Food Processing by Ultra High Pressure Twin-Screw Extrusion

Edited by
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TECHNOMIC
PUBLISHING CO., INC.

LANCASTER · BASEL

Food Processing by Ultra High Pressure Twin-Screw Extrusion
a **TECHNOMIC**® publication

Published in the Western Hemisphere by
Technomic Publishing Company, Inc.
851 New Holland Avenue
Box 3535
Lancaster, Pennsylvania 17604 U.S.A.

Distributed in the Rest of the World by
Technomic Publishing AG

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

Main entry under title:
Food Processing by Ultra High Pressure Twin-Screw Extrusion

A Technomic Publishing Company book
Bibliography: p.
Includes index p. 147

Library of Congress Card No. 91-66457
ISBN No. 87762-821-1

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Preface

This collection of papers is written on the subject of extrusion cooking and on fundamental research concerning the use of ultra high pressure for food processing. Some of these papers appeared originally in other sources, such as the following: *Extrusion Cooking* (1987) edited by the Association for the Development of Extrusion Cooking Technology in Japan; *Chem. Eng.; J. of the Japanese Soc. for Food Sci. and Technol.; J. Fac. Agric. Kyushu Univ.* and several other technical journals. A few of these papers expand upon brief presentations made at the International Symposium on Extrusion Food Cooking at Seoul, organized by Professor Cherl-Ho, Lee (Seoul, June 1988) and upon presentations made at the Second International Symposium on the Use of the Twin-Screw Extruder in the Food Industry, organized by President Saburo Kikuchi (Tokyo, November 1988). Both areas of research have been promoted by their respective national organizations in Japan—the Association of Extrusion Cooking Technology Development (1984–86) and the Association of Ultra High Pressure Technology Development (1989–1992). I have been fortunate enough to participate in both national research projects, as a member of both of these committees.

Extrusion cooking has already been popularized in the food processing industry, but fundamental research on the extrusion cooking process seems to be less popular than research into practical applications. This collection contains up-to-date research related to extrusion cooking, concerning such processes as texturization and texturizing mechanisms of extrudate from full fat soybean flour; and the effectiveness of using a surface-active agent both as the antifriction element for starch processing and as a means of emulsifying in the barrel the oils contained in the full fat soybean flour during texturizing. The effects of temperature and pressure on some physicochemical properties of soybean protein during extrusion are also studied in detail, as are new applications of extrusion cooking for starch hydrolysis with α-amylase and the deduction of screw effects using the impulse-response method.

The study of ultra high pressure was initiated 70 years ago by Nobel Laureate P. W. Bridgman. Despite Professor Bridgman's prestige, few other scientists were interested in this research field, since an ultra high pressure experimental apparatus typically proved to be prohibitively expensive due to the particularly strong structure necessary to contain the ultra high pressure environment. Three separate studies of ultra high pressure are presented in this volume. One of the most promising applications of ultra high pressure technology within the food industry concerns the development of nonheat-sterilization methods. New discoveries in materials science and technology promise to bring about the creation of super-strong materials, sufficient to construct an ultra high pressure vessel. In the near future, studies in this field will almost certainly bring breakthroughs that will allow heat-sterilization methods currently used in food processing to be replaced by methods utilizing pressure.

In order to investigate the effects of ultra high pressure on microorganisms, researchers have studied the effects of liquids containing univalent or bivalent salts, sugars, and alcohols on the pressure resistivity of baker's yeast (*Saccharomyces cerevisiae*) under high pressure (500–600 MPa, pressurized for 5 min.). The reactivation of α-amylase by the conditions of ultra high pressure and high temperature (70°C) are discussed in another chapter. The characteristics of ovalbumin and of bovine serum albumin (BSA) denatured by guanidine hydrochloride, urea, heating, and pressurization are investigated through spectrofluorometry, specific rotation dispersion, polyacrylamide gel electrophoresis (PAGE), and differential scanning calorimetry. Completely opposite results are indicated for both of these denatured proteins, and the reasons for this are discussed.

