DEVELOPMENT OF EMULSION GEL AS FAT REPLACER IN CHICKEN MEAT EMULSION FOR THE PRODUCTION OF REDUCED-FAT MEAT PRODUCTS

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Chairman : Ismail Fitry bin Mohammad Rashedi, PhD
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In recent years, reduced-fat meat products have surged in popularity as they are healthier compared to meat products with animal fats. Animal fat gives good quality characteristics to meat products but it is associated with non-communicable diseases. Structured oils made from emulsion gels have garnered interest in replacing animal fat. Thus, this study consisted of four objectives, which generally aimed to produce reduced-fat chicken products for different meat rigor conditions with developed emulsion gels as fat replacers. In the first objective, different types of animal fats such as chicken skin, beef fats and lamb fats were compared in terms of physicochemical, molecular and microstructural characteristics. The fatty acid compositions of chicken skin, beef and lamb fats ranging from 55.43 to 72.02% for saturated fatty acids. X-ray diffraction (XRD) showed that chicken skin crystallised in a beta prime (β') polymorph while lamb and beef fat crystallised in an alpha (α) polymorph. Microscopic images showed that lamb and beef fats had a larger and more heterogeneous structure compared to chicken skin which was evenly distributed. For the second objective, three systems were studied: emulsion gel A (EGA) and emulsion gel B (EGB), which promoted electrostatic interaction, and emulsion gel C (EGC), which did not. Smaller particle size ($p<0.05$) in EGA and EGB increased gel strength, hardness and oxidative stability. Smaller droplets would result in a better-aggregated network of three-dimensional structures which leads to better physicochemical properties of the emulsion gels. Electrostatic protein-polysaccharide interactions were most enhanced by EGA, making it suitable for use for the third objective. Following this, the chicken meat emulsion properties of pre- and post-rigor using chicken skin and EGA as a fat replacer were determined. The findings showed that the EGA-replaced chicken emulsion had higher moisture and lower fat ($p<0.05$). EGA also reduced saturated fat in chicken emulsion from 68% to 34%. EGA-replaced chicken emulsion had the smoothest surface regardless of rigor states, thus, indicating that the meat emulsion was well emulsified. The fourth objective indicated chicken sausage combined with EGA had a considerably ($p<0.05$) decreased fat content. This work established that the water holding capacity (WHC) of the chicken sausage with emulsion gel could mimic the WHC of chicken sausage with animal fat. This could be attributed to the presence of hydrocolloids present in the emulsion gel which could bind to water. Sensory analysis showed that panellists did not detect any significant differences ($p>0.05$) between the chicken sausage samples. Conclusively, the current study successfully demonstrated that the incorporation of EGA as fat replacers in chicken emulsion and sausage reduced fat content compared to the control sample while maintaining quality regardless of rigor conditions. This

study ascertained that the meat products developed could serve as a valuable resource for researchers and also contribute to the development of healthier meat products. Thus, it can be concluded that emulsion gel has the potential as a fat replacer in the production of reduced-fat meat products.

Keywords: animal fat; emulsion gel; fat replacer; meat emulsion; rigor conditions; sausages

SDG: GOAL 2: Good Health and Well-being

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN GEL EMULSI SEBAGAI PENGGANTI LEMAK DALAM EMULSI DAGING AYAM UNTUK PENGELUARAN PRODUK DAGING KURANG LEMAK

Oleh

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Dalam beberapa tahun kebelakangan ini, produk daging rendah lemak telah meningkat dalam populariti kerana mereka lebih sihat berbanding produk daging dengan lemak haiwan. Lemak haiwan memberikan ciri kualiti yang baik kepada produk daging tetapi ia dikaitkan dengan penyakit tidak berjangkit. Minyak berstruktur yang diperbuat daripada gel emulsi semakin mendapat perhatian untuk menggantikan lemak haiwan. Oleh itu, kajian ini mengandungi empat objektif, yang secara amnya bertujuan untuk menghasilkan produk ayam kurang lemak untuk pelbagai jenis keadaan daging dengan gel emulsi yang dibangunkan sebagai pengganti lemak. Dalam objektif pertama, pelbagai jenis lemak haiwan seperti kulit ayam, lemak lembu dan lemak kambing telah dibandingkan dari segi ciri kualiti fizikokimia, molekul dan mikrostruktur. Komposisi asid lemak kulit ayam, lemak lembu dan lemak kambing adalah antara 55.43 hingga 72.02% untuk asid lemak tepu. Pembelauan sinar-X (XRD) menunjukkan bahawa kulit ayam terhablur dalam polimorf beta prima

