserman *et al.,* 1991).

- **Dynamic exercise and resistance exercise**

The oxidation of BCCAs like leucine, valine, and isoleucine is stimulated by sustained dynamic exercise. Sustained dynamic exercise also encourages ammonia production (increasing ureagenesis and loss of nitrogen) in proportion to exercise intensity. Energy expenditures (exercise) greater than energy input (food) generally results in a loss of body mass, particularly when continued over an appreciable period of time. Also, when intense physical activity is associated with insufficient input, wasting of lean-tissue mass is inevitable unless an eating protocol is established (Butterfiled, 1999). Even though, Butterfield & Calloway (1984) demonstrated that an increased level of physical activity actually increased the efficiency of protein utilization; Lemon, (1998); Phillips *et al.,* (1993); and Tarnopolsky *et al.,* (1992) have concluded that regular exercise will place, on physically active people, a requirement of eating more protein than they would otherwise do if they are to maintain their weight.

Weight lifting and other types of resistance exercises do not have effect on whole-body leucine oxidation (Tarnopolsky, 1991), this may be due to the fact that protein is not used as fuel by the human body in this kind of activity; instead it is used to remold the muscle; therefore, an increased in protein intake is needed. Resistance exercise cause little changes in amino acid oxidation but probably depresses protein synthesis and increases breakdown acutely. Protein synthesis rebound is observed after ≤48 h of exercise; nonetheless, breakdown remains elevated, and net positive balance is achieved only if amino acid availability is increased (Rennie & Tipton, 2000).

It is clear that high exercise intensities produces a net loss of muscle protein as a result of decreased in protein synthesis, increased breakdown, or both; and some amino acids are oxidized as fuel, while the rest provide substrates for gluconeogenesis and possibly for acid-based

regulation. According to Layman & Rodriguez (2009), muscle recovery from exercise, both dynamic and resistance, seems to be dependent on dietary leucine. Leucine is a critical element in regulating muscle protein synthesis and may be the key amino acid defining the increased needs for EAA to optimize skeletal muscle mass; moreover, increased tissue levels of leucine combined with circulating insulin to allow skeletal muscles to manage protein metabolism and fuel selection in relation to diet composition.

2.5 Effect of Dietary Omega-3 Fatty Acids on Athletes' Performance

Recently, attention has been given to the benefits of the intake of omega-3 fatty acids on the athletes' performance. The benefits attributed to the omega-3 fatty acids intake includes the improvement in the delivery of oxygen and nutrients to muscles and other tissues due to the reduction of blood viscosity; this causes an improvement in aerobic metabolism because of enhanced delivery of oxygen to cells. Moreover, the intake of omega-3 fatty acids is also associated with an improved release of somatotropin (growth hormone) in response to normal stimuli, such as exercise, sleep, and hunger, which may have an anabolic effect; and the reduction of inflammation caused by muscular fatigue and overexertion; this may improve postexercise recovery time. The prevention of tissue inflammation may be also associated to the intake of omega-3 fatty acids (Bucci, 1993). Nevertheless, evaluations of the effectiveness of the consumption of omega-3 fatty acids have demonstrated no improvements in strength, endurance, and muscle soreness (Brilla & Landerholm,1990; Lenn *et al.,* 2002). Instead, the benefits of omega-3 fatty acids are more related to the enhancement of aerobic metabolic process, which is an important factor in both athletic performance and in an individual's ability to effectively burn fat as an energy substrate.

CHAPTER 3: MATERIALS AND METHODS

3.1 Materials

Fresh, large, grade AA hen eggs were purchased from a local chain grocery store, in Baton Rouge, Louisiana. The eggs were stored at 4°C, and the storage time did not exceed three days. Refined menhaden fish oil extracted via a rendering process was obtained from Omega Protein Corporation (Houston, TX). Salmon fish oil was obtained from salmon byproducts including viscera, heads, skins, frame, and discarded fish was obtained from a commercial fishmeal processing plant in Alaska. All other chemicals were obtained from Sigma Chemical Co. (St. Louis, MO).

3.2 Methods

3.2.1 Proximate Analysis of Liquid Egg Whites (EW)

Moisture content, total lipids, crude protein and ash were determined for EW. Moisture content was measured in triplicate according to the AOAC official method 930.15 (AOAC 1999). Total lipids content was quantified in dry samples by an automated FAS-9001 fat analyzer (CEM Corporation, Matthews, NC, NC) using methylene chloride as the solvent. Approximately 3 g of dry sample were place between two filter papers; afterwards, the filter papers were placed into the fat analyzer and the weight of the defatted sample was recorded and calculated the fat content of the samples. Crude protein content was determined according to AOAC official method 992.15 (AOAC, 2006) using a Perkin Elmer Nitrogen Analyzer (Model 2410, Perkin Elmer Instruments, Norwalk, CT). The crude protein (%) was reported as 6.25 times of the nitrogen content (%). Ash content was determined in triplicate according to the AOAC official method 942.05 (AOAC 1999). Approximately 5 g of dried egg white were

placed in a Thermolyne Type 6000 muffle furnace (Thermo Scientific, Lawrence, KS) at 550 °C for 5 h and weighted ash content.

3.2.2 Fatty Acid Methyl Esters (FAMEs) Composition of Menhaden Oil (MO) and Salmon Oil (SO)

The FAMEs composition of the MO and SO were determined at the USDA-ARS Laboratory, University of Alaska Fairbanks, AK. FAMEs were produce using a modified method of Maxwell and Marmer (1983). Approximately 20 mg of oil were poured into a glass test tube, then, 4.5 mL of isooctane, 500 µL internal standard (10 mg methyl tricosanoate (23:0)/ml isooctane) and 500 µL of 2N KOH (1.12g/10 mL MeOH) were added and the mixture was vortexed for 60 s and centrifuge for 3 min at 38.67 x *g*; afterwards, the lower MeOH layer was discarded and 1 ml of saturated ammonium acetate was added into the mixture. The new mixture was again vortexed and centrifuged and the lower layer was removed. The final removal of the lower layer was done after the addition of 3 grams of anhydrous sodium sulfate; the mixture was then vortexed and centrifuge for 15 min. at 38.67 x *g*. The upper layer containing methyl esters and isooctane was used for the gas chromatographic analysis.

The gas chromatographic (GC) with a GC model 7890A (Agilent) fitted with a HP-88 (100m x 0.25mm ID x 0.25 µm film) column was used for FAMEs analysis. The oven program used was 90°C for 8 min, followed by 10 °C/min heating to 175°C for 10 min, 4 °C/min to 190 °C for 10 min, 5 °C/min to 210°C for 5 min and then 20 °C/min to 250°C for 8 min. ChemStation software was used to integrate peaks. Peaks were identified by comparing to reference standards obtained from Sigma: Supelco 37 mix, PUFA #1, PUFA #3 and cod liver oil. Data are expressed as percent of total integrated area.

3.2.3 Moisture Content, Free Fatty Acids (FFA), Peroxide Value (PV), and Color Values of MO and SO

Moisture content of MO and SO was determined by a Karl Fisher titration AOAC method 984.20 (AOAC, 2006) using a moisture meter (Mitsubishi ® CA-21, Japan). Approximately 0.4 g of fish oil were injected into the moisture meter; after the reaction time (approximately 5 minutes), the moisture meter provided the moisture content of fish oil sample expressed in ppm. The FFA content of the purified fish oils was determined by the titration method according to AOCS Ca 5a-40 (1998). Five grams of fish oil was added in 50 mL ethanol (previously neutralized by adding 2 mL phenolphthalein solution and enough 0.1 N NaOH to give a faint permanent pink color). The fish oil and the alcohol mixture were titrated with 0.25 N NaOH until as just permanent pink appeared. The percentage of FFA was expressed as oleic acid equivalent. The peroxide value (PV) of the MO and SO were determined in triplicate by titrating according to AOAC 965.33 (1999). Five grams sample of fish oil were dissolved in 30 mL acetic acid-chloroform (3:2 v:v) solution. Saturated KI solution (0.5 mL) was added and the mixture was shaken for 1 min; afterwards, 30 mL of distilled water was added. The resulting mixture was titrated with 0.1 N $Na_2S_2O_3$ until the blue color disappeared. The results were reported in terms of milliequivalent of peroxides per kg of fish oil. Color of MO and SO was measured by using a LabScan ® XE spectrophotometer (Hunter Associates Laboratory, INC. Resbon, VA). The results of color determination were reported in CIELAB color scales (L* value is the degree of lightness to darkness, a* value is the degree of redness to greenness, and b* value is the degree of yellowness to blueness). Before each measurement, the instrument was previously standardized using the calibrated black and white standards. Chroma and hue angle values were calculated using Eqs.(1) and (2), respectively. Negative values of the hue angle were converted

to positive values by adding 180°, so that it could fall in the 90-180° quadrant (+b* = yellow; -a*=green) (Pu *et al.*,2011).

$$Chroma = [(a^*)^2 + (b^*)^2]^{1/2} \quad (1)$$

$$Hue = \tan^{-1}(b^*/a^*) \quad (2)$$

3.2.4 Preparation of Emulsions

Egg whites were carefully separated from egg yolks. Then, oil-in-water emulsions containing MO/SO and EW for producing microencapsulated fish oil with egg white powder were prepared by mixing distilled water, MO/SO and EW. Two stable emulsions were prepared with 3.43% MO/SO, 56.21% egg whites, and 40.36% distilled water (E-MO-EW, and E-SO-EW). Also, a solution containing 80% EW with distilled water (E-EW) was prepared as a control. Afterwards, the emulsions and the control solution were homogenized for 5 min using an ultrasonic processor (500 Watt Model CPX 500, Cole-Parmer Instrument Co. Vernon Hill, IL) fitted with a 22 mm tip diameter at 82% amplitude with 2x1 pulses (with 1 s delay between pulses). These conditions were selected based on previous studies and published literature (Yin *et al.,* 2009). Samples were held in an ice bath at 4°C during the procedure.

3.2.5 Characterization of Emulsions

3.2.5.1 Color and Emulsion Oxidation

Color of the emulsion was determined in triplicate following the procedure described in section 3.2.3. Thiobarbituric acid-reactive substances (TBARS) were quantified to evaluate the emulsion oxidation. TBARS of the emulsions were determined according to the method described in Mei *et al.,* (1998) with some modifications. A solution of Thiobarbituric acid (TBA) was prepared by mixing 15 g of trichloroacetic acid, 0.375 g of TBA, 1.76 mL of 12 N HCL, and 82.9 mL of H_2O. The TBA solution (100 mL) was mixed with 3 mL of 2% butylated

hydroxytoluene in ethanol, and 2 mL of this solution was mixed with 1 mL of an emulsion sample. The resulting mixture was vortexed for 10 sec and heated in a boiling water bath for 15 min. The mixture was allowed to cool down at room temperature; then, it was centrifuged at 3400 x *g* for 25 min. The absorbance of the supernatant was measured at 532 nm. Concentration of TBARS were determined from standard curves prepared with 0-0.02 mmol/L 1, 1, 3, 3-tetraethoxypropane. The results were expressed in mmol of equivalents of malonaldehyde per kg oil.

3.2.5.2 Flow Behavior and Viscoelastic Properties

Flow behavior and viscoelastic properties of the emulsions were measured in triplicate using an AR 2000 Ex Rheometer (TA Instruments, New Castle, DE) fitted with a plate geometry (acrylic plates with a 40-mm diameter, having a 200 μm gap between the two plates). Each emulsion was placed in the temperature-controlled parallel plate and allowed to equilibrate to either 5, 15, or 25 °C. The shear stress was measured at 5, 15, and at 25°C at varying shear rates from 1 to 100 s^{-1}. The mean values of triplicate samples were reported. The power law (Eq. 3) was used to analyze the flow behavior index of the emulsions.

$$\sigma = K\dot{\gamma}^{n} \quad (3)$$

where σ = shear stress (Pa.s), $\dot{\gamma}$ = shear rate (s^{-1}), K = consistency index ($Pa.s^{n}$), and n = flow behavior index. Logarithms were taken on both sides of Eq. 3, and a plot of log σ versus log γ was constructed. The resulting straight line yielded the magnitude of the K (i.e., intercept) and n (i.e., slope).

Frequency sweep tests were conducted between 0.1 to 10 Hz at a constant temperature of 25°C. The storage modulus and loss modulus of emulsion samples were obtained using Universal Analysis (TA instrument) software and were calculated using Eqs. (4) and (5).

$$G' = \left[\frac{\sigma_0}{\gamma_0}\right]\cos\delta \quad (4)$$

$$G'' = \left[\frac{\sigma_0}{\gamma_0}\right]\sin\delta \quad (5)$$

where *G'* (Pa) is the storage modulus, *G''* (Pa) is the loss modulus, σ is generated stress, and γ is oscillating strain.

3.2.6 Spray Drying of Emulsions

The emulsions containing EW and MO/SO were dried using a pilot plant scale spray dryer (FT80 Tall Form Spray Dryer Armfield Inc., Ringwood, UK) under co-current drying conditions. A schematic representation of the pilot scale FT80 tall form spray dryer is shown in Fig. 3.1. The FT80 spray dryer includes inlet and exhaust air fans, an electrical air heating chamber, a tall dryer chamber, and a cyclone separator. The air velocity and temperature of ambient air were recorded using an anemometer (Anemomaster Model 6162, Kanomax Inc. Japan); and the relative humidity of ambient air was measured using an Omega 4-in-1 multifunctional anemometer (Omega Engineering, Stamford, CT). Ambient air was blown into the air heating chamber by the inlet fan where the ambient air was heated by an electric resistance heater to 130, 140 or 150°C. The heated air (inlet air) was blown into the top of the drying chamber. The temperature of emulsions (E-MO-EW and E-SO-EW) and solution (E-EW) was measured at the beginning of the procedure, and then the emulsion was separately fed through the hygienic progressing cavity pump to a spray nozzle where it was atomized and sprayed into the dryer chamber. The emulsion droplets were dried in the drying chamber yielding dried powder and dust. The dried powder, dust, and air were pulled to the bottom of the drying chamber and then

to the cyclone separator by the exhaust fan. The powder and dust were separated in the cyclone separator. The powder separated by the cyclone separator was collected in the powder collector and the exhaust air was released though filter bag to the atmosphere. The filter bag captured the dust. The internal diameter of ambient air intake pipe and exhaust air pipe, exhaust (outlet) air temperature, and outlet air velocity were measured. The relative humidity and exhaust air temperature that passed through the exhaust fan were recorded. In total, nine egg white powders were obtained, E-EW dried at 130°C (DEW-130), E-EW dried at 140°C (DEW-140), E-EW dried at 150°C (DEW-150), E-MO-EW dried at 130°C (MO-EW-130), E-MO-EW dried at 140°C (MO-EW-140), E-MO-EW dried at 150°C (MO-EW-150), E-SO-EW dried at 130°C (SO-EW-130), E-SO-EW dried at 140°C (SO-EW-140), and E-SO-EW dried at 150°C (SO-EW-150). The E-MO-EW, E-SO-EW, and E-EW egg powder samples and dust were analyzed for moisture content according to the AOAC official method 930.15 (AOAC, 1999). The powder production rate was estimated and compared with the actual powder production rate. The actual powder production rate was the mass of the powder recovered from the powder collector divided by the time of production. The estimated production rate was the sum of the actual production rate and the average rate at which powder was retained within the spray dryer by such mechanisms as sticking to the walls of the spray dryer. The mass flow rate for water entering and leaving the spray dryer and the energy required to dry the emulsion in the production of powder were determined. The resulting powders were stored at 4^{o}C, and the storage time did not exceed four days. The drying procedure was carried out in triplicate.

3.2.6.1 Estimation of Production Rate of Microencapsulated Powders

The material balance expressed as average flow rates of dry solids entering and leaving the spray dryer system (Fig. 3.2) is described by Eq. (6).

$$m_e = mP + m_d \quad (6)$$

The production rate was estimated by the Eq. (7)

$$mP = m_e - m_d \quad (7)$$

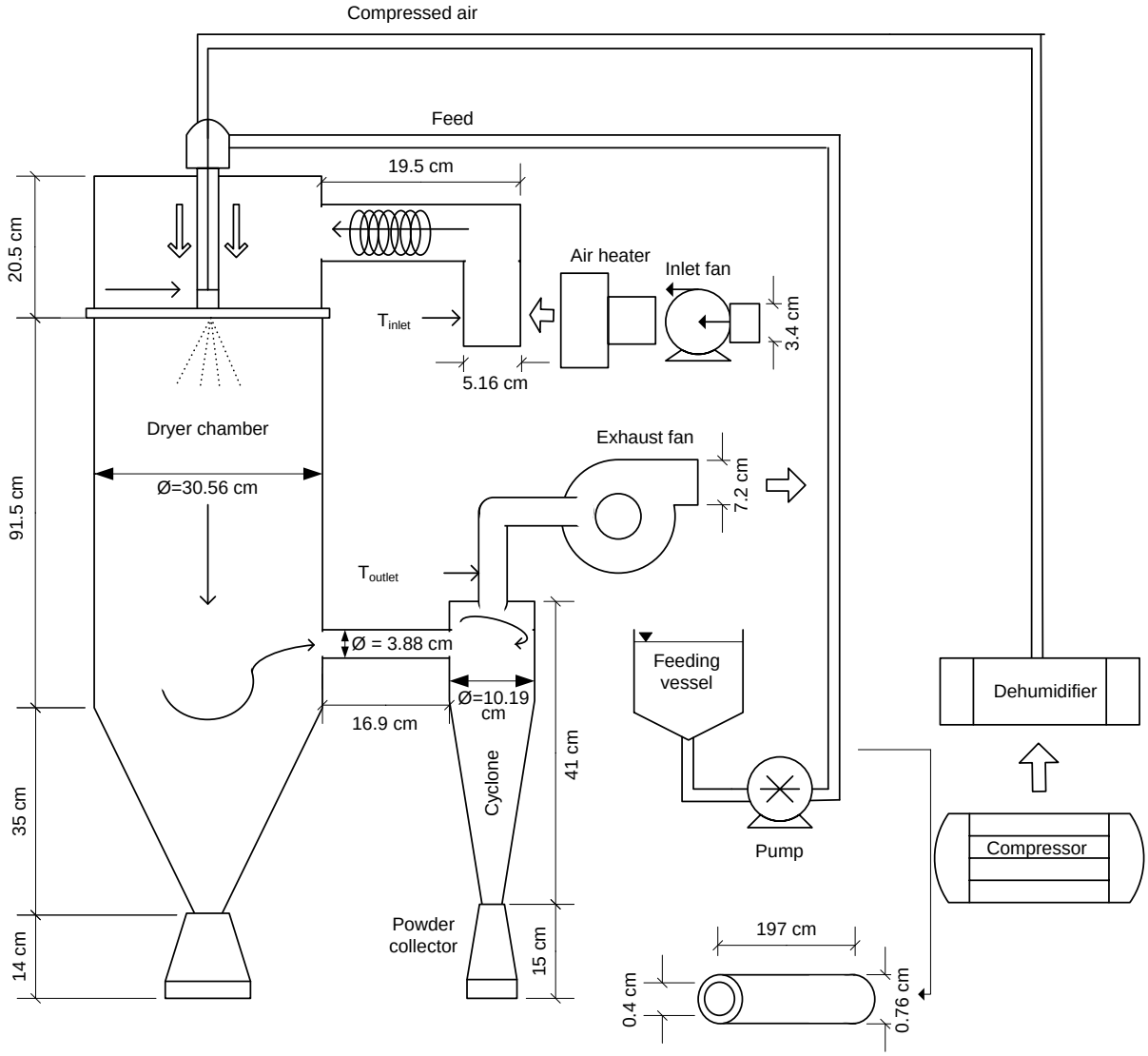

Figure 3.1 Schematic representation of the pilot scale FT80 Tall Form Spray Dryer-Armfield Limited®

where m_e is the average emulsion flow rate (kg dry solids/h); m_d is the average dust flow rate (kg dry solids/h); *mP* is the estimated powder production rate which included both the average actual production flow rate (m_p) for the powder collected through powder collector vessel and product retained in the spray dryer. It was assumed that the physical properties of product retained in the spray dryer were the same as the powder product collected in cyclone collector vessel.

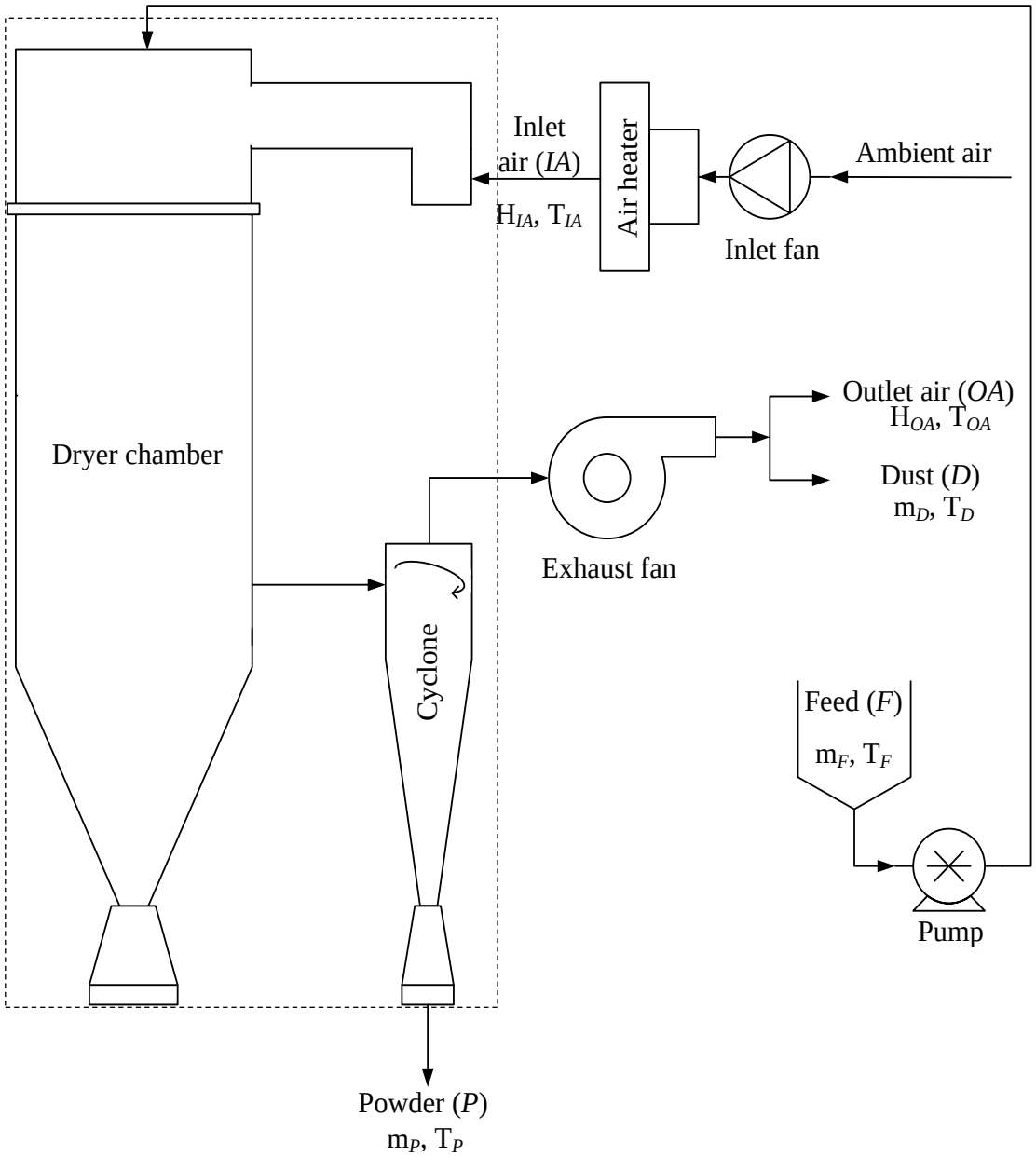

Figure 3.2 Material balance of a spray drying system

3.2.6.2 Estimation of Evaporation Rate

The moisture balance expressed as water entering and leaving the spray dryer system is described by Eq. (8).

$$m_{aa}AH_{aa}+m_ew_e = m_{ao}AH_{ao}+m_dw_d+mPw_p \quad (8)$$

where m_{aa} is the dry air mass flow rate at the inlet (ambient air) (kg dry air/h); m_{ao} is the dry air mass flow rate of outlet air (kg dry air/h); m_e is the mass flow rate of the emulsion (kg dry solids/h); m_d is the mass flow rate of dust (kg dry solids/h); mP included both the product flow rate (m_p) for the powder collected through cyclone vessel and product retained in the spray dryer; AH_{aa} is the absolute humidity of inlet ambient air (kg water/kg dry air); AH_{ao} is the absolute humidity of outlet air (kg water/kg dry air); w_e is the moisture content (dry basis) of emulsion (kg water/kg dry solids); w_d is the moisture content (dry basis) of dust (kg water/kg dry solids); w_p is the moisture content (dry basis) of product (kg water/kg dry solids). It has been assumed that the powder retained in the spray dryer has essentially the same moisture content as the collected powder and that the encapsulation effectively removes that moisture from the air stream.

