Himjyoti Dutta Sanjib Kr Paul Editors

Amylose

Properties, Structure and Functions

FOOD SCIENCE AND TECHNOLOGY

FOOD SCIENCE AND TECHNOLOGY

AMYLOSE

PROPERTIES, STRUCTURE AND FUNCTIONS

No part of this digital document may be reproduced, stored in a retrieval system or transmitted in any form or by any means. The publisher has taken reasonable care in the preparation of this digital document, but makes no expressed or implied warranty of any kind and assumes no responsibility for any errors or omissions. No liability is assumed for incidental or consequential damages in connection with or arising out of information contained herein. This **age and the problem of th**

FOOD SCIENCE AND TECHNOLOGY

Additional books and e-books in this series can be found on Nova's website under the Series tab.

FOOD SCIENCE AND TECHNOLOGY

AMYLOSE

PROPERTIES, STRUCTURE AND FUNCTIONS

HIMJYOTI DUTTA AND SANJIB KUMAR PAUL Editors



Copyright © 2020 by Nova Science Publishers, Inc.

All rights reserved. No part of this book may be reproduced, stored in a retrieval system or transmitted in any form or by any means: electronic, electrostatic, magnetic, tape, mechanical photocopying, recording or otherwise without the written permission of the Publisher.

We have partnered with Copyright Clearance Center to make it easy for you to obtain permissions to reuse content from this publication. Simply navigate to this publication's page on Nova's website and locate the "Get Permission" button below the title description. This button is linked directly to the title's permission page on copyright.com. Alternatively, you can visit copyright.com and search by title, ISBN, or ISSN.

For further questions about using the service on copyright.com, please contact: Copyright Clearance Center Phone: +1-(978) 750-8400 Fax: +1-(978) 750-4470 E-mail: info@copyright.com.

NOTICE TO THE READER

The Publisher has taken reasonable care in the preparation of this book, but makes no expressed or implied warranty of any kind and assumes no responsibility for any errors or omissions. No liability is assumed for incidental or consequential damages in connection with or arising out of information contained in this book. The Publisher shall not be liable for any special, consequential, or exemplary damages resulting, in whole or in part, from the readers' use of, or reliance upon, this material. Any parts of this book based on government reports are so indicated and copyright is claimed for those parts to the extent applicable to compilations of such works.

Independent verification should be sought for any data, advice or recommendations contained in this book. In addition, no responsibility is assumed by the Publisher for any injury and/or damage to persons or property arising from any methods, products, instructions, ideas or otherwise contained in this publication.

This publication is designed to provide accurate and authoritative information with regard to the subject matter covered herein. It is sold with the clear understanding that the Publisher is not engaged in rendering legal or any other professional services. If legal or any other expert assistance is required, the services of a competent person should be sought. FROM A DECLARATION OF PARTICIPANTS JOINTLY ADOPTED BY A COMMITTEE OF THE AMERICAN BAR ASSOCIATION AND A COMMITTEE OF PUBLISHERS.

Additional color graphics may be available in the e-book version of this book.

Library of Congress Cataloging-in-Publication Data

Names: Dutta, Himjyoti, Department of Food Technology, Mizoram University, India, editor. | Kr Paul, Sanjib, CSIR-Indian Institute of Chemical Technology, India, editor. Title: Amylose: Properties, Structure and Functions Description: New York: Nova Science Publishers, [2019] | Series: Food Science and Technology| Includes bibliographical references and index.

Identifiers: LCCN 2019956505 (print) | ISBN 9781536169324 (hardcover) |

ISBN 9781536169409 (adobe pdf)

Published by Nova Science Publishers, Inc. † New York

CONTENTS

	vii
Origin, Structural and Functional Attributes of Amylose: An Overview Sabrina Moriom Elias, Tasnim Zuairia, Umme Habiba Mita and Ishrat Jahan	1
Traditional and Modern Methods of Amylose Isolation, Estimation, and Characterization <i>R. Pandiselvam, K. Gomathy,</i> <i>Anjineyulu Kothakota, Fathima Zehla</i> <i>and V. P. Mayookha</i>	33
High Amylose Cereals: Starch Structure, Biosynthesis, and Commercial Applications <i>Geetika Ahuja and Sarita Jaiswal</i>	95
Influence of Amylose Content in Processed Starch and Starchy Edible Materials Verónica Rocha-Villarreal, Elena I. Mancera-Andrade, Gabriela Montemayor-Mora, Ada M. Williams-González and Ramon Reves-Treio	139
	 Origin, Structural and Functional Attributes of Amylose: An Overview Sabrina Moriom Elias, Tasnim Zuairia, Umme Habiba Mita and Ishrat Jahan Traditional and Modern Methods of Amylose Isolation, Estimation, and Characterization <i>R. Pandiselvam, K. Gomathy,</i> Anjineyulu Kothakota, Fathima Zehla and V. P. Mayookha High Amylose Cereals: Starch Structure, Biosynthesis, and Commercial Applications <i>Geetika Ahuja and Sarita Jaiswal</i> Influence of Amylose Content in Processed Starch and Starchy Edible Materials Verónica Rocha-Villarreal, Elena I. Mancera-Andrade, Gabriela Montemayor-Mora, Ada M. Williams-González and Ramon Reves-Treio

Chapter 5	Amylose Content and Structures Relate to Digestibility of Starch Fatemeh Habibi	199		
Chapter 6	Amylose Inclusion Complexes Febby J. Polnaya	237		
Chapter 7	Use of Amylose in Composite Materials Rosana Colussi, Barbara Biduski and Dianini Hüttner Kringel	275		
Chapter 8	Amylose Nanoparticles: Preparation, Characterization, and Properties <i>Reza Abdollahi and Farhad Akbari Afkhami</i>	317		
Chapter 9	Application of Amylose and Amylose-Based Materials in Food, Medicine, Biological and Other Allied Fields <i>Loveleen Sharma, Sanjib Kumar Paul,</i> <i>Himjyoti Dutta, Charanjiv Singh Saini</i> <i>and Kawaljit Singh Sandhu</i>	351		
About the Editors				
Index		383		
Related Nova Publications				

vi

PREFACE

Amylose is the linear polymeric fraction of starch which has its unique characteristics leading to its specific role in the application of starches and its own. Amylose forms a significant proportion of the macromolecular structure of starch. Written by a selected team of international authors, including academicians and researchers with special expertise on starch chemistry, technology and functions, the book *Amylose: Properties, Structure and Functions* is a unique approach to the multifaceted trends of amylose chemistry, properties, functionality and applications.

Under the collaborative editorial guidance of Dr. Himjyoti Dutta and Dr. Sanjib Kumar Paul, who are experienced in researches on starch, starch-based composite materials and other biomaterials, the book provides an overview of important scientific and technological approaches on amylose. Traditional and recent analytical methods for amylose purification and characterization have been thoroughly discussed in this book. The role of amylose in major starch sources suggesting specific usage in food and other complex edible and non-edible matrices have been covered. Recent findings on its unexpected properties, directing it to the ever growing world of functional biopolymers have been discussed. Amylose polymorphism and complex formation with non-starch components have been elaborated for optimum knowledge dissemination on its potential use as nano-scale material for food, drug, nutraceutical and pharmaceutical industries.

Looking into the unavailability of an exclusive book on amylose and its various modern aspects, the editorial team, with the collaboration of authors throughout the globe, executed the idea of bringing a reference book on amylose in the name of *Amylose: Properties, Structure and Functions*. The editors emphasized to include all the present day aspects of amylose to address the need of students, researchers and industry experts in a global perspective. Wide coverage of informations with recent findings along-with short and long term consequences and future prospects, a novel attempt was made to make the book as an ideal reference book on amylose for the readers. In: Amylose

ISBN: 978-1-53616-932-4 Editors: H. Dutta and S. K. Paul © 2020 Nova Science Publishers, Inc.

Chapter 6

AMYLOSE INCLUSION COMPLEXES

Febby J. Polnava*

Department of Agricultural Product Technology, Faculty of Agriculture, Pattimura University, Ambon, Indonesia

ABSTRACT

Amylose is a naturally occurring linear polysaccharide, with a helical conformation of α -(1 \rightarrow 4)-glycosidic linkages. Amylose is known as a host compound that can form inclusion complexes with a variety of lowmolecular-weight compounds or small molecules, such as iodine, alcohol, the aroma compounds, fatty acids, and esters. Inclusion interactions occur in the hydrophobic part of the guest molecule with the cavity of amylose. Amylose inclusion complexes are generally called V-amylose or Vpolymorph pattern. As a result of the conversion, the inside of the inclusion is hydrophobic, while the outside is hydrophilic. The ability of amylose to form inclusion complexes affects the quality attributes of almost all foodstuffs containing starch. Current developments show that inclusion complexes can be utilized in the food and pharmaceutical industries. Several factors affecting the amylose-inclusion complex include thermal treatment, lipid structure, and amylose chain length, in

^{*}Corresponding Author's E-mail: febbyjpolnaya@yahoo.com; febby.polnaya@faperta.unpatti.ac.id.

addition to pH, the ratio of starch and fatty acids, and temperature. The value of amylose-inclusion complexes can be determined using the complex index value. The molecular structure of amylose-inclusion complexes can be demonstrated by Fourier-transform infrared (FT-IR) spectroscopy, X-ray diffraction (XRD), differential scanning calorimetry (DSC) and ¹³C solid-state CP/MAS NMR and electron paramagnetic resonance (EPR). The previous studies indicate that the application of amylose-inclusion complexes can be applied for various purposes. These applications include flavor and bioactive releases, composite films, retardation of starch retrograde, and emulsifying behavior. The results of research on amylose-inclusion complexes have shown that the material has extreme potential in food and pharmaceutical sector to play significant role in coming days.

Keywords: starch, amylose, inclusion complexes, V-amylose, molecular struture

1. INTRODUCTION

Starches are the mainly abundant biological source and high molecular weight carbohydrate in nature, as a result of photosynthesis. Starch can be found in all green plant tissues, including tubers, stems, roots, trunks, leaves, and others. Green plants produce starch for energy storage in a granular form. The utilization of starch is very comprehensive, either in food products (for example: bakery, ice cream, thicken sauces, soups, confectionery, syrups, snacks, soft drinks, beer, fat replacers, edible film) or in non-food applications (for example: pharmaceuticals applications, cosmetic, bioplastic and textile, paper, adhesives, packing material) (Amagliani, et al. 2016; Copeland, et al. 2009; Hay, et al. 2018; Konieczny and Loos 2018; Liu, et al. 2018; Mazzocchetti, et al. 2014). As a food ingredient, starch provides almost 70% of energy for a human diet and the glucose molecules given by the starch metabolism is fundamentally used as a substrate in the brain and red blood cells (Copeland, et al. 2009).

Starch is a polymeric carbohydrate of α -D-glucose units as a monomer. It is composed of two main components, namely amylose and amylopectin. Amylose is a linear polyglucan in which each glucose unit-linked via α -

 $(1\rightarrow 4)$ -glycosidic linkage, whereas, amylopectin is a branched polyglucan, composed of α - $(1\rightarrow 4)$ -glycosidic linkage of glucose molecules with some additional α - $(1\rightarrow 6)$ branch points (Ciric and Loos 2013; Hanashiro 2015; Lewandowski, 2015; van der Vlist, et al. 2008; van der Vlist, et al. 2012). The amylose consisting of 15-30% and amylopectin typically the major component of native starch granules (Copeland, et al. 2009; Hanashiro 2015; Manca, et al. 2015). The rest of the components cover a small number of lipids (Maphalla and Emmambux 2016), phosphate monoester (Polnaya, et al. 2012; Polnaya, et al. 2013), minerals, and protein/enzymes.

Amylose exhibits a unique ability to form inclusion complexes spontaneously with hydrophobic guest molecules (Condepetit, et al. 2006; Maphalla and Emmambux 2016). In the presence of suitable molecules, amylose would undergo a conformation transformation. Lu, et al. (2019) suggested that the presence of fatty acids would induce the formation of amylose helices and stretch fatty acids. Usually, the guest molecules embedded in the helices, and occasionally, the guest's molecules trapped between the helices (Rondeau-Mouro, Bail and Buleon 2004). The driving force for the helical conformation is the tendency of hydrogen bonds with water molecules and repulsive contact to the hydrophobic part of the starch. The complex formation produces a single, left-handed helix structure which is called V-type amylose complexes (Biais, et al. 2006; Eliasson 2004; Gelders, et al. 2004; Kawada and Marchessault 2010; Obiro, Ray and Emmambux 2012; Vamadevan, et al. 2014; Waduge, Xu and Seetharaman 2010; Wulff, Avgenaki and Guzmann 2005), that may crystallize in an antiparallel arrangement (Kong, et al. 2018). The use of the name V-type amylose as an equivalent to the amylose-inclusion complex has been explained by Putseys, Lamberts and Delcour (2010) in their article.

Colin and de Claubry first demonstrated the interaction of starch and iodine in 1814 (Saenger 1984). Starch can form inclusion complexes with many kinds of molecules or ligands, including aliphatic alcohols and ketones, fatty acids, aromatic aldehydes, hydrocarbons, iodine, dyes, pesticides, and emulsifier and lipid, dimethyl sulfoxide (DMSO), potassium bromide, potassium hydroxide, and aroma compounds

(Condepetit, Escher and Nuessli 2006; Gotanda, Yamamoto and Kadokawa 2016; Itthisoponkul, et al. 2007; Kim and Lim 2009; Kong, et al. 2018; Milani, et al. 2009; Wulff, Avgenaki and Guzmann 2005). The acting fraction is amylose, which can form a threaded building surrounding these other molecules (Lu, et al. 2019). Depending on the type of ligands, different types of V-amylose complexes are produced, which can be between V6 to V8 by their X-ray diffraction patterns, where the numbers represent the number of anhydro-glucose units per turn (Le Bail, Rondeau and Buleon 2005). In the case of the V6 type, which is mostly formed with fatty acids or glycerides, there are three subtypes of crystalline packing (V6-I, II and III) differing in the location of the guest ligands trapped within or between the single helices (Brisson, Chanzy and Winter 1991; Condepetit, Escher and Nuessli 2006) that is stabilized by hydrophobic interactions and hydrogen bonding (Condepetit, Escher and Nuessli 2006).