(β') manakala lemak kambing dan lemak lembu terhablur dalam polimorf alfa (α). Imej mikroskopik menunjukkan bahawa lemak kambing dan daging lembu mempunyai struktur yang lebih besar dan lebih heterogen berbanding kulit ayam yang diagihkan sama rata. Dalam objektif yang kedua, tiga sistem telah dikaji: gel emulsi A (EGA) dan gel emulsi B (EGB), yang menggalakkan interaksi elektrostatik, dan gel emulsi C (EGC), yang tidak menggalakkan. Saiz zarah yang lebih kecil ($p<0.05$) dalam EGA meningkatkan kekuatan gel, kekerasan, dan kestabilan oksidatif. Saiz zarah lebih kecil akan menghasilkan rangkaian terkumpul yang lebih baik bagi struktur tiga dimensi yang membawa kepada sifat kualiti fizikokimia gel emulsi yang lebih baik. Interaksi elektrostatik protein- polisakarida paling banyak dipertingkatkan oleh EGA, menjadikannya sesuai untuk digunakan untuk objektif ketiga. Berikutan itu, sifat emulsi daging ayam sebelum dan selepas rigor menggunakan kulit ayam dan EGA sebagai pengganti lemak telah ditentukan. Dapatan kajian menunjukkan bahawa emulsi ayam yang digantikan dengan EGA mempunyai kelembapan yang lebih tinggi dan lemak yang lebih rendah ($p<0.05$). EGA juga mengurangkan lemak tepu dalam emulsi ayam daripada 68% kepada 34%. Emulsi ayam yang digantikan dengan EGA mempunyai permukaan yang paling licin tanpa mengira keadaan rigor, oleh itu, ia menunjukkan bahawa emulsi daging telah diemulsikan dengan baik. Objektif keempat menunjukkan sosej ayam yang digabungkan dengan EGA mempunyai kandungan lemak yang berkurangan dengan ketara ($p<0.05$). Kajian ini membuktikan bahawa kapasiti memegang air (WHC) sosej ayam dengan gel emulsi boleh menyamai WHC sosej ayam dengan lemak haiwan. Ini boleh dikaitkan dengan kehadiran hidrokoloid yang terdapat dalam gel emulsi yang boleh mengikat air. Analisis deria

menunjukkan ahli panel tidak dapat mengenal pasti sebarang perbezaan yang ketara ($p>0.05$) antara sampel sosej ayam. Secara kesimpulannya, kajian semasa berjaya menunjukkan bahawa penggabungan EGA sebagai pengganti lemak dalam emulsi ayam dan sosej mengurangkan kandungan lemak berbanding sampel kawalan sambil mengekalkan kualiti tanpa mengira keadaan rigor. Kajian ini memastikan bahawa produk daging yang dihasilkan boleh menjadi sumber yang berharga untuk penyelidik dan juga menyumbang kepada penghasilan produk daging yang lebih sihat. Oleh itu, dapat disimpulkan bahawa gel emulsi berpotensi sebagai pengganti lemak dalam penghasilan produk daging kurang lemak.