The evaporation rate (E_{va}) was estimated from the moisture removed by the dry air as shown by Eq. (9).

$$E_{va} = m_{ao}AH_{ao} - m_{aa}AH_{aa} \quad (9)$$

Also, the evaporation rate (E_{vp}) was estimated based on the moisture content of emulsion, powder collected through cyclone vessel and dust using Eq. (10).

$$E_{vp} = m_ew_e - m_dw_d - mPw_p \quad (10)$$

The dry air mass flow rate of inlet ambient air and dry mass flow rate of outlet air were estimated as described by the AlChE Equipment Testing Procedure (2003) using Eq. (11).

$$m = \frac{V}{V'} \quad (11)$$

where *m* is the dry air mass flow rate (kg dry air/h); *V* is the volumetric flow rate of inlet or outlet air (m^3/h); *V'* is the specific volume of inlet or outlet dry air (m^3/kg dry air).

The volumetric flow rate of inlet ambient air and outlet air was calculated as described by Eq. (12)

$$V = v \, x \, A \quad (12)$$

where *v* is the average velocity of the inlet or outlet air (m/s) and *A* is the cross sectional area of the inlet or outlet air pipe (m^2).

The specific volumes of inlet or outlet dry air were calculated using Eq. (13) as described by Singh and Heldman (2001).

$$V' = (0.082T + 22.4)\left(\frac{1}{29} + \frac{AH}{18}\right) \quad (13)$$

where *T* is the temperature of inlet ambient or outlet air (°C); *AH* is the absolute humidity of inlet ambient or outlet air (kg water/kg dry air).

The absolute humidity of the inlet ambient and the outlet air were calculated as Eq. (14) as described by AlChE Equipment Testing Procedure (2003)

$$AH = 0.622x\frac{p_w}{101.325 - p_w} \quad (14)$$

where *AH* is the absolute humidity of the inlet ambient or outlet air (kg water/kg dry air); and p_w is the partial pressure exerted by water vapor (kPa).

The partial pressure exerted by water vapor is estimated with Eq. (15) as described by Singh and Heldman (2001)

$$p_w = p_v \, x \, RH \quad (15)$$

where p_w is the partial pressure exerted by water vapor (kPa); p_v is the saturation pressure of water vapor (kPa); *RH* is the relative humidity (%).

3.2.6.3 Estimation of Energy Used to Dry the Emulsions

The estimation of the energy required to dry the emulsions was obtained with Eq. (16) as described by Singh and Heldman (2001).

$$Q = m_{aa}c_p\Delta T = m_{aa}(c_{aa} + c_v AH_{aa})(T_{ad} - T_{aa}) \quad (16)$$

where m_{aa} is dry air mass flow rate of inlet ambient air (kg dry air/h); c_p is specific heat of inlet ambient air (kJ/[kg K]); c_{aa} is specific heat of inlet ambient dry air (kJ/[kg K]); c_v is the specific heat of water vapor (kJ/[kg K]); AH_{aa} is the absolute humidity of inlet ambient air (kg water/kg dry air); ΔT is the temperature difference between inlet ambient air and heated air (K); T_{ad} is the temperature of the inlet drying air (K); and T_{aa} is the temperature of inlet ambient air (K).

3.2.7 Determination of Microencapsulation Efficiency and Color of Egg White Powders

The total lipid content (O_T) and the amount of the surface oil (O_S) were determined to calculate the microencapsulation efficiency (ME). The total lipid content (O_T), which included both the encapsulated oil (O_E) and (O_S), was determined using the method described by Shahidi & Wanasundara (1995). Surface oil was determined by adding hexane (50 ml) to an accurately weighted amount (5 g) of microencapsulated powder followed by stirring for 10 min at 25°C. The suspension was then filtered using filter paper and the residue rinsed thrice by passing 20 m of hexane through each time. The residual powder was then air dried for 30 min and weighed. The amount of surface oil (O_S) was calculated by the difference in weights of the microcapsules.

$$O_S = Original\ weight - Final\ weight\ of\ microcapsules \quad (17)$$

Total lipid content (O_T) was determined by dissolving 5 g of microencapsulated powder in 25 mL of a 0.88% (w/v) (g/mL) KCl solution. Then 50 ml of chloroform, 25 ml of methanol and a few crystals of tert-butylhydroquinone (TBHQ) were added. The mixture was then homogenized using a high speed mixer (Model RW 20 D S1, IKA ®, USA) for 5 min at 10.96 x *g*. The

mixture was transferred to a separatory funnel; the chloroform layer was separated and then evaporated using a rotavapor (Model Büichi RE121, Büichi Lab, Switzerland) at 60°C to recover the oil.

The O_E and the ME were calculated as described by Eqs. (18) and (19), respectively.

$$O_E = O_T - O_S \quad (18)$$

$$ME = \frac{O_E}{O_T} * 100 \quad (19)$$

Color determination of egg white powders was carried out in triplicate following the method described in section 3.2.3.

3.2.8 Fatty Acid Methyl Esters (FAMEs) and Lipid Oxidation of Egg White Powders

Fatty acid methyl ester profiles of the egg powders were determined at the USDA-ARS Laboratory, University of Alaska Fairbanks, AK. The oil samples were extracted from MO-EW, and SO-EW powders using the method described in section (3.2.7). FAMEs composition and FFAs were determined for the lipid extracts following the methods detailed in sections (3.2.2) and (3.2.3) for FAMEs composition and FFA, respectively.

TBARs analysis was carried out following the procedure described in section (3.2.5.1). A 0.5 g sample of egg white powder was dispersed in 5 mL of distilled water and vortexed for 5 min.; afterwards, 1 mL of this mixture was mixed with 2 mL of TBARs solution, vortexed and placed in boiling water for 15 min. The mixture was allowed to cool down at room temperature, then it was centrifuged at 3400 x *g* for 25 min. and absorbance was measured at 532 nm. TBARs content was determined using a standard curve of 1,1,3,3-tetraethoxypropane. The results were expressed in mmol of equivalents of malonaldehyde per kg oil.

3.2.9 Crude Protein, Total Lipids, Ash and Water Activity (a_w) of Egg White Powders

Crude protein, total lipids, ash and water activity (a_w) were determined for the egg white powder samples. The methods used to determine crude protein, and ash content are described in section (3.2.1). Total lipids were quantified according the method described in section (3.2.7). Water activity (a_w) was determined using an AquaLab water activity meter (Model Series 3 TE, Decagon Devices, Inc., Pullman, WA, USA). All of the measurements were carried out in triplicate.

3.2.10 Amino Acid and Mineral Analysis

Amino acid profiles of the egg white powders were determined by the AAA Service Laboratory Inc., Boring, OR. Powder samples were hydrolyzed with 6N HCl and 2% phenol at 110 °C for 22 h. Amino acids were quantified using a Beckman 6300 analyzer with post-column ninhydrin derivatization. Tryptophan and cysteine content were not determined. We analyzed only the most common 16 amino acids plus hydroxyproline and hydroxylysine. This method is not satisfactory for determining the amino acids including tryptophan, cysteine, and taurine. Determination of tryptophan and cysteine require a different hydrolysis procedure because the condition used (6NHCL at 110 for 22 h) for analyzing the most 16 amino acids; will destroy significant quantities of these two amino acids. A different hydrolysis procedure is required to determine cysteine and tryptophan (Simpson *et al.*, 1976). The AAA Service laboratory does analyze for these amino acids but the cost of each of these amino acids analysis is the same as for the standard hydrolysis procedure. Due to the increased cost, determination of tryptophan and cysteine were not performed.

The mineral profile analysis of the egg powder samples was carried out in triplicate by the acid digestion method involving microwave technology (CEM microwave, MDS-2000, CEM

Corp., Matthews, N.C., U.S.A.). A 0.5 g sample was placed in a vessel and 6 mL HNO_3 was added. The sealed vessel was heated until digestion was completed. The samples were cooled for 5 min. The inductively coupled argon plasma system (Model CIROS, SPECTRO Analytical Instruments, Kleve, Germany) was utilized to determine the mineral profile.

3.2.11 Scanning Electron Microscopy (SEM) and Particle Size Distribution of Microencapsulated Powders

The microstructure of the egg powders was evaluated by scanning electron microscopy (SEM) (JSM-6610LV, JEOL Ltd. Japan) working with a voltage of 10 kV. The samples were mounted on aluminum SEM stubs, and then coated with gold: palladium (60:40) in an Edwards S150 sputter coater (Edwards High Vacuum International, Wilmington, MA). The powders were systematically observed at 1000X of magnification.

The particle size distribution was determined by a Microtrac S3500 system (MicroTrac, Largo FL). The system works with three solid state lasers fixed at 780 nm with a computer controlled single lens alignment. The system has a measurement capability from 0.24 to 2800 microns. A small amount of powder samples were place into the test chamber with circulating ethyl-alcohol in each trail. A period of 10 sec ultrasound mixing at 20 watts was used before each test. Then the sample was pumped through sample cell at 40% of the maximum flow rate. Light was scattered from the tri-lasers from low to high angles (0-163 degrees). The whole light scatter pattern was collected. The volume distribution of the particle size was calculated using modified MIE-scattering technique.

3.2.12 Statistical Analysis

All data was analyzed using SAS software version 9.2 (SAS Institute Inc., 2008). Means and standard deviations of the data were presented. ANOVA and Tukey's studentized range test were carried out to determine differences among treatments at the significant level of $P < 0.05$.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Proximate Composition of Egg Whites (EW)

The proximate composition of egg white can be seen in Table 4.1. The total liquid weight of a large, grade AA egg was 50.6±0.23 g, of which 33.2±0.36 g were egg white and 16.5±0.30 g represented the weight of egg yolk. The results are similar to those reported in AEB (1999). Lipid content of egg white was 2.56 (g/100 g, dry basis). Mine (1995) reported that the total lipid content in fresh egg white was almost negligible.

Table 4.1 Proximate analysis of egg white (EW)[a]

	Egg white
Moisture (%) (wet basis)	87.25±0.05
Total lipids (g/100 g, dry basis)	2.56±0.31
Crude protein (g/100 g, dry basis)	88.28±0.32
Ash (g/100 g, dry basis)	5.36±0.06

[a] Values are means ± SD of triplicate determination.

4.2 FAMEs Composition of MO and SO

The FAMEs composition of MO and SO are presented in Table 4.2. MO contained 13.41±0.05% and 12.80±0.17% of EPA and DHA, respectively. Moreover, the total omega-3 fatty acids and polyunsaturated fatty acids in MO accounted for 32.38±0.44 and 34.94±0.43, respectively. These results are similar to those reported by Wan *et al.*, (2011) except for the total omega-3 which was higher. EPA, DHA, total omega-3, and total polyunsaturated fatty acids in SO accounted for 11.29±0.18 %, 11.06±0.09 %, 23.66±0.11% and 25.19±0.12%, respectively. Similar results are reported by Wu & Bechtel (2008). MO and SO were good sources of omega-3 fatty acids, similar findings are reported by Yin & Sathivel (2010).

4.3 Moisture Content, FFA, PV and Color Values of MO and SO

The moisture content, FFA, and PV of MO and SO are presented in Table 4.3. According to the FDA- Standard of identity (2006), MO and SO are considered generally recognized as safe

(GRAS) when they have FFA content below 0.1 percent. The FFA (%) of MO and SO were 0.15 and 0.18, respectively. Even though these values were higher than the maximum levels established by the FDA; they were considered acceptable, since the initial determination of FFA in MO and SO was needed to observe the effect of the microencapsulation processing on the degree of hydrolysis of MO and SO; also, the resulting microencapsulated fish oil with egg white powder was not intended for human consumption. The peroxide value of MO and SO were lower than the maximum limit established by the FDA (5 milliequivalents per kg of oil) (FDA, 2006). As in the case of FFA, the initial determination of PV in MO and SO was needed to observe the effect of the microencapsulation processing on the oxidation of MO and SO. MO had a yellowish color; meanwhile, SO had a slightly reddish color (Table 4.3).

Table 4.2 FAMEs profile of MO and SO (% of total integrated area)[a]

FAME	MO	SO
14:0	9.20±0.16	4.80±0.08
14:1n5	0.38±0.00	ND
15:0	0.92±0.02	ND
16:0	21.23±0.52	10.12±4.07
16:1n7	11.35±0.05	3.71±2.91
18:0	3.86±0.07	2.12±0.03
18:1n9c	6.11±0.07	12.16±0.11
18:1n5	3.03±0.02	2.72±0.02
18:2n6c	1.46±0.01	1.53±0.02
18:3n3	1.62±0.04	1.31±0.00
20:5n3 (EPA)	13.41±0.05	11.29±0.18
22:6n3 (DHA)	12.80±0.17	11.06±0.09
ω-3 total	32.38±0.44	23.66±0.11
ω-6 total	2.55±0.01	1.53±0.02
SAFA	51.88±4.04	17.04±4.00
MUFA	11.66±0.08	18.60±2.79
PUFA	34.94±0.43	25.19±0.12
ω-3/ω-6	12.70±0.22	15.50±0.16
P/S	0.68±0.06	1.54±0.42

[a] Values are means ± SD of triplicate determination. MO= purified menhaden oil, SO= salmon oil. SAFA = total saturated fatty acids; MUFA= total monounsaturated fatty acids; PUFA= total polyunsaturated fatty acids. ND = not detected.

Table 4.3 Moisture content, FFA, PV and color of MO and SO[a]

	MO	SO
Moisture (ppm)	375.23±35.15	435.18±35.85
FFA (%)	0.15±0.01	0.18±0.01
PV(mEq/ kg oil)	3.15±0.12	3.45±.0.06
L*	43.20±0.03	42.65±0.52
a*	11.73±0.02	23.98±0.49
b*	44.27±0.02	54.05±1.67
Chroma	45.79±0.01	59.13±2.54
Hue angle	75.16±0.02	66.07±1.24

[a] Values are means ± SD of triplicate determination. MO= purified menhaden oil, SO= refined salmon oil.

4.4 Characterization of Emulsions

4.4.1 Color and Emulsion Oxidation

The color values of E-EW, E-MO-EW, and E-SO-EW are presented in Table 4.4. E-EW, E-SO-EW, and E-MO-EW were light in color. *L** value is a measurement of the lightness of the emulsions; meanwhile, *a** and *b** indicate the redness and yellowness color of emulsions, respectively. *L** values of E-EW, E-MO-EW, and E-SO-EW were 68.64±0.02, 83.08±0.03, and 75.17±0.31, respectively. It was observed that the *a** value of E-EW was significantly ($P<0.05$) lower than those of E-MO-EW, and E-SO-EW. Meanwhile, *b** value of E-MO-EW was significantly ($P<0.05$) higher than those of E-EW and E-SO-EW. Chroma value is an indicator of the vividness of color (the higher the value, the more vivid color). Chroma values of E-EW, E-MO-EW, and E-SO-EW were 2.89±0.05, 11.65±0.05, and 4.68±0.33, respectively. Hue angle describes color based on a circle, so a hue angle of 0°, 90°, 120°, 240° indicates a red, yellow, green, and blue color, respectively. The hue angle of E-EW, E-MO-EW, and E-SO-EW was 152.95±1.47, 96.57±0.05, and 117.28±0.80, respectively. The formation of TBARS after emulsion preparation is shown in Table 4.4. E-MO-EW showed a significantly ($P<0.05$) greater TBARS (mmol kg/oil) value compared to that of E-SO-EW.

Table 4.4 Color values and emulsion oxidation of E-EW, E-MO-EW, and E-SO-EW*

Parameter	E-EW	E-MO-EW	E-SO-EW
L*	68.64±0.02^{c}	83.08±0.03^{a}	75.17±0.31^{b}
a*	-2.58±0.02^{c}	-1.33±0.02^{a}	-2.14±0.09^{b}
b*	1.32±0.09^{c}	11.57±0.05^{a}	4.16±0.33^{b}
Chroma	2.89±0.05^{c}	11.65±0.05^{a}	4.68±0.33^{b}
Hue angle	152.95±1.47^{a}	96.57±0.05^{c}	117.28±0.80^{b}
TBARS (mmol /kg oil)	ND	0.04±0.00^{a}	0.03±0.00^{b}

*Values are means and SD of triplicate determination. ^{abc} means with different letters in each row are significantly different ($p< 0.05$). E-EW = egg white mixture, E-MO-WE = emulsion containing egg white and menhaden oil, E-SO-WE= emulsion containing egg white and salmon oil. TBARS = Thiobarbituric acid-reactive substances. ND = not detected.

4.4.2 Flow Behavior and Viscoelastic Properties

The flow behavior index (*n*), consistency index (*K*), and apparent viscosity at 5, 15, and 25°C of E-EW, E-MO-EW, and E-SO-EW are shown in Table 4.5, 4.6, and 4.7. The *n*-values of E-EW, and E-MO-EW, and E-SO-EW were significantly ($P<0.05$) higher at 25°C compared to those at 5°C. Even more, the *n*-values of E-EW, E-MO-EW, and E-SO-EW were lower than 1.0 regardless of the temperature, which indicated that they behaved as pseudoplastic fluids (Paredes *et al.,*1989). It has been reported that unmixed egg white behaves like a pseudoplastic and time-dependent fluid. (Tung *et al,* 1970). According to Singh & Heldman (2001), a pseudoplastic fluid may appear homogeneous to the naked eye; however, it may contain microscopic particles submerged in it. Moreover, when these fluids are subjected to a shear, the randomly distributed particles may orient themselves in the direction of flow and agglomerated particles may break up into smaller particles; therefore, an increase in "fluidity" is observed. In this study, the pseudoplastic fluid behavior of the emulsions may be due to the microscopic fish oil droplets. The tiny oil droplets may align themselves in the direction of increasing shear, and therefore a decreased of the emulsion viscosity is observed. The *K*-values of E-EW, E-MO-EW, and E-SO-EW were significantly ($P<0.05$) lower at 25°C than those at 5°C. The apparent viscosities of E-EW, E-MO-EW, and E-SO-EW at 5, 15, and 25°C are presented in Figures 4.1, 4.2, and 4.3. It

was observed that at a shear rate of 100 s^{-1}, the apparent viscosity of E-EW was not affected by the temperature; however, the apparent viscosity of E-MO-EW and E-SO-EW was significantly ($P<0.05$) higher at 5°C compared than those at 15 and 25°C (Tables 4.5, 4.6, and 4.7). According to the Equipment Testing Procedures Committee of the American Institute of Chemical Engineers (2003), the viscosity and fluidity of the solution are modified by the feed temperature. Since the spray drying rate of the spray dryer is altered by the viscosity and fluidity of the feed; it was important to study the rheological properties of E-EW, E-MO-EW, and E-SO-EW.

Table 4.5 Flow behavior properties of E-EW*

Temperature (°C)	*n*	*K*(Pa.s^n)	Apparent Viscosity (Pa s) at 100 s^{-1} (shear rate)
5	0.34±0.04^c	0.011±0.002^a	0.008±0.002^a
15	0.49±0.02^b	0.009±0.001^a	0.007±0.001^a
25	0.76±0.02^a	0.003±0.001^b	0.006±0.001^a

*Values are means and SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p< 0.05$). *n* = flow index, *K* = consistency index. E-WE= egg white mixture.

Table 4.6 Flow behavior properties of E-MO-EW*

Temperature (°C)	*n*	*K*(Pa.s^n)	Apparent Viscosity (Pa s) at 100 s^{-1} (shear rate)
5	0.43±0.02^b	0.44±0.03^a	0.02±0.00^a
15	0.59±0.04^a	0.21±0.02^b	0.01±0.00^b
25	0.62±0.03^a	0.18±0.02^b	0.01±0.00^b

*Values are means and SD of triplicate determination. ^{ab} means with different letters in each column are significantly different ($p< 0.05$). *n* = flow index, *K* = consistency index. E-MO-WE= emulsion containing egg white and purified menhaden oil.

Table 4.7 Flow behavior properties of E-SO-EW*

Temperature (°C)	*n*	*K*(Pa.s^n)	Apparent Viscosity (Pa s) at 100 s^{-1} (shear rate)
5	0.46±0.01^c	0.39±0.03^a	0.02±0.00^a
15	0.57±0.03^b	0.24±0.02^b	0.01±0.00^b
25	0.69±0.02^a	0.16±0.02^c	0.01±0.00^b

*Values are means and SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p< 0.05$). *n* = flow index, *K* = consistency index. E-SO-WE= emulsion containing egg white and salmon oil.

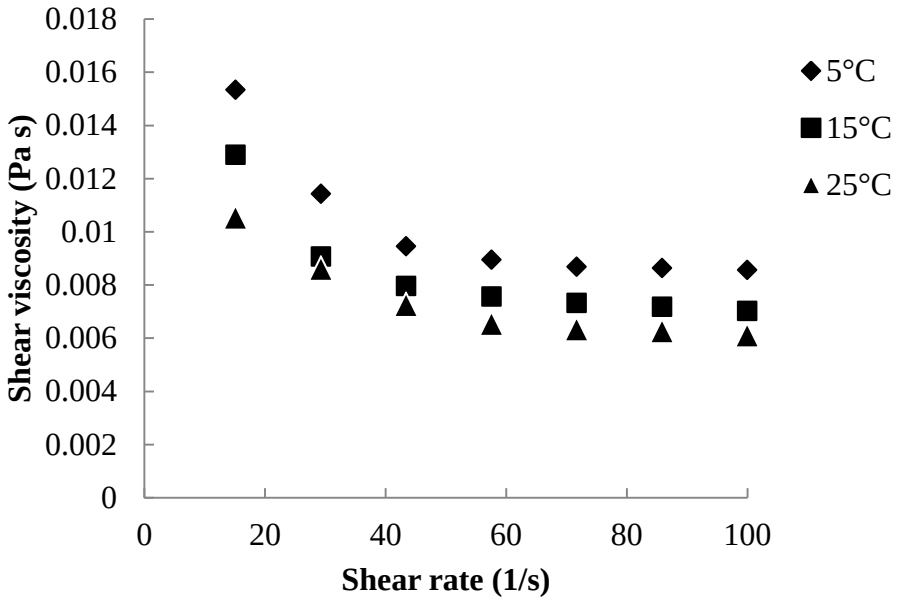

Figure 4.1 Apparent viscosity of E-EW as a function of shear rate.
E-EW= egg white mixture.

