THE EFFECT OF PROCESSING PARAMETERS ON TEXTURAL PROPERTIES OF SWEET TARO PASTE

By

Suphachai Raksaphol

An Independent Study Submitted in Partial Fulfillment of the Requirements for the Degree
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ผลของปัจจัยในกระบวนการผลิตต่อคุณภาพเนื้อสัมผัสของไส้เผือกกวน

โดย
นายศุภชัย รักษาพล

การค้นคว้าอิสระนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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บัณฑิตวิทยาลัย มหาวิทยาลัยศิลปากร
ปีการศึกษา 2552

The Graduate School, Silpakorn University has approved and accredited an independent study title of "The Effect of Processing Parameters on Textural Properties of Sweet Taro Paste" submitted by Mr.Suphachai Raksaphol as a partial fulfillment of the requirements for the degree of Master of Science in Food Technology.

……………………………………………….......
(Associate Professor Sirichai Chinatungkul, Ph.D.)
Dean of Graduate School
........../........../..........

An Independent Study Advisor
Assistant Professor Bhundit Innawong, Ph.D.

An Independent Study Examination Committee

…………………………………..Chairman
(Assistant Professor Eakaphan Keowmaneechai, Ph.D.)
........../........../..........

…………………………………..Member
(Assistant Professor Sopark Sonwai, Ph.D.)
........../........../..........

…………………………………..Member
(Assistant Professor Bhundit Innawong, Ph.D.)
........../........../..........

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The effect of emulsifier and arabic gum (AG) addition on the textural characteristics of taro paste was investigated. The obtained results revealed that the addition of glycerol monosterate (GMS) and sodium stearoyl 2 lactylate (SSL) in taro paste caused a decrease in toughness of the formulated taro paste during 8 weeks of storage. In contrast, the addition of arabic gum into the produced paste provided dominantly rubbery characteristic of this product. It noticed that the higher gum (10% and 15%) usage, the lower shear stress and greater shear strain of the tested samples obtained. According to the textural mapping, an increasing gum level in taro paste leaded to a progressive appearance of rubbery characteristic. However, GMS and SSL directly affected the toughness of the product. As expected to the effect of microwave treatment on taro paste, the different powers of microwave (450, 600, 850 and 1,000 watts) were applied to remove excess water in the taro pastes. The result showed that the taro paste which was treated by microwave heating at 1,000 watts for 20 minutes could rapidly decrease the water activity to less than 0.85 without discoloration as compared to the others. In addition, it did not exhibit more toughness development during 8 weeks of storage. In contrast, 450 W-treated taro pastes resulted longest time for 54 minutes to achieve the reduction of Aw in the taro paste and exhibited the hardest textural characteristic. Less compression force was obtained in 600 watts/38 minutes treated taro paste and at this conditions, less toughness development during storage were presented.

Department of Food Technology Graduate School, Silpakorn University Academic Year 2009

Student's signature……………………………………………………………………...

Independent Study Advisor's signature………………………………………

49403304 : สาขาวิชาเทคโนโลยีอาหาร

คำสำคัญ : เผือกกวน / ไมโครเวฟ / อิมัลซิไฟเออร์ / กัมอะราบิค / เนื้อสัมผัส

ศุภชัย รักษาพล :ผลของปัจจัยในกระบวนการผลิตต่อคุณภาพเนื้อสัมผัสของไส้เผือกกวน อาจารย์ที่ปรึกษาการค้นคว้าอิสระ: ผศ. ดร.บัณฑิต อินณวงศ์. 92 หน้า.