As a result of this transformation, central channel forms that pass through the axis of the helix, resulting in a hydrophobic helical cavity (Immel and Lichtenthaler 2000), while the outside surface produces a hydrophilic. The hydrophobicity caused by the axial O-1, H-3, H-5, and 6-CH₂ fragments, which engage the inner surface of the helix, while the hydroxyl groups be a factor in the hydrophilicity of the outer surface. The inner cavity is more hydrophobic, which is a guest molecule binding site with the same properties (Immel and Lichtenthaler 2000; Putseys, Lamberts and Delcour 2010). The alternating rotation of the inclusion complexes helix stabilized by various van der Waals forces and hydrogen bonds. The driving force for the formation of inclusion complexes is related to the hydrophobic interactions (Immel and Lichtenthaler 2000) that occur when guest molecules are transferred from an aqueous to a less polar environment (Wang, et al. 2017). An explanation of amyloseinclusion complexes about the formation, identity, and physicochemical properties have described by Putseys, Lamberts and Delcour (2010).

Several specific techniques such as homogenization (Lesmes, Barchechath and Shimoni 2008; Meng, et al. 2014a), steam jet-cooking (Fanta, et al. 2008), microwave heating (Felker, et al. 2013), and extrusioncooking (Raphaelides, et al. 2010) have been applied to prepare V-amylose

complexes. These techniques aim to increase the solubility of amylose and ligands under the conditions of high-shearing and high-heating temperature, to increase complexation.

2. AMYLOSE-INCLUSIONS COMPLEXES WITH LIPIDS

In recent years, the increase in consumer preference for clean label starches is being observed (Arocas, Sanz and Fiszman 2009) compared to the synthetic chemicals. Lipids can be classified as food-friendly chemicals for clean label starches. The binding of lipids to starch molecules naturally or the addition of lipids to starch often changes their properties, for example, reducing swelling power in water (Ahmadi-Abhari, et al. 2013b; Vasiliadou, Raphaelides and Papastergiadis 2015), retarding retrogradation (Singh, et al. 2003; Tufvesson, et al. 2001), decreasing viscosity of gelatinized starch (Gelders, Goesaert and Delcour 2006), protection of oxygen sensitive molecules (Floros and Ziegler 2011; Lalush, et al. 2005; Lay Ma, Yang, Gu and Zhang 2009), carbon nanotubes (Yang, et al. 2008), suppress colon carcinogenesis (Zhao, et al. 2011), and increasing the content of resistant starch (Liu, et al. 2019; Putseys, et al. 2010; Wang, et al. 2016). Amylose can interact with lipids resulting in the formation of amylose-lipid complexes (Maphalla and Emmambux 2016) and it is schematically represented (Figure 1). The successive helical turns stabilized by many intra- and inter-helical van der Waals bonds and hydrogen bonds. In the amylose-lipid inclusion complex, the aliphatic (hydrocarbon chain) portion of the lipid located in the lipophilic core of the amylose helix, while the polar type located outside the helix. After amylose-inclusion complexed by palmitic acid, the gelatinization temperature leached amylose content, swelling power, and relative crystallinity were generally decreased (Kim, et al. 2017; Nakazawa and Wang 2004). The main factors leading to the formation of complexes are the solubility or dispersibility of the fatty acid in water. Tang and Copeland (2007) suggested that one of the disadvantages of palmitic acid to form complexes with amylose is that they are difficult to dissolve in water.



Figure 1. Schematic representation of the amylose-lipid inclusion complexes.

Lu, et al. (2019) suggested that the amylose in starch granules located as individual chains, which are between the chains of amylopectin in amorphous and semi-crystalline regions. Inclusion complexes cause the amylose chain or small amount of amylopectin helices to bind to fatty acids, while uncomplexed fatty acids dispersed between helices in the crystalline regions of the amorphous regions (Biais, et al. 2006; Lu, et al. 2019). Lu, et al. (2019) suggested that in the organization of lamellar structures, amylose-fatty acid complexes and amylopectin formed the crystalline phase, while the branching points of amylopectin, amylose, which does not form complex and free fatty acids will form the amorphous phase.

Previous studies showed that the amylose chain length (Garcia, et al. 2016; Kawai, et al. 2012; Zabar, et al. 2009; Zhou, et al. 2013), characteristics of lipids including lipid type, chain length and saturation (Kanicky and Shah 2002; Uri, Barchechath and Eyal 2008; Zhou, et al. 2013), and complexes temperature (Marinopoulou, et al. 2016) are very influential on the formation of the amylose-lipid complex. Amylose content is an essential factor affecting the formation of complexes. Garcia, et al. (2016) reported that the amylose content had a positive relationship with the number of amylose-lipid inclusion complexes, where exceptionally long amylose chains are useful for forming more stable V-type complexes. Whereas Exarhopoulos and Raphaelides (2012) suggested that the characteristics and level of inclusion complex crystallinity depend on the amylose content, chain length of fatty acids, and different heating methods.

2.1. Complexing Index

The complexing index value can be used to show the level of inclusion of amylose-lipids in complex formation. Li, et al. (2019), Meng, et al. (2014a) and Wang, et al. (2019) use complexing index values to indicate the level of inclusion complexes.

The complexing index was evaluated using the following equation (Li, et al. 2019; Meng, et al. 2014a; Wang, et al. 2019):

Complexing index (%) =
$$(A_{control} - A_{sample})/A_{control} \times 100\%$$
 (1)

where, $A_{control}$ is the absorbance of the starch without guest molecule, and A_{sample} is the absorbance of amylose-inclusion complexes.

Li, et al. (2019) showed that the complexing index value increases with increasing concentration of palmitic acid, although at specific concentrations, the value decreases. Li, et al. (2019) revealed that the decline in value could be caused by increased cell-aggregation palmitic acid. Meanwhile, Lebail, et al. (2000) suggests that at high free fatty acids, lipids can get trapped in amylose chains without forming a complex. The results from the study of Wang, et al. (2019) showed the fact that the higher number of amylose molecules produced during the branch removal process encourages more formation of amylose-lipid inclusion (Jane, et al. 1999). Pullulanase debranching method is one of the best methods that can produce a high complexing index. The amylose polymer produced as a result of cutting by the enzyme provides more free polymers and can form inclusion complexes (Wang, et al. 2019). The complex index value is also positively correlated with DPPH radical scavenging activity (Li, et al. 2019).

Wang, et al. (2019) suggest that the different methods for producing amylose-inclusion complexes cause differences in the value of complexing indexes. The value of the complexing index of potato starch-lauric acid inclusion complexes was determined using the dimethyl sulfoxide heating method (26.92%), ultrasound treatment (33.24%), and the pullulanase debranching method (47.26%), and observed higher than the control

(22.12%). The dimethyl sulfoxide solvent used in the dimethyl sulfoxide heating method promotes amylose release from potato starch swollen. Therefore, dimethyl sulfoxide heating samples have higher complexing index value than control samples. The same stated by Singh, et al. (2006), that the formation of the amylose-lipid complex would inhibit the development of starch granules. In the ultrasound method, ultrasonic treatment destroys potato starch granules to release amylose molecules, which increases the chance of contact between amylose and lauric acids. Ultrasonic treatments increased the dispersion of lauric molecules in swollen potato starch paste (Liu, et al. 2018). Therefore, the value of the complexing index increases after the ultrasonic treatment of potato starchlauric acid complexes. For the pullulanase debranching method, Zhang, et al. (2012) stated that the debranching pretreatment can facilitate the formation of V-type complexes. This result can be ascribed to the fact that higher the number of amylose molecules produced in the branch removal process encourages more formation of amylose-lipid inclusion complexes with the pullulanase debranching method (Jane, et al. 1999). The pullulanase debranching method shows a higher index value than the other methods. Wang, et al. (2019) suggested that there are relatively more free amylose molecules produced by the pullulanase debranching method involved in complexing reactions compared to other methods.

2.2. Amylose-Inclusion Complexes Structure

Structures and physicochemical properties of amylose-inclusion complexes need to be known to improve their use in future. Zabar, et al. (2010) through his research using an acidification method showed how to characterize the structure of amylose-inclusion complexes with fatty acids. The molecular structure of fatty acid molecular inclusion complexes was then verified using Fourier-transform infrared (FT-IR) spectroscopy, X-ray diffraction (XRD), differential scanning calorimetry (DSC) and ¹³C solid-state CP/MAS NMR. The results of XRD analysis can be used to confirm the formation of amylose-inclusion complexes (Li, et al. 2019; Wang, et al.

2017; Zabar, et al. 2010). Lesmes, et al. (2009) suggested that the structure and physicochemical properties of V-amylose are essential to study because of their future use.

Li, et al. (2019) suggested that the use of FT-IR spectroscopy can monitor changes in starch structures that have experienced inclusion complexes. Starch complexes show structural changes compared to their native starch. There are two additional bands at 1705 cm⁻¹ and 2846 cm⁻¹ that show amylose-palmitic acid complexes.

Amylose inclusion complex with other molecules causes changes in molecular structure. This can be indicated by the emergence of a new peak based on XRD testing. The peaks formed are Bragg angels of $2\theta = 7.40^{\circ}$, 13.10°, and 19.80°. The temperature of crystallization also affects the formation of new peaks, but not for all fatty acids. Zabar, et al. (2010) suggested that the amylose-stearic acid inclusion complexes do not produce new peaks, but complexes with linoleic acid and conjugated linoleic acid produce new peaks. The peak located in Bragg angels of $2\theta = 14.90^{\circ}$, 17.10°, and 22.60°. These results indicate that the crystallization temperature induces the formation of type-A amylose crystals for inclusion complexes. Wang, et al. (2017) reported that the inclusion of new peaks formed in the high amylose maize starch (HAMS) complex-salicylic acid (SA), HAMS-1-naphthol (1-NPL) and HAMPS-2-naphthol (2-NPL). The three complexes also show differences in the new peaks formed (Table 1).

Complex X-ray diffraction patterns of all samples (except for linolenic acid) show two main peaks, corresponding to the Bragg (2θ) around 13.0° dan 20,0° and minor peaks at 7.0°, which present a typical V6-I type complex consists of six anhydro-glucose units per turn (Le Bail, Rondeau and Buleon 2005; Lesmes, et al. 2009). In the case of linolenic acid, especially at the reaction temperature at 90°C, it shows a double peak at 13.0° and a new peak at 18.0°. These results may indicate that the amylose-linolenic acid complex formed in V7 type crystals. Also, some researchers report that when V7-type complexes drained, the crystalline structure partially transformed into V6 form (Nuessli, et al. 2003; Rondeau-Mouro, Bail and Buleon 2004). It can be assumed that the linolenic acid is trapped inside and/or between a single amylose helix (V6-II and III). That the

peaks at around 20° degrees 2θ also found in low-amylose cereal starch and amylose-free potato starch (Vamadevan, et al. 2014; Varatharajan, et al. 2011; Varatharajan, et al. 2010), and therefore, can not be expressly demonstrated to be associated with amylose-lipid complexes (Bertoft 2017). This condition indicates that other peaks in XRD are needed to prove the formation of amylose inclusion complexes (Table 1). Based on the crystallization conditions (temperature and type of ligand), there are structural differences in the shape of the amylose-lipid complex in the solid-state, namely: type I (form I) and type II (form II). Type I demonstrates an amorphous X-ray pattern, while Type II shows a typical V-type pattern. The state of the complex represents an energy-favorable situation for both amylose and surfactant molecules, which is reflected by the fact that the complexes formed are difficult to separate. Type I polymorphs measured by DSC analysis is generally formed in a random arrangement with a single helix, which is not easily detectable by XRD analysis. However, the type I polymorphic complex, as observed in the DSC thermogram shows the type V6-I diffraction pattern, probably due to dehydration.

Five allomorphic families of compact-helix V-amylose have reported, in which three contain 6-fold helix, one contains 7-fold helix, and one contains 8-fold helix. Helbert (1994) proposed a nomenclature system for the compact-helix V-amylose based on the number of residues per turn and volume of inter-helical space. Consequently, the three 6-fold V-amylose families can be called as V6I, V6II and V6III as a function of the volume of inter-helical space. The7- and 8-fold V-amylose families can be called V7 and V8, respectively.

Probes such as salicylic acid (SA), 1-naphthol (1-NPL), and 2-naphthol (2-NPL), are used to show the amylose-inclusion complexes better. XRD is usually used to confirm the formation of inclusion complexes between high-amylose maize starch (HAMS) and probes. The results from the study (Wang, et al. 2017) indicated that the HAMS can be complexes with SA, 1-NPL, and 2-NPL, and produce HAMS-fluorescent probe inclusion complexes. The SA probe is observed to be the best fluorescent probe that is determined based on the degree of crystalline and the encapsulation rate.