Kata Kunci: emulsi daging; gel emulsi; keadaan rigor; lemak haiwan; pengganti lemak; sosej

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Al-Isra verse 24

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LIST OF ABBREVIATIONS

%	Per cent
APS	Ammonium Persulfate
ATP	Adenosine tripolyphosphate
DSC	Differential scanning calorimetry
EFAT	Expressible fat
EGA	Emulsion gel A
EGB	Emulsion gel B
EGC	Emulsion gel C
FAME	Fatty acid methyl esters
FDA	Food and drug administration
GRAS	Generally recognized as safe
Kcal	Kilocalorie
KDa	Kilodalton
mg/g	milligram per gram
mol/L	Moles per litre
MUFA	Monounsaturated fatty acids
N	Newton
nm	Nanometer
PCA	Principal component analysis
PUFA	Polyunsaturated fatty acids
SDS PAGE	Sodium Dodecyl Sulphate-Polyacrylamide Gel Electrophores
SEM	Scanning electron microscope
SFA	Saturated fatty acids
STPP	Sodium tripolyphosphate
TAGs	Triacylglycerols
TBARS	Thiobarbituric acid reactive substances

TEF	Total expressible fluid
TPA	Texture profile analysis
USFA	Unsaturated fatty acids
WHC	Water holding capacity
WHO	World health organization
XRD	X-ray diffraction

CHAPTER 1

INTRODUCTIONS AND RESEARCH OBJECTIVES

1.1 Introduction

Meat and meat products have always been among the most important goods of consumer shopping preferences due to their high nutritional value, which includes high-quality proteins, iron, zinc, selenium, and B-complex vitamins (Akhter et al., 2022). One of the most important elements in the production of meat products is fat as it helps to improve emulsion stability, textural characteristics and sensory properties (Kim et al., 2021a; Rezaee and Aider, 2023). Meat products, on the other hand, include a high concentration of saturated fatty acids, salt and additives, which are not compatible with a healthy diet (dos Santos et al., 2020a). The fat contentof meat products may range from 5% to 50%, with a notably higher percentage of saturated fatty acids (SFAs) than polyunsaturated fatty acids (PUFAs) (Grasso et al., 2014; Muguerza et al., 2004). The World Health Organization recommends reducing SFAs and increasing unsaturated fat consumption to prevent obesity, which is linked to chronic diseases like diabetes, heart disease, and high blood pressure (WHO, 2007). Thus, reformulating meat products to make them healthier is a significant strategy, because they are frequently perceived as unhealthy by consumers (Guo et al., 2022; Pintado et al., 2015).

Consequently, the food industry is making considerable efforts to develop low-fat foods to address the problem stated above (Wang et al., 2023a). However, compared to their full-fat counterparts, low-fat foods are inferior in terms of taste, texture, appearance and functionality (Rios et al., 2014). A great deal of study has been conducted on the lowering of fat content in meat products (Rezaee and Aider, 2023). As a result, consumer acceptance of low-fat foods might be considerably increased with the proper development of fat replacers in meat products (Kew et al., 2020). Replacing animal fat with vegetable and marine oils, which are linked to a lower risk of numerous chronic diseases, is one of the most employed strategies used for this purpose (Munekata et al., 2017). However, the inclusion of liquid oil in meat products may have a negative impact on the technological and product quality characteristics of meat products (Bolumar et al., 2015). For instance, using liquid oils as a replacement for animal fat in meat products can increase hardness and decrease sensory acceptability (de Carvalho et al., 2020). Structuring oils creates lipid systems with a better fatty acid profile and solid-like characteristics, lowering fat content while retaining sensory acceptability (Pintado et al., 2015). Thus, there is an urgent need to shift towards a healthier source of fat such as emulsion gels for better physicochemical properties and healthier meat products.

Emulsion gels (EGs) can exhibit a physical behaviour similar to that of fat in the functional characteristics of meat products because of their soft-solid texture (dos Santos et al., 2020a). EGs are soft-solid materials that can be created by dispersing emulsified droplets in a continuous gel matrix or aggregating dispersed droplets in a particulate gel (Dickinson, 2012). These materials, mostly structured liquid oil contained in a three-dimensional gel matrix, improve meat product cooking yield, nutritional profile, and taste (Badar et al., 2021). There are two steps involved in the preparation of emulsion gel: 1) emulsions are stabilized by emulsifiers to prepare a stable emulsion; and 2) emulsion gels are formed by gelation of the emulsion through heat treatment methods (Lin et al., 2020). However, studies are scarce on the processes by which emulsion gel mimics the functions of animal fats in meat products. Furthermore, the factors influencing the animal fat-mimicking abilities of emulsion gel have not been well explored.