การศึกษาผลของการเติมอิมัลซิไฟเออร์ ประกอบด้วย โซเดียมสเตียรอล 2-แลคไทเลต, กลีเซอรอล โมโนสเตียเรท และกัมอะราบิค ที่ระดับความเข้มข้นต่างๆ กันในการผลิตไส้เผือกกวน พบว่า การเติมอิมัลซิไฟเออร์จำพวก โซเดียมสเตียรอล 2-แลคไทเลต และ กลีเซอรอล โมโนสเตียเรท มีผลต่อความนุ่มของเผือกกวน โดยช่วยลดความแน่นเนื้อของเผือกกวนตลอดช่วง 8 สัปดาห์ของการเก็บรักษาที่อุณหภูมิห้อง นอกจากนี้การเติมกัมอะราบิค จะช่วยปรับปรุงเนื้อสัมผัสเผือกกวนให้ลักษณะนิ่มเหนียวคล้ายยางมากขึ้น จากการสังเกตพบว่าปริมาณกัมที่มากขึ้น (ร้อยละ 10 และ 15) ทำให้ทั้งค่าความเค้นเฉือนของเผือกกวนลดลง แต่ค่าความเครียดเฉือนกลับเพิ่มขึ้น โดยสอดคล้องกับแผนภาพลักษณะเนื้อสัมผัสที่แสดงให้เห็นว่าปริมาณกัมที่มากขึ้นทำให้เนื้อสัมผัสของเผือกกวนมีแนวโน้มนิ่มเหนียวเพิ่มมากขึ้น ในขณะที่ โซเดียมสเตียรอล 2-แลคไทเลต และ กลีเซอรอล โมโนสเตียเรท มีอิทธิพลโดยตรงกับการลดลงของค่าแน่นเนื้อของเผือกกวน สำหรับการให้ความร้อนด้วยพลังงานไมโครเวฟที่ระดับต่างๆกัน (450, 600, 850 และ 1,000 วัตต์) ในการผลิตเผือกกวนเพื่อศึกษาผลกระทบต่อเนื้อสัมผัสของเผือกกวนนั้น พบว่า การให้พลังงานที่ระดับพลังงาน 1,000 วัตต์ เป็นเวลา 20 นาที เป็นวิธีการผลิตเผือกกวนที่ใช้เวลาน้อยที่สุดที่จะลดค่าน้ำอิสระ (A_w) ให้ต่ำกว่า 0.85 โดยไม่มีผลต่อการเปลี่ยนแปลงทางด้านลบต่อลักษณะสีที่ปรากฏและเนื้อสัมผัสตลอดช่วง 8 สัปดาห์ของการเก็บรักษา เมื่อเปรียบเทียบกับพลังงานไมโครเวฟที่ระดับอื่นๆ จากการศึกษายังพบว่า ที่ระดับ 450 วัตต์ จะต้องใช้เวลาในการผลิตนานมากที่สุด คือ 54 นาที และมีผลทำให้เนื้อสัมผัสมีความแน่นเนื้อมากที่สุด ในขณะที่ระดับ 600 วัตต์ เป็นเวลา 38 นาที จะทำให้ได้เผือกกวนที่มีลักษณะนิ่มเหนียวมากที่สุด

ภาควิชาเทคโนโลยีอาหาร บัณฑิตวิทยาลัยศิลปากร ปีการศึกษา 2552
ลายมือชื่อนักศึกษา..
ลายมือชื่ออาจารย์ที่ปรึกษาการค้นคว้าอิสระ...

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TABLE OF CONTENTS

Page

English Abstract …… d

Thai Abstract …… e

Acknowledgement …… f

List of Tables …… i

List of Figures …… j

Chapter

1 Introduction …… 1

Background …… 1

References …… 2

2 Literature Review …… 3

Taro …… 3

Starch …… 8

Emulsifier …… 12

Influence of emulsifier on starch …… 15

Interactions between surfactants and starch during gelatinization …… 19

Arabic gum …… 23

Food texture; definitions of mechanical properties …… 24

The principle of microwave heating …… 26

References …… 44

3 Influence of Emulsifier and Arabic Gum Addition on Textural Characteristics of Taro Paste …… 52

Abstract …… 52

Introduction …… 53

Materials and methods …… 54

Results and discussions …… 56

Conclusion …… 59

References …… 59

Chapter Page

4 Effect of Microwave Heating on Color and Textural Characteristics of Taro Paste …………………………………. 67

Abstract ……………………………………………….. 67

Introduction …………………………………………… 68

Materials and methods ………………………………... 69

Results and discussions ……………………………….. 70

Conclusion ……………………………………………. 72

References …………………………………………….. 72

5 Summary …………………………………………………… 79

References ………………………………………………………………..…..... 80

Appendix …………………………………………………………………… 90

Biography ..………………………………………..………………………… 92

LIST OF TABLES

Tables Page

1 Proximate compositions of the taro corm on a fresh weight basis …… 6

2 Percentage compositions of taro corm carbohydrate …………………. 7

3 HLB and characteristic behavior related to water ……………………. 18

4 The chemical analysis of fresh made taro paste with different emulsifier proportions …………………………..…………. 63

5 The chemical analysis of fresh made taro paste with different gum concentrations ………………………………………………… 63

6 The compression force of taro paste in different storage times ………. 64

7 The chemical analysis of fresh-made taro paste with various microwave heatings ……………………………………….... 75

8 The compression force of taro paste in different storage times ………. 77

9 The changes of color (L^*) of taro paste during 8 weeks of storage time ……………………………………………... 78

10 The changes of color (a^*) of taro paste during 8 weeks of storage time ……………………………………………... 78

11 The changes of color (b^*) of taro paste during 8 weeks of storage time ……………………………………………... 78

LIST OF FIGURES

Figures Page

1 X-ray diffraction of native *Java* starch ……………………………….. 7

2 Taro starch granule (5000x) observed from scanning electron microscope ………………………………………………… 8

3 Representative partial structure of amylose and amylopectin ………... 9

4 Structure of Amylopectin …………………………………………….. 11

5 Type A and B crystalline starch pattern …………………………... 12

6 Schematic illustration of a surfactant molecule ………………………. 12

7 Properties of emulsifier ………………………………………………. 14

8 HLB and emulsifier in water/oil ……………………………………… 15

9 Action of emulsifier on starch ………………………………………... 16

10 Molecular modeling representation of the amylose-fatty acid complexes showing the inclusion of the hydrophobic part (C12) of the fatty acid inside the hydrophobic cavity of the amylose single helix .. 19

