UNIVERSITI PUTRA MALAYSIA

RHEOLOGICAL AND PHYSICAL PROPERTIES OF VARIOUS FLOUR EXTRUDATES AT DIFFERENT BARREL TEMPERATURES

LIM SUE SHAN

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RHEOLOGICAL AND PHYSICAL PROPERTIES OF VARIOUS FLOUR EXTRUDATES AT DIFFERENT BARREL TEMPERATURES

By

LIM SUE SHAN

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

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RHEOLOGICAL AND PHYSICAL PROPERTIES OF VARIOUS FLOUR EXTRUDATES AT DIFFERENT BARREL TEMPERATURES

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LIM SUE SHAN

June 2016

Chairperson : Hjh Rabiha Hj Sulaiman, PhD
Faculty : Food Science and Technology

Extrusion process is a high-temperature short time cooking process. The aim of this study was to evaluate the effect of barrel temperature and flour types on the residence time distribution, physical properties and rheological properties of various pregelatinized flour. Corn flour, rice flour, and their blends with 30% potato starch (w/w, d.b), were extruded under extrusion conditions at screw speed of 75 rpm, feed moisture at 25% (w/w, w.b.), barrel temperature ranging from 80 °C to 140 °C and die size of 1.88 mm. The extrudates were dried at 50 °C overnight, ground and further analyzed. The results showed that an increase in extruder barrel temperature significantly decreased the mean residence time ($p \leq 0.05$), total collection time ($p \leq 0.05$) and mean collection time ($p \leq 0.05$) of the extrudates. Analysis on the physical properties (expansion ratio, rehydration ratio, water absorption index, water solubility index, color, and water activity) and the rheological properties (steady shear, dynamic shear, and cohesiveness of powder) were done on the extrudate sample. The results showed that increase in barrel temperature significantly increased expansion ratio ($p \leq 0.05$), water absorption index, WAI ($p \leq 0.05$), water solubility index, WSI ($p \leq 0.05$), and the yellowness, *b* ($p \leq 0.05$) of the extrudates while decreased the shear thinning behavior (n become closer to 1), and decreased the apparent viscosity of the extrusion dispersion at shear rate 100 s^{-1}. The addition of potato starch influences the properties such as increases the WSI at 140°C, decreases the WAI at 140°C and decreases the overall gel strength of the pregelatinized flours. Corn flour blended with potato starch extrudates and rice flour extrudates were well fitted ($R^2 > 0.8$) into the Arrhenius equation with a decreasing E_a with increasing extruder barrel temperature. All extrudate samples showed shear thinning behavior for the dispersion and a solid-like gel. The additional of potato starch on the extrudates extruded barrel temperature of 80 °C and 100 °C make the extrudates less frequency dependency with a moderate but consistent G′ across the frequency range tested. The addition of potato starch caused properties different such as an increase in WAI, WSI and decrease in overall G′ and G″ of the pregelatinized flours. The pregelatinized flours' cohesiveness was not affected by barrel temperature ($p > 0.05$). Corn flour blended with potato starch extrudates showed a good thickening and gelling properties. Both, the effects of barrel temperature and flour type play important roles in the rheological and physical properties of the pregelatinized flours.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Sarjana Sains