I would like to take the time here to say that many of the fruitful results appearing in this collection are due to the dedicated study and experimentation of my coworkers, and to the best set of graduate students a professor could ask for.

I owe a debt of gratitude to Mr. Kohichi Shimaoka, President of Kowa Kogyo Co., Ltd., whose special appreciation of our research into twin-screw extrusion made many of our best results possible. I also owe gratitude to Mr. Kazuichi Yamamoto, President of Yamamoto Suiatu Kogyosho Co., Ltd., for his great support of ultra high pressure research. Many thanks also to Mr. Joseph L. Eckenrode, Director of Editorial Development at Technomic Publishing Co., Inc., who provided me with the chance to publish this special collection of my new theses and research.

I would like to take this opportunity to express my gratitude finally to those many research foundations that have supported my studies: The Research Foundation of the Japanese Educational Bureau, Mitsubishi Kasei Corporation Foundation, The Foundation for Food Science and Technology, Kowa Kogyo Corporation Foundation, Ito Foundation, Towa Food Science Foundation, Senba Tohka Industries Foundation, Takeda Research Foundation, Mishima Kaiun Memorial Foundation and Sugiyo Corporation Foundation.

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Contents

Texturization Mechanism Made of Whole Soybean Using a Twin-Screw Extruder

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ABSTRACT: Good meat-like extrudates were manufactured from full fat soybean flour using a twin-screw extruder. From the results of FT-IR analysis, no noteworthy new chemical bonds were present in the formation of the matrix, and deamidation was observed. From the results of flow double refraction analysis, viscosity measurement, FT-IR analysis, and sodium dodecyl sulfate polyacrylamide gel electrophoresis, the S—S bond did not play an important role in the formation of the matrix, and a large number of molecules in the product underwent a reduction in molecular weight and shifted to chain structure. It was considered that the matrix was formed by entanglements of linearized proteins and polysaccharides in soybeans by shearing into the materials molten by high temperature and high pressure in the presence of water.

INTRODUCTION

Many kinds of foods such as various snacks, texturized products from vegetable proteins, and brewing materials for beer and alcohol fermentation are processed in a single-screw (Katoh and Hayakawa, et al., 1985) or a twin-screw extruder (Association of Extrusion Cooking Technology Development, 1987; Gomez et al., 1984; Phillips et al., 1984; Noguchi et al., 1984; Davidoson et al., 1984). However, a method for the direct manufacture of products possessing a meat-like texture from full fat soybean flour has not been established. In this study, a method for continuous manufacture of products with a texture similar to that of meat using a twin-screw extruder is described. This study concerned the mechanism of texture formation from full fat soybean flour through extrusion cooking. The properties of the extrudates were examined under a scanning electron microscope. Also, the molecular configuration of the raw material and extrudates was studied with a flow double refractometer (flow birefringence meter) and a viscometer, and the distribution of molecular weight was measured by electrophoresis. Fourier-transform-IR (FT-IR) analysis of the raw material and the product was also done to find whether newly formed chemical bonds contributed to formation of a matrix in the extrudates.

MATERIALS AND METHODS

Materials

Dehulled soybeans grown in the northern part of the U.S. Midwest were used. General analysis of the sample showed 37.8% protein (by Kjeldahl method, nitrogen × 5.71), 25.5% lipids (by extraction with equal volumes of chloroform and methanol), 27.7% sugars (subtraction method), 4.3% ash, and 10.7% moisture (by drying at 105°C).

Extrusion Cooking

A twin-screw extruder (model KEI-45, Kowa Kogyo, Ltd.) with length/diameter of 12 was used for present study with water addition. High shearing screw configurations were used in this experiment. The feed rate of the sample was 15–25 kg/hr, and water was added to maintain the 35–50% moisture in the products. The temperature of the material inside the barrel during extrusion was measured using a heat-sensitive paint mixed with the sample. The color changes of the mixture were observed after the extruder was stopped.