11 DSC thermogram obtained during the gelatinization of wheat starch showing the endothermic transition attributed to the dissociation of the AM-lipid complex ………………………... 21

12 Schematic representation of the main structural features of the gum arabic molecule ……………………………………………….. 24

13 Nominal force-extension plot showing definitions of strength & toughness ………………………………………………………... 25

14 Common state of stress ……………………………………………….. 26

15 The electromagnetic spectrum and the ISM frequency ………………. 27

16 A propagating electromagnetic wave ………………………………… 27

17 Origin of different types of losses in heterogeneous mixtures containing water; X is extension for water containing ions ……………….. 29

18 Temperature dependence of e’ (a) and e’’ (b) for various food substances at 2.8 GHz ……………………………………….. 32

19 Dielectric properties food map at 20-25°C, 2450 MHz ………………. 33

Figures Page

20 The effect of the diameter on the relative microwave power level (P/Pav) near center and at surface of a) spheres and b) cylinders …….. 36

21 The household microwave oven ……………………………………… 38

22 Flowchart of the preparation of sweetened taro paste ………………... 62

23 Texture map of taro paste containing emulsifier during storage ……... 65

24 Texture map of taro paste containing gum and emulsifier during storage ………………………………………………… 66

25 Flowchart of the preparation of sweetened taro paste ………………... 74

26 Compression force value of MW-treated taro paste during storage ….. 75

27 Texture map of MW-treated taro paste during storage ……………… 76

CHAPTER 1

INTRODUCTION

BACKGROUND

Taro (*Colocasia esculenta* (L.) Schott) is a major tuber crop cultivated in the tropical and subtropical regions of the world (Tatiyakul et al., 2006). In many countries of Asia, especially in China, Japan and Thailand, the corps are usually used for the preparation of a sweetened paste for dessert or as a bakery filling. Traditionally, sweetened taro paste is prepared by the combined processes of cooking, peeling and mashing to obtain a smooth paste before mixed with other ingredients such as sugar and salt, after that the mixed paste was agitating with heat into the vegetable coated pan for a while, usually took long time, until paste became dry, smooth and was not sticky on surface of pan. However, its commercial production is generally limited by a number of factors: first, the traditional processing of sweetened taro paste is tedious, long time consumption and labor intensive and second, product normally has short shelf life period, however, for its shelf-life extension by keeping under refrigeration. For this reason, the hardening of textural characteristics as known as staling or retrogradation becomes the basis problem (Lai et al., 1998).

As with most starchy foods, sweetened taro paste, retrogradation of the starch component may be the primary reason for the staling of taro paste during long term storage. The rate of starch retrogradation is affected by many factors including the source, concentration of starch, and storage condition. To retard starch retrogradation during storage, addition of polyols, hydrocolloids and emulsifiers has been examined with starch gel system (Charutigon et al., 2008; Kim & Yoo 2006; Turabi et al.; Zhou et al., 2007).

The purposes of this study were to determine the effect of the utilization of arabic gum and emulsifiers including SSL and GMS on the textural properties of sweet taro paste with respect to improve the textural properties and retard the staling of starch components in the sweetened taro paste during storage. In addition, this study was focused on the influence of microwave heating process on textural properties of the sweetened taro paste under the different microwave powers.

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CHAPTER 2
LITERATURE REVIEW

TARO

FAO Corporate document repository mentions that the term taro is used to refer to *Colocasia esculenta* (L.) Schott. Taro is postulated to have originated in southern or south-east Asia, and to have been dispersed to Oceania through the Island of New Guinea very many centuries ago. The crop has evolved with the cultures of the people of the Asia/Pacific region. Among the food crops in Oceania, the adulation and prestige attached to taro is equaled only by yam in certain localities. (Onwueme, 1999).

The taro corm is a very awkward market commodity. It is bulky, consisting of two-thirds water. It is fragile and easily bruised. It is perishable and can only store for a few days at ambient temperatures. Yet most of taro marketing takes place in form of the fresh corm, with few suitable processed forms available. The effectiveness of the taro cash crop system is therefore dependent on an adequate marketing structure. Unfortunately, very few of the producing countries have such structures (Lai et al., 1998).

Classification and Genetics

Taro belongs to the genus *Colocasia*, within the sub-family Colocasioideae of the monocotyledonous family Araceae. Because of a long history of vegetative propagation, there is considerable confusion in the taxonomy of the genus *Colocasia*. Cultivated taro is classified as *Colocasia esculenta*, but the species is considered to be polymorphic. There are at least two botanical varieties (Purseglove, 1972):

i) *Colocasia esculenta* (L.) Schott var. *esculenta*;

ii) *Colocasia esculenta* (L.) Schott var. *antiquorum* (Schott) Hubbard & Rehder which is synonymous with C. *esculenta* var. *globulifera* Engl. & Krause.

C. esculenta var. *esculen a* is characterized by the possession of a large cylindrical central corm, and very few cormels. It is referred at agronomical as the dasheen type of taro. C. *esculenta* var. *antiquorum*, on the other hand, has a small globular central corm, with several relatively large cormels arising from the corm. This variety is referred to agronomical as the eddoe type of taro. Most of the taro grown in the Asia/Pacific region is of the dasheen type.