Different gelling agents, such as hydrocolloids, have been used alone or in different combinations, giving the emulsion gels a variety of textures and structures (Paglarini et al., 2022). For instance, various kinds of emulsion gels made from different ingredients are being incorporated in meat products such as carrageenans (Heck et al., 2019), inulin, (de Souza Paglarini et al., 2021), chia mucilage (Câmara et al., 2021) and alginate (Kim et al., 2020c). In the food industry, the use of polysaccharides alone as structuring agents, stabilisers, or thickening agents in emulsion gels is well-established (Rezaee and Aider, 2023). Nevertheless, single-component-producing emulsion gels (such as proteins or polysaccharides) applied as fat replacers have not demonstrated outstanding fat simulation capability in the characteristics of the emulsion gels (Wang et al., 2023b). The functional properties of protein-polysaccharide complexes and conjugates are enhanced in comparison to those of either component alone (Bascuas et al., 2021). Polysaccharides and proteins may broaden the application of emulsion structural agents and create fat replacers with better performance, availability, and nutrition (Pintado and Cofrades, 2020). Previous studies have found that the protein of the emulsion interface interacting with polysaccharides in the continuous phase might increase the mechanical strength of emulsion gels (Dickinson, 2012). In addition, the formation of high-quality gel-based foods can be accomplished through the modification of polysaccharides or proteins using the applications of various technologies, suchas biological, physical and/or chemical treatments (Li et al., 2022c). Therefore, it is crucial to determine the characteristics of the fat replacer before application into the food system.

One of the key determinants of important eating quality of a meat product is the result of the intrinsic properties of the raw materials used (Purslow, 2014; Wrona et al., 2017). Due to the intricate nature of the matrix, determining the quality of products containing minced meat can be challenging. Consequently, meat emulsion is frequently used as a model to investigate the impact of various parameters on the quality of minced meat products (Zhao et al., 2019). Several biochemical processes, including rigor mortis, ageing, and deterioration of meat, take place after an animal is slaughtered (Ertbjerg and Puolanne, 2017). The main difference between aged meat and hot-fresh meat is that aged meat has undergone the entire process of rigor mortis, whereas rigor mortis has not occurred in hot-fresh meat (Wang et al., 2019a, Xiao et al., 2020). Therefore, aged meat can be considered post-rigor, whereas hot-fresh meat can be considered pre-rigor (Li et al., 2022b). Several studies have demonstrated that pre- and post- rigor meat quality possesses distinct characteristics (Yan et al., 2022). Previous literature reported that protein solubility and emulsification are enhanced in pre-rigor beef, and the meathas higher water retention and nutritional value (Xiao et al., 2020). On the other hand, tenderness and flavour are improved in post-rigor meat (Xiao et al., 2020; Li et al., 2019a). Thus, it is of utmost importance to observe the characteristics of meat products processed with meat from different conditions. Understanding the qualitative characteristics of pre- and post-rigor meat is essential for improving meat products. However, there is a lack of understanding of how meat products made using pre- and post-rigor states of meat differ in physicochemical, texture and sensory characteristics.

1.2 Problem Statements

In the production of meat products, one of the main ingredients incorporated is fats. The incorporation of animal fats in meat products is commercially and technically importantsince it not only affects the physicochemical properties of the final product quality but also affects the sensory properties of the meat products. For instance, different qualitiesof animal fats affect the stability of sausage emulsions such hardness and they also have a crucial role in determining the qualities of sausages, including their juiciness, mouthfeel, texture, flavour, and energy content (Qi et al., 2020; Teye et al., 2006). Therefore, the characteristics of different types of animal fats i.e. lamb fat, beef fat and chicken skin are very crucial towards the development of meat products. Besides, the physicochemical characteristics of the animal fats can also be used as a reference to compare with the physicochemical characteristics of the developed fat replacer i.e. emulsion gel in the next chapter.