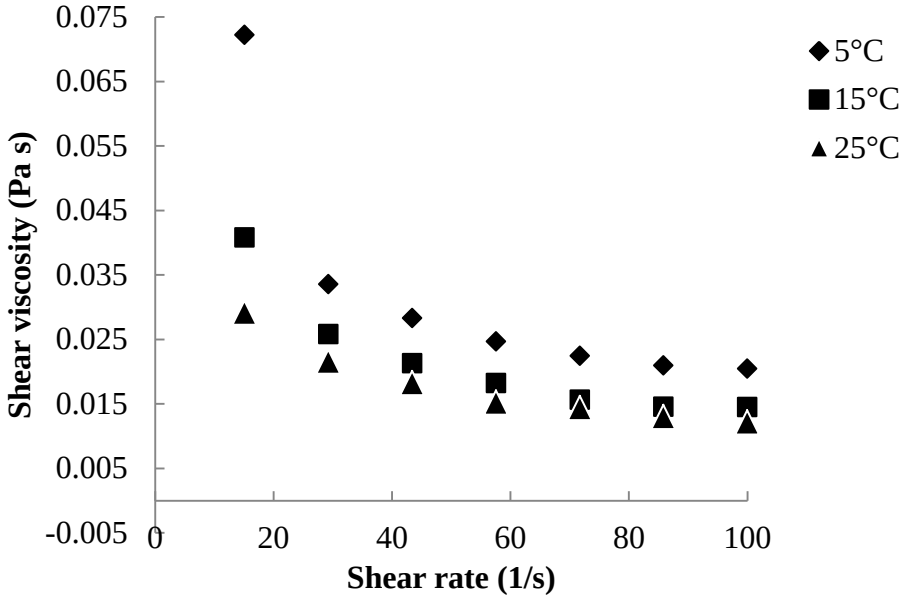

Figure 4.2 Apparent viscosity of E-MO-EW as a function of shear rate.
E-MO-EW = emulsion containing egg white and purified menhaden oil.

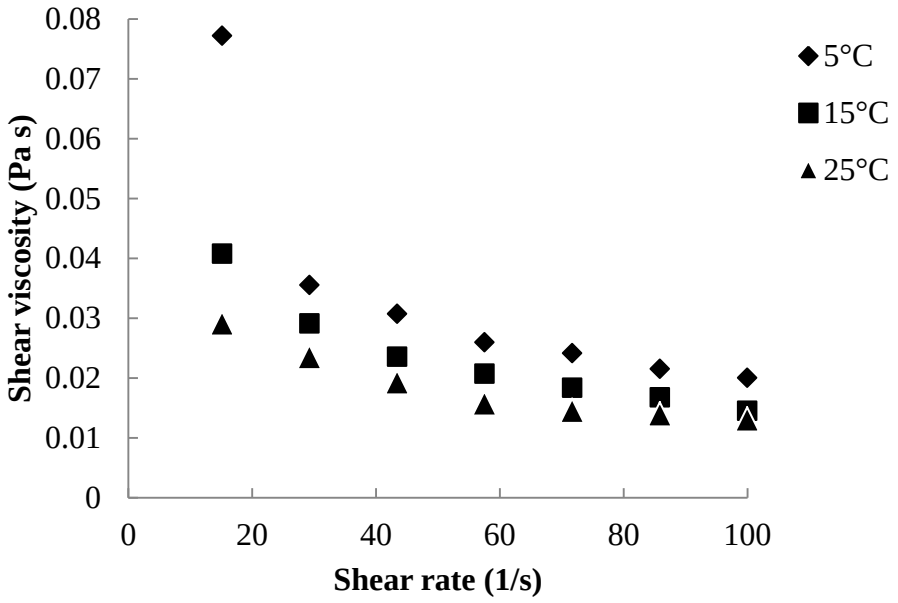

Figure 4.3 Apparent viscosity of E-SO-EW as a function of shear rate.
E-SO-EW = emulsion containing egg white and refined salmon oil.

Dynamic rheological tests described viscoelastic properties of E-EW, E-MO-EW, and E-SO-EW (Figures 4.4, 4.5, and 4.6). The G' (an elastic or storage modulus) and G'' (a viscous or loss modulus) of the emulsions were determined as a function of frequency (ω) at a fixed temperature of 25°C. According to Rao (1999), G' is a measure of energy recovered per cycle of sinusoidal shear deformation and G'' is an estimate of energy dissipated as heat per cycle. E-EW, E-MO-EW, and E-SO-EW showed a gradual increase in both G' and G'' with increasing frequency. G' was always higher than G'' in all the cases. These results indicated that E-EW, E-MO-EW, and E-SO-EW behaved like a viscoelastic material because they presented a higher G' than G''; this also indicated that the emulsions (E-MO-EW, and E-SO-EW) were stable. Moschakis *et al.*, (2005) reported that an emulsion with viscoelastic characteristics would retard the rearrangement of macroscopic phase separation. Spray drying of stable E-MO-EW, and E-SO-EW emulsions may result in high microencapsulation efficiency. Ovalbumin, ovotransferrin, and ovomucoid are the main proteins found in egg white (Powrie & Nakai, 1985).

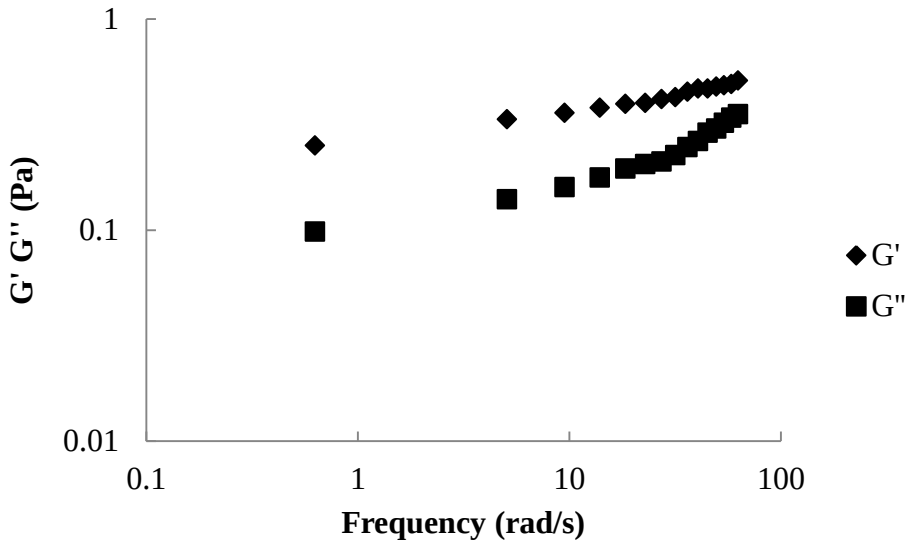

Figure 4.4 Viscoelastic properties of E-EW.
E-EW = egg white mixture; G'=storage modulus; G''=loss modulus.

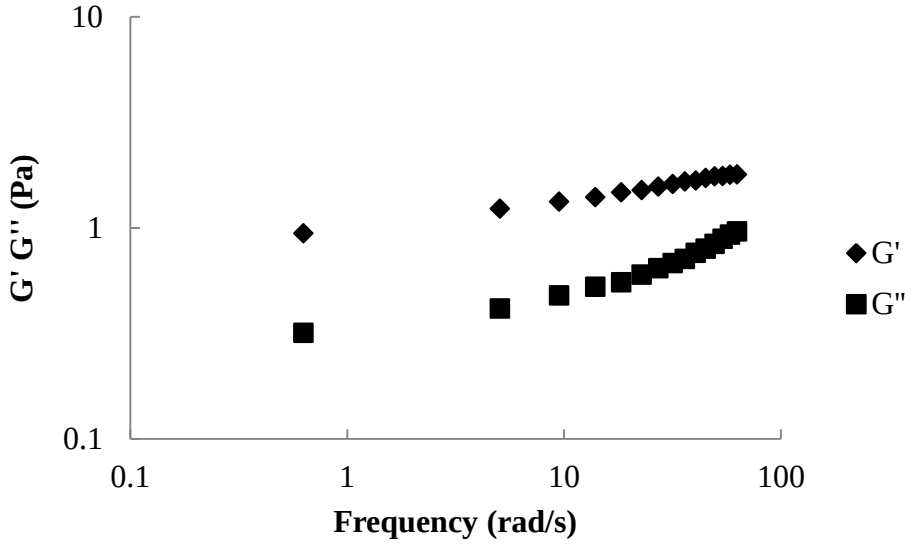

Figure 4.5 Viscoelastic properties of E-MO-EW
E-MO-EW = emulsion containing egg white and purified menhaden oil; G'=storage modulus; G''=loss modulus.

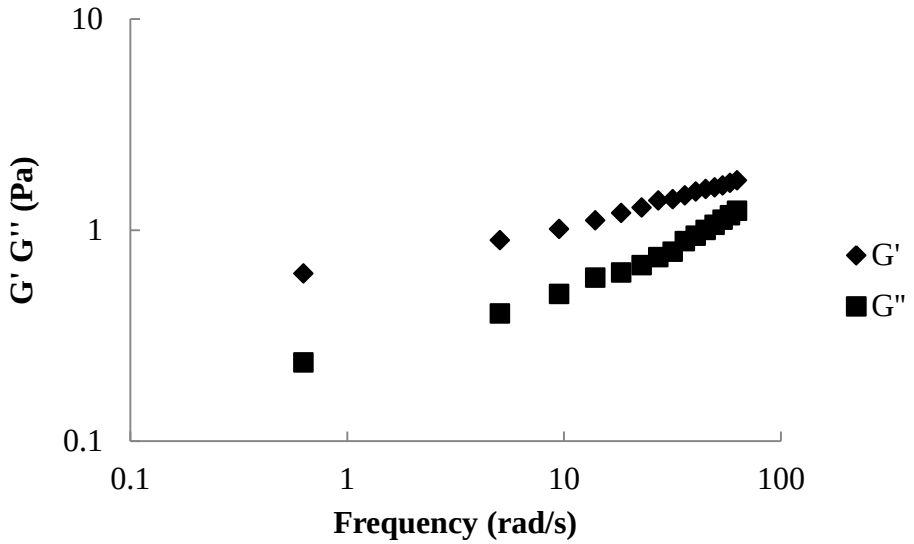

Figure 4.6 Viscoelastic properties of E-SO-EW.
E-SO-EW = emulsion containing egg white and refined salmon oil; G'=storage modulus; G''=loss modulus.

It is reported that in an oil-in water (o/w) emulsion system made with corn oil, egg white and water; ovalbumin was key egg white protein responsible for the emulsion stability (Drakos & Kiosseoglou, 2006). The ovalbumin molecule has four cysteine residues and one disulfide bridge. After adsorption to air-water interfaces, ovalbumin molecules unfold and rearrange; this exposes hydrophobic and sulfur amino acids. Strong droplet aggregate formation may be the result of hydrophobic interactions between the oil droplets and the unfolded protein molecules; which will interact through hydrophobic and sulfide bonds (Doi & Kitabatake, 1997).

4.5 Spray Drying of E-EW, E-MO-EW, and E-SO-EW

The estimated production rates for egg white powders containing fish oils ranged from 0.056 to 0.062 (kg dry solids/h) and the actual production rates ranged from 0.056 to 0.060 kg dry solids/h (Table 4.8). It was observed that the actual production rates were lower than the estimated production rates. This may be the result of the retention of the powder particles in dryer chamber wall, pipes, joints and cyclone separator walls.

Table 4.8 Data for the estimation of the production rate of egg white powders*

		Moisture content (wet basis, %)	Moisture content (dry basis, kg water/kg dry solids)	Mass flow rate x 10^{-3} (kg/h)	Mass flow rate x 10^{-3} (dry basis, kg dry solids/h)	Estimated production rate x 10^{3} (kg dry solids/h)
E-EW		89.41±0.02	8.44±0.01	685.00±20.00	72.56±0.10	
	Powder	7.59±0.27[a]	0.08±0.00	59.55±0.63	55.88±0.16[B]	61.88±0.10[A]
DEW-130	Dust	7.16±0.02	0.08±0.00	11.51±0.55	10.68±0.00	
	Powder	5.88±0.20[b]	0.06±0.01	59.19±1.10	56.91±0.32[B]	61.26±0.11[A]
DEW-140	Dust	6.22±0.04	0.07±0.00	13.15±1.10	11.31±0.01	
	Powder	5.10±0.03[c]	0.05±0.00	60.28±1.10	58.36±0.07[B]	61.25±0.11[A]
DEW-150	Dust	6.18±0.04	0.07±0.00	13.15±1.10	11.31±0.01	
E-MO-EW		89.41±0.02	8.44±0.01	674.33±4.04	71.43±0.49	
	Powder	6.25±0.12[a]	0.07±0.00	58.82±1.14	55.53±1.04[B]	60.24±0.86[A]
MO-EW-130	Dust	7.16±0.02	0.08±0.00	12.06±0.55	11.19±0.51	
	Powder	5.52±0.30[b]	0.06±0.01	59.19±1.64	56.91±1.75[A]	58.76±1.54[A]
MO-EW-140	Dust	6.22±0.04	0.07±0.00	13.52±1.38	12.68±1.29	
	Powder	5.18±0.11[c]	0.06±0.00	62.66±2.21	60.66±2.15[A]	61.13±0.53[A]
MO-EW-150	Dust	6.18±0.04	0.07±0.00	12.24±1.38	10.63±0.59	
E-SO-EW		89.41±0.02	8.44±0.01	653.33±10.41	69.21±1.01	
	Powder	6.15±0.14[a]	0.07±0.00	58.82±1.14	55.53±1.04[B]	58.08±1.43[A]
SO-EW-130	Dust	7.16±0.02	0.08±0.00	11.94±0.79	11.19±0.51	
	Powder	5.67±0.11[b]	0.06±0.01	59.19±1.64	56.91±1.75[A]	57.26±1.74[A]
SO-EW-140	Dust	6.22±0.04	0.07±0.00	13.52±1.38	11.94±0.79	
	Powder	5.04±0.16[c]	0.05±0.00	60.66±2.21	58.66±2.15[A]	58.93±1.01[A]
SO-EW-150	Dust	6.18±0.04	0.07±0.00	10.96±0.38	10.28±0.29	

*Values are means ± SD of triplicate determination. Estimated powder production rate included both powder collected through collector vessel and product stored on the cambers, pipes, joints and chamber walls. [abc]Means with same letter in each column are not significantly different ($p<0.05$). [AB]Means with same letter in each row are not significantly different. DEW-130= E-EW spray dried at 130°C, DEW-140= E-EW spray dried at 140°C, DEW-150= E-EW spray dried at 150°C, MO-EW-130= E-MO-EW spray dried at 130°C, MO-EW-140= E-MO-EW spray dried at 140°C , MO-EW-150= E-MO-EW spray dried at 150°C, SO-EW-130= E-SO-EW spray dried at 130°C, SO-EW-140= E-SO-EW-140 spray dried at 140°C, SO-EW-150 = E-SO-EW spray dried at 150°C.

Table 4.9 Summary of inlet air conditions for spray drying the E-EW, E-MO-EW, and E-SO-EW***

Parameter	DEW-130	DEW-140	DEW-150	MO-EW-130	MO-EW-140	MO-EW-150	SO-EW-130	SO-EW-140	SO-EW-150
Ambient air temperature (AAT) (°C)	23.43±0.38	21.80±0.53	20.80±0.44	23.43±0.38	21.80±0.53	20.80±0.44	23.43±0.38	21.80±0.53	20.80±0.44
Inlet air velocity (km/h)	76.56±0.81	75.24±1.22	75.44±0.09	74.56±0.37	72.91±0.74	75.44±0.09	72.23±0.63	71.56±0.20	71.62±0.11
Internal pipe diameter (m)	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
Volumetric flow rate inlet air (m^3/h)	69.51±0.74	68.31±1.11	68.49±0.08	67.70±0.34	66.19±0.67	68.49±0.08	65.58±0.57	64.97±0.18	65.03±0.10
Relative humidity of inlet air (%)	44.83±0.85	49.87±0.35	49.33±0.40	44.83±0.85	49.87±0.35	49.33±0.40	44.83±0.85	49.87±0.35	49.33±0.40
Partial pressure exerted by water vapor at the inlet point (kPa)	1.34±0.03	1.31±0.01	1.23±0.01	1.34±0.03	1.31±0.01	1.23±0.01	1.34±0.03	1.31±0.01	1.23±0.01
Saturation pressure of water vapor at the inlet point (kPa)*	2.99	2.62	2.49	2.99	2.62	2.487	2.99	2.62	2.49
Absolute humidity x 10^{-3} of inlet air (kg water/kg dry air)	8.33±0.16	8.12±0.06	7.62±0.06	8.33±0.16	8.12±0.06	7.62±0.06	8.33±0.16	8.12±0.06	7.62±0.06
Specific volume of inlet air (m^3/kg dry air)	0.85±0.00	0.84±0.00	0.84±0.00	0.85±0.00	0.84±0.00	0.84±0.00	0.85±0.00	0.84±0.00	0.84±0.00
Mass flow rate of inlet air (kg dry air/h)	81.79±0.94	80.84±1.18	81.40±0.16	79.65±0.29	78.34±0.66	81.40±0.16	77.16±0.67	76.89±0.24	77.28±0.03
Specific heat of dry air at AAT (kJ/kg K)*	1.0124	1.0122	1.0121	1.0124	1.0122	1.0121	1.0124	1.0122	1.0121
Specific heat of water vapor at AAT (kJ/kg K)**	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88
Temperature of drying inlet air (K)	403.00±2.60	413±2.00	423±1.50	403.00±3.00	413.00±2.00	423±1.50	403±3.00	413±2.00	423±1.50

*Obtained from appendix A 4.2 and A 4.4, respectively (Singh and Heldman 2001).

** Selected as 1.88 kJ/(kg K) according to Singh and Heldman (2001).

***Values are means ± SD of triplicate determination. See Table 4.8 for a brief description of DEW-130, DEW-140, DEW-150, MO-EW-130, MO-EW-140, MO-EW-150, SO-EW-130, SO-EW-140, and SO-EW-150.

Table 4.10 Summary of outlet air conditions for spray drying the E-EW, E-MO-EW, and E-SO-EW[a]

Parameter	DEW-130	DEW-140	DEW-150	MO-EW-130	MO-EW-140	MO-EW-150	SO-EW-130	SO-EW-140	SO-EW-150
Outlet air temperature (°C)	62.60±0.70	63.5±0.51	67.1±0.55	62.60±0.70	63.50±0.51	67.10±0.55	62.6±0.70	63.50±0.51	67.10±0.55
Outlet air velocity (km/h)	19.50±0.36	19.2±0.06	19.7±0.05	19.1±0.06	18.9±0.05	19.7±0.05	18.50±0.14	18.40±0.04	18.9±0.05
Internal pipe diameter (m)	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
Volumetric flow rate of outlet air (m^3/h)	79.57±1.45	78.25±0.23	80.01±0.20	77.73±0.23	76.95±0.20	80.01±0.20	75.51±0.55	74.87±0.15	76.75±0.20
Relative humidity of outlet air (%)	11.0±0.06	10.60±0.15	8.7±0.03	11.1±0.06	10.60±0.15	8.7±0.03	11.1±0.06	10.7±0.03	8.7±0.03
Partial pressure exerted by water vapor (kPa)	2.49±0.01	2.50±0.04	2.41±0.01	2.50±0.01	2.50±0.04	2.41±0.01	2.50±0.01	2.51±0.01	2.40±0.01
Saturation pressure of water vapor (kPa)*	22.59	23.5	27.62	22.56	23.5	27.62	22.59	23.503	27.62
Absolute humidity x 10^{-3} (kg water/kg dry air)	15.69±0.08	15.73±0.23	15.14±0.05	15.73±0.08	15.73±0.23	15.14±0.05	15.73±0.08	15.81±0.04	15.08±0.05
Specific volume of outlet air (m^3/kg dry air)	0.97±0.00	0.98±0.00	0.99±0.00	0.97±0.00	0.98±0.00	0.99±0.00	0.97±0.00	0.98±0.00	0.99±0.00
Mass flow rate of outlet air (kg dry air/h)	81.75±1.63	80.16±0.36	81.17±0.33	79.84±0.33	78.83±0.15	81.17±0.33	77.57±0.42	76.69±0.27	77.87±0.31

[a] Values are means ± SD of triplicate determination.

*Obtained from appendix A 4.2 and A 4.4, respectively (Singh and Heldman 2001).

See Table 4.8 for a brief description of DEW-130, DEW-140, DEW-150, MO-EW-130, MO-EW-140, MO-EW-150, SO-EW-130, SO-EW-140, and SO-EW-150.

The moisture content of the resulting powders was affected by the air inlet temperature; emulsions spray dried at a 150°C inlet air temperature produced powders with significantly ($P<0.05$) lower moisture content compared to those powders produced at a 130 and 140°C inlet air temperature. A number factors including inlet and outlet temperatures of the air (Masters, 1991), evaporation rate (Goula & Adamopoulos, 2005), and droplet size (Obón *et al.*, 2009) may influence the moisture content of spray dried food powders. The summary of the inlet and outlet air conditions for spray drying E-EW, E-MO-EW, and E-SO-EW are presented in Tables 4.9 and 4.10.

The estimated evaporation rate based on moisture uptake by the dry air was the same as the evaporation rate estimated based on the moisture content of the powders and dust for each individual emulsion at each of the drying (inlet) temperatures (Table 4.11). According to Goula & Adamopoulos (2005), the evaporation rate is affected by the inlet temperature and the dryness of the air; however, in this study the average evaporation rate was not significantly affected by the inlet air temperature. It is reported that the evaporation of water during spray drying occurs in two stages. Because most of the water is removed from the emulsion droplets in the first stage; it shows a higher evaporation rate than that of the second moisture evaporation stage (Keey & Pham, 1976). In this study, the methods used to estimate the evaporation rate was an average of both stages, therefore, an average evaporation rate was calculated and differences were not observed. The experimentally determined dry air mass flow rate of the inlet air and outlet air were similar; this indicated that the technique, instrumentation and measurements used to calculate air flow rates were accurate.

The energy used to heat the air in the spray drier for E-EW, E-MO-EW, and E-SO-EW was significantly ($P<0.05$) higher at 150 °C (Table 4.11). The required power (kJ) to spray dry an

amount (kg) of emulsion is the energy required (kJ/kg) to heat the air to spray dry the same amount of emulsion (kg) in a given time (s). The required power was determined as 1.70, 1.87, and 2.05 kW for spray drying E-EW at 130, 140, and 150°C, respectively. Furthermore, the required power for spray drying E-MO-EW at 130, 140, and 150°C was estimated as 1.63, 1.78, and 2.02 kW, respectively. Meanwhile, the required power for spray drying E-SO-EW at 130, 140, and 150°C of inlet ambient was calculated as 1.54, 1.70, and 1.87 kW, respectively. The heat energy for heating the ambient air was generated by an electric heater. The power requirements in this study were well within the available power of the electric heater (4.5 kW) of the FT80/81 Tall Form spray dryer (Spray dryer manual, Armfield, Ringwood, UK).