SIFAT RHEOLOGI DAN FIZIKAL EKSTRUDAT-EKSTRUDAT DARI PELBAGAI JENIS TEPUNG PADA SUHU BAREL YANG BERBEZA

Oleh

LIM SUE SHAN

Jun 2016

Pengerusi : Hjh Rabiha Hj Sulaiman, PhD
Fakulti : Sains dan Teknologi Makanan

Proses penyemperitan merupakan sejenis teknik pemprosesan makanan yang menglibatkan suhu tinggi dalam masa yang singkat. Kajian ini bertujuan untuk mengkaji kesan suhu barel penyemperit dan jenis tepung ke atas pengagihan masa pemastautinan, sifat fizikal dan sifat reologi tepung pra-masak. Tepung jagung, tepung beras dan campuran tepung dengan 30% kanji ubi kentang (w/w, d.b) disemperit dalam keadaan seperti kelajuan skru 75 rpm, kelembapan tepung 25% (w/w, w.b), suhu barel penyemperit dari 80 °C sehingga 140 °C, dan saiz die 1.88 mm. Ekstrudat-ekstrudat dikeringkan pada suhu 50 °C semalaman, dikisar dan dianalisis. Hasil analisis menunjukkan bahawa peningkatan suhu barel penyemperit dapat mengurangkan masa purata bermastautin ($p \leq 0.05$), jumlah masa pengutipan sampel ($p \leq 0.05$), dan masa purata pengutipan ($p \leq 0.05$) sampel ekstrudat-ekstrudat. Analisis ke atas sifat fizikal (nisbah pengembangan, nisbah rehidrasi, indeks penyerapan air, indeks kebolehlarutan air, warna, dan aktiviti air) dan sifat rheologi (ricih mantap, ricih dinamik dan kejelekitan serbuk ekstrudat) telah dijalankan. Peningkatan suhu barel penyemperit menunjukkan peningkatan ketara ke atas nisbah pengembangan ($p \leq 0.05$), index penyerapan air, WAI ($p \leq 0.05$), index kebolehlarutan air, WSI ($p \leq 0.05$) dan warna kekuningan, *b* ekstrudat ($p \leq 0.05$), manakala sifat pseudoplastik (n semakin mendekati 1) dan kelikatan pada kadar ricih 100 s^{-1} semakin mengurang. Penambahan kanji ubi kentang mempengaruhi sifat-sifat ekstrudat seperti peningkatan WAI, WSI dan penurunan kekuatan gel keseluruhan serbuk ekstrudat. Ekstrudat campuran tepung jagung dengan kanji ubi kentang dan tepung beras dapat mematuhi persamaan Arrhenius ($R^2 > 0.8$) dengan tenaga pengaktifan yang berkurangan dengan peningkatan suhu barel penyemperit. Semua ekstrudat menunjukkan sifat penipisan ricih bagi larutan ekstrudat dan gel ekstrudat yang bersifat pepejal. Penambahan kanji ubi kentang pada suhu barel penyemperit 80 °C dan 100 °C mengurangkan pergantungan ekstrudat ke atas frekuensi, mempunyai G′ yang sederhana dan konsisten merangkumi frekuensi yang ditetapkan. Penambahan kanji ubi kentang menyebabkan perbezaan sifat-sifat ekstrudat seperti peningkatan WAI, WSI dan pengurangan G′ dan G″ serbuk ekstrudat secara keseluruhan. Kejelekitan serbuk ekstrudat didapati tidak bergantung pada suhu barel penyemperit ($p > 0.05$). Ekstrudat campuran tepung jagung dengan kanji ubi kentang didapati mempunyai sifat pemekatan dan gel yang baik. Kedua-dua

suhu barel penyemperit dan jenis tepung memainkan peranan yang penting dalam sifat rheologi dan fizikal serbuk ekstrudat.

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I certify that a Thesis Examination Committee has met on 16 June 2016 to conduct the final examination of Lim Sue Shan on her thesis entitled "Rheological and Physical Properties of Various Flour Extrudates at Different Barrel Temperatures" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Chong Gun Hean, PhD
Associate Professor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Chairman)

Roselina binti Karim, PhD
Associate Professor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Internal Examiner)

Azhar Mat Easa, PhD
Professor
School of Industrial
Universiti Sains Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 26 July 2016

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Hjh. Rabiha Hj. Sulaiman, PhD
Senior Lecturer
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Chairman)

Maimunah Sanny, PhD
Senior Lecturer
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Member)

Nur Hanani Zainal Abedin, PhD
Senior Lecturer
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Member)

BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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Signature: ______________________
Name of
Chairman of
Supervisory
Committee: Dr. Hjh Rabiha Hj Sulaiman

Signature: ___________________
Name of
Member of
Supervisory
Committee: Dr. Maimunah Sanny

Signature: ________________________
Name of
Member of
Supervisory
Committee: Dr. Nur Hanani Zainal Abedin

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LIST OF ABBREVIATIONS

AACC	American Association of Cereal Chemists
ASTM	American Society for Testing and Materials
BT	barrel temperature
CF	corn flour
Conc.	concentration
CP	corn flour with potato starch
ER	expansion ratio
Freq.	frequency
HTST	High temperature-short time
MRT	mean residence time
RF	rice flour
RP	rice flour with potato starch
RR	rehydration ratio
RTD	residence time distribution
T / Temp.	temperature
t_c	total collection time
t_m	mean collection time
TVP	textured vegetable protein
WAI	water absorption index
WSI	water solubility index

CHAPTER 1

INTRODUCTION

Extrusion is a process involving an extruder, where the input materials are forced out from a narrow orifice with a cross section of any desirable shape (Berk, 2008). The input materials or feed for extrusion process can be ranging from liquid to semi- liquid product, depending on the type of extruder used (Maskan and Altan, 2012). There are two basic types of extruder, single screw extruder and twin screw extruder. In current food industry application, more than 70% of the extruders used are single screw extruder while the others are twin screw extruders with specific functions (Karwe, 2003). Single screw extruders, as called by the name, have only one screw to shear the feed out, while twin screw extruders have two screws either counter rotating or co-rotating to shear the feed out. The different in screw caused the different in price, performance and capacity of the equipment. Single screw extruder is cheaper but has limitation on the feed composition, where only raw materials with <17% of fat in their formula can be used. Higher fat content in the feed will act as lubricant and limits the mechanical shear of the extruder, causing less mechanical energy produced and transformed into heat energy for cooking purpose (Maskan and Altan, 2012; Guy, 2001). On the other hand, twin screw extruder can handle feed with wider moisture content range or fresh meats, which cannot be done using single screw extruder.