Inclusion Complexes	Peak (2θ)													DC	References
	5°	6°	7°	11°	12°	13°	14°	16°	17°	18°	19°	21°	22°		
HAMS-SA		6.10			12.65			16.40						34.20	(Wang, et al. 2017)
HAMS-1-NPL	5.98				12.74			16.48						29.49	(Wang, et al. 2017)
HAMS-2-NPL		6.72		11.50						18.06				28.85	(Wang, et al. 2017)
Amylose-FA	5.0		7.4			13.1	14.9		17.1		19.80	21.7	22.6	28-43*	Zabar, et al., (2010);
															(Lu, et al. 2019)
Amylose-LA							14.9		17.1				22.6		Zabar, et al., (2010)
Amylose-CLA							14.9		17.1				22.6		Zabar, et al., (2010)
Amylose-palmitic			7.5		12.5							21.5	23.5		(Li, et al. 2019);
acid															(Wang, et al. 2016)
Amylose-x-DSA						13.5						20.5			(Kong, et al. 2018)
Amylose-fatty					12.8						19.9				(Hay, et al. 2019)
sodium salt															
Amylose-β-CD			7.3			13.0								14-17	(Tian, et al. 2010)
Amylose-FeA			7.5			13.0					19.5				(Kenar, et al. 2016)
dG50-LA-AP					12.88						19.80				(Liu, et al. 2019)

Table 1. New peaks formed after the amylose-inclusion complexes with several guest molecules

Description: HAMS = high-amylose Maize starch; 1-NPL = 1-napthol; 2-NPL = 2-napthol; FA = fatty acids; FeA = ferulic acid; dG50-LA-AP = balanced High amylose corn starch-lauric acid-atmospheric pressure; DC = degree of crystallinity; *DC samples produced by various methods.

The intensity of fluorescence probes can reflect the formation of inclusion complexes. The results from the study (Wang, et al. 2017) showed that the potential fluorescence probe method can be used to determine the capability inclusion complexes.

Based on thermal behavior analysis using DSC, it can be stated that the production temperature of amylose-inclusion complexes also affect the melting temperature (Zabar, et al. 2010). Other findings also showed almost similar results, like melting temperature of the complexes correlated with the melting temperature of the fatty acids (Tufvesson, Wahlgren and Eliasson 2003a). Lauric acid has a lower melting temperature than conjugated lauric acid or stearic acid. Besides melting temperature, melting enthalpy of stearic acid complexes is also higher than amylose-conjugated lauric acid and amylose-lauric acid complexes. Zabar, et al. (2010) suggested that the differences between stearic and lauric acids complexes might be due to differences in their chemistry. Some research (Tufvesson, Wahlgreen and Eliasson 2003a; Tufvesson, Wahlgreen and Eliasson 2003b) results showed that the thermal stability and melting enthalpy of the crystal complex depend on the chemical properties of the complexing ligands (chain length, unsaturation, nature of polar head groups), the degree of amylose polymerization and the conditions (temperature, time and solvent) used during complexation. Kong, et al. (2018) suggested that the based-on the measurements of DSC, fatty acid chain length increases the thermal stability of amylose-fatty acid inclusion complexes.

Analysis using ¹³C and CP NMR shows that C1 and C4 carbon of amylose are susceptible to binding to a guest molecule, such as fatty acid. The peaks formed for carbon of fatty acids in the chemical shift range of 15-35 ppm. Differences in the type of fatty acids in the inclusion complexes can cause different molecular mobility. This difference is greatly influenced by fatty acid saturation. Molecular mobility of saturated stearic acid is higher than unsaturated linoleic acid, and hence amylose-linoleic acid inclusion complexes (Zabar, et al. 2010).

Electron paramagnetic resonance (EPR) spectroscopy can also be used to study the microenvironments of the biological system. One of them is

inclusion complexes (Bardelang, et al. 2006; Mezzina, et al. 2007). EPR provides essential information about molecular dynamics and local polarity of fatty acids and probes within these systems. Specific spin probes, especially those derived from fatty acids, may thus be used to interact with amylose and fatty acids in forming inclusion complexes. For example, 5- and 16-doxyl-stearic acids (5-DSA and 16-DSA) are derivatives of stearic acid and carry a doxyl ring moiety containing a nitroxide radical, which makes them EPR-active.

3. Amylose-Inclusions Complexes with Glycerol Monostearate

Glycerol monostearate functions to bind materials, become lubricants during extrusion, prevent the development of extrudates, make extrudates not stick to each other, and reduce product cooking loss during the cooking process (Kaur, Singh and Singh 2005; Singh, Sharma and Singh 2000). Glycerol monostearate is known to form a helical inclusion complex with amylose (Gultom 2014). The complex can prevent starch granules from expanding, which can lead to reduced development strength and solubility. Fatty acids have hydrophobic and hydrophilic parts, such as glycerol monostearate. Therefore, it can be presumed that the amylose and glycerol monostearate can form the same structure like fatty acids.. The effect of adding glycerol monostearate in extrusion of corn grits reduces water solubility index, specific energy consumption, and expansion (product development) but increases water absorption index. This function is needed to make analog rice, which processed at high extrusion temperatures (Gultom 2014).

Glycerol monostearate form helical inclusion complexes with amylose by occupying the hydrophobic amylose helical core. The complex can prevent starch granules from expanding to reduce the strength of development and solubility. Glycerol monostearate includes an emulsifier that has a fat fraction with high melting temperature, has the role of

facilitating shear, uniformity of extrudate formation, and protecting the dough from stickiness so that the extrusion process becomes easier (Moscicki 2011).

4. AMYLOSE-FLAVORING INCLUSION COMPLEXES

The background of the hydrolysis study of inclusion complexes between amylose and flavoring compounds is far less comprehensive than lipids as ligands. However, monitoring of α -amylase catalysis during starch processing is attractive both for the production of resistant starch and for its effect on guest release, which modulates the perception of aroma and taste during consumption of certain products (Sajilata, Singhal and Kulkarni 2006). In this case, Heinemann, et al. (2005) studied hydrolysis of the inclusion complex between amylose and various flavoring compounds such as geraniol, γ -nonalactone and δ -dodecalactone when using porcine pancreatic a-amylase, even though hydrolysis was carried out directly on the dispersion system after the heating step (without drying steps). In subsequent research, Tietz, Buettner and Conde-Petit (2008) analyzed the interactions between menthone flavor and native tapioca flour in aqueous suspension, without performing special procedures intended to obtain inclusion complexes. Several studies of amylose-inclusion complexes with flavors such as linalool, citronellol, limonene, ß-pinene, geraniol, menthol (Ades, et al. 2012) and menthone (Ades, et al. 2012; Tietz, Buettner and Conde-Petit 2008), camphor, thymol (Heinemann, et al. 2005; Tapanapunnitikul, et al. 2007; Yeo, Thompson and Peterson 2016) etc. are reported.

Haryadi (1993) suggested that the amylose-inclusion complexes with flavor compounds are weak. The compound is released when amylose attacked by an enzyme. This behavior is used to trap or encapsulate flavors in the extrusion process and other processes. Many types of flavor have brewed in dried starch powder for various purposes. Furthermore, it was stated by Haryadi (1993) that complex inclusion also occurred in the storage of rice. As long as it is stored, some lipids on rice are broken into

monoglycerides and diglycerides. These fragments can form complexes with amylose. In new rice, there is a minimal amylose-lipid complex. A small portion of amylose released from rice grains during cooking. This contributes to the appearance of adhesiveness between rice grains. The waxiness of starch depends on the presence of oryzenin which dissolves and escapes from the granules, which interact with starch molecules. In rice that has been stored for a long time, some amylose forms a complex with lipids resulting from the breakdown of rice oil enzymes until it is insoluble and does not escape when cooking rice.

The formation of complex amylose inclusion will reduce the tendency of amylose to undergo retrogradation, thereby inhibiting the speed of increased viscosity during heating (Haryadi 1993; Suarni and Aqil 2013) and the further leaching of amylose (Putseys, et al. 2010).

5. INCLUSION COMPLEX WITH PUFA AND OMEGA 3

Zabar, et al. (2010) suggested that various encapsulation techniques had been carried out to improve control over the release of lipophilic nutraceuticals such as PUFAs and omega-three rich oils. Furthermore, the study of amylose inclusion-complexes showed that the complex could control the delivery system for PUFA. The results of the study show that there are two primary forms of polymorphic crystalline, namely types I and II. Type I consist of amorphous regions, while type II is semi-crystalline. Type II shows three peaks based on the XRD pattern, which is 7.4°, 13.1°, and 19.8° (Lesmes, et al. 2009). Based on transmission electron microscopy (TEM) testing, the form of inclusion of the amylose-fatty acid complex is uniaxial.

Zabar, et al. (2009) combine molecular-level investigations with nanostructure and microscopic characteristics. Research of Zabar, et al. (2010) shows that amylose inclusion complexes can be developed by different production methods, and are more suitable for food application. The amylose complex with 18:0 saturated stearic acid,18:2 linoleic acid, and 18:2 mixture of isomeric conjugated linoleic acid produced using the

acidification method (Zabar, et al. 2010). The XRD diffractogram shows the formation of amylose-fatty acid's inclusion. The three main peaks formed after the inclusion complex are as stated (Lesmes, et al. 2009). However, the inclusion of the amylose-linoleic acid or conjugated linoleic acid complex, which crystallized at 90°C, results in additional lowintensity peaks, namely $2\theta = 14.9^{\circ}$, $17,1^{\circ}$, and 22.6° . These results indicate that the high crystallization temperature induces the formation of A-type amylose crystals. All complexes with stearic acid produce a new peak of $2\theta = 21.7^{\circ}$ which is V-amylose polymorphism.

DSC shows a complex thermal behavior of inclusion. Melting temperature increases with increasing production temperature. The type of fatty acids also determines a high melting temperature. Melting the linoleic acid temperature is lower than conjugated linoleic acid and stearic acid.

Zabar, et al. (2010) stated that the resolution of carbon C1 and C4 amylose is very sensitive to the inclusion complex of amylose-fatty acids, for linoleic acid or stearic acid, based on ¹³C and CP NMR testing. There is a difference between linoleic acid and stearic acid, which may be due to molecular mobility in the sample. Their saturation largely determines increased molecular mobility of the inclusion complexes of amylose-fatty acids. The mobility of saturated fatty acids (stearic acid) is higher than that of unsaturated fatty acids (linoleic acid). Zabar, et al. (2010) suggested that the amylose complexes produced with linoleic acid demonstrate more spatial structures than the complexes produced with stearic acid.

The inclusion complex of amylose-fatty acids causes changes in the morphology of amylose particles. Zabar, et al. (2010) reported the changes between the titration becomes an acid condition (t = 0 h) and the completion of the crystallization process (t = 24 h). Surface roughness measurements also indicate this change. SEM images of amylose-fatty acids inclusion complexes are also affected by production temperatures, but this is not indicated by conjugated linoleic acid and stearic acid. Products produced at low temperatures (<60°C) shows smooth surface properties, and there is almost no difference at the micronic level. Production at high temperatures (~90°C) produces formation of amorphous structure. Amorphous structures are formed as a result of the presence of

bubbles as they approach the boiling point of water when precipitated. The interaction of amylose with fatty acids leads to the formation of molecular inclusion complexes, which arranged in the lamella packaged in aggregated spheroids. The presence of fatty acids induces segments in the amylose chain to form helices that bind fatty acids.

Thermogravimetric analysis was used to confirm the formation of amylose-inclusion complexes - the temperature range used for analysis is 50° to 600°C. Weight loss of the inclusion complexes starts at a temperature of 155° to 165°C and decomposed at more than 220° to 250°C. This shows that amylose-inclusion complexes cause thermal properties to be more stable (Wang, et al. 2017).

Lauric acid has been included in starch to prepare the amylose-lipid inclusion complexes (Chang, He and Huang 2013; Zhang, et al. 2012). Lauric acid is more strongly bound to amylose than other fatty acids with longer carbon chain lengths (Tang and Copeland 2007). Meng, et al. (2014b) found that the corn starch with long carbon chain fatty acids had index complexes value lower than corn starch with lauric acid because of low dispersivity in gelatin starch. According to Kawai, et al. (2012), melting enthalpy (the number of inclusion complexes) decreases with an increasing number of carbon atoms in saturated fatty acids containing lauric acid C12:0, myristic acid C14:0, palmitic acid C16:0, stearic acid C18:0.

6. THE CRYSTALLINITY OF AMYLOSE-FATTY ACIDS INCLUSION COMPLEXES

A number of studies have been carried out on the formation of the amylose-lipid complex and its crystalline properties, reporting that these characteristics are strongly influenced by thermal treatment, lipid structure, and amylose chain length. Complex formation reactions at relatively low temperatures (90°C) forms complexes such as lamella (type II) because nucleation is slow, and propagation for crystallization is adequately

processed (Biliaderis and Galloway 1989; Karkalas, et al. 1995). Regarding the starch chain length and linearity appear to be the most important structural features for the formation and V-complex characteristics. It is reported that longer amylose chains preferred for the formation of stable complexes (Gelders, et al. 2004; Zhou, et al. 2013). Many researchers study the effects on the chemical structure of lipids in the formation of complex inclusions with starch. It reported that the longer the fatty acid chains in lipids form a more stable complex of heat, and the addition of double-bonds in fatty acids (unsaturated) interferes with the formation of the V-amylose complex (Eliasson and Krog 1985; Zabar, et al. 2009; Zabar, et al. 2010). Most studies of the formation of V-amylose complexes for fatty acids have been carried out during thermal analysis primarily using differential scanning calorimeters, and large-scale elaborate preparations.

7. EFFECT OF PH ON INCLUSION COMPLEXES

Seo, Kim and Lim (2015) reported that pH has a significant role on amylose-fatty acids inclusion complexes. The experiment uses stearic and oleic acids. Recovery of stearic acids are 74.72% at pH 7, while oleic acid is 72.68% at pH 6. The recovery value reaches a maximum when the pH is neutral. The recovery of starch also shows relatively similar results. Seo, Kim and Lim (2015) showed that the low pH conditions could cause partial hydrolysis when starch heated at high temperatures (121°C). Partial starch hydrolysis causes short amylose chain formation and causes the opportunity to form lower amylose-inclusion complexes. Also, alkaline conditions can increase the hydrogen bond between starch and water, which also affects the interaction between starch and fatty acids.