Table 4.11 Estimated evaporation rates and energy used to spray dry E-EW, E-MO-EW, and E-SO-EW*

	Inlet temp. (°C)	**E-EW**	**E-MO-EW**	**E-SO-EW**
Evaporation rate (kg water/h)[1]	130	0.601±0.040 ^{aA}	0.593±0.015 ^{aA}	0.578±0.008 ^{aA}
	140	0.604±0.018 ^{aA}	0.603±0.021 ^{aA}	0.587±0.004 ^{aA}
	150	0.608±0.004 ^{aA}	0.608±0.004 ^{aA}	0.585±0.012 ^{aB}
Evaporation rate (kg water/h)[2]	130	0.608±0.00 ^{bA}	0.598±0.00 ^{aA}	0.580±0.009 ^{aB}
	140	0.609±0.00 ^{aA}	0.600±0.003 ^{aA}	0.581±0.010 ^{aB}
	150	0.610±0.00 ^{aA}	0.600±0.004 ^{aA}	0.581±0.009 ^{aB}
Energy required to heat the air in the spray drier (kJ/kg)	130	8958.75±103.36^{cA}	8724.64±31.86 ^{cB}	8451.64±73.02 ^{cC}
	140	9818.38±143.38^{bA}	9513.95±79.89 ^{bB}	9338.32±28.89 ^{bB}
	150	10794.24±20.56^{aA}	10794.24±20.56 ^{aA}	10248.13±4.22 ^{aB}

*Values are means ± SD of triplicate determination. [1]Calculated based on the moisture uptake by the dry air (kg water/h). [2]Calculated based on the moisture content of the E-EW/E-MO-EW/E-SO-EW emulsions, powder collected through collector vessel, and dust (kg water/h). ^{abc}Means with same letter in each column are not significant different ($p<0.05$). ^{ABC}Means with same letter in each row are not significant different ($p<0.05$). See Table 4.4 for brief description of E-EW, E-MO-EW and E-SO-EW.

4.6 Microencapsulation Efficiency (ME) and Color Values of Egg White Powders

The results of surface oil (OS) are presented in Table 4.12. The OS of the microencapsulated powders was around 0.89 (g/g powder) regardless of the inlet air temperature.

Table 4.12 Color of and ME of DEW, MO-EW, and SO-EW*

	Inlet Temp (°C)	DEW	MO-EW	SO-EW
OS (g/g powder)	130	-	0.089 ± 0.001^{aA}	0.089 ± 0.002^{aA}
	140	-	0.089 ± 0.001^{aA}	0.089 ± 0.001^{aA}
	150	-	0.089 ± 0.002^{aA}	0.089 ± 0.002^{aA}
OT (g/g powder)	130	-	0.32 ± 0.001^{aA}	0.32 ± 0.003^{aA}
	140	-	0.32 ± 0.002^{aA}	0.32 ± 0.002^{aA}
	150	-	0.32 ± 0.001^{aA}	0.32 ± 0.002^{aA}
Microencapsulation Efficiency (ME) (%)	130	-	72.26 ± 1.57^{aA}	72.03 ± 1.59^{aA}
	140	-	72.32 ± 1.56^{aA}	72.62 ± 1.36^{aA}
	150	-	72.96 ± 1.43^{aA}	72.80 ± 1.33^{aA}
L*	130	92.61 ± 0.02^{bB}	94.24 ± 0.02^{aA}	90.71 ± 0.01^{bC}
	140	91.86 ± 0.01^{cA}	89.39 ± 0.01^{cB}	85.32 ± 0.00^{cC}
	150	92.54 ± 0.01^{aA}	93.16 ± 0.02^{bB}	90.92 ± 0.01^{aC}
a*	130	-0.69 ± 0.00^{bC}	-0.20 ± 0.01^{aB}	2.09 ± 0.01^{aA}
	140	-1.00 ± 0.01^{cB}	-1.07 ± 0.02^{cC}	-0.77 ± 0.01^{cB}
	150	-0.43 ± 0.01^{aB}	-0.88 ± 0.03^{bC}	1.14 ± 0.02^{bA}
b*	130	10.42 ± 0.03^{cC}	12.38 ± 0.03^{bB}	16.10 ± 0.03^{aA}
	140	15.25 ± 0.03^{aA}	11.88 ± 0.03^{cC}	13.42 ± 0.01^{bB}
	150	12.19 ± 0.03^{bC}	14.74 ± 0.05^{aA}	12.42 ± 0.03^{cB}
Chroma	130	10.44 ± 0.03^{cC}	12.38 ± 0.03^{bB}	16.24 ± 0.02^{aA}
	140	15.28 ± 0.03^{aA}	11.93 ± 0.03^{cC}	13.44 ± 0.01^{bB}
	150	12.20 ± 0.03^{bC}	14.76 ± 0.05^{aA}	12.48 ± 0.03^{cB}
Hue	130	93.81 ± 0.02^{aA}	90.94 ± 0.07^{cB}	82.61 ± 0.05^{cC}
	140	93.75 ± 0.03^{aB}	95.16 ± 0.06^{aA}	93.30 ± 0.02^{aC}
	150	92.02 ± 0.04^{bB}	93.40 ± 0.11^{bA}	84.77 ± 0.08^{bC}

*Values are means ± SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p< 0.05$). ^{ABC} means with different letters in each row are significantly different ($p< 0.05$). DEW= egg white powder, MO-EW=egg white powder containing purified menhaden oil, SO-EW= egg white powder containing refined salmon oil. OS= surface oil content; OT= total oil content; - = not quantified.

Surface oil, also known as non-encapsulated oil, is usually prone to oxidation and developing off-flavors that may affect the acceptability of the product (Drusch & Berg, 2008). The results for microencapsulation efficiency (ME) are detailed in Table 4.12. It was observed that the ME of MO-EW, and SO-EW powders was the same regardless of the inlet air temperature. Microencapsulated efficiency is a relationship between the encapsulated oil and the total lipid content of the food powder. Microencapsulated efficiency was 72.26, 72.32, and 72.96

for MO-EW powders obtained at 130, 140, and 150°C of inlet air temperature; meanwhile, the ME (%) of SO-EW powders spray dried at 130, 140, and 150°C of inlet air temperature was 72.03, 72.62, and 72.80, respectively. Color values of DEW, MO-EW, and SO-EW powders are shown in Table 4.12. All the powders were whitish in color. MO-EW and SO-EW presented slightly higher values of yellowness that that of DEW powders, this might be the result to the presence of MO and SO.

4.7 FAMEs Composition and Lipid Oxidation of Egg White Powders

The FAMEs composition of MO-EW and SO-EW powders are presented in Table 4.13. The FAMEs composition was not determined in DEW powders because they contained significantly ($P<0.05$) lower total lipids than MO-EW, and SO-EW powders.

The EPA, DHA, total omega-3, and polyunsaturated fatty acids content in MO-EW and SO-EW were similar to MO and SO values (Table 4.13). Hence, the spray drying procedure did not have any effect on the FAMEs composition of MO and SO. Degradation of fatty acids has been related to fatty acid oxidation and acidification (Pereda *et al.,* 2008).

The formation of FFA and TBARS content after the spray drying procedure in DEW, MO-EW, and SO-EW are shown in Table 4.14. The spray drying procedure increased the FFA (%) content in MO-EW and SO-EW regardless of the inlet air temperature. Additionally, the TBARS values in MO-EW and SO-EW powders were higher than those values of the emulsions (Table 4.4); this may be the result of the of production of secondary lipid oxidation compounds that arise from the decomposition of fatty acid hydroperoxides during processing (Damodaran *et al.,* 2008). Moreover, the formation of TBARS was significantly ($P<0.05$) lower at 130°C compared to those of 140 and 150°C of inlet air temperature. Baik *et al.,* (2004), Boon *et al.,* (2008) and Klinkesorn *et al.,* (2005) have reported that with increasing time and temperature, the formation of TBA in microencapsulated oil powders is also increased.

Table 4.13 FAMEs composition of MO-EW and SO-EW powders (% of total integrated area)*

FAME	MO-EW			SO-EW		
	Inlet temperature (°C)			Inlet temperature (°C)		
	130	140	150	130	140	150
14:0	9.15±0.16	9.08±0.18	9.12±0.20	4.78±0.08	4.85±0.09	4.76±0.10
16:0	21.23±0.50	21.24±0.0.32	21.24±0.40	10.12±4.07	10.01±2.03	9.98±1.65
16:1n7	11.38±0.05	11.21±0.06	11.39±0.07	3.71±2.91	3.65±0.87	3.60±0.67
18:0	3.86±0.09	3.82±0.09	3.88±0.07	2.09±0.01	2.14±0.01	2.11±0.02
18:1n9c	6.11±0.04	6.07±0.09	6.08±0.06	12.18±0.11	12.17±0.09	12.18±0.10
18:1n5	3.03±0.02	3.08±0.04	3.05±0.05	2.70±0.02	2.74±0.01	2.71±0.05
18:2n6c	1.48±0.01	1.42±0.02	1.49±0.03	1.50±0.02	1.51±0.01	1.48±0.03
18:3n3	1.62±0.04	1.72±0.05	1.66±0.05	1.26±0.01	1.29±0.02	1.23±0.01
20:5n3 (EPA)	13.41±0.05	13.44±0.07	13.45±0.09	11.29±0.18	11.27±0.20	11.28±0.21
22:6n3 (DHA)	12.87±0.17	12.78±0.12	12.85±0.15	11.07±0.09	11.14±0.10	11.09±0.10
ω-3 total	32.35±0.40	32.40±0.42	32.42±0.35	23.38±0.26	23.28±0.29	23.14±0.35
ω-6 total	2.55±0.01	2.56±0.02	2.59±0.02	1.58±0.08	1.62±0.09	1.52±0.10
SAFA	50.20±0.77	51.34±0.61	50.76±0.96	32.79±3.02	33.05±2.65	33.15±2.85
MUFA	12.02±0.07	12.85±0.12	12.02±0.13	11.13±2.69	10.96±2.70	10.98±2.82
PUFA	34.94±0.43	35.02±0.48	35.12±0.51	51.04±0.18	50.98±0.22	50.94±0.24
ω-3 / ω-6	12.70±0.22	12.66±0.23	12.59±0.21	3.34±0.03	3.34±0.05	3.35±0.05
P/S	0.67±0.03	0.67±0.04	0.65±0.03	1.54±0.12	1.54±0.10	1.54±0.13

*Values are means ± SD of triplicate determination. See Table 3.8 for a brief description of MO-EW-130, MO-EW-140, MO-EW-150, SO-EW-130, SO-EW-140, and SO-EW-150. FAMEs compositions of DEW powders were not determined.

Table 4.14 FFA and TBARS of MO-EW, and SO-EW powders*

	FFA (%)	TBARS (mmol/kg oil)
MO-EW-130	0.30±0.03[a]	0.12±0.00[b]
MO-EW-140	0.27±0.04[a]	0.14±0.00[a]
MO-EW-150	0.29±0.04[a]	0.14±0.00[a]
SO-EW-130	0.35±0.05[a]	0.11±0.00[b]
SO-EW-140	0.38±0.06[a]	0.12±0.00[a]
SO-EW-150	0.39±0.06[a]	0.12±0.00[a]

*Values are means ± SD of triplicate determination. [ab] means with different letters in each column are significantly different ($p < 0.05$).

4.8 Crude Protein, Total Lipids, Ash and Water Activity (a_w) of DEW, MO-EW, and SO-EW Powders

Crude protein, total lipids, ash, and a_w of egg white powders are presented Table 4.15. MO-EW and SO-EW powders had lower crude protein content than the control (DEW). The

recommend daily allowance (RDA) for protein in the USA is 0.8 to 0.9 g/kg body weight/day (National Research Council, 1989). Athletes performing dynamic exercise requires from 1.2 to 1.8 g protein/kg body weight/day (Lemon, 1991a). Meanwhile, athletes performing resistance exercise may require from 1.5 to 2.5 g protein/kg body weight/day (Lemon, 1991b). According to Brounds (1993), athletes may require some protein supplementation to complete their protein requirements per day to retain normal nitrogen balance and to decrease impairment in training status. Milk protein, milk protein hydrolysates, whey protein and caseinates have been used for athletes as protein supplementation due to their low fat, and cholesterol free content. A 50 g of MO-EW of SO-EW powders contained more than 30 g of protein which could be used for athletes as alternative protein supplementation.

MO-EW and SO-EW powders had greater total lipid content than that of DEW powders. This result was expected since the experimental MO-EW and SO-EW were formulated to have around 30% total lipid content. Moreover, the inlet temperature did not affect the total lipid content in DEW, MO-EW, and SO-EW powders. It has been reported that polyunsaturated fatty acids has an influence on the structure of the membranes of red blood cells. Dietary omega-3 PUFA increases red blood cell plasticity, maximal oxygen consumption and better blood oxygen levels in subjects exercising at altitude (Guezennec *et al.*,1991).

Ash content in DEW powders was significantly ($P<0.05$) greater than those of MO-EW and SO-EW powders. The USDA reported proximate composition of dried egg white as 86.01, 0.00, and 5.6 g/100 g, dry basis of protein, total lipid, and ash content, respectively (USDA, 2009b).

Water activity (a_w) measures the available free water in food that is necessary for biochemical reactions to proceed and is an important index to determine food stability, safety, microbial growth, and other properties (Damodaran *et al*., 2008). The powder produced at the

inlet temperature of 130°C had significantly (P<0.05) higher water activity than those produced at 140 or 150°C (Table 4.15). Normally food is considered microbiologically stable if the water activity is less than 0.6 (Quek *et al.*, 2007), and no microbial proliferation is reported at a_w below 0.5 (Beuchat, L.R., 1981). In this study all egg white powders showed a a_w below 0.4; hence, they were microbiologically stable.

Table 4.15 Crude protein, total lipids, ash content and a_w of DEW, MO-EW, and SO-EW*

	Inlet Temp (°C)	DEW	MO-EW	SO-EW
Crude protein (g/100 g, dry basis)	130	88.30 ± 2.35^{aA}	64.73 ± 1.85^{aB}	65.10 ± 1.63^{aB}
	140	88.08 ± 1.89^{aA}	64.75 ± 1.68^{aB}	64.54 ± 1.59^{aB}
	150	88.80 ± 2.07^{aA}	64.70 ± 1.53^{aB}	63.90 ± 1.45^{aB}
Total lipids (g/100 g, dry basis)	130	2.06 ± 0.05^{aB}	32.27 ± 0.13^{aA}	32.06 ± 0.35^{aA}
	140	2.11 ± 0.04^{aB}	32.09 ± 0.17^{aA}	32.48 ± 0.24^{aA}
	150	2.15 ± 0.04^{aB}	32.33 ± 0.09^{aA}	32.48 ± 0.22^{aA}
Ash (g/100 g, dry basis)	130	6.21 ± 0.04^{aA}	5.58 ± 0.09^{abB}	5.54 ± 0.05^{aB}
	140	5.92 ± 0.09^{bA}	5.67 ± 0.05^{aB}	5.43 ± 0.01^{aC}
	150	$6.03\pm0.18a^{bA}$	5.39 ± 0.16^{bB}	5.58 ± 0.20^{aAB}
Water activity (a_w)	130	0.350 ± 0.003^{aA}	0.270 ± 0.002^{aB}	0.269 ± 0.001^{aB}
	140	0.302 ± 0.007^{bA}	0.271 ± 0.002^{aB}	0.212 ± 0.002^{bC}
	150	0.207 ± 0.002^{cB}	0.259 ± 0.003^{bA}	0.210 ± 0.002^{bB}

*Values are means ± SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p< 0.05$). ^{ABC} means with different letters in each row are significantly different ($p< 0.05$). DEW= egg white powder, MO-EW=egg white powder containing purified menhaden oil, SO-EW= egg white powder containing refined salmon oil.

4.9 Amino Acid and Mineral Content of DEW, MO-EW, and SO-EW

DEW, MO-EW, and SO-EW contained all the essential amino acids (EAA) including Leucine (Table 4.16). Total essential amino acids (TEAA) content (mg/g protein) of DEW powders was similar than those of MO-EW and SO-EW powders. Furthermore, it was observed that the inlet air temperature did not have any effect in the amino acid profile of DEW, MO-EW, and SO-EW powders. Even though, cysteine and tryptophan were not quantified in this study due

to economical issues, AEB (1999) have reported that egg white has a cysteine and tryptophan content (mg/g protein) of 25.90 and 12.24, respectively.

According to Damodaran *et al.,* (2008), denaturation is a phenomenon wherein a well-defined initial state of protein formed under physiological conditions is transformed into an ill-defined final state under nonphysiological conditions by a denaturing agent such heat; however, it doesn't involve any chemical changes in the protein structure. Even though, egg white proteins may have undergone denaturation by heat, their amino acid profiles remain the same.

Leucine was the main EAA found in DEW, MO-EW, and SO-EW powders followed by valine and phenylalanine. According to Tarnopolsky (2004) human skeletal muscle can oxidize at least eight amino acids (alanine, asparagine, aspartate, glutamate, isoleucine, leucine, lysine and valine); nevertheless, during exercise, the branched-chain amino acids (BCAA; isoleucine, leucine, and valine) are preferentially oxidized. It has been reported that an increase in lysine oxidation occurs during endurance exercise at high intensities (Wagenmakers *et al.*, 1991), and muscle recovery from exercise has been associated with dietary leucine (Layman & Rodriguez, 2009). DEW, MO-EW, and SO-EW powders would be expected to improve athletes' performances due to their amino acid content. Potassium, magnesium and phosphorus were the main minerals found in DEW, MO-EW, and SO-EW powders (Table 4.17). DEW powders contained greater amounts of phosphorus, potassium, calcium, and magnesium than those of MO-EW and SO-EW powders. These results can also be associated to the dilution effect observed in the TEAA due to the addition of MO or SO. In addition, all of the egg white powders were a good source of copper, which is an essential trace element needed in energy metabolism, tissue synthesis and protection against free radicals (Brounds, 1993).

Potassium is an important element needed for the transmission of nerve impulses, muscle cell contraction, and maintenance of normal blood pressure. During exercise, potassium is lost from the muscle cell in the urine and in sweat because of the damage of the muscle cells during mechanical stress; therefore, an additional potassium intake is needed for individuals under high intensity exercise (Brounds, 1993). Magnesium in a mineral required for biosynthetic processes, energy metabolism, and in neuromuscular transmission and activity. Low magnesium disposal causes impaired energy metabolism, greater fatigue and the occurrence of muscle cramps (Clarkson, 1991). It is reported that phosphorus and calcium are essential elements for bone formation. Calcium plays a key role at the beginning of muscle contraction; while phosphorus is an important element in enzymes as well as in energy metabolism (Brounds, 1993).

Table 4.16 Amino-acid composition of DEW, MO-EW, and SO-EW*

Amino acid (mg/g protein)	DEW			MO-EW			SO-EW		
	Inlet Temp. (°C)			Inlet Temp. (°C)			Inlet Temp. (°C)		
	130	140	150	130	140	150	130	140	150
Aspartic acid	104.83	105.33	103.61	104.67	105.12	105.79	105.86	106.46	104.21
Threonine[a]	47.57	47.16	47.79	47.00	47.03	46.97	45.98	47.04	46.43
Serine	72.97	71.56	73.20	73.09	71.42	72.60	71.42	72.11	72.24
Glutamic acid	108.25	111.25	103.07	111.22	108.82	109.39	114.01	109.69	108.56
Proline	37.09	36.84	36.94	35.92	34.93	34.81	35.25	35.00	34.55
Glycine	32.25	32.29	32.49	32.18	31.91	31.79	31.66	31.92	31.54
Alanine	57.25	57.62	57.82	57.50	56.78	56.54	56.73	56.53	56.29
Valine[a]	70.76	71.08	70.38	70.36	70.21	70.32	71.14	70.98	70.31
Methionine[a]	42.13	42.15	42.35	41.30	41.39	41.10	41.32	41.19	41.13
Isoleucine[a]	55.44	55.39	55.74	54.59	54.56	54.30	54.58	54.74	54.49
Leucine[a]	93.94	93.61	94.25	92.71	92.25	92.46	91.81	92.24	91.92
Tyrosine[a]	44.35	44.56	45.08	43.28	44.24	43.51	42.58	42.87	43.23
Phenylalanine[a]	67.73	67.58	67.95	66.73	66.58	66.31	66.22	66.38	66.33
Histidine[a]	25.80	25.65	25.90	25.51	25.80	25.60	25.31	25.67	25.37
Lysine[a]	64.71	63.30	66.63	65.43	64.47	65.08	62.76	65.92	65.64
Arginine	63.90	63.77	64.66	63.12	63.00	63.51	62.33	62.82	63.54
TEAA	512.43	510.46	516.07	506.91	506.52	505.63	501.69	507.03	504.86
TAA	988.98	989.11	987.87	984.61	978.51	980.06	978.96	981.56	975.79

*Values are means of triplicate determinations. See table 4.15 for brief description of DEW, MO-EW, and SO-EW. TEAA= total essential amino acids. TAA= Total amino acid. [a] Essential amino acid.

**Cysteine and Tryptophan were not determined.

Table 4.17. Mineral profile of egg white powders*

	DEW			MO-EW			SO-EW			Recommended dietary allowance for mineral (mg/day)[a]
	Inlet Temp. (°C)			Inlet Temp. (°C)			Inlet Temp. (°C)			
	130	140	150	130	140	150	130	140	150	
P (g/100 g powder)	0.07	0.08	0.07	0.06	0.06	0.05	0.04	0.06	0.07	800/1400
K (g/100 g powder)	1.18	1.24	1.21	0.98	1.05	0.94	1.03	0.93	0.88	2000/3500
Ca (g/100 g powder)	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	800/900
Mg (g/100 g powder)	0.08	0.08	0.07	0.06	0.07	0.06	0.07	0.07	0.07	350/350
Cu (mg/100 g powder)	1.15	1.31	1.19	0.49	0.66	0.58	0.65	0.68	0.55	1.5/3.0
Zn (mg/100 g powder)	<1	<1	<1	<1	<1	<1	<1	<1	<1	10/15
Mn (mg/100 g powder)	<1	<1	<1	1	<1	1	<1	1	<1	
Fe (mg/100 g powder)	<1	8	4	<1	<1	<1	<1	<1	<1	12/12

*Values are means of triplicate determinations. See Table 4.8 for a brief description of EW-130, EW-140, EW-150, MO-EW-130, MO-EW-140, MO-EW-150, SO-EW-130, SO-EW-140, and SO-EW-150.

[a]Compiled from Brounds (1993) for male athletes from 25 to 50 years old.

4.10 SEM and Particle Size Distribution of EW, MO-EW, and SO-EW Powders

Analysis of the microstructure of the spray-dried egg white powder particles was carried out with a three-dimensional characterization through SEM. Figure 4.7 presents the photomicrographs of the particles of DEW, MO-EW, and SO-EW powders obtained by electronic microscopy. It was observed that DEW powders did not have spherical microcapsules; this might be due to the lack of core material (fish oil). Higher shrinkage was observed in MO-EW-150 and in SO-EW-150 than other MO and SO microencapsulated at 130 and 140 ^{o}C. This might be explained with moisture transport during the falling rate period (Walton, 2000). At the constant rate, the rate of water diffusion from the inside of particle to its surface is equal to the surface evaporation rate; once the droplet reaches a critical moisture content, a dry crust is formed at the feed droplet surface and the drying rate quickly decreases. The particles could tend to voids inflate and break when evaporation occurs at higher temperatures during the falling rate period (Oakley, 1997; Rosenberg, 1988; Gharsallaoui *et al.*, 2007).