Solubility

The solubility of the raw material and the product was expressed by nitrogen soluble index according to the method of Saio (1974, 1975).

Cryo-Scanning Electron Microscopy (Cryo-SEM)

For observation of products, a SEM (model JSM-T330, JEOL Co. Ltd.) was used. Samples were frozen in liquid nitrogen and observed at −40°C according to the criteria of SEM (Kanto Branch of Japanese Electron Microscope Society, 1985; Samejima et al., 1986; Hitachi, 1979a, 1979b, 1985).

Infrared Analysis

The Fourier-transform infrared analysis (FT-IR) for the full fat soybean flour and the product was taken on a wide-range mercury-cadmiumtelluride detector (model JIR-3500, JEOL Co. Ltd.) (Silverstein et al., 1964).

Measurement of Flow Double Refraction

The flow double refraction (flow birefringence) for the 5% solutions of the raw material and extrudates was measured at room temperature (23 °C) by a flow double refraction apparatus (Mizojiri Kogyo Co. Ltd.) under the following conditions—light path: 30 mm, rotation speed: 60 rpm (Ishino et al., 1986; Nakagaki, 1968).

Measurement of Viscosity

The viscosity of the 5% protein solution was measured at 30°C by Ostwald viscometer.

Electrophoresis

Sodium dodecyl sulfate–polyacrylamide gel electrophoresis (SDS–PAGE) (Weber and Osborn 1969. Saio et al., 1975) was carried out on a 12% polyacrylamide gel in presence of 2% SDS according to the method of Weber and Osborn (1969). A sample solution of the raw material or the product containing 25μg of protein was put on the gel, and a current of 20 mA was applied. The buffer contained 2% SDS in absence or presence of a 2% 2-mercaptoethanol stained by Coomassie Brilliant Blue R-250. The density of the stained bands corresponding to different molecular weights was measured by a densitometer (DMU-33C, Advantec Co. Ltd.) at 640 nm.

RESULTS

Solubility and Temperature of Specimens with Various Screw Positions

Since the protein solubility was affected strongly by thermal modification, the change in solubility with the temperature distribution along the screws was investigated. Changes in solubility of specimens at different locations along the longitudinal screw shaft in the barrel are shown in Figure 1-1. The protein in the full fat soybean flour became insoluble, i.e., nitrogen solubility index (NSI) decreased when the sample entered the heating region in the barrel. The total heat generation is quite substantial in this region, because heat transfer from the barrel heater is considerable under high pressure and frictional heat generation among the flour particles is also great under high pressure heat. One friction is between the inside surface of the barrel and the material; the other is between the screw

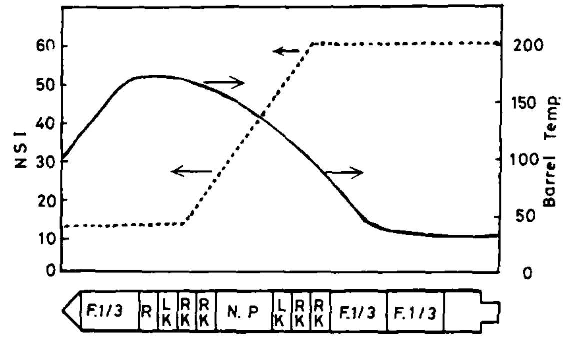

Figure 1-1. Relationship between screw configurations and sample temperature and nitrogen solubility index (NSI) of specimens. NP: paddle screw (normal direction). F: normal pitch (forward screw). Rk: kneading screw (turn to the right). 1/3F: 1/3 pitch (forward screw). Lk: kneading screw (turn to the left). 2/3F: 2/3 pitch (forward screw). 1 pitch = 78 mm (double screws). Forward direction → turn to the right. Screw rotation = corotating screw.

surface and the material. Thus, since the screw configuration affects the frictional heat generation, protein solubility changes at the different locations along the screw. The full fat soybean flour becomes impossible to resolve. When the soybeans are heated sufficiently in the high temperature zone, the materials are texturized after melting.