The formation of amylose-polyunsaturated fatty acids (linoleic and linolenic acids) is limited to inclusion complexes when reactions occur under acidic conditions (pH 5 and 6). Recovery of both polyunsaturated fatty acids and starch increases due to increased reaction pH. Yotsawimonwat, et al. (2008) suggested that an increase in PUFA recovery

with an increase in pH might be from an increase in solubility of PUFA by ionization. The pKa value also determines suitability for alkaline conditions. PUFA has a pKa value that is lower than stearic and oleic acids, causing PUFA to have higher suitability in alkaline conditions.

8. THE RATIO OF STARCH AND FATTY ACIDS

The weight ratio between starch and fatty acids in the inclusion complex can be plotted as a function of fatty acid recovery. The weight ratio of the two components within the complex is not constant but decreases as the recovery of fatty acids increases. This trend shows that the inclusion of multi-molecular fatty acids may be in the amylose unit chain, although the formation of the V-amylose complex is relatively unstable with unsaturated fatty acid glycerides (Eliasson and Krog 1985; Zabar, et al. 2010).

Stearic, oleic, and linolenic acid reached a maximum recovery value of about 75% by weight, but the maximum recovery for linoleic acid was much lower (less than 30%). These results indicate that the formation of complexes between amylose and fatty acids does not always have a positive correlation with the degree of saturation. In particular, the exceptionally high recovery rate of linolenic acid, even though it is prone to thermal oxidation, is very interesting (Seo, Kim and Lim 2015). Karkalas, et al. (1995) suggests that the free rotation of C-C bonds near unsaturated bonds allows unsaturated fatty acids to form quasi-linear conformations around double bonds. This structural transformation can produce behavior similar to saturated fatty acids. Oleic and linolenic acids produce the same results in complex formation, but linoleic acid shows lower results, although only several fatty acids tested. Based on these observations, it can be hypothesized that even unsaturated bonds numbered in fatty acids may not form quasi-linear or U-forms for suitable complex formations. Additional research must be followed to verify this hypothesis.

9. EFFECT OF TEMPERATURE

Ahmadi-Abhari, et al. (2013a) suggested that the temperature played an essential role in the susceptibility of starch enzymes. We observe that temperature at 60°C the action of amylase is much slower than at higher temperatures; therefore, a lower amount of reducing sugar is formed even after 240 minutes of digestion. The research of Ahmadi-Abhari, et al. (2013b) reported loss of starch crystalline at 60°C. The crystallinity loss was a prerequisite for the development of swelling and an increase in the suspension viscosity of starch, which does not occur below 60°C. Increasing the temperature of 5°C to 65°C increases the amount of reducing sugar as a function of digestive time. More than 60% of reducing sugars observed after 240 minutes of enzyme hydrolysis at 65°C. This sharp temperature effect was related to changes in the crystal structure of starch granules. By heating at a temperature that exceeds the temperature of gelatinization of starch, the rate of digestion increases because the crystalline phase melts, the entry of water and accessibility for the enzyme increases. That leads to a sharp increase in reducing sugar. When starch heated to 90-95°C, the amount of reducing sugar increases further to more than 70%. Interestingly, this increase is relatively small compared to the effect of losing crystallinity.

Seo, Kim and Lim (2015) s uggested that the crystallinity represented by peak intensity positively correlated with recovery of fatty acids: the lowest peak intensity as the reaction temperature of 50°C and the highest intensity at 90°C. All the fatty acids tested in this study show the ability of the type V crystal complex with amylose, especially when the reaction temperature is 90°C. The consistency between fatty acid recovery and crystallinity shows that the inclusion of fatty acids occurs primarily for the formation of long-range crystal structures detected by XRD. However, Seo, Kim and Lim (2015) suggested that the additional studies are still needed to understand the relationship between reaction parameters and structural characteristics of amylose fatty acids.

10. DIGESTIBILITY OF AMYLOSE-INCLUSION COMPLEXES

Starch digestibility determines the Glycemic Index; the level of glucose released into the blood. Unfortunately, rapid digestibility causes high GIs, resulting in overweight and obesity, ultimately contributing to several diseases, such as type II diabetes (Soong, Goh and Henry 2013). V-amylose would modulate the glycemic response due to an increased resistance to hydrolysis (Obiro, Ray and Emmambux 2012; Putseys, et al. 2010) and would help to improve glycemic regulation and may help in the prevention and management of insulin resistance and metabolic syndrome (Hasjim, et al. 2010; Lau, Zhou and Henry 2016).

Starch, based on digestibility can be classified in to three categories: RDS (starch which can be digested quickly, which is digested into glucose after 20 minutes), SDS (slow digestible starch, starch digested into glucose between 20 and 120 minutes) and RS (resistant starch, starch which cannot be digested but fermented in the large intestine) which is characterized by the level and duration of the glycemic response (Cummings 1992; Englyst, Kingman and Englyst, et al. 1999). In general, starch digestion is a complex process that is highly dependent upon the substrate, the enzyme adsorption by the substrate, and the presence of other components such as lipids and proteins (Lehmann and Robin 2007). It is possible to increase the resistance of starch components to enzyme hydrolysis. For example, endogenous lipids and phospholipids in cereal starch can complex with amylose (Kwasniewska-Karolak, Nebesny and Rosicka-Kaczmarek 2008) making amylose more susceptible to amylolytic enzymes (Zhang, Ao and Hamaker 2006; Zhang, Venkatachalam and Hamaker, 2006). In vivo and in vitro digestibility studies of the effects of these components have shown that they can slow enzymatic digestion (Singh, Dartois and Kaur 2010).

Recent studies have reported the low digestion of V-complexes (Putseys, Lamberts and Delcour 2010). The V-complex characterized by a specified X-ray diffraction pattern and formed between the aliphatic lipid chain and the amylose molecule. Lysophosphatidylcholine as a complexing agent who has demonstrated high complexing capabilities with amylose, as shown by DSC (Ahmadi-Abhari, et al. 2013b). Furthermore, the formation

of V-amylose has been shown to reduce the digestibility of starch and increase the resistance to enzymatic hydrolysis.

Another factor that affects starch hydrolysis is the formation of inclusion complexes between amylose and other natural components or added during starch processing. Native starch contains a proportion of natural lipids that form complex inclusions with amylose components when they gelatinise in the presence of these lipids. Two general results from various studies are that, first, the inclusion complex shows resistance to enzymatic hydrolysis compared to uncomplexed amylose and control starch and second, the rate of hydrolysis reaches a steady-state values several hours after the initiation of an enzymatic reaction (Ai, Hasjim and Jane 2013; Kawai, et al. 2012; Rodríguez and Bernik 2014). Putseys, et al. (2010) suggested that the amylose-lipid complex influenced the characteristics of starch gels and could reduce the rate of digestion. This is possible because of the release of the short amylose chain in a controlled manner, which then undergoes amylose crystallization. This amylose crystallization will form the RS.

On the other hand, Putseys, Lamberts and Delcour (2010) also proposed that with the inclusion complex, the hydrolysis process occurred in two stages. The first stage, characterized by high hydrolysis rate, is associated with enzymatic attacks to amorphous regions, such as amylose residues between helical structures; whereas the second stage achieved when hydrolysis involves the attack of the enzyme into the inclusion complex itself, which takes place at a slower rate. Li, et al. (2019) suggested that the amylose-palmitic acid had the potential to reduce cholesterol.

Ahmadi-Abhari, et al. (2013a) suggested that the complexation of amylose with lysophosphatidylcholine reduces the susceptibility of wheat starch granules to α -amylase, compared to native wheat starch, which rapidly degraded. Depending on the concentration of lysophosphatidylcholine, the amylose molecule develops an inclusion complex and becomes more easily degraded. Digestive differences between samples containing lysophosphatidylcholine and references, based on the amount of reducing sugars, illustrate the accessibility of lower

inclusion complexes to enzymes. The difference is increasing after digestion for 240 minutes. Conformation barriers to enzymatic attacks due to the new V-helix form, explain the decrease in α-amylolysis. Complex formation inhibits digestive enzymes to access glycosidic bonds throughout the helix. Depending on complex stability, this even leads to full resistance of the amylose-lysophosphatidylcholine complex to amylolysis. So, in principle (Ahmadi-Abhari, et al. 2013a) suggested that the formation of inclusion complexes causes the starch to be more difficult to digest. This result also proved through DSC analysis, which showed that there was a decrease in enzymes to access starch as a result of the formation of amylose-LPC complexes. Also, the inability of starch to swollen as a result of inclusion complexes causes low accessibility of amylase to starch molecules (Ahmadi-Abhari, et al. 2013a). The reduced digestive complexes increase the potential of amylose-fatty acid inclusion complexes to suppress colon carcinogenesis. Zhao, et al. (2011) suggests that rat fed cooked with inclusion complexes can reduce azoxymethaneinduced preneoplastic lesions (colonic cancer precursors) in the colon of rat. Meanwhile, Liu, et al. (2019) expressed the same opinion, and there was an increase in slowly digestible starch and resistant starch contents for starch complexes.

CONCLUSION

Starch is part of the human diet, so that it gets much attention in the development of its use. Starch is composed of two main glucose polymers, amylose, and amylopectin. Amylose, a straight-chain polymer, has a special feature to form inclusion complexes with hydrophobic guest molecules, where the guests are embedded in the helical interior of starch. Hydrogen bonds and the repulsive contact to hydrophobic part of starch are two critical things to encourage inclusion complexes. Guest molecules or ligands generally form inclusion complexes with amylose such as aliphatic alcohols and ketones, fatty acids, aromatic aldehydes, hydrocarbons, iodine, dyes, pesticides, emulsifiers and lipids, DMSO, potassium bromide,

potassium hydroxide, and aroma compounds. Amylose-lipids inclusion complexes can cause changes in their physicochemical properties, such as reducing swelling power, retarding retrogradation, decreasing viscosity of gelatinized starch etc. The main factors that play a role in the formation of inclusion complexes are the solubility of fatty acids in water. The level of amylose-inclusion complexes can be shown using complexing index values. The higher value of the complexing index shows the high inclusion complexes that formed. The structure of amylose-inclusion complexes and physicochemical properties is essential to know to increase their utilization. The molecular structure of amylose-inclusion complexes can be demonstrated using FT-IR, XRD, DSC, NMR, and EPR. Analysis using XRD shows new peaks after the formation of inclusion complexes, but not always. The use of a probe scan further clarifies understanding using XRD about amylose-inclusion complexes. DSC can be used to study the effect of production temperature on inclusion complexes. The position of C1 and C4 carbon of amylose is susceptible to binding to a guest molecule. It can be indicated by the analysis using ¹³C and CP NMR when there is a difference in molecular mobility. EPR spectroscopy can also be used to study microenvironments of inclusion complexes.

Amylose-inclusion complexes that have been studied to include complexes with fatty acids and flavorings. Changes in the crystallinity of amylose-inclusion complexes is influenced by various factors such as thermal treatment, lipid structure, and the length of the amylose chain. Amylose-inclusion complexes are strongly influenced by pH, the ratio of starch and fatty acids, and temperature. The recovery of starch and fatty acid's increases at pH is neutral. Unsaturated bonds, even in fatty acids, may not form suitable complex formations, although further research needed for verification. Temperature influences change in the starch crystal structure and positively correlated with the recovery of fatty acids. Amylose-inclusion complexes also influence the digestibility of starch. Inclusion complexes cause low starch digestibility due to resistance to enzymatic hydrolysis.

REFERENCES

- Ades, H, E Kesselman, Y Ungar, and E Shimoni. "Complexation with starch for encapsulation and controlled release of menthone and menthol." *LWT Food Science and Technology* 45 (2012): 277-288.
- Ahmadi-Abhari, S, A J J Woortman, A A C M Oudhuis, R J Hamer, and K Loos. "The influence of amylose-LPC complex formation on the susceptibility of wheat starch to amylase." *Carbohydrate Polymers* 97 (2013a): 436-440.
- Ahmadi-Abhari, S, A J J Woortman, R J Hamer, A A C M Oudhuis, and K Loos. "Influence of lysophosphatidylcholine on the gelation of diluted wheat starch suspensions." *Carbohydrate Polymers* 93 (2013b): 224– 231.
- Ai, Y, J Hasjim, and J Jane. "Effects of lipids on enzymatic hydrolysis and physical properties of starch." *Carbohydrate Polymers* 92 (2013): 120-127.
- Amagliani, L, J O'Regan, A L Kelly, and J A O'Mahony. "Chemistry, structure, functionality and applications of rice starch." *Journal of Cereal Science* 70 (2016): 291-300.
- Arocas, A, T Sanz, and S M Fiszman. "Clean label starches as thickeners in white sauces. Shearing, heating and freeze/thaw stability." *Food Hydrocolloids* 23 (2009): 2031-2037.
- Bardelang, D, A Rockenbauer, L Jicsinszky, J -P Finet, H Karoui, S Lambert, S R A Marque, and P Tordo. "Nitroxide bound β-cyclodextrin: Is there an inclusion complex?" *Journal of Organic Chemistry* 71 (2006): 7657-7667.
- Bertoft, E. "Understanding starch structure: Recent progress." *Agronomy* 7 (2017): 56.
- Biais, B, B P Le, P Robert, B Pontoire, and A Buléon. "Structural and stoichiometric studies of complexes between aroma compounds and amylose. Polymorphic transitions and quantification in amorphous and crystalline areas." *Carbohydrate Polymers* 66 (2006): 306-315.