Huang *et al.,* (2006) have reported that low inlet air temperatures cause low evaporation rates and produce powders with high moisture contents, and agglomerated powder particles; meanwhile, high air inlet temperature causes excessive evaporation and produce low quality powders.

The particle size of DEW, MO-EW, and SO-EW powders ranged from 10 to 40 µm (Figures 4.8, 4.9 and 4.10). Most of the powder particles fall in the size range around 20 to 30 µm. Similar results have reported by Kagami *et al.,* (2003) on the microencapsulation of fish oil by spray drying using protein and dextrin wall materials; moreover, the microencapsulated fish oil powder particle size is not affected by type of wall material and oil loading rate. It was also observed that

the addition of MO or SO didn't affect the particle size of EW regardless of the inlet air temperature. According to AIChE Equipment Testing Procedure (2003), particle size of spray dried powders depends on the spray drying operation conditions such as feed temperature, air inlet temperature, and air outlet temperature; meanwhile, Hogan *et al.*, (2001) have reported that that the particle size of spray dried powders increases with the increasing of total solids content and /or apparent viscosity of the feed.

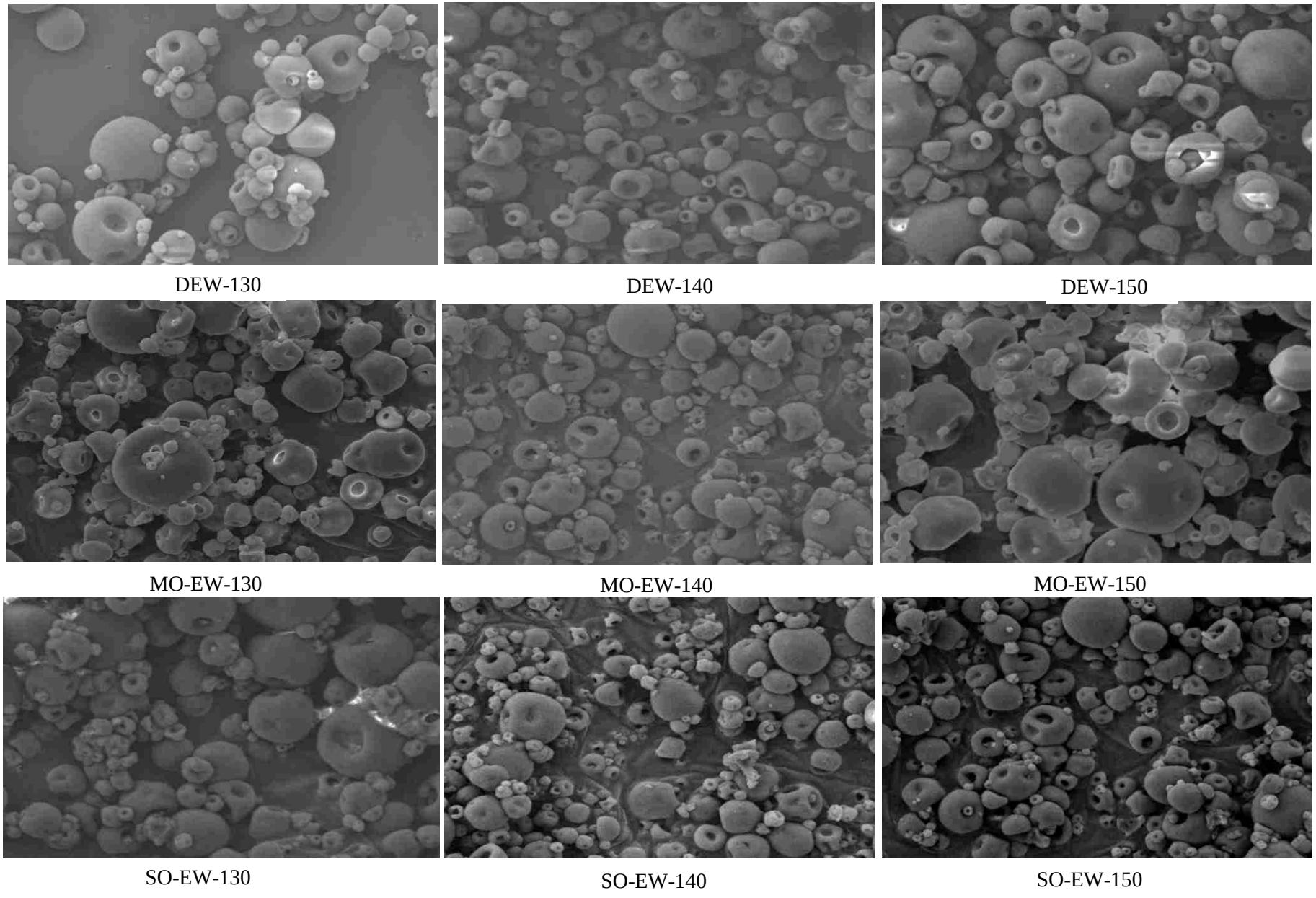

Figure 4.7 Scanning electron microscopy of the egg white powders.

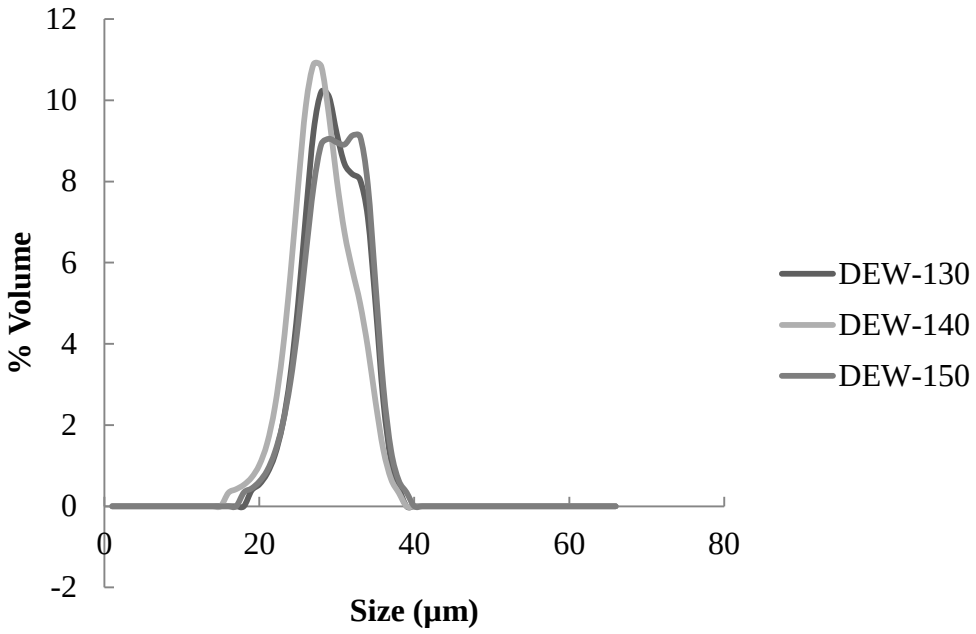

Figure 4.8 Particle size distribution of DEW-130, DEW-140, and DEW-150.

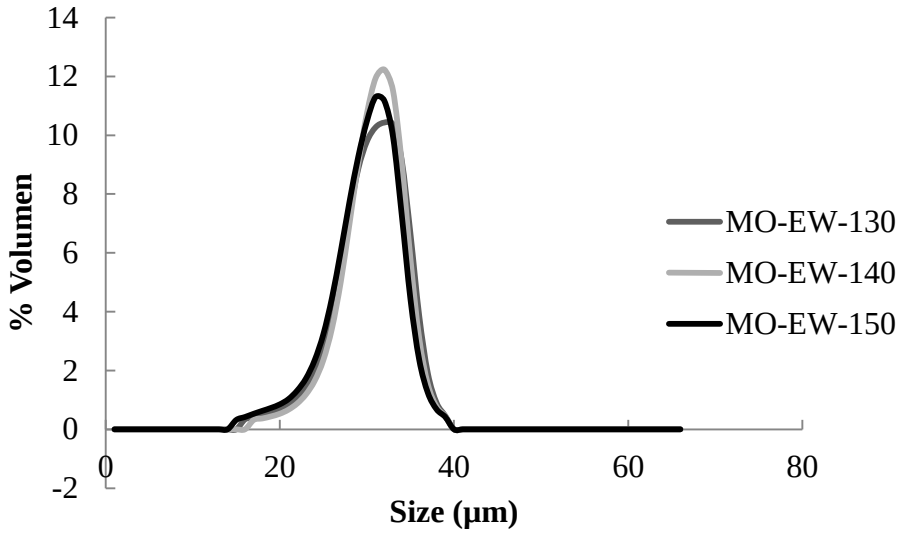

Figure 4.9 Particle size distribution of MO-EW-130, MO-EW-140, and MO-EW-150.

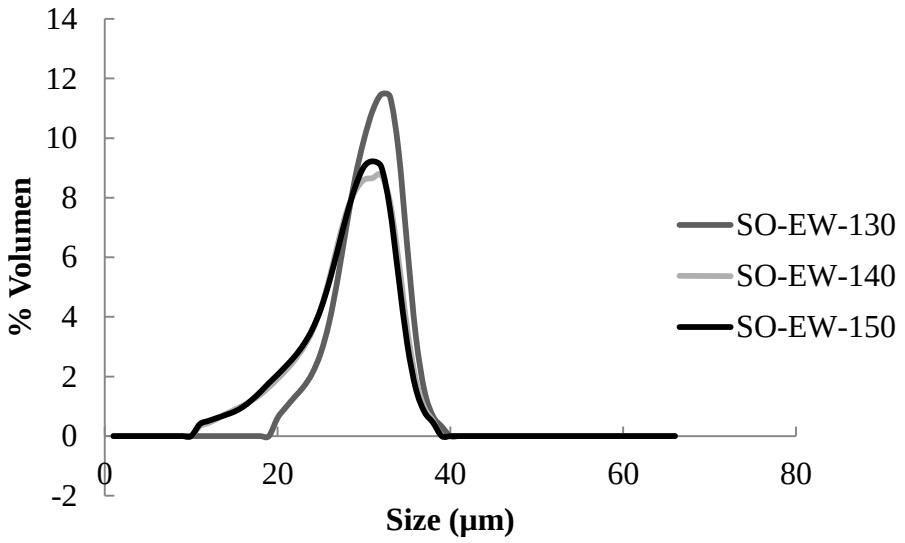

Figure 4.10 Particle size distribution of SO-EW-130, SO-EW-140, and SO-EW-150.

CHAPTER 5: SUMMARY AND CONCLUSIONS

Hen eggs are an excellent source of high quality proteins, vitamins and minerals. They are also considered one of the most important foods across the world due to their nutritional content and relative low cost. China is the world's largest producer of hen eggs followed by the United States of America, and India. en egg production is divided into two categories: hatching eggs and table eggs. However, only table eggs are intended for human consumption as food products. The U.S. table egg production had a value of approximately 4.24 billion dollars in 2009. In recent years, many concerns have arisen about the consumption of hen eggs due to cholesterol issues. All the egg's cholesterol is located in yolk. Egg white contains all nine essential amino acids including leucine, valine and isoleucine. Thus egg whites could supply many of the benefits of whole eggs without the consumption of cholesterol. The oxidation of leucine, valine and isoleucine is stimulated during dynamic exercise. Moreover, leucine is used to remold the muscle after weight lifting and other types of resistance exercises, hence, additional intake of these essential amino acids especially leucine may be helpful for people participating in high levels of exercise.

Purified menhaden oil (MO) and salmon oil (SO) are a good sources of omega-3 polyunsaturated fatty acids (ω-3 PUFA) especially eicosapentaenoic acid (EPA) (C20:5) and docosahexaenoic acid (DHA) (C22:6). Several studies have shown positive roles for ω-3 PUFA in human health including a beneficial effect in infant development, cancer, coronary heart diseases, hypertension, obesity, type II diabetes; and more lately, in various mental illnesses, including depression, attention-deficit hyperactivity disorder and dementia. Furthermore, many benefits have been attributed to the intake of ω-3 PUFA on athletes' performances. These purported benefits include the improvement in the delivery of oxygen and nutrients to muscles

and other tissues due to the reduction of blood viscosity; and the reduction of inflammation caused by muscular fatigue and overexertion; which may improve post-exercise recovery time. Nevertheless, evaluations of the effectiveness of the consumption of omega-3 fatty acids have demonstrated no improvements in strength, endurance, and muscle soreness. Instead, the benefits of omega-3 fatty acids are more related to the enhancement of aerobic metabolic process, which is an important factor in both athletic performance and in an individual's ability to effectively burn fat as an energy substrate.

Attempts to increase ω-3 PUFA content in hen eggs has been done through the manipulation of the hen's diet, which has increased the ω-3 PUFA content in hen's egg by up to three times. Nevertheless, since a conventional egg is not a rich source of ω-3 PUFA; even a three-fold increase in ω-3 PUFA is considered small. Due to the limitations of these conventional attempts to increase ω-3 PUFA content of hen eggs, the feasibility to increase ω-3 PUFA content in hen eggs through processing was approached in this study. The objective of this study were (1) to develop a spray dried microencapsulated fish oil with egg white power for athletes, (2) to evaluate the nutritional components and physical properties of 3 PUFA-fortified egg white powder, and (3) to evaluate the spray drying conditions to produce ω-3 PUFA-fortified egg white powder.

Two stable emulsions were prepared with 3.43% purified menhaden oil (MO) or refined salmon oil (SO), 56.21% egg whites (EW), and 40.36% water (E-MO-EW and E-SO-EW). The emulsions were spray dried at an inlet air temperature of 130, 140, and 150^{o}C. EW without fish oil (E-EW) was separately spray dried for a control. Nine powders were produced including E-EW spray dried at 130°C of inlet temperature (DEW-130), E-EW spray dried at 140°C of inlet temperature (DEW-140), E-EW spray dried at 150°C of inlet temperature (DEW-150), E-MO-

EW spray dried at 130°C of inlet temperature (MO-EW-130), E-MO-EW spray dried at 140°C of inlet temperature (MO-EW-140), E-MO-EW spray dried at 150°C of inlet temperature (E-MO-EW), E-SO-EW spray dried at 130°C of inlet temperature (SO-EW-130), E-SO-EW spray dried at 140°C of inlet temperature (SO-EW-140), and E-SO-EW spray dried at 150°C inlet temperature (SO-EW-150).

The study demonstrated that egg white (EW) contained 88.28 (g/100 g of dry powder) of protein. EPA and DHA were the main ω-3 PUFA in MO and SO. The total ω-3 PUFA levels in MO and SO were 32.58 and 23.66%, respectively. E-EW, E-MO-EW, and E-SO-EW were stable at 25°C and behaved as pseudoplastic fluids at 5, 15, and 25°C. The estimated production rate ranged from 0.056 to 0.062 kg dry solids/h and was slightly higher than the actual production rate which ranged from 0.056 to 0.060 kg dry solids/h. The evaporation rate of water from E-EW, E-MO-EW, and E-SO-EW during spray drying ranged from 0.593 to 0.610 (kg water/h) and was not affected by the inlet air temperature. Higher energy requirements were needed to obtain DEW-150, MO-EW-150, and SO-EW-150. The microencapsulation efficiency (ME) was not significantly affected by the inlet air temperature; as evidenced by the MEs of MO-EW and SO-EW powders which ranged from 72.03 to 72.96%.

The microencapsulation process did not affect the EPA and DHA content of MO and SO. The protein content in MO-EW and SO-EW powders ranged from 63.90 to 65.10 g/100 g of dry powder which was lower than that of DEW powders which ranged from 88.30 to 88.80 g/100 g of dry powder. MO-EW and SO-EW powders had higher total lipid content than the control (DEW powders). Moisture content and water activity (a_w) of the powders were significantly ($P<0.05$) lower for the powder produced at 150 °C inlet air temperature. All of the powders contained all essential amino acids (EAA). Leucine was the main EAA found in all the egg white

powders. The leucine content in DEW, MO-EW, and SO-EW powders ranged from 91.81 to 94.25 mg/g protein. Potassium, magnesium, and phosphorus were the main minerals found in DEW, MO-EW, and SO-EW powders. Most of the powder particles ranged in size from 20 to 30 μm. A 50 g of MO-EW or SO-EW powders can provide about 30 g of protein containing 15.67 g of essential amino acid including 2885 mg of leucine. The powders can provide 14 g of menhaden oil containing 13.43% EPA and 12.83% DHA or 14 g salmon oil containing 11.28% EPA and 11.11% DHA. The powders also can provide 480 mg of potassium, and 1.80 mg of copper.

In summary, the study has shown that egg white powder containing purified menhaden or salmon oil can be effectively produced with spray drying technology. Higher quality microencapsulated fish oil with protein can be produced at 130°C inlet temperature. The data obtained in this research could be useful to scale up the process. Microencapsulated fish oil with egg white powder may be beneficial for athletes performing high intensity exercise.

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APPENDIX A. RESULTS OF THE PRODUCTION AND PROCESS OF MICROENCAPSULATED OMEGA-3 FISH OIL WITH EGG YOLK POWDER

Table A.1 Proximate composition of egg yolk (EY)[a]

	Egg yolk (EY)
Moisture (%) (wet basis)	54.01±0.30
Total lipids (g/100 g, dry basis)	64.24±0.33
Protein (g/100 g, dry basis)	35.20±0.21
Ash (g/100 g, dry basis)	3.23±0.06

[a]Values are means and SD of triplicate determination.

Table A.2 Color values and emulsion oxidation of E-EY, E-MO-EY, and E-SO-EY[*]

	E-EY	**E-MO-EY**	**E-SO-EY**
L*	80.82±0.03[c]	85.63±0.03[b]	88.17±0.01[a]
a*	-1.15±0.00[c]	-0.77±0.02[b]	0.61±0.01[a]
b*	13.61±0.01[c]	19.98±0.01[a]	16.28±0.01[b]
Chroma	13.66±0.01[c]	19.99±0.01[a]	16.29±0.01[b]
Hue angle	94.83±0.00[a]	92.22±0.04[b]	87.87±0.02[c]
TBARS (mmol/kg emulsion)	0.03±0.00[b]	0.07±0.01[a]	0.07±0.01[a]

[*]Values are means and SD of triplicate determination. [abc] means with different letters in each row are significantly different ($p < 0.05$). E-EY = egg yolk emulsion, E-MO-EY = emulsion containing egg yolk and menhaden oil, E-SO-EY= emulsion containing egg yolk and salmon oil. TBARS = Thiobarbituric acid-reactive substances.

Table A.3 Flow behavior properties of E-EY*

Temperature (°C)	***n***	***K*(Pa.sn)**	**Apparent Viscosity (Pa s) at 100^{-1} (Shear rate)**
5	0.80±0.03[b]	0.013±0.003[a]	0.005±0.000[a]
15	0.85±0.03[ab]	0.007±0.001[b]	0.003±0.000[b]
25	0.88±0.01[a]	0.005±0.000[b]	0.003±0.000[c]

[*]Values are means and SD of triplicate determination. [ab] means with different letters in each column are significantly different ($p < 0.05$). *n* = flow index, *K* = consistency index. E-EY= egg yolk emulsion.

Table A.4 Flow behavior properties of E-MO-EY*

Temperature (°C)	***n***	***K*(Pa.sn)**	**Apparent Viscosity (Pa s) at 100^{-1} (Shear rate)**
5	0.70±0.01[b]	0.04±0.00[a]	0.008±0.00[a]
15	0.73±0.01[a]	0.02±0.00[b]	0.006±0.00[b]
25	0.75±0.00[a]	0.02±0.00[c]	0.005±0.00[c]

[*]Values are means and SD of triplicate determination. [abc] means with different letters in each column are significantly different ($p < 0.05$). *n* = flow index, *K* = consistency index. E-MO-EY= emulsion containing egg yolk and menhaden oil.

Table A.5 Flow behavior properties of E-SO-EY*

Temperature (°C)	*n*	*K*(Pa.sn)	Apparent Viscosity (Pa s) at 100^{-1} (Shear rate)
5	0.77±0.01[b]	0.02±0.00[a]	0.006±0.000[a]
15	0.78±0.01[ab]	0.01±0.00[ab]	0.005±0.000[b]
25	0.80±0.01[a]	0.01±0.00[b]	0.004±0.000[c]

*Values are means and SD of triplicate determination. [abc] means with different letters in each column are significantly different ($p < 0.05$). *n* = flow index, *K* = consistency index. E-SO-EY= emulsion containing egg yolk and salmon oil.

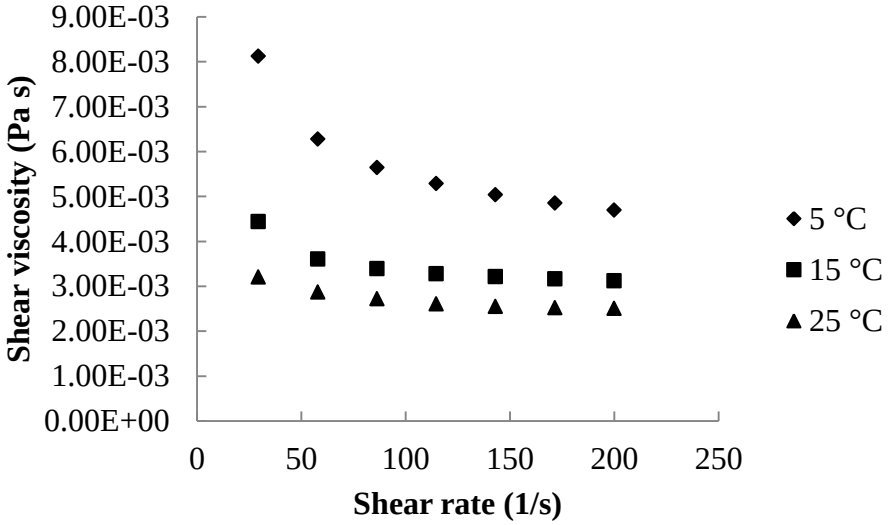

Figure A.1 Apparent viscosity of E-EY as a function of shear rate.
E-EY = egg yolk emulsion.

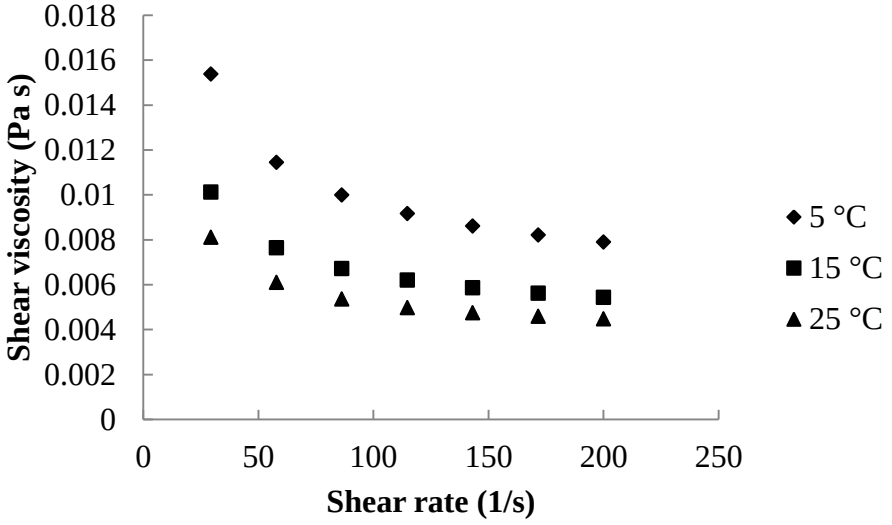

Figure A.2 Apparent viscosity of E-MO-EY as a function of shear rate.
E-MO-EY= emulsion-n containing egg yolk and menhaden oil.