There are hundreds of agronomic cultivars of taro grown throughout the world. These are distinguished on the basis of corm, cormel, or shoot characteristics, or on the basis of agronomic or culinary behavior. Examples of taro cultivars in various places are given in subsequent chapters that deal with taro cultivation in various countries.

Taro Cultivation in Thailand

Food crop agriculture in Thailand is dominated by rice. Taro is a minor crop, and is eaten mainly as a dessert or snack. However, it is grown as a lucrative cash crop for export. The largest area and production occur in the northern part of the country. In the Taro production in Thailand has been successfully integrated into the rice production system. Taro is grown on the same land after harvesting rice. Planting occurs once the rice crop has been harvested. Alternatively, rice is followed by vegetables, after which the taro is then grown. The main taro crop is planted in February/March, while some upland taro is also planted in July/August. For planting, the land is tilled and harrowed, and soil amendments such as lime or burned rice husk may be added during tillage. The soil is made into raised beds. Each bed is 4-5 m wide, with 1 m space between beds. The furrows between the beds serve for irrigation and for drainage. Preferred varieties include Chiang Mai, Surin, Srisaket, Petchaboon, and Ubon. (Onwueme, 1999; Tatiyakul et al., 2006).

Physical, Chemical Properties and Composition of the Taro Corm

The main economic parts of the taro plant are the corms and cormels, as well as the leaves. The fresh weight composition of the taro corm is shown in Table 1. The fresh corm has about two-thirds water and 13-29% carbohydrate. The carbohydrate content in taro flour was not affected by corm size, but cultivating location. The proximate composition (dry basis) of taro starch were 96.9-98.2% carbohydrate, 0.7-1.9% protein, 0.1-0.3% fat, fiber 0.1-0.9% and 0.1-0.3 ash. The starch contained 182.0-200.1 mg/100 g calcium oxalate (Tattiyakul et al., 2006). The composition of the carbohydrate fraction is shown in Table 2, indicating that the predominant carbohydrate is starch. The starch itself is about four fifths amylopectin and one-fifth amylose. There indicated that taro has low amylose content and the susceptibility of their starch granules to hog pancreatin was very high (Tattiyakul et al., 2006). The amylopectin has 22 glucose units per molecule, while the amylose has 490 glucose units per molecule. They present an A-type crystallographic pattern which resulted in low swelling power and low solubility (Fig.1) (Maeda et al., 2004; Tattiyakul et al., 2006). The starch grains are irregular shape, polygonal, and small (Fig. 2) (Tattiyakul et al., 2006) therefore easily digestible, its digestibility has been estimated to be 98% (Longworthy & Deuel, 1922). This factor makes taro suitable as a specialty food for allergic infants and persons with alimentary disorders. However, the smallness of the starch grains makes taro less suitable as a source of industrial starch. The starch in the corm is more concentrated at the corm base than at the corm apex.

According to that starch thermal properties may reflect differences in starch granule size, the gelatinization onset temperature, range of gelatinization, and enthalpy increased with decreasing granule size (Knutson et al., 1982). Taro starch is gelatinized at high temperature (Tattiyakul et al., 2006; Maeda et al., 2004). The rheological and pasting properties of taro starches are influenced by the amylose content and the chain-length distribution of amylopectin, whereas swelling power and solubility only depend on the amylose content of starch. Taro starch with relatively high amylose content, high short-to-long-chain ratio, and long average chain length of long-chain fraction of amylopectin displayed high elasticity and strong gel during heating.

Proximate analyses of the taro flours indicated they were low in fat, protein and ash, but rich in starch and total dietary fibre (Tagodoe & Nip, 1994). Dried taro composed of 83.1-91.7% carbohydrates, 4.2-9.3% protein, 1.1-3.5% fiber, 2.0-5.1% ash and 0.3-0.9% fat, in dry basis. It also contained calcium oxalate in the range of 284.8 - 456.2 mg/100 g dry basis (Tattiyakul et al., 2006). Their protein content on a dry weight basis is more than yam, cassava or sweet potato. The protein fraction is low in histidine, lysine, isoleucine, tryptophan, and methionine, but otherwise rich in all the other essential amino acids. The protein content of the corm is higher towards the corm's periphery than towards its centre. This implies that care should be taken when peeling the corm; otherwise a disproportionate amount of the protein is lost in the peel.