Extrusion cooking is being used extensively in most food industries due to its low production cost, ability for continuous production, high productivity and low waste production (Emin, Mayer-Miebachand Schuchmann, 2012; Breitenbach, 2002; Guy, 2001; Akdogan, 1999; Harper, 1981). The most well established application of extrusion cooking is on production of pasta and snacks such as crisp and breakfast cereal. Other than consuming the extrudates directly as ready-to-eat food products, extrudates can also being milled back into flour and use as food ingredient in products such as baby food or instant beverages (Wu, Li, Wang, Özkanand Mao, 2010). During cooking extrusion process, the feed (usually flour or starches) undergo many different reactions due to the pressure and high temperature inside the barrel. These reactions include structural transformation, chemical reactions and nutritional changes, for example, gelatinization and degradation of starches, denaturation of proteins, oxidation of lipids, development of color and aroma due to Maillard reactions, degradation of vitamins and others (Mościcki and Wójtowicz, 2011; Zhao, Wei, Wang, Chen and Ojokoh, 2011; Riaz, Asif and Ali, 2009; Singh, Gamlath and Wakeling, 2007b). These reactions, either desirable or undesirable, depend closely on the exposure of the feed under the specified extrusion process conditions (Lee, 2012). The parameters that affect gelatinization process during the extrusion are raw materials, barrel temperature, screw speed and die nozzle size, where barrel temperature showed the most prominent effect on the properties of the extrudates (Meng, Threinen, Hansen and Driedger, 2010; Guha and Ali, 2006; Hagenimana, Ding and Fang, 2006; Guha, Ali and Bhattacharya, 1997; Chiang and Johnson, 1977).

The feed that are commonly used in extrusion cooking include cereals, flours and brans of cereals where the extrusion process gelatinizes the starch and/or denature the protein. Extrudates are usually dried after process to maintain the desired shape and to reduce the moisture. Protein products such as milk and whey also can be processed by extrusion process as reported by Tunick and Onwulata (2006). This study used corn flour, rice flour and their mixtures with potato starch as the raw material, where these are the most commonly used flour in the industry. Potato starch of 30% was chosen to blend with the cereal flour with the reason of combining the cereal starch with tuber starch which has large starch granule and higher solubility (Grommers and van der Krogt, 2009), while 30% of mixtures are normally used in the blend in extrusion study, as done by Seth and Rajamanickam (2012), Sun and Muthukumarappan (2002) and Iwe, van Zuilichem and Ngoddy (2000). There were many studies on the rheological and physical properties of the extruded products under different processing conditions or different combination of raw materials, where these properties affect the process control and the consumer perception on the products' quality (Walsh and Wood, 2010; Wu et al., 2010; Hagenimana et al., 2006; Grenus, Hsieh and Huff, 1993). These differences produce a wide variety of extrudates which can be used in different applications.

The common physical properties which were important for extrudates are the expansion ratio, rehydration ratio, water activity, water solubility index, water absorption index and color of the extrudate. Residence time distribution helps to understand the retention time of the feed inside the extruder barrel, which affects the nutritional value of the extrudates, and to determine the performance of the extruder (Unlu and Faller, 2002). The main objective in this study is to produce pregelatinized flours which have a better control in viscosity during pumping the product in pipeline. On the other hand, knowledge on rheological properties of the extrudates is important for better handling of the material during processing. Steady shear aids in the understanding of the non-Newtonian behavior, as affected by the shear, whereas frequency sweep aids in understanding the storage modulus and solid-liquid behavior of the extrudates. In addition, understanding how the pregelatinized flours' cohesiveness can help in understanding the flowability of the powders during handling.

Current industries are producing food such as instant beverage powder or baby food using native flour as ingredient. They often faced problem of pump failure which was caused by changing of viscosity during gelatinizing with changing temperature in the pipeline. By using pregelatinized flour which has more consistency in term of apparent viscosity at specified temperature can help to minimize the problem of pressure drop during pumping the product.

In this study, the raw materials that was fed into the extruder have the moisture range of 25% and very low fat content, where fell in the range of the chosen cost-friendly single screw extruder. Combination of common cereal and tuber starch has not been extensively done previously. Pregelatinized flour produced from extrusion process using corn flour, rice flour and potato starch can be apply in the industry as part of their formulation, such as added into instant food products like instant soup or instant gravy by adding in cool or warm water, without needing to cook the food to achieve the required thickness.

This study aimed to determine the physical properties and residence time distribution of the extrudate from corn flour, rice flour, and their mixtures with potato starch under the same extrusion processing condition. In addition, this study also targeted to evaluate the effect of potato starch addition and extruder's barrel temperature on the rheological properties of the pregelatinized flours.

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