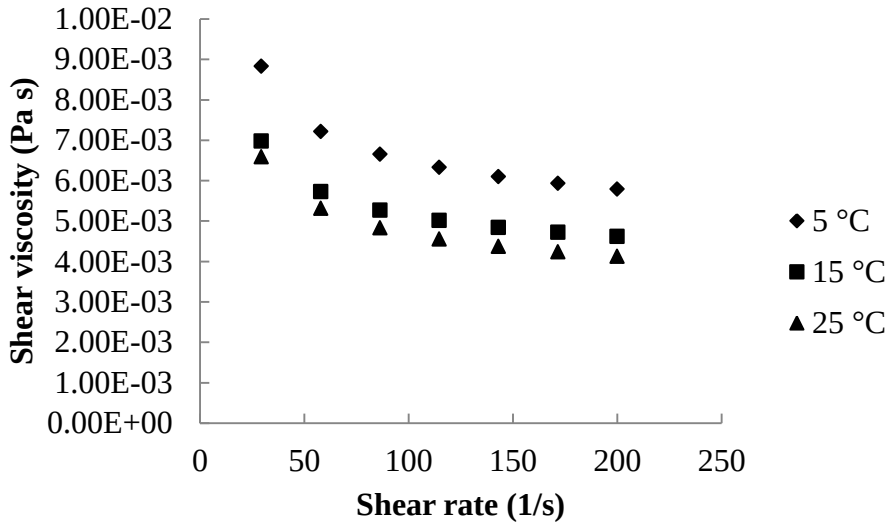

Figure A.3 Apparent viscosity of E-SO-EY as a function of shear rate.
E-SO-EY= emulsion containing egg yolk and salmon oil.

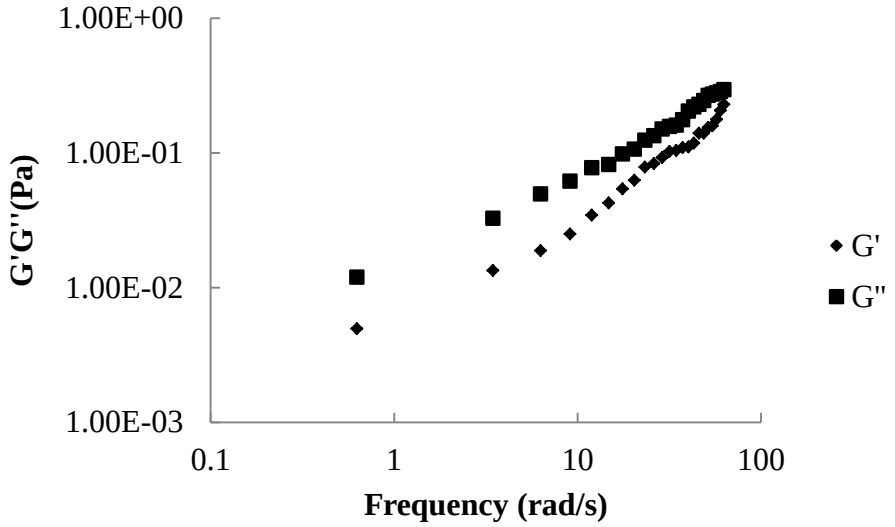

Figure A.4 Viscoelastic properties of E-EY.
E-EY = egg yolk emulsion; G'=storage modulus; G''=loss modulus.

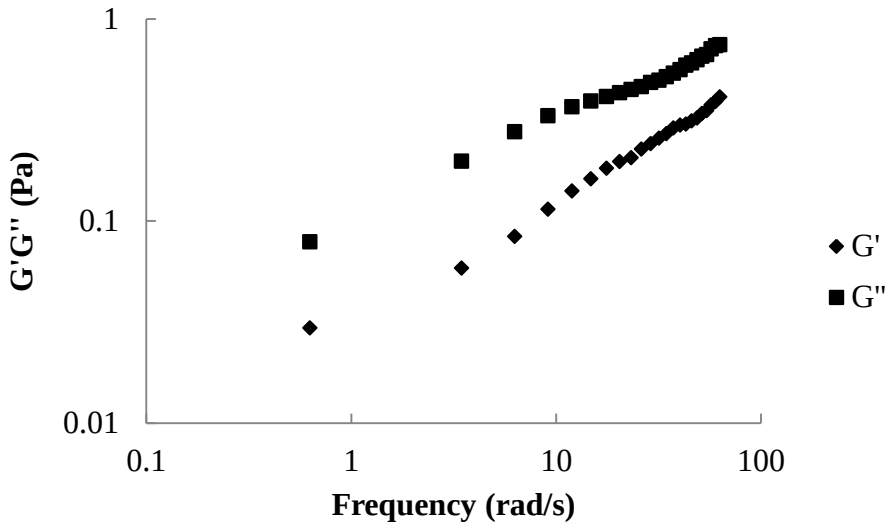

Figure A.5 Viscoelastic properties of E-MO-EY.
E-MO-EY = emulsion containing egg yolk and menhaden oil; G'=storage modulus; G''=loss modulus.

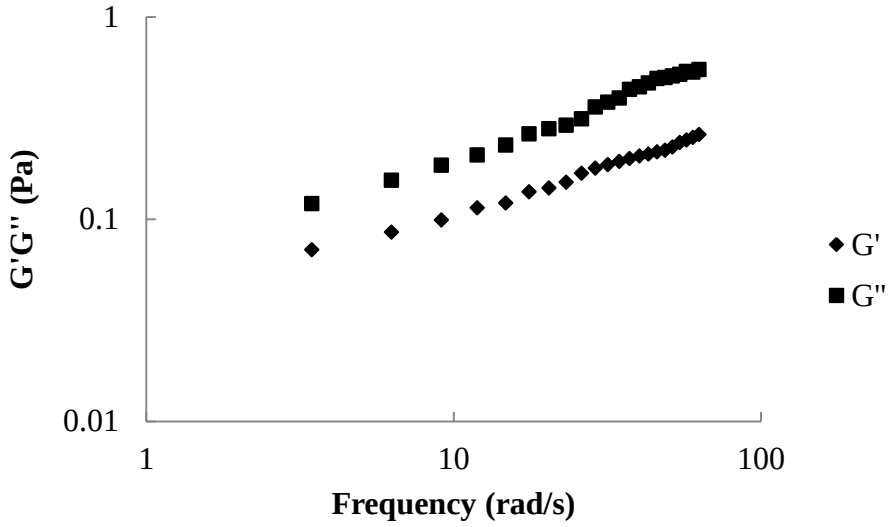

Figure A.6 Viscoelastic properties of E-SO-EY.
E-SO-EY = emulsion containing egg yolk and salmon oil; G'=storage modulus; G''=loss modulus.

Table A.6 Data for the estimation of the production rate of egg yolk powders*

		Moisture content (wet basis, %)	Moisture content (dry basis, kg water/kg dry solids)	Mass flow rate x 10^3 (kg/h)	Mass flow rate x 10^3 (dry basis, kg dry solids/h)	Estimated production rate x 10^3 (kg dry solids/h)
E-EY		89.36±0.04	8.40±0.03	860.00±10.00	91.48±0.33	
	Powder	2.39±0.68	0.02±0.01	80.60±0.20	78.67±0.55	85.72±0.06
DEY-130	Dust	7.16±0.02	0.08±0.00	6.00±1.00	5.57±0.00	
	Powder	2.32±0.10	0.02±0.00	76.69±0.01	77.83±0.08	86.60±0.06
DEY-140	Dust	6.22±0.04	0.07±0.00	5.00±1.00	4.69±0.00	
	Powder	3.18±0.11	0.03±0.00	65.92±0.02	63.82±0.07	86.41±0.08
DEY-150	Dust	2.32±0.22	0.02±0.00	6.00±1.00	4.88±0.01	
E-MO-EY		89.36±0.04	8.40±0.03	823.33±15.28	87.58±1.93	
	Powder	2.39±0.68	0.02±0.01	80.60±0.10	78.67±0.48	80.94±2.12
MO-EY-130	Dust	7.16±0.02	0.08±0.00	6.00±1.00	5.57±0.93	
	Powder	2.32±0.10	0.02±0.00	79.65±0.03	77.80±0.09	81.82±2.13
MO-EY-140	Dust	6.22±0.04	0.07±0.00	5.00±1.00	4.69±0.94	
	Powder	3.18±0.11	0.03±0.00	65.91±0.04	63.82±0.04	80.65±3.59
MO-EY-150	Dust	2.32±0.22	0.02±0.00	5.67±2.08	5.54±2.05	
E-SO-EY		89.36±0.04	8.40±0.03	810.00±13.23	86.16±1.72	
	Powder	2.39±0.68	0.02±0.01	80.60±0.10	78.67±0.48	79.62±1.74
SO-EY-130	Dust	7.16±0.02	0.08±0.00	6.00±1.00	5.57±0.93	
	Powder	2.32±0.10	0.02±0.00	79.65±0.03	77.80±0.09	80.50±1.76
SO-EY-140	Dust	6.22±0.04	0.07±0.00	5.00±1.00	4.69±0.94	
	Powder	3.18±0.11	0.03±0.00	65.91±0.04	63.82±0.04	79.32±3.21
SO-EY-150	Dust	2.32±0.22	0.02±0.00	5.67±2.08	5.54±2.05	

*Values are means ± SD of triplicate determination. DEY-130= E-EY spray dried at 130°C, DEY-140=E-EY spray dried at 140°C, DEY-150= E-EY spray dried at 150°C, MO-EY-130= E-MO-EY spray dried at 130°C, MO-EY-140= E-MO-EY spray dried at 140°C , MO-EY-150= E-MO-EY spray dried at 150°C, SO-EY-130= E-SO-EY spray dried at 130°C, SO-EY-140= E-SO-EY spray dried at 140°C, SO-EY-150 = E-SO-EY spray dried at 150°C.

Table A.7 Summary of inlet and ambient air conditions for spray drying E-EY, E-MO-EY, and E-SO-EY***

Parameter	DEY-130	DEY-140	DEY-150	MO-EY-130	MO-EY-140	MO-EY-150	SO-EY-130	SO-EY-140	SO-EY-150
Ambient air temperature (AAT) (°C)	23.40±0.40	22.07±0.49	21.10±0.26	23.40±0.40	22.07±0.49	21.10±0.26	23.40±0.40	22.07±0.49	21.10±0.26
Outlet air velocity (km/h)	73.46±0.57	77.16±0.02	76.19±0.06	71.13±0.02	74.16±0.02	76.19±0.06	69.19±0.08	70.16±0.02	70.24±0.04
Internal pipe diameter (m)	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
Volumetric flow rate of inlet air (m^3/h)	66.70±0.52	70.06±0.01	69.17±0.05	64.58±0.02	67.33±0.01	69.17±0.05	62.82±0.07	63.70±0.01	63.78±0.04
Relative humidity of inlet air (%)	46.67±1.15	46.53±0.38	49.59±0.50	46.67±1.15	46.53±0.38	49.59±0.50	46.67±1.15	46.53±0.38	49.59±0.50
Partial pressure exerted by water vapor (kPa)	1.39±0.03	1.27±0.01	1.36±0.01	1.39±0.03	1.27±0.01	1.36±0.01	1.39±0.03	1.27±0.01	1.36±0.01
Saturation pressure of water vapor (kPa)*	2.985	2.736	2.736	2.985	2.736	2.736	2.985	2.736	2.736
Absolute humidity x 10^{-3} (kg water/kg dry air)	8.67±0.22	7.91±0.07	8.44±0.09	8.67±0.22	7.91±0.07	8.44±0.09	8.67±0.22	7.91±0.07	8.44±0.09
Specific volume of inlet air (m^3/kg dry air)	0.85±0.00	0.85±0.00	0.84±0.00	0.85±0.00	0.85±0.00	0.84±0.00	0.85±0.00	0.85±0.00	0.84±0.00
Mass flow rate (kg dry air/h)	78.44±0.49	82.86±0.16	82.02±0.06	75.95±0.13	79.64±0.16	82.02±0.06	73.88±0.12	75.35±0.15	75.62±0.02
Specific heat of dry air at AAT (kJ/kg K)*	1.0124	1.0122	1.0121	1.0124	1.0122	1.0121	1.0124	1.0122	1.0121
Specific heat of water vapor at AAT(kJ/kg K)**	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88
Temperature of drying air (K)	403±2.60	413±2.00	423±1.50	403±3.00	413.00±2.00	423.00±1.50	403±3.00	413±2.00	423±1.50

*Obtained from appendix A 4.2 and A 4.4, respectively (Singh and Heldman 2001).

** Selected as 1.88 kJ/(kg K) according to Singh and Heldman (2001).

*** Values are means ± SD of triplicate determination.

See Table A.6 for a brief description of DEY-130, DEY-140, DEY-150, MO-EY-130, MO-EY-140, MO-EY-150, SO-EY-130, SO-EY-140, and SO-EY-150.

Table A.8 Summary of outlet air conditions for spray drying E-EY, E-MO-EY, and E-SO-EY [a]

	DEY-130	DEY-140	DEY-150	MO-EY-130	MO-EY-140	MO-EY-150	SO-EY-130	SO-EY-140	SO-EY-150
Outlet air temperature (°C)	65.2±0.15	63.80±0.40	67.50±0.65	65.2±0.15	63.80±0.40	67.50±0.65	65.20±0.15	63.80±0.40	67.50±0.65
Out air velocity (km/h)	18.9±0.03	19.70±0.26	19.90±0.09	18.4±0.10	19.20±0.11	19.90±0.09	17.9±0.06	18.3±0.10	18.40±0.05
Internal pipe diameter (m)	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
Volumetric flow rate outlet air (m^3/h)	76.88±0.12	80.37±1.07	80.86±0.35	74.82±0.42	78.06±0.45	80.86±0.35	72.95±0.24	74.30±0.41	74.92±0.20
Relative humidity of outlet air (%)	11.7±0.10	11.5±0.03	10.0±0.12	11.60±0.06	11.40±0.03	9.90±0.06	11.70±0.05	11.60±0.05	10.10±0.03
Partial pressure exerted by water vapor (kPa)	2.93±0.03	2.73±0.01	2.82±0.03	2.90±0.01	2.72±0.01	2.77±0.02	2.93±0.01	2.75±0.01	2.85±0.01
Saturation pressure of water vapor (kPa)*	25.03	23.81	28.11	25.03	25.81	28.11	25.03	23.81	28.11
Absolute humidity x 10^{-3} (kg water/kg dry air)	18.51±0.16	17.25±0.04	17.81±0.21	18.30±0.09	17.15±0.04	17.50±0.11	18.51±0.08	17.35±0.08	17.97±0.05
Specific volume of outlet air (m^3/kg dry air)	0.99±0.00	0.98±0.00	0.99±0.00	0.99±0.00	0.98±0.00	0.99±0.00	0.99±0.00	0.98±0.00	0.99±0.00
Mass flow rate of outlet air (kg dry air/h)	78.02±0.11	82.07±1.15	81.61±0.31	75.95±0.43	79.73±0.51	81.65±0.30	74.03±0.21	75.86±0.47	75.59±0.19

[a] Values are means ± SD of triplicate determination.

*Obtained from appendix A 4.2 and A 4.4, respectively (Singh and Heldman 2001).

See Table A.6 for a brief description of DEY-130, DEY-140, DEY-150, MO-EY-130, MO-EY-140, MO-EY-150, SO-EY-130, SO-EY-140, and SO-EY-150.

Table A.9 Estimated evaporation rates and energy used to spray dry the egg yolk emulsions*

	Inlet Temp (°C)	E-EY	E-MO-EY	E-SO-EY
Evaporation rate (kg water/h)[1]	130	0.76 ± 0.01^{aA}	0.73 ± 0.02^{aA}	0.73 ± 0.02^{aA}
	140	0.76 ± 0.02^{aA}	0.74 ± 0.01^{aAB}	0.72 ± 0.01^{aB}
	150	0.76 ± 0.01^{aA}	0.74 ± 0.01^{aAB}	0.72 ± 0.01^{aB}
Evaporation rate (kg water/h)[2]	130	0.77 ± 0.00^{aA}	0.73 ± 0.01^{aB}	0.72 ± 0.01^{aB}
	140	0.77 ± 0.00^{aA}	0.73 ± 0.01^{aB}	0.72 ± 0.01^{aB}
	150	0.77 ± 0.00^{aA}	0.73 ± 0.01^{aB}	0.72 ± 0.01^{aB}
Energy required to spray dry CJP (kJ/kg)	130	8599.90 ± 53.66^{cA}	8326.81 ± 14.15^{cB}	8099.70 ± 13.67^{cC}
	140	10043.35 ± 19.66^{bA}	9652.88 ± 18.97^{bB}	9132.25 ± 18.04^{bC}
	150	10869.33 ± 7.71^{aA}	10869.33 ± 7.71^{aA}	10021.41 ± 2.46^{aB}

*Values are means ± SD of triplicate determination. [1]Calculated based on the moisture uptake by the dry air (kg water/h). [2]Calculated based on the moisture content of the E-EY/E-MO-EY/E-SO-EY emulsions, powder collected through collector vessel, and dust (kg water/h). [abc]Means with same letter in each column are not significant different ($p<0.05$). [ABC]Means with same letter in each row are not significant different ($p<0.05$). See Table 4.2 for brief description of E-EY,E-MO-EY and E-SO-EY.

Table A.10 Color and microencapsulation efficiency (ME) of EY, MO-EY, and SO-EY*

	Inlet temp. (°C)	DEY	MO-EY	SO-EY
L*	130	90.18 ± 0.01^{aA}	89.10 ± 0.01^{bB}	88.01 ± 0.02^{aC}
	140	86.89 ± 0.01^{cB}	89.30 ± 0.01^{aA}	85.77 ± 0.00^{cC}
	150	89.80 ± 0.01^{bA}	85.71 ± 0.01^{cC}	86.88 ± 0.01^{bB}
a*	130	2.69 ± 0.02^{bB}	1.78 ± 0.02^{bC}	3.70 ± 0.01^{bA}
	140	3.19 ± 0.01^{aA}	2.21 ± 0.02^{aB}	0.63 ± 0.01^{cC}
	150	2.63 ± 0.01^{cB}	0.11 ± 0.00^{cC}	3.77 ± 0.02^{aA}
b*	130	25.30 ± 0.01^{bB}	27.78 ± 0.01^{aA}	25.32 ± 0.02^{bB}
	140	27.28 ± 0.01^{aB}	27.57 ± 0.01^{bA}	23.91 ± 0.01^{cC}
	150	23.24 ± 0.01^{cB}	13.98 ± 0.02^{cC}	26.35 ± 0.03^{aA}
Hue	130	83.92 ± 0.05^{aB}	86.33 ± 0.03^{bA}	81.68 ± 0.02^{cC}
	140	83.32 ± 0.03^{cC}	85.41 ± 0.04^{cB}	88.48 ± 0.04^{aA}
	150	83.54 ± 0.03^{bB}	89.55 ± 0.00^{aA}	81.84 ± 0.04^{bC}
Chroma	130	25.44 ± 0.01^{bC}	27.84 ± 0.01^{aA}	25.59 ± 0.02^{bB}
	140	27.46 ± 0.00^{aB}	27.66 ± 0.01^{bA}	23.92 ± 0.02^{cC}
	150	23.39 ± 0.00^{cB}	13.98 ± 0.02^{cC}	26.62 ± 0.02^{Aa}
Microencapsulation Efficiency (%)	130	72.33 ± 0.50^{aA}	47.22 ± 0.43^{aB}	46.61 ± 0.60^{aB}
	140	70.63 ± 0.15^{bA}	47.36 ± 0.33^{aB}	47.03 ± 0.23^{aB}
	150	70.23 ± 0.15^{bA}	47.48 ± 0.42^{aB}	47.61 ± 0.46^{aB}

*Values are means ± SD of triplicate determination. [abc] means with different letters in each column are significantly different ($p< 0.05$). [AB] means with different letters in each row are significantly different ($p< 0.05$). DEY = egg yolk powder; MO-EY= egg yolk powder containing menhaden oil; SO-EY= egg yolk powder containing salmon oil.

Table A.11 FAMEs profile of DEY (% of total integrated area)*

FAME (%)	Inlet Temperature (°C)		
	130	140	150
14:0	0.38±0.00	0.39±0.01	0.39±0.00
16:0	26.31±0.07	26.22±0.02	26.70±0.08
16:1n7	2.51±0.02	2.58±0.00	2.65±0.00
17:0	0.21±0.01	0.20±0.00	0.20±0.01
18:0	10.46±0.45	10.22±0.19	9.75±0.24
18:1n9c	38.35±0.62	38.87±0.18	38.83±0.26
18:1n5	1.45±0.01	1.51±0.00	1.49±0.01
18:2n6c	16.82±0.10	16.42±0.01	16.30±0.06
18:3n3	0.45±0.01	0.45±0.00	0.44±0.00
20:1n9	---	---	0.29±0.03
20:4n6	1.62±0.07	1.65±0.01	1.50±0.04
22:5n6	0.39±0.04	0.42±0.00	0.45±0.04
22:6n3	0.46±0.02	0.47±0.02	0.47±0.04

*Values are means ± SD of triplicate determination. DEY= egg yolk powder.

Table A.12 FAMEs profile of MO-EY (% of total integrated area)*

FAME (%)	Inlet Temperature (°C)		
	130	140	150
14:0	4.75±0.09	3.69±0.04	4.09±0.02
15:0	0.47±0.01	0.37±0.01	0.42±0.00
16:0	22.68±0.63	24.10±0.11	24.47±0.13
16:1n7	7.98±0.16	6.77±0.04	6.93±0.02
17:1n11	0.66±0.03	0.48±0.00	0.51±0.01
18:0	6.94±0.27	7.94±0.17	7.72±0.07
18:1n9c	21.96±0.51	26.61±0.34	25.31±0.09
18:1n5	2.37±0.02	2.15±0.00	2.19±0.01
18:2n6c	8.70±0.04	10.93±0.04	10.32±0.04
18:3n3	1.14±0.03	0.97±0.01	1.01±0.01
20:4n6	1.50±0.01	1.57±0.02	1.46±0.01
20:3n3	0.98±0.02	---	---
20:5n3	7.71±0.26	5.66±0.07	6.06±0.07
22:5n3	1.57±0.05	1.17±0.03	1.25±0.01
22:6n3	7.72±0.20	5.86±0.05	6.17±0.04

*Values are means ± SD of triplicate determination. MO-EY= egg yolk powder containing menhaden oil.