Table 1 Proximate compositions of the taro corm on a fresh weight basis

Component	Content
Moisture	63-85%
Carbohydrate (mostly starch)	13-29%
Protein	1.4-3.0%
Fat	0.16-0.36%
Crude Fibre	0.60-1.18%
Ash	0.60-1.3%
Vitamin C	7-9 mg/100 g
Thiamine	0.18 mg/100 g
Riboflavin	0.04 mg/100 g
Niacin	0.9 mg/100 g

Source: Onwueme (1999)

Table 2 Percentage compositions of taro corm carbohydrate

Carbohydrate	**%**
Starch	78
Pentosans	2.6
Crude Fibre	1.4
Dextrin	0.5
Reducing sugars	0.5
Sucrose	0.1

Source: Onwueme (1999)

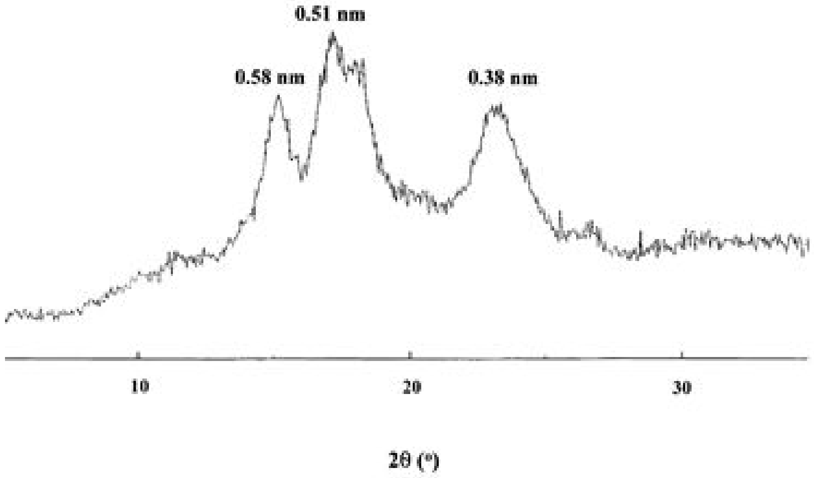


Fig. 1 X-ray diffraction of native *Java* starch

Source: Maeda et al., (2004)

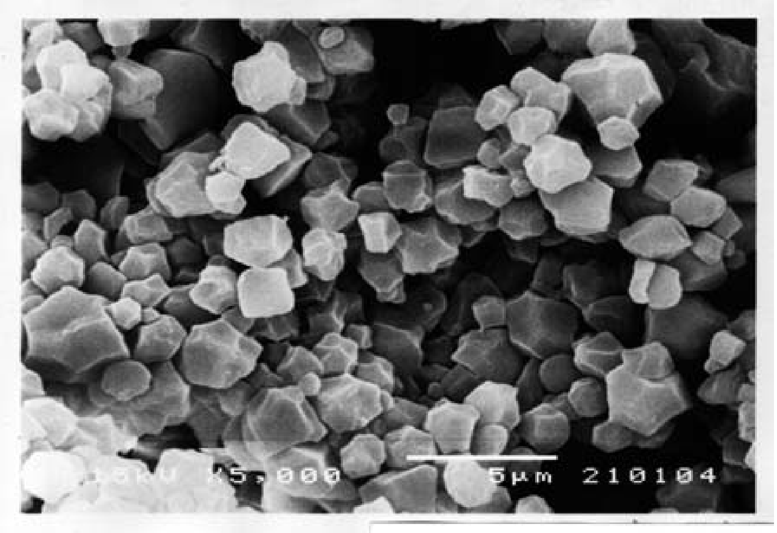


Fig. 2 Taro starch granule (5000x) observed from scanning electron microscope. Source: Tattiyakul et al, (2006)

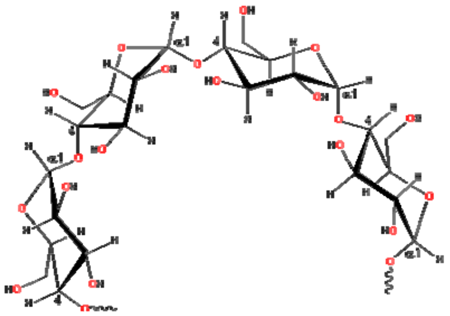
STARCH

Structural Unit

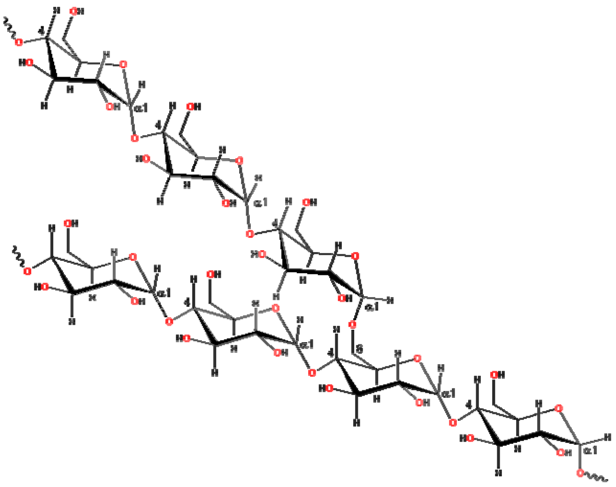
Starch consists of two types of molecules, amylose (normally 20-30%) and amylopectin (normally 70-80%). Both consist of polymers of α -D-glucose units in the $^{4}C_{1}$ conformation. In amylose these are linked -(1→4)-, with the ring oxygen atoms all on the same side, whereas in amylopectin about one residue in every twenty or so is also linked -(1→6)- forming branch-points. The relative proportions of amylose to amylopectin and -(1→6)- branch-points both depend on the source of the starch, for example, amylomaizes contain over 50% amylose whereas 'waxy' maize has almost none (~3%) (Singh et al., 2003).