- Biliaderis, C G, and G Galloway. "Crystallization behavior of amylose-V complexes: structure-property relationships." *Carbohydrate Research* 189 (1989): 31-48.
- Brisson, J, H Chanzy, and W Winter. "The crystal and molecular structure of VH amylose by electron diffraction analysis." *International Journal of Biological Macromolecules* 13 (1991): 31-39.
- Chang, F, X He, and Q Huang. "Effect of lauric acid on the V-amylose complex distribution and properties of swelled normal corn starch granules." *Cereal Science* 58 (2013): 89-95.
- Ciric, J, and K Loos. "Synthesis of branched polysaccharides with tunable degree of branching." *Carbohydrate Polymers* 93 (2013): 31-37.
- Condepetit, B, F Escher, and J Nuessli. "Structural features of starch-flavor complexation in food model systems." *Trends Food Science Technology* 17 (2006): 227-235.
- Copeland, L, J Blazek, H Salman, and M C Tang. "Form and functionality of starch." *Food Hydrocolloids* 23 (2009): 1527–1534.
- Eliasson, A -C. *Starch in food: Structure, function and applications*. CRC Press, 2004.
- Eliasson, A -C, and N Krog. "Physical properties of amylosemonoglyceride complexes." *Journal of Cereal Science* 3 (1985): 239-248.
- Englyst, H N, S M Kingman, and J H Cummings. "Classification and measurement of nutritionally important starch fractions." *European Journal of Clinical Nutrition* 46 (1992): 33-50.
- Englyst, K N, H N Englyst, G J Hudson, T J Cole, and J H Cummings. "Rapidly available glucose in foods: An *in vitro* measurement that reflects the glycemic response." *American Journal of Clinical Nutrition* 69 (1999): 448-454.
- Exarhopoulos, S, and S N Raphaelides. "Morphological and structural studies of thermally treated starch-fatty acid systems." *Cereal Science* 55 (2012): 139-152.
- Fanta, G F, F C Felker, R L Shogren, and J H Salch. "Preparation of spherulites from jet cooked mixtures of high amylose starch and fatty

acids. Effect of preparative conditions on spherulite morphology and yield." *Carbohydrate Polymers* 71 (2008): 253-262.

- Felker, F C, J A Kenar, G F Fanta, and A Biswas. "Comparison of microwave processing and excess steam jet cooking for spherulite production from amylose-fatty acid inclusion complexes." *Starch-Stärke* 65 (2013): 864-874.
- Garcia, M C, M A Pereira-Da-Silva, S Taboga, and C M Franco. "Structural characterization of complexes prepared with glycerol monoestearate and maize starches with different amylose contents." *Carbohydrate Polymers* 148 (2016): 371-379.
- Gelders, G G, H Goesaert, and J A Delcour. "Amylose-lipid complexes as controlled lipid release agents during starch gelatinization and pasting." *Journal of Agricultural and Food Chemistry* 54 (2006): 1493-1499.
- Gelders, G G, T C Vanderstukken, H Goesaert, and J A Delcour. "Amyloselipid complexation:a new fractionation method." *Carbohydrate Polymers* 56 (2004): 447-458.
- Gotanda, R, K Yamamoto, and J I Kadokawa. "Amylose stereoselectively includes poly (d-alanine) to form inclusion complex in vine-twining polymerization: a novel saccharide–peptide supramolecular conjugate." *Macromolecular Chemistry and Physics* 217 (2016): 1074-1080.
- Gultom, R J. Optimization of the Pregelatinization Process in Analogues Rice Forming by Using a Twin Roll Machine based on Response Surface Methodology. Thesis, Bogor: Sekolah Pascasarjana, Institut Pertanian Bogor, 2014.
- Hanashiro, I. "Fine Structure of Amylose." Dans *Starch: Metabolism and Structure*, édité par Y Nakamura, 41-60. Japan: Springer, 2015.
- Haryadi. "Dasar-dasar pemanfaatan ilmu dan teknologi pati." Agritech 13 (1993): 37-42. ["The basics of the use of starch science and technology." Agritech 13 (1993): 37-42].
- Hasjim, J, S O Lee, S Hendrich, S Setiawan, Y Ai, and J Jane. "Characterization of a novel resistant-starch and its effects on

postprandial plasma-glucose and insulin responses." *Cereal Chemistry* 87 (2010): 257-262.

- Hay, W T, G F Fanta, F C Felker, S C Peterson, C D Skory, M P Hojilla-Evangelista, G Biresaw, and G W Selling. "Emulsification properties of amylose-fatty sodium salt inclusion complexes." *Food Hydrocolloids* 90 (2019): 490-499.
- Hay, W T, G F Fanta, S C Peterson, A J Thomas, K Dutt, K A Walsh, V M Boddu, and G W Selling. "Improved hydroxypropyl methylcellulose (HPMC) films through incorporation of amylose-sodium palmitate inclusion complexes." *Carbohydrate Polymers* 188 (2018): 76-84.
- Heinemann, C, M Zinsli, A Renggli, F Escher, and B Conde-Petit. "Influence of amylose-flavor complexation on build-up and breakdown of starch structures in aqueous food model systems." *LWT - Food Science and Technology* 38 (2005): 885-894.
- Helbert, W. Données sur la structure du grain d'amidon et des produits de recristallisation de l'amylose. Doctoral dissertation, Université de Grenoble, 1994. [Data on the structure of starch grain and amylose recrystallization products. Doctoral Dissertation, University of Grenoble, 1994.]
- Immel, S, and F W Lichtenthaler. "The hydrophobic topographies of amylose and its blue iodine complex." *Starch-Stärke* 52 (2000): 1-8.
- Itthisoponkul, T, J R Mitchell, A J Taylor, I A Farhat. "Inclusion complexes of tapioca starch with flavour compounds." *Carbohydrate Polymers* 69 (2007): 106-115.
- Jane, J, Y Y Chen, L F Lee, A E McPherson, K S Wong, MRadosavljevic, and TKasemsuwan." Effects of amylopectin branch chain length and amylose content on the gelatinization and pasting properties of starch." *Cereal Chemistry* 76 (1999): 629-637.
- Kanicky, J R, and D O Shah. "Effect of degree, type, and position of unsaturation on the pKa, of long-chain fatty acids." *Journal of Colloid Interface Science* 256 (2002): 201-207.
- Karkalas, J, S Ma, W R Morrison, and R A Pethrick. "Some factors determining the thermal properties of amylose inclusion complexes with fatty acids." *Carbohydrate Research* 268 (1995): 233-247.

- Kaur, L, J Singh, and N Singh. "Effect of glycerol monostearate on the physic- chemical, thermal, rheological and noodle making properties of corn and potato starch." *Food Hydrocolloids* 19 (2005): 839-849.
- Kawada, J, and R H Marchessault. "Solid state NMR and X-ray studies on amylose complexes with small organic molecules." *Starch-Stärke* 56 (2010): 13-19.
- Kawai, K, S Takato, T Sasaki, and K Kajiwara. "Complex formation, thermal properties, and in-vitro digestibility of gelatinized potato starchefatty acid mixtures." *Food Hydrocolloids* 27 (2012): 228-234.
- Kenar, J A, D L Compton, J A Little, and S C Peterson. "Formation of inclusion complexes between high amylose starch andoctadecyl ferulate via steam jet cooking." *Carbohydrate Polymers* 140 (2016): 246-252.
- Kim, H I, H R Kim, S J Choi, C Park, and T W Moon. "Preparation and characterization of the inclusion complexes between amylosucrasetreated waxy starch and palmitic acid." *Food Science & Biotechnology* 26 (2017): 323–329.
- Kim, J Y, and S T Lim. "Preparation of nano-sized starch particles by complex formation with n-butanol." *Carbohydrate Polymers* 76 (2009): 110-116.
- Kong, L, U Yucel, R Yoksan, R J Elias, and G R Ziegler. "Characterization of amylose inclusion complexes using electron paramagnetic resonance spectroscopy." *Food Hydrocolloids* 82 (2018): 82-88.
- Konieczny, J, and K Loos. "Facile esterification of degraded and nondegraded starch." *Macromolecular Chemistry and Physics* 219 (2018): 1-6.
- Kwasniewska-Karolak, I, E Nebesny, and J Rosicka-Kaczmarek. "Characterization of amylose-lipid complexes derived from different wheat varieties and their susceptibility to enzymatic hydrolysis." *Food Science and Technology* 14 (2008): 29–37.
- Lalush, I, H Bar, I Zakaria, S Eichler, and E Shimoni. "Utilization of amylose–lipid complexes as molecular nanocapsules for conjugated linoleic acid." *Biomacromolecules* 6 (2005): 121-130.

- Lau, E, W Zhou, and C J Henry. "Effect of fat type in baked bread on amylose–lipid complex formation and glycaemic response." *British Journal of Nutrition* 115 (2016): 2122-2129.
- Lay Ma, U V, J D Floros, and G R Ziegler. "Formation of inclusion complexes of starch with fatty acid esters of bioactive compounds." *Carbohydrate Polymers* 83 (2011): 1869-1878.
- Le Bail, P, C Rondeau, and A Buleon. "Structural investigation of amylose complexes with small ligands: helical conformation, crystalline structure and thermostability." *International Journal of Biological Macromolecules* 35 (2005): 1-7.
- Lebail, P, A Buleon, D Shiftan, and R H Marchessault. "Mobility of lipid in complexes of amylose–fatty acids by deuterium and ¹³C solid state NMR." *Carbohydrate Polymers* 43 (2000): 317-326.
- Lehmann, U, and F Robin. "Slowly digestible starch Its structure and health implications: A review." *Trends in Food Science & Technology* 18 (2007): 346-355.
- Lesmes, U, J Barchechath, and E Shimoni. "Continuous dual feed homogenization for the production of starch inclusion complexes for controlled release of nutrients." *Innovative Food Science & Emerging Technologies* 9 (2008): 507-515.
- Lesmes, U, S H Cohen, Y Shener, and E Shimoni. "Effects of long chain fatty acid unsaturation on the structure and controlled release properties of amylose complexes." *Food Hydrocolloids* 23 (2009): 667-675.
- Lewandowski, C M. A brief mindfulness intervention on acute pain experience: An examination of individual difference. Dissertation, Southern Illinois University Carbondale, 2015.
- Li, X, X Gao, J Lu, X Mao, Y Wang, D Feng, J Cao, L Huang, W Gao. "Complex formation, physicochemical properties of different concentration of palmitic acid yam (*Dioscorea pposita* Thunb.) starch preparation mixtures." *LWT - Food Science and Technology* 101 (2019): 130-137.
- Liu, K, C Chi, X Huang, X Li, and L Chen. "Synergistic effect of hydrothermal treatment and lauric acid complexation under different

pressure on starch assembly and digestion behaviors." *Food Chemistry* 278 (2019): 560-567.

- Liu, P F, R Wang, X M Kang, B Cui, and B Yu. "Effects of ultrasonic treatment on amyloselipid complex formation and properties of sweet potato starch-based films." *Ultrason Sonochem* 44 (2018): 215-222.
- Lu, X, C Shi, J Zhu, Y Li, and Q Huang. "Structure of starch-fatty acid complexes produced via hydrothermal treatment." *Food Hydrocolloids* 88 (2019): 58-67.
- Manca, M, A J J Woortman, K Loos, and M A Loi. "Imaging inclusion complex formation in starch granules using confocal laser scanning microscopy." *Starch-Stärke* 67 (2015): 132-138.
- Maphalla, T G, and M N Emmambux. "Functionality of maize, wheat, teff and cassava starches with stearic acid and xanthan gum." *Carbohydrate Polymers* 136 (2016): 970-978.
- Marinopoulou, A, E Papastergiadis, S N Raphaelides, and M G Kontominas. "Structural characterization and thermal properties of amylose-fatty acid complexes prepared at different temperatures." *Food Hydrocolloids* 58 (2016): 224-234.
- Mazzocchetti, L, T Tsoufis, P Rudolf, and K Loos. "Enzymatic synthesis of amylose brushes revisited: details from x-ray photoelectron spectroscopy and spectroscopic ellipsometry." *Macromolecular Bioscience* 14 (2014): 186-194.
- Meng, S, Y Ma, D -W Sun, L Wang, and T Liu. "Properties of starchpalmitic acid complexes prepared by high pressure homogenization." *Journal of Cereal Science* 59 (2014a): 25-32.
- Meng, S, Y Ma, J Cui, and D W Sun. "Preparation of corn starch-fatty acid complexes by high-pressure homogenization." *Starch-Starke* 66 (2014b): 809-817.
- Mezzina, E, F Cruciani, G F Pedulli, and M Lucarini. "Nitroxide radicals as probes for exploring the binding properties of the cucurbit [7] uril host." *Chemistry-A European Journal* 13 (2007): 7223-7233.
- Milani, A, F N Aiman, L Brambilla, M Del Zoppo, C Castiglioni, G Zerbi, R Stradi. "Hydrogen bonding in amylose/DMSO complexes studied by

vibrational spectroscopy and density functional theory calculations." *Journal of Raman Spectroscopy* 40 (2009): 1110-1116.

- Moscicki, L. Extrusion-Cooking Techniques Applications, Theory and Sustainability. Germany (DE): WILEY-VCH Verlag & Co. KGaA, 2011.
- Nakazawa, Y, and Y Wang. "Effect of annealing on starch–palmitic acid interaction." *Carbohydrate Polymers* 57 (2004): 327-335.
- Nuessli, J, J L Putaux, P L Bail, and A Buleon. "Crystal structure of amylose complexes with small ligands." *International Journal of Biological Macromolecules* 33 (2003): 227-234.
- Obiro, W C, S S Ray, and M N Emmambux. "V-amylose structural characteristics, methods of preparation, significance, and potential applications." *Food Reviews International* 28 (2012): 412-438.
- Park, H, S Xu, and K Seetharaman. "A novel in situ atomic force microscopy imaging technique to probe surface morphological features of starch granules." *Carbohydrate Research* 346 (2011): 847-853.
- Polnaya, F J, Haryadi, D W Marseno, and M N Cahyanto. "Effects of phosphorylation and cross-linking on the pasting properties and molecular structure of sago starch." *International Food Research Journal* 20 (2013): 1609-1615.
- Polnaya, F J, Haryadi, D W Marseno, and M N Cahyanto. "Preparation and characteristics of phosphorylated sago starches." Sago Palm 20 (2012): 3-11.
- Putseys, J A, L Lamberts, and J A Delcour. "Amylose-inclusion complexes: Formation, identity and physico-chemical properties." *Journal of Cereal Science* 51 (2010): 238-247.
- Putseys, J A, L J Derde, L Lamberts, E Östman, I M Björck, and J A Delcour. "Functionality of short chain amylose-lipid complexes in starch-water systems and their impact on *in vitro* starch degradation." *Journal of Agricultural and Food Chemistry* 58 (2010): 1939-1945.
- Raphaelides, S, K Arsenoudi, S Exarhopoulos, and Z M Xu. "Effect of processing history on the functional and structural characteristics of starch-fatty acid extrudates." *Food Research International* 43 (2010): 329-341.