Table A.13 FAMEs profile of SO-EY (% of total integrated area)*

FAME (%)	Inlet Temperature (°C)		
	130	140	150
14:0	2.43±0.02	2.33±0.01	2.36±0.02
16:0	21.05±0.14	21.40±0.06	20.97±0.13
16:1n7	4.21±0.02	4.10±0.01	4.09±0.04
18:0	6.82±0.06	7.10±0.01	6.81±0.04
18:1n9c	27.18±0.14	27.73±0.01	27.32±0.09
18:1n5	2.07±0.01	2.05±0.00	2.06±0.02
18:2n6c	10.01±0.07	10.57±0.00	10.57±0.06
18:3n3	0.75±0.00	0.74±0.00	0.76±0.01
20:1n9	4.86±0.01	4.65±0.01	4.77±0.05
20:4n6	1.16±0.00	1.26±0.01	1.19±0.01
20:3n3	0.79±0.00	0.78±0.01	0.76±0.01
20:5n3	5.13±0.01	4.90±0.01	5.03±0.13
22:5n3	1.08±0.02	1.03±0.02	1.05±0.01
22:6n3	5.28±0.02	5.04±0.02	5.12±0.05

*Values are means ± SD of triplicate determination. SO-EY= egg yolk powder containing salmon oil.

Table A.14 FFA and TBARS of egg yolk powders*

	FFA (%)	TBARS (mmol/kg oil)
DEY-130	0.31±0.03^{a}	0.05±0.02^{a}
DEY-140	0.35±0.03^{a}	0.04±0.01^{a}
DEY-150	0.38±0.03^{a}	0.05±0.01^{a}
MO-EY-130	0.71±0.03^{a}	0.14±0.00^{b}
MO-EY-140	0.77±0.04^{a}	0.15±0.00^{a}
MO-EY-150	0.78±0.04^{a}	0.15±0.00^{a}
SO-EY-130	0.81±0.06^{a}	0.14±0.00^{b}
SO-EY-140	0.80±0.07^{a}	0.14±0.00^{b}
SO-EY-150	0.81±0.07^{a}	0.15±0.00^{a}

*Values are means ± SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p< 0.05$).^{ABC} means with different letters in each row are significantly different ($p< 0.05$). See Table A.6 for a brief description of DEY-130, DEY-140, DEY-150, MO-EY-130, MO-EY-140, MO-EY-150, SO-EY-130, SO-EY-140, and SO-EY-150.

Table A.15 Nutritional properties of DEY, MO-EY, and SO-EY*

	Inlet temp. (°C)	DEY	MO-EY	SO-EY
Moisture (%)	130	4.59 ± 0.20^{aA}	4.72 ± 0.19^{aA}	4.78 ± 0.22^{aA}
	140	4.47 ± 0.12^{aA}	4.32 ± 0.10^{aA}	4.20 ± 0.20^{bA}
	150	3.69 ± 0.19^{bB}	4.32 ± 0.22^{aA}	4.10 ± 0.12^{bAB}
Protein (g/100 g, dry basis)	130	33.54	12.89	14.25
	140	33.15	13.73	14.15
	150	34.13	14.41	14.26
Lipids (g/100 g, dry basis)	130	62.63 ± 0.94^{aC}	85.78 ± 0.17^{aA}	84.18 ± 0.09^{bB}
	140	63.94 ± 1.29^{aB}	85.31 ± 0.39^{aA}	85.20 ± 0.35^{aA}
	150	63.68 ± 1.43^{aB}	85.66 ± 0.59^{aA}	84.77 ± 0.27^{abA}
Ash (g/100 g, dry basis)	130	4.43 ± 0.11^{aA}	2.58 ± 0.05^{aC}	2.96 ± 0.04^{aB}
	140	4.27 ± 0.08^{aA}	2.56 ± 0.06^{aC}	2.90 ± 0.09^{aB}
	150	4.45 ± 0.26^{aA}	2.60 ± 0.03^{aB}	2.84 ± 0.03^{aB}
Water activity (a_w)	130	0.320 ± 0.004^{aA}	0.313 ± 0.004^{aA}	0.298 ± 0.003^{aB}
	140	0.285 ± 0.002^{bA}	0.276 ± 0.003^{bB}	0.263 ± 0.002^{bC}
	150	0.225 ± 0.004^{cB}	0.240 ± 0.003^{cA}	0.225 ± 0.003^{cB}

*Values are means ± SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p< 0.05$).^{ABC} means with different letters in each row are significantly different ($p< 0.05$). DEY= egg yolk powder, MO-EY= egg yolk powder containing menhaden oil, SO-EY= egg yolk powder containing salmon oil.

Table A.16 Amino acid profile of DEY, MO-EY, and SO-EY*

Amino acid (mg/g protein)	DEY			MO-EY			SO-EY		
	Inlet Temp. (°C)			Inlet Temp. (°C)			Inlet Temp. (°C)		
	130	140	150	130	140	150	130	140	150
Aspartic acid	107.68	103.66	109.56	98.23	100.28	9905.59	102.24	101.13	101.22
Threonine[a]	55.05	54.39	55.61	50.84	51.19	5120.44	52.04	50.53	50.69
Serine	66.72	65.48	67.22	84.58	86.43	8673.48	87.65	84.95	85.10
Glutamic acid	85.60	95.83	84.01	95.83	87.65	9303.24	93.60	88.81	85.13
Proline	31.28	31.58	31.45	34.58	34.92	3588.54	35.24	35.67	32.62
Glycine	27.79	27.88	27.67	25.88	25.93	2626.13	26.61	25.80	25.63
Alanine	45.68	46.39	45.85	45.44	45.58	4644.89	47.25	45.60	45.21
Valine[a]	62.41	60.86	63.62	61.46	61.26	6080.32	62.93	60.25	61.76
Methionine[a]	25.39	25.07	26.05	27.18	27.16	2677.31	28.00	39.46	27.17
Isoleucine[a]	51.59	50.69	52.92	53.34	53.17	5277.96	54.82	52.38	53.65
Leucine[a]	89.14	88.64	90.71	87.31	87.53	8796.23	90.00	87.32	87.99
Tyrosine[a]	45.67	45.77	46.69	43.71	44.30	4428.64	46.09	44.85	45.76
Phenylalanine[a]	50.51	50.09	52.07	44.74	45.80	4418.30	47.94	45.46	47.46
Histidine[a]	22.06	21.59	22.56	26.43	26.63	2644.84	27.57	27.38	27.63
Lysine[a]	97.72	97.45	99.28	89.17	90.13	9103.22	92.72	88.93	88.52
Arginine	63.07	61.71	64.46	76.34	76.54	7661.09	78.26	75.28	76.96
TEAA	364.73	360.14	372.11	353.16	355.34	35322.38	366.02	364.39	356.88
TAA	927.38	927.08	939.73	945.08	944.48	94950.21	972.95	953.80	942.51

*Values are means of triplicate determinations. See Table A.10 for brief description of DEY, MO-EY, and SO-EY. TEAA= total essential amino acids; TAA= total amino acids

[a] Essential amino acids

**Cysteine and tryptophan were not quantified.

Table A.17 Mineral profile of egg yolk powders*

	DEY			MO-EY			SO-EY			Recommended dietary allowance for mineral (mg/day)[a]
	Inlet Temp. (°C)			Inlet Temp. (°C)			Inlet Temp. (°C)			
	130	140	150	130	140	150	130	140	150	
P (g/100 g powder)	0.61	0.64	0.65	0.49	0.59	0.57	0.55	0.58	0.58	800/1400
K (g/100 g powder)	0.50	0.40	0.08	0.22	0.19	0.27	0.22	0.45	0.36	2000/3500
Ca (g/100 g powder)	0.07	0.07	0.07	0.18	0.22	0.21	0.21	0.22	0.24	800/900
Mg (g/100 g powder)	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	350/350
Cu (mg/100 g powder)	<.01	0.18	0.22	1.63	1.71	1.82	1.86	1.86	2.14	1.5/3.0
Zn (mg/100 g powder)	<1	<1	<1	56	60	57	57	61	65	10/15
Mn (mg/100 g powder)	<1	<1	<1	2	2	3	2	3	2	
Fe (mg/100 g powder)	<1	<1	<1	55	49	59	48	53	67	12/12
As (mg/100 g powder)	<0.40	<.40	<.40	<.40	<.40	<0.40	2.20	3.23	2.19	
Pb (mg/100 g powder)	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	

*Values are means of triplicate determinations. See Table A.6 for a brief description of DEY-130, DEY-140, DEY-150, MO-EY-130, MO-EY-140, MO-EY-150, SO-EY-130, SO-EY-140, and SO-EY-150.

[a]Compiled from Brounds (1993) for male athletes from 25 to 50 years old.

APPENDIX B. RESULTS OF THE PRODUCTION AND PROCESS OF MICROENCAPSULATED OMEGA-3 FISH OIL WITH WHOLE EGG POWDER

Table B.1 Proximate composition of whole egg (WE)[a]

	Whole egg (WE)
Moisture (%) (wet basis)	77.11±0.11
Total lipids (g/100 g, dry basis)	43.44±0.29
Protein (g/100 g, dry basis)	52.33±0.21
Ash (g/100 g, dry basis)	4.02±0.10

[a]Values are means and SD of triplicate determination.

Table B.2 Color values and emulsion oxidation of E-WE, E-MO-WE, and E-SO-WE[*]

	E-WE	**E-MO-WE**	**E-SO-WE**
L*	72.31±0.05[c]	84.57±0.01[a]	80.90±0.09[b]
a*	3.58±0.04[a]	-0.10±0.04[c]	0.71±0.02[b]
b*	22.82±0.30[a]	18.74±0.12[b]	10.17±0.05[c]
Chroma	23.10±0.31[a]	18.74±0.12[b]	10.19±0.05[c]
Hue angle	81.08±0.04[c]	90.32±0.13[a]	86.01±0.08[b]
TBARS (mmol/kg emulsion)	0.01±0.00[b]	0.05±0.01[a]	0.05±0.01[a]

[*]Values are means and SD of triplicate determination. [abc] means with different letters in each row are significantly different ($p < 0.05$). E-WE = whole egg emulsion, E-MO-WE = emulsion containing whole egg and menhaden oil, E-SO-WE= emulsion containing whole egg and salmon oil. TBARS = Thiobarbituric acid-reactive substances.

Table B.3 Flow behavior properties of E-WE*

Temperature (°C)	***n***	***K*(Pa.s^n)**	**Apparent Viscosity (Pa s) at 100^{-1} (Shear rate)**
5	0.49±0.03[c]	0.54±0.08[a]	0.006±0.003[a]
15	0.63±0.01[b]	0.03±0.01[b]	0.003±0.000[b]
25	0.76±0.08[a]	0.01±0.00[c]	0.003±0.000[b]

[*]Values are means and SD of triplicate determination. [abc] means with different letters in each column are significantly different ($p < 0.05$). *n* = flow index, *K* = consistency index. E-WE= whole egg emulsion.

Table B.4 Flow behavior properties of E-MO-WE*

Temperature (°C)	***n***	***K*(Pa.s^n)**	**Apparent Viscosity (Pa s) at 100^{-1} (Shear rate)**
5	0.66±0.03[c]	0.014±0.002[a]	0.004±0.000[a]
15	0.77±0.02[b]	0.010±0.001[b]	0.003±0.000[b]
25	0.92±0.03[a]	0.004±0.001[c]	0.003±0.000[c]

[*]Values are means and SD of triplicate determination. [abc] means with different letters in each column are significantly different ($p < 0.05$). *n* = flow index, *K* = consistency index. MO-EY= emulsion containing whole egg and menhaden oil.

Table B.5 Flow behavior properties of E-SO-WE*

Temperature (°C)	*n*	*K*(Pa.s^n)	Apparent Viscosity (Pa s) at 100^{-1} (Shear rate)
5	0.84±0.06^a	0.008±0.003^a	0.004±0.000^a
15	0.84±0.02^a	0.005±0.001^a	0.002±0.000^b
25	0.93±0.03^a	0.003±0.000^a	0.002±0.000^b

*Values are means and SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p < 0.05$). *n* = flow index, *K* = consistency index. E-SO-EY= emulsion containing whole egg and salmon oil.

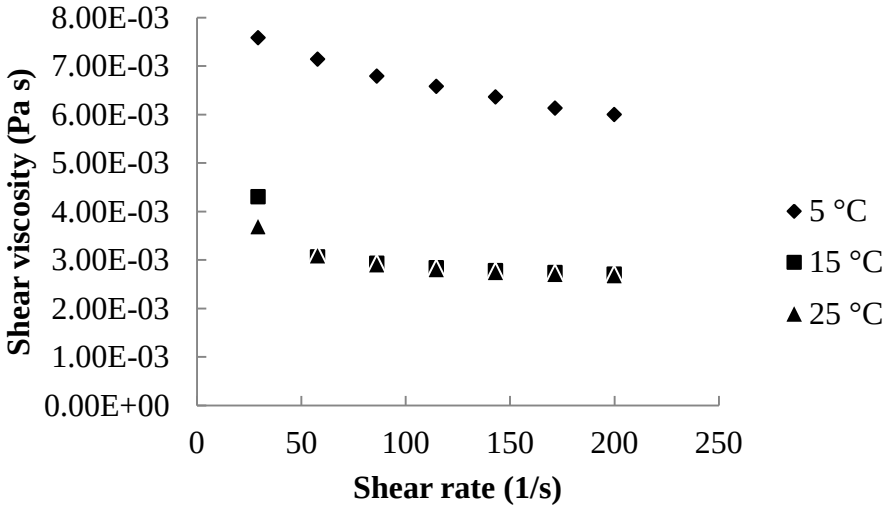

Figure B.1 Apparent viscosity of E-WE as a function of shear rate.
E-EW = whole egg emulsion

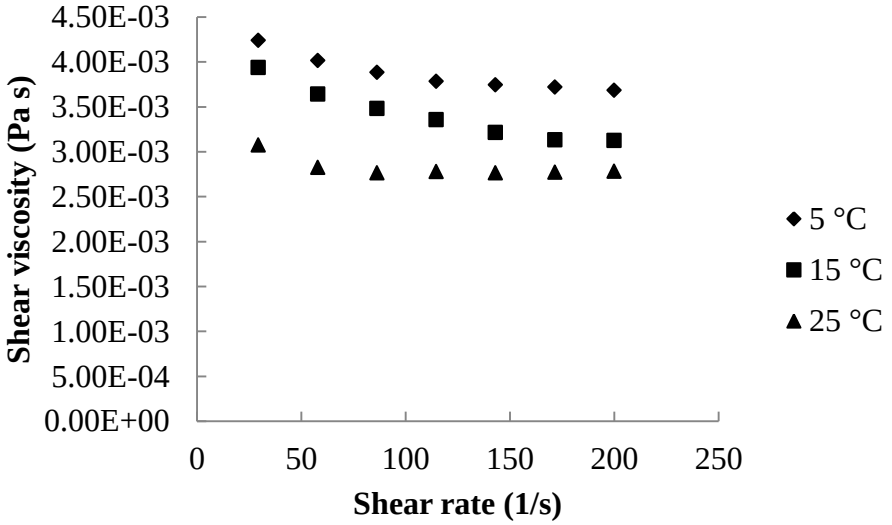

Figure B.2 Apparent viscosity of E-MO-WE as a function of shear rate.
E-MO-WE = emulsion containing whole egg and menhaden oil.

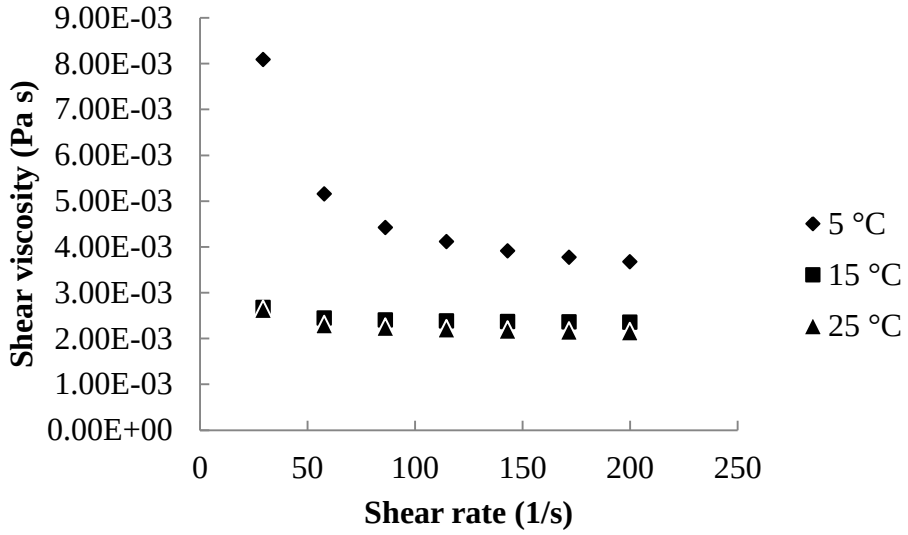

Figure B.3 Apparent viscosity of E-SO-WE as a function of shear rate.
E-SO-WE= emulsion containing whole egg and salmon oil.

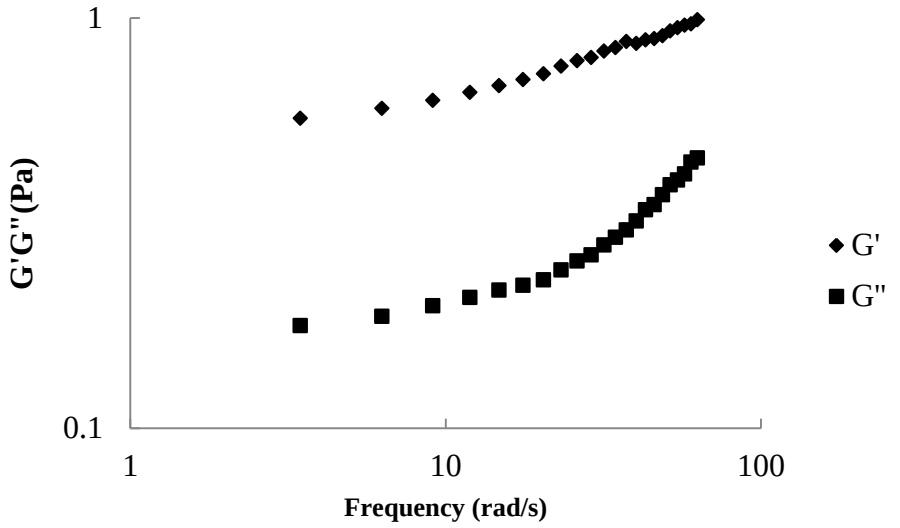

Figure B.4 Viscoelastic properties of E-WE.
E-WE = whole egg emulsion; G'=storage modulus; G''=loss modulus.

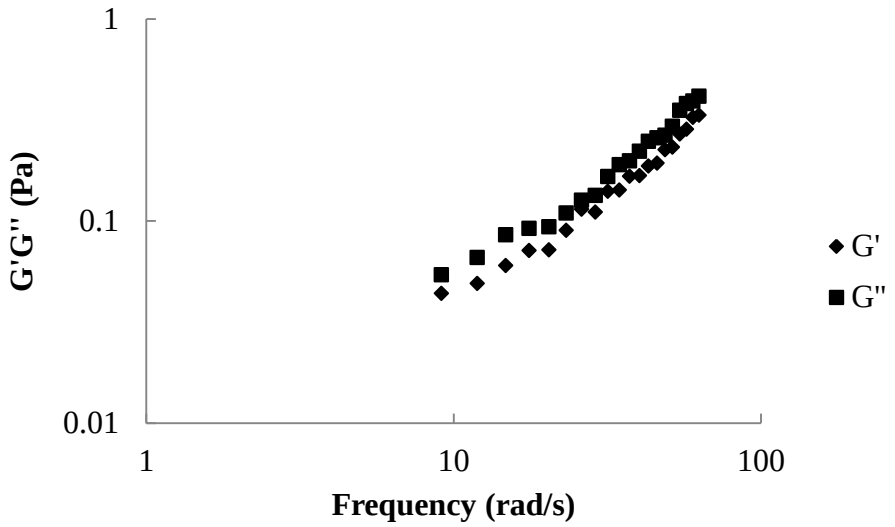

Figure B.5 Viscoelastic properties of E-MO-WE.
E-MO-WE= emulsion containing whole egg and menhaden oil; G'=storage modulus; G''=loss modulus.

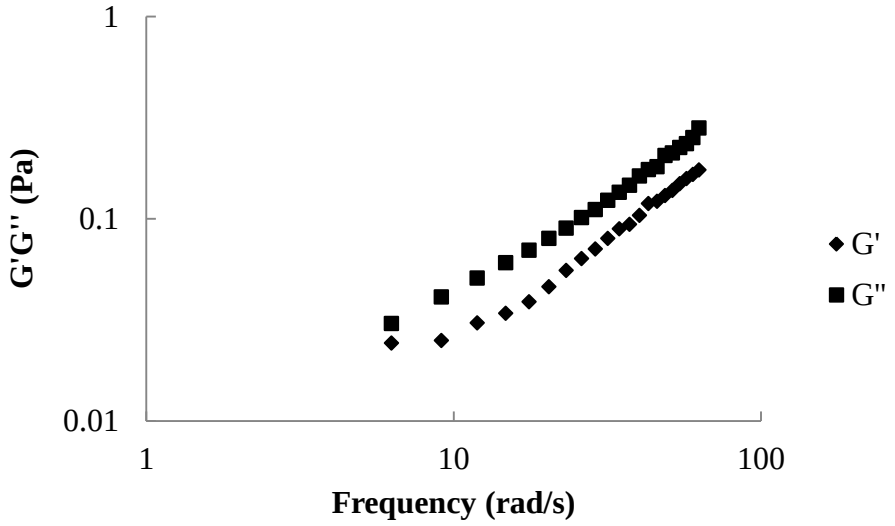

Figure B.6 Viscoelastic properties of E-SO-WE.
E-SO-WE= emulsion containing whole egg and salmon oil; G'=storage modulus; G''=loss modulus.

Table B.6 Data for the estimation of the production rate of whole egg powders*

		Moisture content (wet basis, %)	Moisture content (dry basis, kg water/kg dry solids)	Mass flow rate x 10^3 (kg/h)	Mass flow rate x 10^3 (dry basis, kg dry solids/h)	Estimated production rate x 10^3 (kg dry solids/h)
E-WE		89.34±0.02	8.38±0.01	810.00±10.00	87.44±0.13	
	Powder	3.66±0.69	0.04±0.01	68.70±0.10	66.19±0.48	79.94±0.12
DWE-130	Dust	6.21±0.04	0.07±0.00	8.00±1.00	7.50±0.00	
	Powder	3.56±0.10	0.04±0.00	68.48±0.02	66.04±0.07	78.06±0.13
DWE-140	Dust	6.22±0.04	0.07±0.00	10.00±2.00	9.38±0.00	
	Powder	2.49±0.17	0.03±0.00	68.00±0.20	66.50±0.12	76.69±0.14
DWE-150	Dust	2.32±0.22	0.02±0.00	11.00±2.00	10.74±0.02	
E-MO-WE		89.34±0.02	8.38±0.01	790.00±10.00	84.24±1.03	
	Powder	3.66±0.69	0.04±0.01	68.10±0.52	65.61±0.36	75.80±1.97
MO-WE-130	Dust	6.21±0.04	0.07±0.00	9.00±1.00	8.44±0.94	
	Powder	3.56±0.10	0.04±0.00	68.47±0.06	66.3±0.04	72.67±3.39
MO-WE-140	Dust	6.22±0.04	0.07±0.00	12.33±2.52	11.57±2.36	
	Powder	2.49±0.17	0.03±0.00	67.73±0.50	66.05±0.58	71.87±3.08
MO-WE-150	Dust	2.32±0.22	0.02±0.00	12.67±2.08	12.37±2.06	
E-SO-WE		89.34±0.02	8.38±0.01	790.00±10.00	84.24±1.03	
	Powder	3.66±0.69	0.04±0.01	68.10±0.52	65.61±0.36	75.80±1.97
SO-WE-130	Dust	6.21±0.04	0.01±0.00	9.00±1.00	8.44±0.94	
	Powder	3.56±0.10	0.04±0.00	68.47±0.06	66.03±0.04	72.67±3.39
SO-WE-140	Dust	6.22±0.04	0.07±0.00	12.33±2.52	11.57±2.36	
	Powder	2.49±0.17	0.03±0.00	67.73±0.50	66.05±0.58	71.87±3.08
SO-WE-150	Dust	2.32±0.22	0.02±0.00	12.67±2.08	12.37±2.06	

*Values are means ± SD of triplicate determination.DEW-130= E-WE spray dried at 130°C, DWE-140= E-WE spray dried at 140°C, DWE-150= E-WE spray dried at 150°C, MO-WE-130= E-MO-WE spray dried at 130°C, MO-WE-140= E-MO-WE spray dried at 140°C , MO-WE-150= E-MO-WE spray dried at 150°C, SO-WE-130= E-SO-WE spray dried at 130°C, SO-WE-140= E-SO-WE spray dried at 140°C, SO-WE-150 = E-SO-WE spray dried at 150°C.