Molecular structure

Amylose and amylopectin are inherently incompatible molecules; amylose having lower molecular weight with a relatively extended shape whereas amylopectin has huge but compact molecules. Most of their structure consists of α-(1→4)-D-glucose units. Although the α -(1→4) links are capable of relatively free rotation around the (φ) phi and (ψ) psi torsions, hydrogen bonding between the O3' and O2 oxygen atoms of sequential residues tends to encourage a helical conformation. These helical structures are relatively stiff and may present contiguous hydrophobic surfaces.



Amylopectin



Amylose

Fig. 3 Representative partial structure of amylose and amylopectin
Source: Singh et al. (2003)

Amylose

Amylose molecules consist of single mostly-unbranched chains with 500-20,000 α-(1→4)-D-glucose units dependent on source (a very few α-1→6 branches and linked phosphate groups may be found, but these have little influence on the molecule's behavior). Amylose can form an extended shape (hydrodynamic radius 7-22 nm) but generally tends to wind up into a rather stiff left-handed single helix or form even stiffer parallel left-handed double helical junction zones. Single helical amylose has hydrogen-bonding O2 and O6 atoms on outside surface of the helix with only the ring oxygen pointing inwards. Hydrogen bonding between aligned chains causes retrogradation and releases some of the bound water (syneresis). The aligned chains may then form double stranded crystallites that are resistant to amylases. These possess extensive inter- and intra-strand hydrogen bonding, resulting in a fairly hydrophobic structure of low solubility. The amylose content of starches is thus the major cause of resistant starch formation (RS_3).

Single helix amylose behaves similarly to the cyclodextrins by possessing a relatively hydrophobic inner surface that holds a spiral of water molecules, which are relatively easily lost to be replaced by hydrophobic lipid or aroma molecules. It is also responsible for the characteristic binding of amylose to chains of charged iodine molecules (for example, the polyiodides; chains of I_3^- and I_5^- forming structures such as I_9^{3-} and I_{15}^{3-}; note that neutral I_2 molecules may give polyiodides in aqueous solution and there is no interaction with I_2 molecules except under strictly anhydrous conditions) where each turn of the helix holds about two iodine atoms and a blue color is produced due to donor-acceptor interaction between water and the electron deficient polyiodides.

Amylopectin

Amylopectin is formed by non-random α-1⟶6 branching of the amylose-type α-(1⟶4)-D-glucose structure. This branching is determined by branching enzymes that leave each chain with up to 30 glucose residues. Each amylopectin molecule contains a million or so residues, about 5% of which form the branch points. There are usually slightly more 'outer' unbranched chains (called A-chains) than 'inner' branched chains (called B-chains). There is only one chain (called the C-chain) containing the single reducing group.

Each amylopectin molecule contains up to two million glucose residues in a compact structure with hydrodynamic radius 21-75 nm. The molecules are oriented radially in the starch granule and as the radius increases so does the number of branches required to fill up the space, with the consequent formation of concentric regions of alternating amorphous and crystalline structure. In the diagram below: A - shows the essential features of amylopectin. B - shows the organization of the amorphous and crystalline regions (or domains) of the structure generating the concentric layers that contribute to the “growth rings“ that are visible by light microscopy. C - shows the orientation of the amylopectin molecules in a cross section of an idealized entire granule. D - shows the likely double helix structure taken up by neighboring chains and giving rise to the extensive degree of crystallinity in granule. (Fig. 4) There is some debate over the form of the crystalline structure but it appears most likely that it consists of parallel left-handed helices with six residues per turn. An alternative arrangement of interconnecting clusters has been described for some amylopectins. Some amylopectin (for example, from potato) has phosphate groups attached to some hydroxyl groups, which increase its hydrophilicity and swelling power. Amylopectin double-helical chains can either form the more open hydrated Type B hexagonal crystallites or the denser Type A crystallites, with staggered monoclinic packing, dependent on the plant source of the granules. Type A, with unbroken chain lengths of about 23-29 glucose units is found in most cereals. Type B, with slightly longer unbroken chain lengths of about 30-44 glucose units is found in banana, some tubers such as potato and high amylose cereal starches. There is also a type C structure, which is a combination of types A and B and found in peas and beans. Starch granule architecture has been recently described.