- Rodríguez, S D, and D L Bernik. "Flavor release by enzymatic hydrolysis of starch samples containing vanillin-amylose inclusion complexes." *LWT - Food Science and Technology* 59 (2014): 635-640.
- Rondeau-Mouro, C, P L Bail, and A Buleon. "Structural investigation of amylose complexes with small ligands: inter- or intra-helical associations." *International Journal of Biological Macromolecules* 34 (2004): 251-257.
- Saenger, W. "The structure of the blue starch-iodine complex." *Naturwissenschaften* 71 (1984): 31-36.
- Sajilata, M G, R S Singhal, and P R Kulkarni. "Resistant starche a review." *Comprehensive Reviews in Food Science and Food Safety* 5 (2006): 1-17.
- Seneviratne, H D, and C G Biliaderis. "Action of α-amylases on amyloselipid complex superstructure." *Journal of Cereal Sciences* 13 (1991): 129-143.
- Seo, T R, J Y Kim, and S T Lim. "Preparation and characterization of crystalline complexes between amylose and C18 fatty acids." LWT -Food Science and Technology 64 (2015): 889-897.
- Singh, J, A Dartois, and L Kaur. "Starch digestibility in food matrix: A review." *Trends in Food Science & Technology* 21 (2010): 168-180.
- Singh, N, J Singh, L Kaur, N S Sodhi, and B S Gill." Morphological, thermal and rheological properties of starches from different botanical sources." *Food Chemistry* 81 (2003): 219-231.
- Singh, N, L Kaur, K S Sandhu, J Kaur, and K Nishinari. "Relationship between physicochemical, morphological, thermal, rheological properties of rice starches." *Food Hydrocolloids* 20 (2006): 532-542.
- Singh, N, S Sharma, and B Singh. "The effect of sodium bicarbonate and glycerol monostearate addition on the extrusion behaviour of maize grits." *Journal of Food Engineering* 46 (2000): 61-66.
- Soong, Y Y, H J Goh, and C J K Henry. "The influence of saturated fatty acids on complex index and *in vitro* digestibility of rice starch." *International Journal of Food Sciences and Nutrition* 64 (2013): 641-647.

- Suarni, I U Firmansyah, and M Aqil. "Keragaman mutu pati beberapa varietas jagung." Jurnal Penelitian Pertanian Tanaman Pangan 32 (2013): 50-56. ["Variability of starch quality among corn varieties." Journal of Agricultural Food Research 32 (2013): 50-56].
- Tang, M C, and L Copeland. "Analysis of complexes between lipids and wheat starch." *Carbohydrate Polymers* 67 (2007): 80-85.
- Tapanapunnitikul, O, S Chaiseri, D G Peterson, and D B Thompson. "Water solubility of flavor compounds influences formation of flavor inclusion complexes from dispersed high-amylose maize starch." *Journal of Agricultural and Food Chemistry* 56 (2007): 220-226.
- Tian, Y, N Yang, Y Li, X Xu, J Zhan, and Z Jin. "Potential interaction between b-cyclodextrin and amylose–lipid complex in retrograded rice starch." *Carbohydrate Polymers* 80 (2010): 581-584.
- Tietz, M, A Buettner, and B Conde-Petit. "Changes in structure and aroma release from starche aroma systems upon α-amylase addition." *European Food Research and Technology* 227 (2008): 1439-1446.
- Tufvesson, F, M Wahlgren, and A C Eliasson. "Formation of amylose lipid complexes and effect of temperature treatment. Part 1: monoglycerides." *Starch-Stärke* 55 (2003a): 61-71.
- Tufvesson, F. M Wahlgren, and A C Eliasson. "Formation of amylose-lipid complexes and effects of temperature treatment. Part 2. Fatty acids." *Starch-Stärke* 55 (2003b): 138-149.
- Tufvesson, F, V Skrabanja, I Bjorck, H L Elmstahl, and A C Eliasson. "Digestibility of starch systems containing amylose-glycerol monopalmitin complexes." *LWT - Food Science and Technology* 34 (2001): 131-139.
- Uri, L, J Barchechath, and S Eyal. "Continuous dual feed homogenization for the production of starch inclusion complexes for controlled release of nutrients." *Innovative Food Science & Emerging Technologies* 9 (2008): 507-515.
- Vamadevan, V, R Hoover, E Bertoft, and K Seetharaman. "Hydrothermal treatment and iodine binding provide insights into the organization of glucan chains within the semi-crystalline lamellae of corn starch granules." *Biopolymers* 101 (2014): 871-885.

- van der Vlist, J, M Faber, L Loen, T J Dijkman, L Asri, and K Loos. "Synthesis of hyperbranched glycoconjugates by the combined action of potato phosphorylase and glycogen branching enzyme from Deinococcus geothermalis." *Polymers* 4 (2012): 674-690.
- van der Vlist, J, M P Reixach, M van der Maarel, L Dijkhuizen, A J Schouten, and K Loos. "Synthesis of branched polyglucans by the tandem action of potato phosphorylase and Deinococcus geothermalis glycogen branching enzyme." *Macromolecular Rapid Communications* 29 (2008): 1293-1297.
- Varatharajan, V, R Hoover, J Li, T Vasanthan, K K M Nantanga, K Seetharaman, Q Liu, E Donner, S Jaiswal, and R N Chibbar. "Impact of structural changes due to heat-moisture treatment at different temperatures on the susceptibility of normal and waxy potato starches towards hydrolysis by porcine pancreatic alpha amylase." *Food Research International* 44 (2011): 2594-2606.
- Varatharajan, V, R. Hoover, Q Liu, and K Seetharaman. "The impact of heat-moisture treatment on the molecular structure and physicochemical properties of normal and waxy potato starches." *Carbohydrate Polymers* 81 (2010): 466-475.
- Vasiliadou, E, S N Raphaelides, and E Papastergiadis. "Effect of heating time and temperature on partially gelatinized starch-fatty acid interactions." *LWT - Food Science and Technology* 60 (2015): 698-707.
- Waduge, R N, S Xu, and K Seetharaman. "Iodine absorption properties and its effect on the crystallinity of developing wheat starch granules." *Carbohydrate Polymers* 82 (2010): 786-794.
- Wang, R, P Liu, B Cui, X Kang, and B Yu. "Effects of different treatment methods on properties of potato starch-lauric acid complex and potato starch-based films." *International Journal of Biological Macromolecules* 124 (2019): 34-40.
- Wang, S, J Wang, J Yu, and S Wang. "Effect of fatty acids on functional properties of normal wheat and waxy wheat starches: A structural basis." *Food Chemistry* 190 (2016): 285-292.

- Wang, S, J Zhan, Z Jin, and Y Tian. "Enhanced fluorescence of starchfluorescence guest complexes enables evaluation of the encapsulation properties of maize starches." *Food Hydrocolloids* 63 (2017): 286-292.
- Wulff, G, G Avgenaki, and M S Guzmann. "Molecular encapsulation of flavours as helical inclusion complexes of amylose." *Journal of Cereal Science* 41 (2005): 239-249.
- Yang, L, B Zhang, Y Liang, B Yang, T Kong, and L -M Zhang. "*In situ* synthesis of amylose/single-walled carbon nanotubes supramolecular assembly." *Carbohydrate Research* 343 (2008): 2463-2467.
- Yang, Y, Z Gu, and G Zhang. "Delivery of bioactive conjugated linoleic acid with self-assembled amylose–CLA complex." *Journal of Agricultural and Food Chemistry* 57 (2009): 7125-7130.
- Yeo, L, D B Thompson, and D G Peterson. "Inclusion complexation of flavor compounds by dispersed high-amylose maize starch (HAMS) in an aqueous model system." *Food Chemistry* 199 (2016): 393-400.
- Yotsawimonwat, S, K Sriroth, S Kaewvichit, K Piyachomkwan, J-L Jane, and J Sirithunyalug. "Effect of pH on complex formation between debranched waxy rice starch and fatty acids." *International Journal of Biological Macromolecules* 43 (2008): 94-99.
- Zabar, S, U Lesmes, I Katz, E Shimoni, and H Bianco-Peled. "Structural characterization of amylose-long chain fatty acid complexes produced via the acidification method." *Food Hydrocolloids* 24 (2010): 347-357.
- Zabar, S, U Lesmes, I Katz, E Shimoni, and H Bianco-Peled. "Studying different dimensions of amylose-long chain fatty acid complexes: molecular, nano and micro level characteristics." *Food Hydrocolloids* 23 (2009): 1918-1925.
- Zhang, B, Q Huang, F X Luo, and X Fu. "Structural characterizations and digestibility of debranched high-amylose maize starch complexed with lauric acid." *Food Hydrocolloids* 28 (2012): 174-181.
- Zhang, G, M Venkatachalam, and B R Hamaker. "Structural basis for the slow digestion property of native cereal starches." *Biomacromolecules* 7 (2006): 3259-3266.
- Zhang, G, Z Ao, and B R Hamaker. "Slow digestion property of native cereal starches." *Biomacromolecules* 7 (2006): 3252-3258.

- Zhao, Y S, J Hasjim, L Li, J L Jane, S Hendrich, and D F Birt. "Inhibition of azoxymethane-induced preneoplastic lesions in the rat colon by a cooked stearic acid complexed high-amylose corn starch." *Journal of Agricultural and Food Chemistry* 59 (2011): 9700-9708.
- Zhou, X, R Wang, Y Zhang, S H Yoo, and S T Lim. "Effects of amylose chain length and heat treatment on amylose-glycerol monocaprate complex formation." *Carbohydrate Polymers* 95 (2013): 227-232.

INDEX

A

ADP-glucose, 96, 108 ADP-glucose pyrophosphorylase, 108

AGPase, 5, 6, 7, 96, 109

allele, 9, 10, 29, 31, 110

- allomorphs, 100, 101, 118, 294
- alpha-1,4, 109
- amorphous lamellae, 16, 17
- amylase, 23, 34, 35, 47, 79, 80, 81, 83, 84, 90, 120, 146, 151, 159, 177, 199, 202, 204, 205, 206, 208, 210, 211, 212, 213, 219, 220, 222, 223, 224, 228, 250, 256, 258, 261, 270, 271, 300, 321, 326, 363
- AMYLON^(R), 111

amyloplasts, 108, 135, 200

361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377

amylose-inclusion complex, 237, 239, 240, 241, 243, 244, 246, 247, 248, 250, 253,

254, 257, 260, 295, 296, 297, 299, 352

amylose-lipid, 12, 17, 63, 94, 102, 143, 147, 150, 151, 152, 156, 161, 163, 206, 207, 213, 224, 227, 233, 241, 242, 243, 244,

246, 251, 253, 258, 265, 268, 269, 270,

297, 311, 329, 338, 348, 361, 365, 376

annealing, 130, 153, 154, 215, 226, 234, 268

antisense RNA, 136

aqueous solutions, 297, 298, 363

aqueous suspension, 250, 296, 319, 326

Arabidopsis thaliana, 131

ATP, 108

В

benefits, 3, 75, 96, 107, 120, 123, 124, 173, 175, 200, 213, 223, 224, 228, 287, 353, 362 biocompatibility, 173, 177, 302 biodegradability, 173, 176, 177, 287, 289, 302, 305, 314, 364 biomedical applications, 294, 308, 312 biomolecules, 164 bionanocomposites, 302 biopolymers, vii, 19, 178, 199, 353, 370, 379

A-type, 16, 17, 100, 101, 102, 103, 106, 134, 252, 297, 324, 335, 340, 354

- biosynthesis, 2, 3, 6, 8, 15, 25, 26, 28, 29, 31, 99, 108, 110, 112, 115, 117, 118, 129, 132, 134, 224, 225
- bonding, 24, 34, 74, 178, 240, 267, 277, 280, 291, 300, 328, 341
- bonds, 7, 13, 35, 61, 150, 154, 164, 201, 203, 212, 241, 254, 255, 259, 260, 277, 325, 332, 355
- botanical, 36, 89, 95, 104, 128, 129, 134, 142, 153, 154, 159, 164, 179, 203, 228, 269, 278, 354
- branching, 4, 6, 7, 8, 13, 14, 15, 23, 25, 27, 28, 31, 53, 83, 96, 98, 100, 106, 109, 113, 116, 118, 124, 125, 131, 132, 134, 135, 136, 163, 214, 216, 223, 234, 242, 262, 271, 309, 359, 373
- B-type, 16, 17, 100, 101, 102, 103, 106, 151, 180, 199, 210, 229, 294, 297, 307, 335, 340, 354, 373, 377

С

calibration, 57, 71, 74, 78 calorie, 106, 120, 121, 173, 360 calorimetric, 61, 90, 101, 179, 366 carbon atoms, 12, 253, 298, 332 carbon dioxide, 234, 293 carbon materials, 301 carbon nanotubes, 241, 272, 286, 291, 292, 298, 311 carbonyl groups, 277 carboxyl, 167, 171, 212, 310, 337, 344 carboxylic acid, 287 carcinogenesis, 241 carotene, 81, 300, 309, 358, 365, 374 casting, 283, 286 catalysis, 250, 294, 304 catalyst, 172, 302 catalytic activity, 128 catalytic effect, 277