Table B.7 Summary of inlet air condition for spray drying E-WE, E-MO-WE, and E-SO-WE***

Parameter	DWE-130	DWE-140	DWE-150	MO-WE-130	MO-WE-140	MO-WE-150	SO-WE-130	SO-WE-140	SO-WE-150
Ambient air temperature (°C)	23.20±0.36	22.50±0.53	21.33±0.47	23.20±0.36	22.50±0.53	21.33±0.47	23.20±0.36	22.50±0.53	21.33±0.47
Inlet air velocity (km/h)	73.71±0.08	76.25±0.23	76.07±0.10	73.11±0.14	75.25±0.23	75.07±0.10	70.11±0.14	70.25±0.23	70.43±0.25
Internal pipe diameter (m)	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
Volumetric flow rate of inlet air (m^3/h)	66.92±0.07	69.23±0.21	69.06±0.09	66.38±0.13	68.32±0.21	68.15±0.09	63.65±0.13	63.78±0.21	63.95±0.22
Relative humidity of inlet air (%)	48.67±1.53	47.10±1.40	51.14±0.03	48.67±1.53	47.10±1.40	51.14±0.03	48.67±1.53	47.10±1.40	51.14±0.03
Partial pressure exerted by water vapor (kPa)	1.45±0.05	1.26±0.04	1.30±0.00	1.45±0.05	1.26±0.04	1.30±0.00	1.45±0.05	1.26±0.04	1.30±0.00
Saturation pressure of water vapor (kPa)*	2.985	2.673	2.537	2.985	2.673	2.537	2.985	2.673	2.537
Absolute humidity x 10^{-3} (kg water/kg dry air)	9.05±0.29	7.83±0.24	8.07±0.00	9.05±0.29	7.83±0.24	8.07±0.00	9.05±0.29	7.83±0.24	8.07±0.00
Specific volume of inlet air (m^3/kg dry air)	0.85±0.00	0.85±0.00	0.84±0.00	0.85±0.00	0.85±0.00	0.84±0.00	0.85±0.00	0.85±0.00	0.84±0.00
Mass flow rate (kg dry air/h)	78.71±0.06	81.78±0.33	81.87±0.06	78.07±0.27	80.70±0.32	80.79±0.06	74.86±0.27	75.34±0.32	75.81±0.15
Specific heat of dry air at 23.80 °C (kJ/kg K)*	1.0124	1.0123	1.0121	1.0124	1.0123	1.0121	1.0124	1.0123	1.0121
Specific heat of water vapor at 23.80 °C (kJ/kg K)**	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88
Temperature of drying air (K)	403±2.60	413±2.00	423±1.50	403.00±3.00	413±2.00	423.00±1.50	403±3.00	413±2.00	423±1.50

*Obtained from appendix A 4.2 and A 4.4, respectively (Singh and Heldman 2001).

** Selected as 1.88 kJ/(kg K) according to Singh and Heldman (2001).

*** Values are means ± SD of triplicate determination.

See Table B.6 for a brief description of DWE-130, DWE-140, DWE-150, MO-WE-130, MO-WE-140, MO-WE-150, SO-WE-130, SO-WE-140, and SO-WE-150.

Table B.8 Summary of outlet air conditions for spray drying E-WE, E-MO-WE, and E-SO-WE [a]

	DWE-130	DWE-140	DWE-150	MO-WE-130	MO-WE-140	MO-WE-150	SO-WE-130	SO-WE-140	SO-WE-150
Outlet air temperature (°C)	65.00±0.80	64.40±0.51	67.30±0.46	65.00±0.80	64.40±0.51	67.30±0.46	65.00±0.80	64.40±0.51	67.30±0.46
Outlet air velocity (km/h)	19.1±0.10	19.70±0.27	19.80±0.10	18.90±0.10	19.30±0.05	19.60±0.05	18.2±0.05	18.20±0.06	18.50±0.11
Internal pipe diameter (m)	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
Volumetric flow rate of outlet air (m^3/h)	77.77±0.41	80.10±1.10	80.62±0.41	76.95±0.41	78.58±0.20	79.80±0.20	73.90±0.20	74.28±0.25	75.20±0.44
Relative humidity of outlet air (%)	11.50±0.05	10.90±0.05	9.7±0.10	11.40±0.03	10.80±0.03	9.6±0.10	11.50±0.03	11.1±0.13	9.80±0.03
Partial pressure exerted by water vapor (kPa)	2.88±0.01	2.65±0.01	2.70±0.03	2.86±0.01	2.64±0.01	2.67±0.03	2.88±0.01	2.70±0.03	2.74±0.01
Saturation pressure of water vapor (kPa)*	25.03	24.419	27.86	25.03	24.419	27.86	25.03	24.42	27.86
Absolute humidity x 10^{-3} (kg water/kg dry air)	18.19±0.08	16.70±0.08	17.04±0.18	18.06±0.04	16.65±0.05	16.86±0.18	18.22±0.04	17.02±0.21	17.26±0.05
Specific volume of outlet air (m^3/kg dry air)	0.98±0.00	0.98±0.00	0.99±0.00	0.98±0.00	0.98±0.00	0.99±0.00	0.98±0.00	0.98±0.00	0.99±0.00
Mass flow rate of outlet air (kg dry air/h)	79.01±0.37	81.73±1.04	81.50±0.48	78.20±0.53	80.18±0.16	80.70±0.16	75.08±0.03	75.75±0.28	76.00±0.46

[a] Values are means ± SD of triplicate determination.

*Obtained from appendix A 4.2 and A 4.4, respectively (Singh and Heldman 2001).

See Table B.6 for a brief description of DWE-130, DWE-140, DWE-150, MO-WE-130, MO-WE-140, MO-WE-150, SO-WE-130, SO-WE-140, and SO-WE-150.

Table B.9 Estimated evaporation rates and energy used to spray dry whole egg emulsions*

	Inlet Temp. (°C)	E-WE	E-MO-WE	E-SO-WE
Evaporation rate (kg water/h)[1]	130	0.725±0.020 ^{aA}	0.706±0.025 ^{aA}	0.691±0.023 ^{aA}
	140	0.725±0.005 ^{aA}	0.703±0.018 ^{aA}	0.699±0.005 ^{aA}
	150	0.729±0.011 ^{aA}	0.709±0.014 ^{aA}	0.700±0.011 ^{aA}
Evaporation rate (kg water/h)[2]	130	0.729±0.000 ^{bA}	0.702±0.009 ^{aB}	0.702±0.009 ^{aB}
	140	0.729±0.000 ^{bA}	0.702±0.009 ^{aB}	0.702±0.009 ^{aB}
	150	0.730±0.000 ^{aA}	0.704±0.009 ^{aB}	0.704±0.009 ^{aB}
Energy required to spray dry CJP (kJ/kg)	130	8623.97±6.55 ^{cA}	8553.79±29.77 ^{cB}	8202.78±29.20 ^{cC}
	140	9873.04±39.25 ^{bA}	9743.56±39.07 ^{bB}	9096.15±38.15 ^{bC}
	150	10638.94±7.62 ^{aA}	10499.08±7.51 ^{aB}	9851.02±18.85 ^{aC}

*Values are means ± SD of triplicate determination. [1]Calculated based on the moisture uptake by the dry air (kg water/h). [2]Calculated based on the moisture content of the E-WE/E-MO-WE/E-SO-WE emulsions, powder collected through collector vessel, and dust (kg water/h). ^{abc}Means with same letter in each column are not significant different ($p<0.05$). ^{ABC}Means with same letter in each row are not significant different ($p<0.05$). See table B.2 for brief description of E-WE, E-MO-WE and E-SO-WE.

Table B.10 Color and microencapsulation efficiency (ME) of WE, MO-WE, and SO-WE*

	Inlet Temp. (°C)	DWE	MO-WE	SO-WE
L*	130	91.46±0.02 ^{aA}	86.65±0.01 ^{aB}	84.35±0.02 ^{cC}
	140	92.90±0.01 ^{aA}	86.46±0.02 ^{bB}	85.21±0.01 ^{bC}
	150	86.70±0.01 ^{cA}	85.65±0.03 ^{cB}	85.53±0.01 ^{aC}
a*	130	1.14±0.01 ^{cC}	3.42±0.02 ^{cB}	5.60±0.01 ^{aC}
	140	1.31±0.02 ^{bC}	5.29 ±0.01 ^{aA}	2.21±0.01 ^{cB}
	150	3.75±0.02 ^{aC}	4.18±0.01 ^{bB}	4.49±0.02 ^{bA}
b*	130	16.03±0.01 ^{cC}	19.20±0.02 ^{cB}	23.18±0.01 ^{bA}
	140	18.25±0.01 ^{bC}	22.18±0.01 ^{aB}	22.21±0.01 ^{cA}
	150	24.37±0.00 ^{aA}	21.10±0.01 ^{bC}	23.28±0.02 ^{aB}
Hue	130	85.93±0.03^{aA}	79.91±0.05 ^{aB}	76.42±0.01 ^{cC}
	140	85.88±0.07 ^{aA}	76.58±0.03 ^{cC}	84.32±0.02 ^{aB}
	150	81.24±0.05 ^{bA}	78.79±0.02 ^{bC}	79.09±0.04 ^{bB}
Chroma	130	16.07±0.01 ^{cC}	19.50±0.01 ^{cB}	23.84±0.01 ^{aA}
	140	18.30±0.01 ^{bC}	22.80±0.01 ^{aA}	22.32±0.01 ^{cB}
	150	24.65±0.00 ^{aA}	21.51±0.01 ^{bC}	23.71±0.01 ^{bB}
Microencapsulation Efficiency (%)	130	74.40±1.13 ^{aA}	54.69±0.06 ^{bB}	54.43±0.47 ^{aB}
	140	73.50±0.66 ^{aA}	55.06±0.23 ^{abB}	54.63±0.06 ^{aB}
	150	73.57±0.40 ^{aA}	55.09±0.14 ^{aB}	54.64±0.10 ^{aB}

*Values are means ± SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p< 0.05$). ^{AB} means with different letters in each row are significantly different ($p< 0.05$). DWE= whole egg powder, MO-WE= whole egg powder containing menhaden oil, SO-WE= whole egg powder containing salmon oil.

Table B.11 FAMEs profile of DWE (% of total integrated area)*

FAME (%)	Inlet Temp. (°C)		
	130	140	150
14:00	0.41±0.00	0.38±0.01	0.41±0.00
16:00	26.64±0.16	26.41±0.03	26.17±0.19
16:1n7	2.54±0.03	2.48±0.02	2.65±0.04
18:00	10.37±0.19	10.21±0.04	10.14±0.45
18:1n9c	39.39±0.24	40.06±0.10	40.60±0.49
18:1n5	1.49±0.02	1.47±0.01	1.55±0.02
18:2n6c	16.54±0.06	15.52±0.08	15.25±0.05
18:3n3	0.45±0.01	0.44±0.03	0.42±0.01
20:4n6	1.60±0.04	1.52±0.03	1.38±0.06
22:5n3	0.39±0.01	0.39±0.01	0.36±0.02
22:6n3	0.40±0.02	0.43±0.03	0.39±0.01

*Values are means ± SD of triplicate determination. DWE= whole egg powder.

Table B.12 FAMEs profile of MO-WE (% of total integrated area)*

FAME (%)	Inlet Temp. (°C)		
	130	140	150
14:0	5.63±0.02	4.59±0.05	5.20±0.01
15:0	0.55±0.00	0.46±0.00	0.53±0.00
16:0	21.98±0.54	23.82±0.06	24.26±0.17
16:1n7	8.82±0.03	7.64±0.06	7.77±0.07
17:1n11	0.80±0.01	0.61±0.01	0.61±0.01
18:0	6.23±0.32	7.25±0.05	6.85±0.15
18:1n9c	18.60±0.30	22.40±0.06	22.30±0.10
18:1n5	2.53±0.00	2.31±0.01	2.36±0.02
18:2n6c	6.61±0.20	9.55±0.09	8.65±0.01
18:3n3	1.24±0.01	1.09±0.01	1.12±0.01
20:4n6	1.33±0.06	1.45±0.01	1.22±0.03
20:3n3	1.17±0.02	0.93±0.01	0.94±0.01
20:5n3	9.20±0.22	7.11±0.06	7.13±0.08
22:5n3	1.84±0.02	1.45±0.01	1.45±0.02
22:6n3	9.00±0.09	7.21±0.04	7.05±0.06

*Values are means ± SD of triplicate determination. MO-WE= whole egg powder containing menhaden oil.

Table B.13 FAMEs profile of SO-WE (% of total integrated area)*

FAME (%)	Inlet Temp. (°C)		
	130	140	150
14:00	2.72±0.03	2.90±0.01	2.79±0.01
15:00	0.34±0.00	0.35±0.00	0.35±0.00
16:00	20.26±0.07	19.00±0.09	19.56±0.05
16:1n7	4.44±0.03	4.50±0.02	4.38±0.00
18:00	6.15±0.08	5.65±0.08	5.91±0.02
18:1n9c	25.47±0.09	24.96±0.02	25.73±0.02
18:1n5	2.19±0.02	2.25±0.01	2.19±0.01
18:2n6c	8.88±0.06	8.52±0.04	8.61±0.03
18:3n3	0.78±0.01	0.82±0.01	0.79±0.00
20:1n9	5.51±0.06	5.94±0.02	5.73±0.03
20:4n6	1.05±0.03	0.97±0.02	1.09±0.01
20:3n3	0.90±0.02	0.97±0.02	0.93±0.01
20:5n3	5.89±0.03	6.32±0.04	6.07±0.01
22:5n3	1.23±0.02	1.31±0.01	1.27±0.01
22:6n3	5.90±0.07	6.33±0.05	6.09±0.01

*Values are means ± SD of triplicate determination. SO-WE= whole egg powder containing salmon oil.

Table B.14 FFA and TBARS of whole egg powders*

	FFA (%)	TBARS (mmol/kg oil)
DWE-130	0.21±0.03^{a}	0.03±0.02^{a}
DWE-140	0.25±0.03^{a}	0.03±0.01^{a}
DWE-150	0.28±0.03^{a}	0.04±0.01^{a}
MO-WE-130	0.65±0.03^{a}	0.15±0.00^{b}
MO-WE-140	0.66±0.04^{a}	0.16±0.00^{a}
MO-WE-150	0.66±0.04^{a}	0.16±0.00^{a}
SO-WE-130	0.69±0.06^{b}	0.14±0.00^{b}
SO-WE-140	0.69±0.07^{b}	0.15±0.00^{a}
SO-WE-150	0.70±0.07^{a}	0.15±0.00^{a}

*Values are means ± SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p< 0.05$).^{ABC} means with different letters in each row are significantly different ($p< 0.05$). See Table B.6 for a brief description of DWE-130, DWE-140, DWE-150, MO-WE-130, MO-WE-140, MO-WE-150, SO-WE-130, SO-WE-140, and SO-WE-150.

Table B.15 Nutritional properties of DWE, MO-WE, and SO-WE*

	Inlet Temp. (°C)	DWE	MO-WE	SO-WE
Moisture (%)	130	6.79±0.27 ^{aA}	5.66±0.36 ^{aB}	5.51±0.05 ^{aB}
	140	4.84±0.11 ^{bC}	5.56±0.10 ^{aA}	5.30±0.10 ^{bB}
	150	4.50±0.25 ^{bA}	4.49±0.17 ^{bA}	4.59±0.09 ^{cA}
Protein (g/100 g, dry basis)	130	50.152	19.786	20.186
	140	49.879	19.853	20.089
	150	48.248	20.185	20.845
Lipids (g/100 g, dry basis)	130	42.11±0.27 ^{aB}	71.33±0.15 ^{aA}	71.08±0.04 ^{aB}
	140	42.47±0.80 ^{aB}	72.16±0.26 ^{bA}	70.93±0.16 ^{aA}
	150	42.58±1.29 ^{aB}	71.41±0.27 ^{bA}	70.43±0.21 ^{bA}
Ash (g/100 g, dry basis)	130	3.40±0.05 ^{aA}	2.33±0.06 ^{bB}	2.32±0.06 ^{aB}
	140	3.36±0.17 ^{aA}	2.53±0.16 ^{abB}	2.63±0.30 ^{aB}
	150	3.26±0.04 ^{aA}	2.76±0.12 ^{aB}	2.81±0.07 ^{bB}
Water activity (a_w)	130	0.329±0.003 ^{aA}	0.314±0.004 ^{aB}	0.318±0.004 ^{aB}
	140	0.264±0.004 ^{aA}	0.265±0.002 ^{bA}	0.271±0.004 ^{bA}
	150	0.226±0.003 ^{aA}	0.221±0.003 ^{cA}	0.225±0.004 ^{cA}

*Values are means ± SD of triplicate determination. ^{abc} means with different letters in each column are significantly different ($p< 0.05$). ^{ABC} means with different letters in each row are significantly different ($p< 0.05$). DWE= whole egg powder, MO-WE= egg yolk containing menhaden oil, SO-WE= whole egg powder containing salmon oil.

Table B.16 Amino acid profile of DWE, MO-WE, and SO-WE powders*

Amino acid (mg/g protein)	DWE			MO-WE			SO-WE		
	Inlet Temp. (°C)			Inlet Temp. (°C)			Inlet Temp. (°C)		
	130	140	150	130	140	150	130	140	150
Aspartic acid	111.65	111.05	110.06	107.48	106.17	104.74	106.31	104.59	101.59
Threonine[a]	51.80	51.46	51.46	50.23	49.30	48.70	49.48	48.42	49.46
Serine	75.19	74.61	73.74	80.46	79.84	78.54	79.31	77.57	79.27
Glutamic acid	97.50	100.53	96.04	85.38	87.36	90.86	91.65	90.72	104.07
Proline	34.27	33.98	33.05	32.72	33.11	33.00	33.71	32.70	35.15
Glycine	30.25	30.15	29.50	28.22	28.37	28.18	28.72	28.31	29.23
Alanine	52.22	52.37	51.06	48.62	48.73	48.85	49.67	48.94	51.40
Valine[a]	71.59	70.88	70.45	68.61	66.96	66.21	67.37	65.91	66.55
Methionine[a]	37.63	37.31	36.53	34.64	34.34	34.25	35.04	34.25	34.99
Isoleucine[a]	55.42	55.10	54.89	54.62	53.38	52.87	53.68	52.33	53.52
Leucine[a]	94.95	94.66	94.25	90.28	89.44	89.05	90.59	88.90	90.42
Tyrosine[a]	45.41	45.26	45.20	43.22	43.05	42.84	43.26	42.86	43.22
Phenylalanine[a]	65.30	64.62	63.80	57.82	57.47	57.25	58.47	57.01	58.33
Histidine[a]	25.64	25.28	25.07	25.12	25.61	25.31	25.59	25.21	25.75
Lysine[a]	77.85	77.06	77.60	76.56	75.68	74.79	76.65	74.45	74.42
Arginine	65.56	64.50	64.07	70.40	68.93	68.28	68.89	67.40	68.75
TEAA	525.59	521.63	519.24	501.10	495.23	491.26	500.14	489.33	496.66
TAA	992.24	988.81	976.76	954.39	947.72	943.70	958.40	939.56	966.11

*Values are means of triplicate determinations. See table B.10 for brief description of DWE, MO-WE, and SO-WE. TEAA= total essential amino acids; TAA= total amino acids

[a] Essential amino acids

**Cysteine and tryptophan were not quantified.

Table B.17 Mineral profile of whole egg powders*

	DEY			MO-EW			SO-EW			Recommended dietary allowance for mineral (mg/day)[a]
	Inlet Temp (°C)			Inlet Temp. (°C)			Inlet Temp. (°C)			
Mineral	**130**	**140**	**150**	**130**	**140**	**150**	**130**	**140**	**150**	
P (g/100 g powder)	0.39	0.41	0.43	0.31	0.38	0.38	0.38	0.37	0.36	800/1400
K (g/100 powder)	0.99	0.76	1.05	0.69	0.78	0.69	0.58	0.48	0.41	2000/3500
Ca (g/100 g powder)	0.06	0.06	0.06	0.11	0.14	0.14	0.14	0.13	0.14	800/900
Mg (g/100 g powder)	0.02	0.03	0.02	0.03	0.03	0.03	0.04	0.03	0.04	350/350
Cu (mg/100 g powder)	0.11	0.14	0.19	0.95	1.30	1.19	1.29	1.20	1.29	1.5/3.0
Zn (mg/100 g powder)	<1	<1	<1	30	33	33	32	32	33	10/15
Mn (mg/100 g powder)	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Fe (mg/100 g powder)	<1	<1	<1	43	41	40	39	39	40	12/12
As (mg/100 g powder)	<.40	<.40	<.40	<.40	<.40	<.40	<.40	<.40	<.40	
Pb (mg/100 g powder)	<.01	<.01	0.02	<.01	<.01	<.01	<.01	<.01	<.01	

*Values are means of triplicate determinations. See Table B.6 for a brief description of DWE-130, DWE-140, DWE-150, MO-WE-130, MO-WE-140, MO-WE-150, SO-WE-130, SO-WE-140, and SO-WE-150.

[a]Compiled from Brounds (1993) for male athletes from 25 to 50 years old.

VITA

Kevin Estuardo Mis Solval was born in November 1986, in Samayac, Suchitepequez, Guatemala. He graduated from high school at Escuela Nacional Central de Agricultura in 2002. In December 2009 he obtained his Bachelor of Science in Food Science and Technology from Escuela Agricola Panamericana, El Zamorano, Honduras. In the spring of 2008, he successfully completed an undergraduate internship at the Department of Food Science at Louisiana State University and Agricultural and Mechanical College under the supervision of Dr. Subramaniam Sathivel. He joined Dr. Sathivel's research group as a master student in the spring of 2009. Kevin Mis is experienced in the production of biodiesel, supercritical fluid extraction and the spray drying technologies. He is set to obtain his master's degree in food science in May 2011. Kevin enjoys being active by traveling, swimming, and cooking.