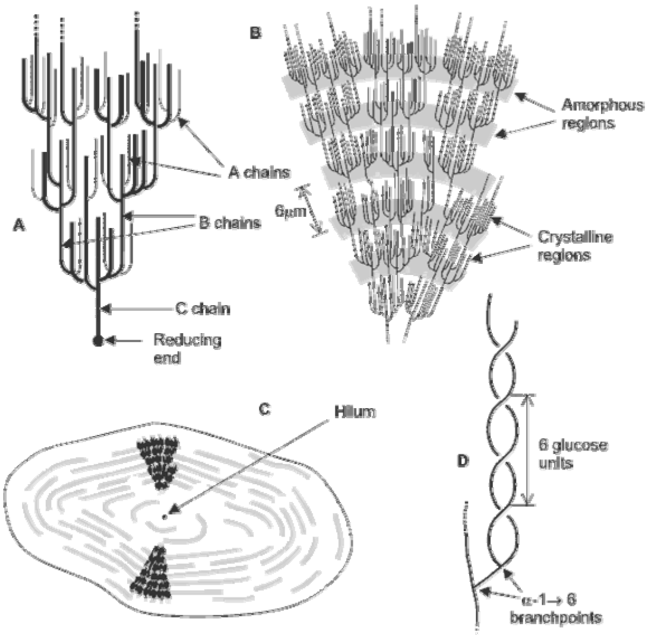


Fig. 4 Structure of Amylopectin

Source: Bertoft (2004)

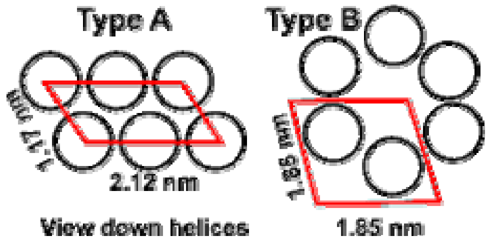


Fig. 5 Type A and B crystalline starch pattern

Source: Parker & Ring (2001)

EMULSIFIER

Surface Active Agent

Surfactants are molecules that consist of two parts, one that is polar (or hydrophilic) and another one that is non-polar (or hydrophobic). Due to their dual nature, these molecules are also commonly referred to as amphiphiles, a word derived from the Greek words *amphi*, which means "both", and *phile*, which means "friend". The hydrophilic part of the surfactant is usually referred to as the "head group" and the hydrophobic part as the "tail" (Figure 6). Surfactants are commonly classified on the basis of the charge of their polar head group.(Jönsson et al., 1998) In consequence, surfactants can be anionic, cationic, non-ionic or zwitterionic, the latter class corresponding to surfactants that contain both an anionic and a cationic charge under normal conditions.

Fig 6 Schematic illustration of a surfactant molecule

As a consequence of their dual polar/non-polar nature, surfactant molecules cannot satisfy their dual affinity neither in a polar solvent, nor in non-polar one. This makes surfactant molecules prone to adsorb at surfaces and interfaces formed by two immiscible phases, where both parts of the molecule can locate themselves in the phase they have more affinity for. By doing so, surfactants lower their free energy and the one of the interface. The interfacial free energy per unit area is commonly referred to as interfacial tension and it can be taken to represent the amount of work required to expand the interface. A second important consequence of the amphiphilic character of surfactants is their tendency to self-associate as their concentration increases in solution. In aqueous solution, the main driving force for this association is the hydrophobic effect. This effect is due to the fact that water molecules interact more strongly with each other than with hydrocarbons. Thus, the non-polar tails tend to associate creating structural aggregates termed micelles. The first formed micelles are often spherical and the concentration at which these start to form is referred to as the critical micelle concentration, cmc. The micellisation phenomenon occurs as a compromise between the effects that favour aggregation, i.e. the hydrophobic effect, and those that oppose to it, namely the electrostatic and/or the steric repulsion between surfactant head groups.

Emulsifier functionality is the direct result of their chemical structure, which consists of two parts. The first is a hydrocarbon chain that is lipophilic. The other part is a hydrophilic polar group. Many substances exhibit this combined hydrophilic/lipophilic nature. One of the most common is monoglyceride. Fats and oils are the raw material for monoglycerides. The glycerin backbone of a fat triglyceride is hydrophilic, but the three fatty acids attached to it make the entire molecule lipophilic. Once the triglyceride is chemically broken into monoglycerides, however, the functional balance tips. Here, the single fatty acid "tail" on the molecule remains lipophilic, but it is now more evenly matched by the hydrophilic properties of the glyceride "head." Many chemical variations of the basic emulsifier structure exist. Some are chemical modifications of monoglycerides -- such as ethoxylated monoglycerides, or organic acid esters of monoglycerides -- while others are totally different substances. One such group of emulsifiers is the stearoyl lactylates made by combining either calcium or sodium with stearic and lactic acids.

Properties of Emulsifiers

An emulsifier consists of water soluble hydrophilic parts and water-insoluble, oil-soluble lipophilic parts within its. When an emulsifier is added to a mixture of water and oil, the emulsifier is arranged on the interface, anchoring its hydrophilic part into water and its lipophilic part into oil. On the interface surface of water and air and of oil and air, the hydrophilic part and the lipophilic part are adsorbed and arranged around the interface. The interfacial tension is reduced by the emulsifier. That is, the force to separate the oil and water is thus weakened, resulting in the easily mixing of oil and water. (Fig 7)