SEM Observation for Extrudates

The good tissue texturized from the full fat soybean flour has been oriented to uniaxial. When such products are chewed from the tissue of the fibrous structure, the texture is similar to that of meat. The tissue of extrudates prepared from soybeans was observed under a scanning electron microscope. A stereomicrograph of meat-like texture under tearing was shown in Figure 1-2. The constitutional structure of the material was completely destroyed and oriented as the fiber during the extrusion. The unclear area in the photograph showed a thin layer of oil on the top. To clarify the textural characteristics in more detail, cryogenic observation was applied to an electron microscope. A cross section of fibrous protein that possessed a meat-like texture was presented as shown in Figure 1-3. The tissues in the extrudate were covered with a thin porous membrane emulsified with oils and water. The results suggested that the inside components under the membrane consisted of oils, proteins, sugars and water. An electron microscopic photograph of an inferior tissue product was shown in Figure 1-4. There are large gaps around the oil-based membrane, which probably decreased the textural compactness.

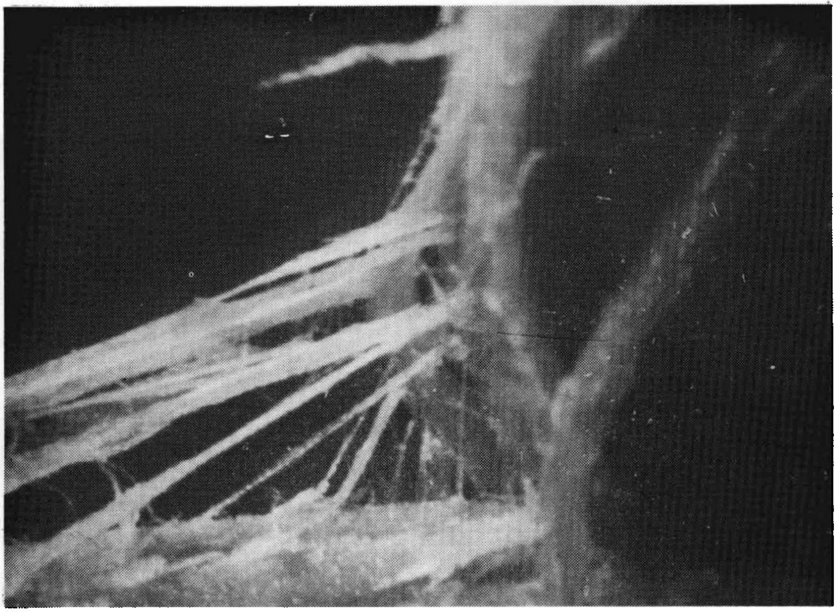

Figure 1-2. *A stereomicrograph of full fat soybean extrudates with meat-like texture. Magnification ×200.*