- cellulose, 40, 122, 174, 176, 282, 283, 284, 306, 307, 310, 311, 314, 349, 352, 370
- cereal starches, 14, 17, 75, 79, 81, 86, 88, 96, 97, 100, 101, 102, 110, 121, 122, 131, 134, 207, 232, 236, 272, 354
- chromatography, 9, 34, 64, 65, 66, 67, 72, 73, 74, 76, 87, 88, 89, 90, 91, 92, 93, 94, 97, 130, 363
- cluster(s), 13, 36, 100, 102, 203, 304
- cluster model, 203, 204
- coatings, 21, 125, 127, 174, 288, 380
- composite material, vi, vii, 177, 188, 275, 276, 277, 278, 281, 284, 285, 286, 287, 290, 293, 314
- composites, 124, 276, 277, 282, 283, 285, 286, 287, 289, 291, 292, 293, 302, 304, 312, 315, 329, 330, 332, 341
- composition, 3, 16, 32, 36, 42, 52, 53, 76, 82, 84, 95, 106, 116, 122, 123, 124, 151, 153, 154, 157, 205, 228, 234, 277, 295, 296, 318, 323, 342, 371, 377
- compounds, 12, 74, 75, 108, 174, 175, 208, 237, 239, 250, 260, 261, 264, 266, 270, 272, 287, 295, 296, 297, 299, 309, 310, 317, 324, 329, 334, 343, 352, 356, 360, 363, 364
- compression, 148, 159, 354
- concavalin-A, 97
- consumption, 2, 4, 26, 96, 106, 119, 121, 131, 140, 142, 152, 200, 204, 210, 213, 223, 250, 329
- cooling, 39, 56, 62, 106, 144, 146, 154, 156, 214, 219, 221, 299, 300, 334, 335, 341, 362
- corn starch, 21, 29, 36, 63, 89, 91, 92, 93, 147, 149, 156, 170, 171, 176, 177, 226, 229, 231, 233, 234, 247, 253, 262, 267, 270, 273, 303, 327, 328, 332, 334, 358, 362, 370, 376
- crystal, 18, 100, 102, 103, 166, 208, 227, 236, 248, 256, 260, 262, 268, 297, 298,

311, 320, 324, 330, 355, 373, 375, 376, 377

- crystal growth, 166, 297, 324
- crystal structure, 100, 256, 260, 311, 320, 330, 373, 376
- crystalline, 3, 5, 14, 15, 16, 17, 18, 23, 36, 37, 84, 85, 94, 101, 102, 104, 109, 126, 127, 146, 147, 148, 150, 153, 154, 161, 162, 165, 200, 202, 204, 205, 206, 207, 209, 211, 213, 214, 228, 240, 242, 245, 246, 251, 253, 256, 260, 261, 266, 269, 270, 297, 300, 303, 309, 319, 320, 324, 325, 327, 338, 343, 353, 354, 363, 364, 366, 367, 373, 374, 377
- crystalline lamellae, 15, 16, 270
- crystallinity, 14, 16, 22, 23, 36, 84, 95, 99, 101, 102, 103, 106, 118, 143, 151, 153, 154, 158, 159, 162, 167, 199, 204, 205, 209, 210, 211, 241, 242, 256, 271, 275, 296, 301, 308, 312, 314, 319, 320, 325, 327, 332, 336, 339, 350, 361, 363
- crystallites, 14, 16, 38, 102, 151, 155, 204, 213, 214, 215, 289, 329, 374
- crystallization, 18, 60, 85, 94, 147, 174, 212, 245, 246, 252, 253, 258, 297
- crystals, 84, 160, 176, 212, 215, 245, 252, 298, 307, 312, 314, 330, 335, 338, 354, 377
- C-type, 101, 136, 211, 325, 339, 354, 361 cytosol, 5, 108

D

degradation, 3, 34, 35, 68, 86, 87, 88, 156, 159, 168, 171, 173, 178, 208, 212, 232, 268, 299, 302, 313, 348, 367, 376 degradation rate, 173 degree of crystallinity, 216, 247, 339 depolymerization, 23, 171, 215 dietary fiber, 81, 107, 111, 119, 120, 121, 123, 222, 315, 360 differential scanning, 63, 93, 207, 238, 244, 254, 339, 365, 366

- differential scanning calorimeter, 254
- Differential Scanning Calorimetry (DSC), 59, 60, 61, 62, 63, 86, 89, 91, 93, 104, 106, 129, 207, 238, 244, 246, 248, 252, 257, 259, 260, 330, 338, 339, 365, 366
- diffraction, 83, 84, 91, 102, 126, 246, 365
- diffusion, 64, 65, 67, 78, 93, 302, 367
- digestibility, vi, 3, 14, 106, 119, 124, 135, 153, 159, 181, 183, 184, 185, 188, 193, 196, 199, 200, 204, 205, 206, 207, 209, 210, 214, 217, 219, 223, 226, 227, 228, 231, 233, 234, 236, 257, 258, 260, 265, 269, 270, 272, 349, 359, 362, 376
- digestion, 4, 9, 18, 23, 24, 26, 107, 163, 199, 202, 204, 205, 208, 209, 210, 211, 213, 216, 217, 218, 219, 220, 221, 222, 223, 224, 226, 228, 229, 230, 231, 232, 235, 236, 256, 257, 258, 259, 267, 272, 295, 305, 314, 362
- digestive enzymes, 18, 153, 207, 208, 210, 211, 216, 259, 361
- domestication, 1, 2, 4, 9, 10, 26
- drug delivery, 19, 172, 178, 287, 295, 299, 302, 304, 348, 350, 352, 353, 361, 363, 367, 368, 370, 371, 376, 377
- drug release, 304, 353, 358, 367
- drying, 22, 40, 88, 142, 143, 147, 150, 151, 152, 174, 222, 250, 300, 301, 304, 314
- DSC, 59, 60, 61, 62, 86, 89, 91, 104, 106, 129, 238, 244, 246, 248, 252, 257, 259, 260, 330, 338, 339 DSC method, 62

Е

electric current, 46, 47, 48 electric field, 22, 157, 158, 165 electrical conductivity, 292 electrodes, 41, 42, 43, 48, 52

electron paramagnetic resonance, 238, 265 encapsulation, 173, 174, 175, 246, 251, 261, 272, 295, 300, 303, 308, 309, 312, 314, 334, 335, 352, 353, 356, 358, 364, 365, 371, 374 endosperm, 2, 5, 8, 10, 26, 27, 28, 29, 30, 96, 110, 113, 116, 118, 126, 129, 130, 132, 133, 137, 159, 225, 230, 236 endothermic, 61, 63, 339 endotherms, 340 energy, 2, 3, 13, 18, 59, 61, 62, 71, 72, 83, 85, 86, 95, 96, 120, 147, 150, 154, 158, 162, 163, 165, 167, 200, 204, 238, 246, 249, 276, 295, 301, 310, 315, 323, 359, 360 energy consumption, 158, 164, 249 engineering, 29, 113, 130, 311, 314 entrapment, 299, 366 entropy, 71, 72 environment, 4, 5, 17, 100, 104, 167, 168, 170, 219, 240, 293, 357 ester, 21, 172 ester bonds, 172 ethanol, 40, 42, 56, 81, 147, 219, 221, 297, 301, 302, 318, 319, 320, 322, 326, 331, 332, 355, 364

F

etherification, 172, 200, 216, 361

fatty acids, 26, 31, 84, 107, 119, 149, 156, 175, 202, 208, 210, 226, 237, 239, 242, 243, 244, 245, 247, 248, 249, 252, 253, 254, 255, 256, 259, 260, 263, 264, 269, 271, 272, 280, 295, 309, 324, 329, 331, 346, 349, 355, 356, 358, 366, 373 fermentation, 146, 210, 218, 233, 380 fiber(s), 19, 100, 120, 121, 123, 144, 147, 159, 282, 283, 293, 309, 360 fiber content, 144, 147, 283, 360 fillers, 311, 353 film formation, 4, 284

- films, 4, 37, 122, 125, 144, 149, 170, 176, 177, 228, 234, 238, 264, 267, 271, 277, 282, 283, 284, 285, 286, 288, 289, 291, 303, 304, 305, 306, 307, 310, 313, 314, 344, 347, 353, 368, 369, 370, 371, 372, 374, 375, 376, 380 food industry, 34, 36, 52, 53, 107, 122, 142, 152, 153, 159, 167, 175, 178, 352 food products, 20, 38, 86, 107, 108, 143, 153, 156, 161, 163, 166, 167, 173, 212, 218, 227, 238, 352, 360, 362, 380 food safety, 157, 233 force, 41, 71, 139, 173, 209, 239, 240, 294, 326.328 Fourier transform infrared spectroscopy (FTIR), 85, 90, 105, 106, 238, 244, 245, 260, 319, 320, 332, 335, 336, 338 fructose-6-phosphate, 108 fruits, 2, 34, 127, 353
- FTIR, 85, 90, 105, 106, 320
- FTIR spectroscopy, 85, 90

G

gamma radiation, 338, 346 gastrointestinal tract, 209, 223, 295 gel formation, 21, 39, 177, 281, 362 gel permeation chromatography, 34 gelatinization, 3, 21, 22, 23, 29, 37, 38, 56, 63, 90, 101, 102, 104, 106, 108, 125, 129, 132, 133, 134, 135, 142, 143, 146, 147, 149, 150, 153, 156, 160, 163, 167, 168, 170, 181, 188, 191, 194, 204, 211, 214, 229, 232, 233, 241, 256, 263, 264, 301, 304, 305, 345, 352, 353, 357 gelatinization temperature, 3, 22, 23, 37, 90, 108, 146, 149, 150, 153, 156, 160, 167, 170, 204, 241 gelation, 39, 83, 131, 261, 285 gene expression, 7, 112, 130, 226

gene silencing, 26, 116 genes, 3, 7, 8, 25, 27, 29, 96, 110, 114, 115, 116, 118, 126, 128 genetic diversity, 2 genetic factors, 207 glass transition temperature, 60, 153, 154, 215 glucan, 3, 6, 34, 81, 95, 96, 98, 100, 102, 104, 105, 106, 109, 110, 113, 117, 123, 131, 135, 154, 200, 202, 207, 225, 270, 352 glucoamylase, 3, 205, 232 glucose, 1, 2, 3, 5, 6, 11, 13, 14, 16, 18, 19, 79, 80, 93, 96, 100, 106, 108, 113, 200, 204, 209, 210, 212, 217, 218, 219, 220, 221, 222, 223, 225, 228, 232, 233, 238, 240, 245, 257, 259, 262, 264, 277, 278, 285, 357, 359, 361, 365, 372 glucose oxidase, 79, 220, 221, 223 glucose-1-phosphate, 108 glycemic, 1, 17, 107, 120, 121, 144, 152, 208, 209, 211, 217, 228, 257, 262, 359 glycerol, 122, 176, 177, 249, 263, 265, 269, 273, 277, 291, 307, 324, 371, 374 glycogen, 271 GPC, 34, 64, 88 grain quality, 2, 24 grain size, 2, 9, 27, 160, 207 granule(s), 1, 5, 6, 7, 8, 13, 14, 15, 16, 17, 21, 22, 24, 25, 28, 29, 31, 91, 95, 96, 98, 100, 101, 102, 103, 104, 105, 109, 113, 114, 122, 123, 126, 129, 130, 131, 133, 134, 136, 142, 146, 150, 153, 154, 155, 157, 159, 160, 162, 165, 170, 171, 181, 202, 203, 204, 205, 207, 208, 211, 215, 222, 224, 226, 229, 231, 232, 234, 235, 276, 352, 353, 361 granule-bound starch synthase, 6, 25, 96, 98, 109, 113, 130, 133, 224

Η

- helical conformation, 237, 239, 266, 280, 297, 374 helices, 16, 48, 52, 100, 106, 127, 146, 157, 202, 204, 205, 206, 215, 239, 240, 242, 253, 294, 297, 300, 329, 354 hemoglobin, 295, 338, 341, 345 heterogeneity, 36 high amylose rice, 2, 116, 143, 153 high performance liquid chromatography (HPLC), 31, 75, 76, 89, 97 high-performance size exclusion chromatography (HPSEC), 34, 62, 68, 69, 70, 71, 74, 75, 77, 78, 86, 87, 88, 93, 98 hilum, 100, 202, 203 Hi-MaizeTM, 108 hydrogen, 11, 24, 74, 101, 142, 148, 150, 162, 165, 178, 202, 206, 215, 239, 240, 241, 254, 277, 280, 289, 291, 300, 320, 328, 336, 341, 352, 353, 355, 357, 361 hydrogen bonds, 142, 148, 150, 202, 206, 239, 240, 241, 289, 320, 336, 352, 353, 355, 357, 361 hydrolysis, 3, 20, 21, 23, 34, 35, 79, 86, 91, 93, 97, 122, 123, 125, 131, 140, 142, 152, 160, 170, 171, 173, 199, 204, 205, 206, 207, 208, 209, 211, 213, 215, 217, 218, 219, 220, 222, 223, 228, 230, 231, 250, 254, 256, 257, 258, 260, 261, 265, 269, 271, 295, 318, 324, 325, 326, 327, 339, 346, 347, 350, 361, 368, 374 hydrophilicity, 176, 240, 277, 284, 291, 365 hydrophobicity, 240, 285, 289, 292, 299, 306, 357
- hydroxide, 11, 220, 221, 222, 239, 260, 297, 356
- hydroxyl groups, 150, 166, 172, 212, 240, 285, 288, 301, 352, 357, 363