The development of an oil structuring method known as emulsion gel has gained a lot of attention as it is utilized as a fat replacer to replace animal fat in meat products. Nevertheless, the physical stability and textural properties of the emulsion gels were affected when the reformulation of these emulsion gels was applied as a single strategy(Khalesi et al., 2019). Simply using emulsion gels without any treatments to replace animal fat in meat products could also cause a decline in meat product quality such as lower levels of hardness. It is noteworthy to mention that emulsion gels composed solely of polysaccharides or proteins have considerable practical limitations, including inadequate emulsification, thermal stability and textural properties (Zhang et al., 2021). For instance, emulsion gels made by the combination of protein and polysaccharide enhanced both the emulsification of individual materials and the stability of emulsion gels (Dai et al., 2018). Therefore, several ingredients with suitable treatment and modification could be used in the reformulation of the emulsion gels to enhance the stability of the emulsion gels.

Common meat emulsion mainly consists of animal fat and meat protein, where the emulsion is the basis of most meat products, namely sausages, burger patties, meatballsand nuggets. These meat products have been part of the diet in Malaysia, especially forchildren due to their convenience. The negative side is that the animal fat in these meat products can be correlated to health problems such as obesity and non-communicable diseases. Nevertheless, animal fat is so important to the characteristics of a stable emulsion, therefore, removing it completely from the meat emulsion system will lead to undesirable meat products such as dry, hard, shrunk and disintegrated products. For instance, decreasing the amount of animal fats in a sausage directly leads to reduced textural characteristics, resulting in a less desirable product (Qi et al., 2020). Fat replacers i.e. emulsion gels have been applied in meat emulsion to imitate the functions of animal fat. However, the emulsions produced are usually unstable and varied based on the types of fat replacers and conditions of meat used (pre- and post-rigor meat). For instance, the usage of pre and post rigor chicken meat emulsion affected the protein gelation of the final products (Choi et al., 2015). Overall, different sources of fat with different conditions of meat could lead to different meat emulsion attributes, however, the comparison in terms of quality and characteristics are yet to be tested scientifically.

Chicken sausage is considered one of the most consumed meat products globally. However, the high amount of fats especially saturated fats (SFA) in chicken skin that is used as a source of animal fat in chicken sausage increases the risk of non-communicable diseases. For example, poultry skin exhibits the highest cholesterol content in comparison to poultry meat or poultry fat which is a significant contributor to coronary heart disease and arteriosclerosis (Milićević et al., 2014). Therefore, fat replacer i.e. emulsion gel is incorporated in chicken sausage as a source of fat. Besides, different conditions of meat (pre- and post-rigor) are used as a source of raw meat in the production of chicken sausage could give different characteristics towards the meat products. For example, the usage of different rigor conditions of raw meat leads to different textural properties of the meat products (Kim & Chin, 2023). The use of fat replacers in meat products has been practised for many years in some parts of the world, but no reports were found where different sources of fat were used with different conditions of meat. Therefore, it is important to study the potential of this fat replacer as a source of fat with different conditions of the meat as a means of providing scientificevidence.

1.3 Research Objectives

a) The overall aim of this current study was to foresight the use of emulsion gels as a fat replacer in meat products with different conditions of the raw meat ingredient. Therefore, the focus of the project was the development of emulsion gels to be used as a fat replacer for the production of reduced-fat meat products.

b) Specifically, the objectives of the current study were:

   i. To investigate the molecular composition, physicochemical properties, and thermal behaviours of various animal fats, including lamb fat, beef fat, and chicken skin.

   ii. To develop emulsion gels using canola oil, modified corn starch, and gelatin through electrostatic interactions, and evaluate their molecular composition, physicochemical properties, and thermal behaviours.

   iii. To assess the physicochemical and microstructural properties of chicken meat emulsion under different rigor states, specifically pre- and post-rigor, using different fat sources (chicken skin or emulsion gel as a fat replacer).

iv. To examine the impact of emulsion gel as a fat replacer on the quality and sensory characteristics of chicken sausage, considering chicken meat at pre- and post-rigor states.

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