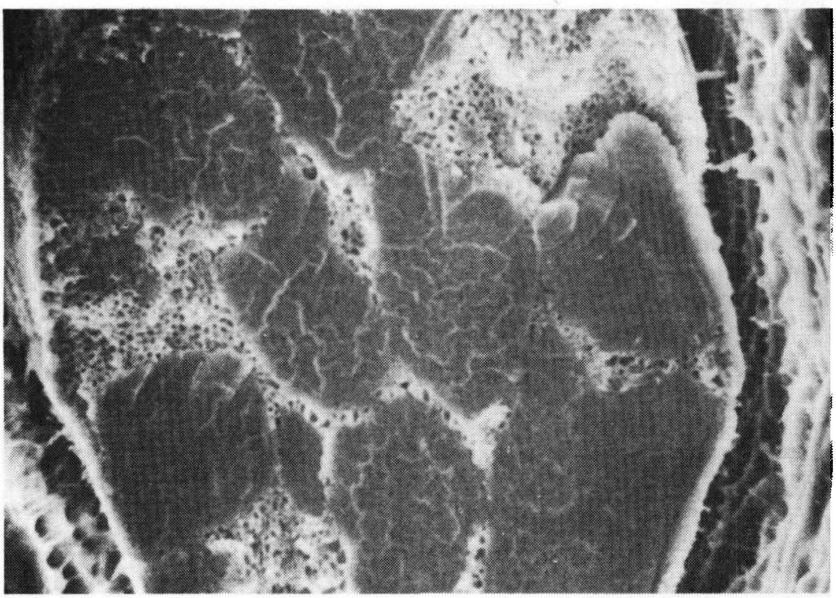

Figure 1-3. *A scanning electron micrograph of full fat soybean extrudates with good texture under cryogenic observation. Magnification ×3000.*

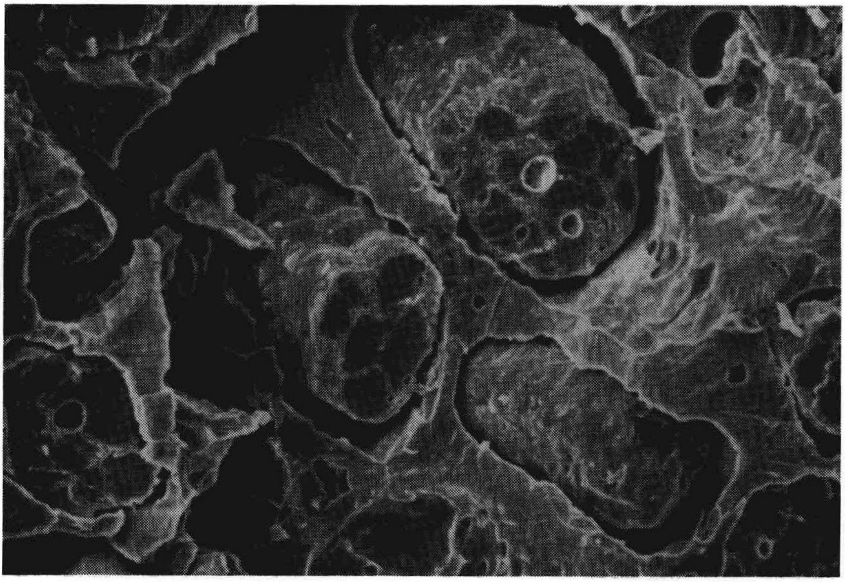

***Figure 1-4.** A scanning electron micrograph of full fat soybean extrudates with inferior texture under cryogenic observation. Magnification ×3000.*

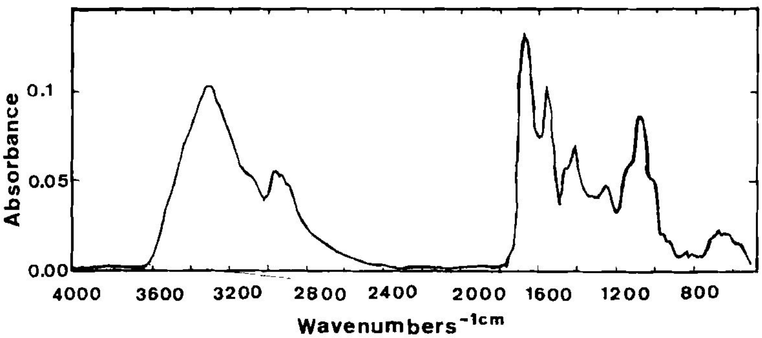

***Figure 1-5.** The subtraction spectrum deducting the FT-IR spectrum of products from that of raw material. Absorbance of carbonyl at 1750 cm^{-1} was used as a standard mark on the computer calculation.*