I

- *in vitro*, 23, 123, 124, 131, 177, 199, 209, 217, 218, 219, 220, 223, 226, 228, 231, 232, 233, 235, 257, 262, 268, 269, 294, 305, 376
- *in vivo*, 119, 200, 217, 218, 223, 224, 226, 227, 228, 231
- inclusion complex, vi, 12, 15, 17, 35, 187, 231, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 258, 259, 260, 261, 263, 264, 265, 266, 267, 268, 269, 270, 272, 276, 278, 285, 294, 295, 296, 297, 298, 299, 306, 307, 308, 309, 310, 312, 314, 315, 330, 344, 346, 349, 355, 356, 357, 358, 365, 366, 367, 368, 369, 371, 374, 376, 377
- inclusion complexes, vi, 15, 17, 187, 231, 237, 238, 239, 240, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 258, 259, 260, 263, 264, 265, 266, 268, 269, 270, 272, 285, 294, 295, 296, 297, 298, 299, 306, 307, 308, 309, 310, 312, 314, 315, 330, 344, 346, 349, 355, 358, 365, 366, 367, 368, 369, 371, 374,

K

ketones, 239, 259, 364 kinetic parameters, 346 kinetics, 224, 225, 226

L

lamellar, 16, 23, 102, 202, 242, 330, 355, 367 light scattering, 75, 76, 88, 91, 105, 319,

338, 363, 369

linoleic acid, 245, 248, 251, 252, 255, 265, 272, 315, 329, 346, 367

lipids, 20, 97, 101, 102, 119, 126, 146, 159, 160, 163, 170, 174, 175, 205, 206, 207, 231, 239, 241, 242, 243, 250, 254, 257, 258, 259, 261, 270, 295, 296, 361

liquid chromatography, 64, 86, 90, 97, 124, 219, 227

low amylose starches, 161, 369

Μ

macromolecular, vii, 64, 87, 103, 263, 265, 267, 271, 275, 276, 298, 308, 312, 314, 377 Maillard reaction, 167 MAS, 94, 238, 244, 330, 348 mass spectrometry, 75, 91 metabolic disorders, 3, 121 metabolic pathways, 25 metabolic syndrome, 257 metabolism, 3, 110, 126, 204, 233, 238, 334 microcrystalline, 125, 347 microcrystalline cellulose, 125 microorganisms, 156, 157, 160, 165, 167, 175 microscopy, 14, 84, 85, 91, 168, 267, 268, 331 microspheres, 300, 301, 303, 310, 337, 348 microstructure(s), 147, 175, 176, 300, 314, 366.375 microwave heating, 69, 164, 240 modifications, 2, 20, 21, 22, 109, 122, 139, 140, 141, 142, 153, 158, 168, 172, 176, 178, 212, 213, 216, 219, 220, 223, 226, 227, 229, 293, 360, 361, 370, 380 modulus, 87, 160, 161, 283, 286 moisture, 19, 31, 56, 63, 122, 128, 139, 141, 147, 150, 152, 153, 154, 156, 163, 174, 176, 200, 214, 226, 228, 229, 233, 271, 276, 282, 283, 293, 308, 360, 371

molecular mass, 74, 75, 88, 172 molecular mobility, 248, 252, 260 molecular reorientation, 154 molecular structure, 28, 82, 85, 128, 129, 130, 204, 214, 217, 223, 226, 228, 231, 238, 244, 245, 260, 262, 268, 271, 310, 373 molecular weight, 3, 12, 13, 70, 75, 77, 78, 91, 104, 147, 168, 201, 238, 281, 355, 364 molecules, 34, 35, 36, 37, 38, 52, 64, 65, 68, 71, 74, 85, 86, 96, 98, 100, 104, 105, 106, 109, 143, 146, 148, 154, 156, 157, 161, 163, 172, 200, 203, 204, 206, 207, 209, 210, 211, 212, 213, 223, 237, 238, 239, 240, 241, 243, 244, 245, 246, 247, 251, 259, 265, 277, 280, 281, 285, 294, 295, 297, 298, 315, 323, 324, 329, 335, 337, 341, 346, 352, 353, 354, 357, 360, 362, 364, 365 morphology, 14, 23, 155, 168, 252, 263, 291, 306, 318, 319, 321, 324, 340, 342, 344, 347 mRNAs, 9, 32 mutant, 8, 25, 26, 30, 103, 114, 116, 118, 230, 278, 373

N

nanocomposites, 283, 289, 291, 300, 303, 306, 307, 308, 309, 310, 311, 313, 314, 345, 348, 363 nanocrystals, 122, 125, 176, 325, 340, 343, 344, 345, 347 nanofibers, 283, 307, 310 nanometer, 283, 289 nanometer scale, 289 nanoparticles, vi, 83, 92, 131, 277, 278, 289, 300, 301, 304, 305, 314, 317, 318, 319, 321, 322, 323, 324, 325, 326, 327, 328, 329, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 348, 349, 350, 352, 358, 361, 363, 364, 371, 372, 376, 377

nuclear magnetic resonance spectroscopy (NMR), 30, 34, 85, 94, 105, 106, 233, 238, 244, 248, 252, 260, 265, 266, 319, 330, 338, 346, 347, 348, 349

0

oxidation, 21, 92, 122, 140, 155, 160, 167, 171, 200, 216, 234, 282, 327, 348, 364 oxide nanoparticles, 277, 304 oxygen, 11, 161, 173, 241, 283, 285, 310, 334, 338, 341, 345, 364, 365, 370

Р

pasting, 21, 22, 23, 27, 31, 37, 38, 93, 104, 105, 107, 124, 129, 131, 133, 134, 135, 143, 147, 154, 162, 165, 167, 170, 191, 194, 195, 204, 229, 233, 263, 264, 268, 312, 344, 345 phenotype, 8, 9, 109, 110, 112, 118, 132 phosphate(s), 5, 6, 21, 108, 119, 140, 239, 367 phosphorylation, 95, 135, 209, 233, 268 photosynthesis, 11, 108, 238, 276, 278 phylogenetic tree, 7 physical characteristics, 160, 227 physical properties, 18, 88, 96, 124, 140, 163, 173, 236, 261, 289, 301, 314, 342, 376 physicochemical properties, 14, 29, 83, 128, 130, 167, 175, 226, 233, 234, 236, 240, 244, 260, 266, 271, 277, 291, 305, 308, 312, 334, 338, 344, 352, 362 polymer blends, 314 polymer chain(s), 149, 361 polymer composites, 292, 305 polymer matrix, 73, 77

polymer nanocomposites, 291, 303, 307, 311 polymeric, vii, 14, 65, 73, 77, 106, 177, 200, 238, 302, 303, 313, 326, 352, 357, 379 polymeric chains, 177, 326 polymeric gels, 65, 77 polymerization, 4, 12, 47, 91, 97, 100, 151, 160, 172, 174, 203, 206, 211, 248, 263, 287, 288, 298, 299, 308, 311, 312, 329, 341, 344, 362 polymorphism, vii, 228, 252, 297 potato starch, 14, 16, 17, 30, 47, 93, 130, 149, 163, 165, 172, 203, 226, 227, 230, 243, 246, 265, 267, 271, 283, 305, 311, 334, 335, 339, 349, 365, 370 potentiometric, 34, 35, 48, 49, 50, 51, 52, 53, 87, 97, 133

Q

quantification, 53, 56, 92, 146, 148, 164, 261, 343

R

reaction temperature, 245, 256, 321, 330, 334, 365 reaction time, 44, 333, 339, 342, 365 reagents, 21, 48, 57, 81, 140, 142, 212, 229 recrystallization, 24, 37, 151, 165, 231, 264, 297, 300, 318, 328 refractive index, 74, 75, 86, 90 regenerated starch nanoparticles (RSNPs), 341 resistant starch, 3, 18, 23, 26, 29, 31, 111, 119, 120, 121, 123, 124, 125, 128, 129, 132, 136, 144, 147, 151, 153, 154, 155, 163, 168, 180, 182, 187, 189, 191, 193, 199, 200, 209, 210, 212, 218, 219, 220, 222, 223, 224, 225, 226, 227, 228, 230, 231, 232, 233, 234, 235, 236, 238, 241, 250, 257, 259, 361, 362, 372, 375

- retrogradation, 14, 17, 20, 21, 22, 24, 37, 38, 39, 104, 105, 106, 108, 120, 123, 129, 131, 133, 135, 144, 147, 150, 151, 154, 155, 156, 163, 166, 167, 168, 170, 171, 189, 205, 211, 214, 215, 216, 233, 241, 251, 260, 280, 282, 300, 341, 349, 361 ribulose-1,5-bisphosphate, 108
- RNA, 28, 30, 113, 116, 125, 127, 132, 350 RNAi, 25, 26, 113, 118

S

- small angle neutron scattering (SANS), 105, 129
- small angle x-ray scattering (SAXS), 104, 129, 330
- solubility, 14, 16, 21, 22, 23, 34, 36, 45, 69, 73, 139, 143, 148, 150, 153, 154, 158, 159, 162, 163, 167, 170, 176, 241, 249, 255, 260, 270, 282, 287, 296, 322, 352, 361, 365
- solution, 18, 22, 37, 39, 40, 41, 42, 43, 44, 45, 48, 49, 50, 51, 52, 53, 55, 56, 62, 64, 66, 67, 79, 80, 88, 97, 176, 177, 208, 221, 222, 277, 281, 286, 288, 289, 290, 292, 293, 296, 297, 298, 301, 302, 304, 318, 319, 322, 323, 328, 329, 331, 332, 334, 335, 343, 344, 364, 365, 366, 369, 374
- spectrophotometric method, 53, 56, 57, 79, 89
- spectrophotometry, 53, 54, 55, 106
- spectroscopy, 34, 85, 90, 105, 233, 238, 244, 245, 248, 260, 265, 268, 338, 367, 369
- starch biosynthesis, 4, 6, 8, 29, 32, 97, 110, 112, 115, 117, 118, 130
- starch blends, 284, 313

starch crystals, 354 starch digestibility, 106, 135, 159, 184, 185, 193, 200, 204, 205, 206, 207, 209, 210, 217, 219, 224, 226, 260 starch granules, 2, 13, 14, 18, 22, 24, 27, 30, 31, 37, 39, 41, 92, 103, 104, 105, 106, 109, 119, 125, 126, 131, 133, 134, 135, 139, 143, 146, 147, 150, 153, 154, 155, 160, 161, 162, 199, 203, 205, 206, 207, 209, 211, 212, 213, 215, 224, 225, 228, 229, 230, 231, 232, 242, 244, 249, 256, 258, 267, 268, 271, 278, 280, 307, 320, 325, 328, 346, 352, 354, 365, 370 starch nanoparticles (SNPs), 2, 9, 31, 92, 114, 323, 325, 326, 327, 328, 333, 339, 340, 341, 344, 345, 346, 348, 349, 350, 364, 376 starch polysaccharides, 213, 227 starch synthases, 6, 98, 109, 113 swelling, 3, 14, 18, 21, 22, 23, 34, 38, 77, 101, 102, 104, 106, 126, 134, 143, 144, 146, 148, 150, 153, 154, 156, 159, 160, 161, 162, 163, 168, 171, 199, 206, 208, 213, 216, 232, 241, 256, 260, 285, 352, 353, 362, 367 synthetic polymers, 281, 293, 308

Т

targeted induced local lesions in genomes (TILLING), 31, 113, 133 thermo-mechanical analysis (TMA), 104 Transmission Electron Microscopy (TEM), 82, 83, 251, 320, 321, 325, 332, 335, 337, 338

300, 309, 311, 329, 349, 356, 357, 364, 366, 372, 375 vitamin D, 333, 335, 345 vitamins, 148, 174, 175, 295, 329

W

waxy, 1, 2, 4, 5, 8, 10, 14, 15, 18, 19, 20, 24, 26, 28, 29, 30, 31, 96, 97, 101, 105, 107, 109, 111, 126, 128, 130, 133, 134, 136, 161, 162, 166, 170, 171, 172, 180, 181, 187, 193, 195, 205, 206, 215, 228, 231, 235, 251, 265, 271, 272, 278, 279, 307, 320, 325, 326, 327, 339, 340, 341, 343, 346, 369 wide angle x-ray scattering (WAXS), 104,

106, 129

Wx gene, 29, 96

Х

- X-ray, 15, 34, 84, 100, 102, 126, 162, 207, 229, 238, 240, 244, 245, 257, 265, 283, 297, 319, 330, 346, 354, 363, 365, 366, 367, 372, 375
- X-ray diffraction (XRD), 34, 84, 100, 102, 162, 207, 238, 240, 244, 245, 257, 283, 297, 319, 324, 327, 330, 332, 335, 336, 337, 338, 354, 363, 365, 366, 367

zinc, 358, 365



V-amylose, 231, 237, 238, 240, 245, 246, 252, 254, 255, 257, 258, 262, 268, 297, β-amylases, 106

Related Nova Publications

GRAPEVINES AT A GLANCE

EDITOR: Josephine Estrada



SERIES: Food Science and Technology

BOOK DESCRIPTION: *Grapevines at a Glance* first presents the results of a morphological and genetic characterization, as well as chemical characterization, of some of the most important indigenous grapevine varieties in the central Balkan, such as: Vranac, Krstač, Smederevka, Prokupac, Žilavka, Plavac Mali, and Istrian Malvasia.

SOFTCOVER ISBN: 978-1-53616-399-5 **RETAIL PRICE:** \$95

HANDBOOK OF CHICKPEAS: NUTRITIONAL VALUE, HEALTH BENEFITS AND MANAGEMENT

EDITORS: Albert T. Lund and Noah D. Schultz



SERIES: Food Science and Technology

BOOK DESCRIPTION: Handbook of Chickpeas: Nutritional Value, Health Benefits and Management discusses the current information regarding the nutritional value of chickpea.

HARDCOVER ISBN: 978-1-53616-374-2 RETAIL PRICE: \$230

To see a complete list of Nova publications, please visit our website at www.novapublishers.com



To see a complete list of Nova publications, please visit our website at www.novapublishers.com