HLB

The hydrophilicity and lipophilicity are different among emulsifiers, and the balance between the two is called HLB value. (Table 3) The value ranges from 0 to 20. An emulsifier with higher lipophilicity shows a lower HLB whereas higher hydrophilicity has high HLB, and the behaviors and functions to water depend on this HLB. All compounds that have hydrophilic parts and lipophilic parts are not always useable as an emulsifier. When hydrophilicity is too great, such compounds disperse into water and the ones with great lipophilicity would disperse into oil. When the hydrophilicity and lipophilicity are well-balanced, the emulsifier exhibits sufficient effects. (Fig 8)

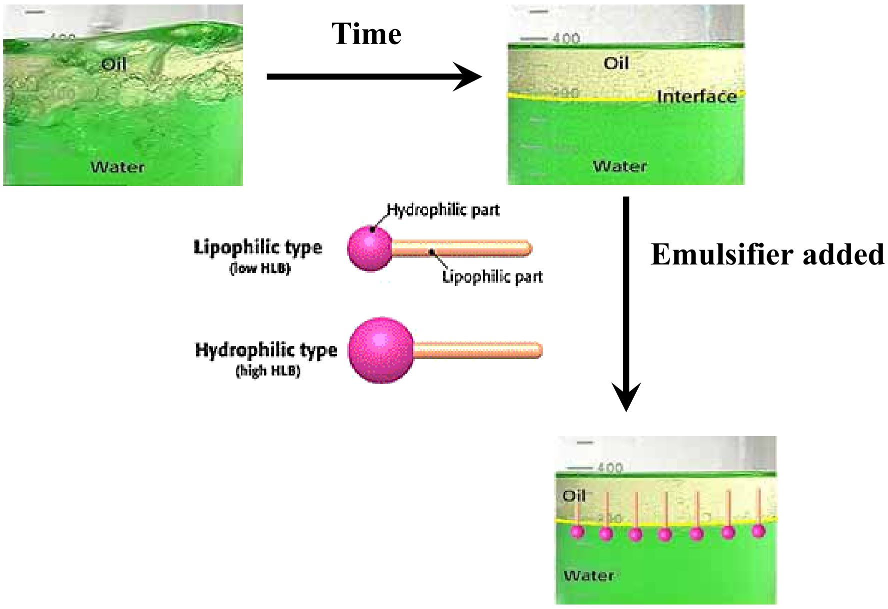


Fig 7 Properties of Emulsifiers

Source: Terry (1984)

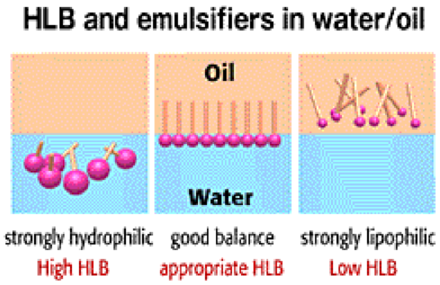


Fig 8 HLB and emulsifier in water/oil

Source: Terry (1984)

Ionic charge

When dispersed in an aqueous medium, certain emulsifiers will exhibit a negative (anionic) charge. These ionic emulsifiers -- including the stearoyl lactylates and diacetyl tartaric acid esters of monoglycerides -- have a carboxylic acid group on the molecule's ester ("head").

INFLUENCE OF EMULSIFIER ON STARCH

Complex function on the starch

Starch particles consist of spherical shaped amylopectin and amylose. Raw starch called beta-starch is insoluble in water. But when heated to a certain temperature, the starch absorbs water and change into the crystalline form of alpha-starch. Amylose gets hard easily with cooling and amylopectin becomes hard gradually with time. The immediate hardening of starch product such as bread by cooling is mainly due to the change of amylose. Amylose changes to a helix structure, a kind of spiral structure by heating. If emulsifiers are introduced, they can be anchored into the helix structure. (Fig 9) Since the anchoring does not change even after cooling, softness is maintained because this physically inhibits the amylose molecule from retrograding. This function is also utilized for instant mashed potatoes, noodles, rice or other starch product.

The effects of lipid surfactants (emulsifiers) on changes in the mechanical properties of concentrated starch systems during heating, cooling and storage were studied. Emulsifier-emulsifier or emulsifier-starch interactions promote the development of a weak network structure. (Nuessli et al., 1999) The fracture stresses and strains of potato and wheat starch gels were lower when glycerol monostearate (GMS) or sodium stearyl-2-lactylate (SSL) were added, while the increase in stiffness of the gels during storage was slightly retarded. (Keetels et al., 1996)

Due to their central role in many food-related applications, most of the research on starch-surfactant interactions has involved the use of food-grade emulsifiers such a long chain (C14-C18) monoglycerides and esters of sucrose. Better-characterised, more water-soluble surfactants such as a sodium dodecyl sulphate (SDS) or alkyl trimethyl ammonium bromides, have also been commonly used in model systems. In the starch literature the first group of surfactants is commonly referred to as “emulsifiers”, whereas the latter ones are sometimes referred to as “detergents”. Moreover, the term “polar lipid” is commonly used to refer to nature´s own surfactants and is thus applied to phospholipids and fatty acids that occur naturally in starch granules. No such distinctions will be made in this study, and the term “surfactant” will be used to refer to molecules with an amphiphilic character regardless of their actual nature or the application they are mostly used for.

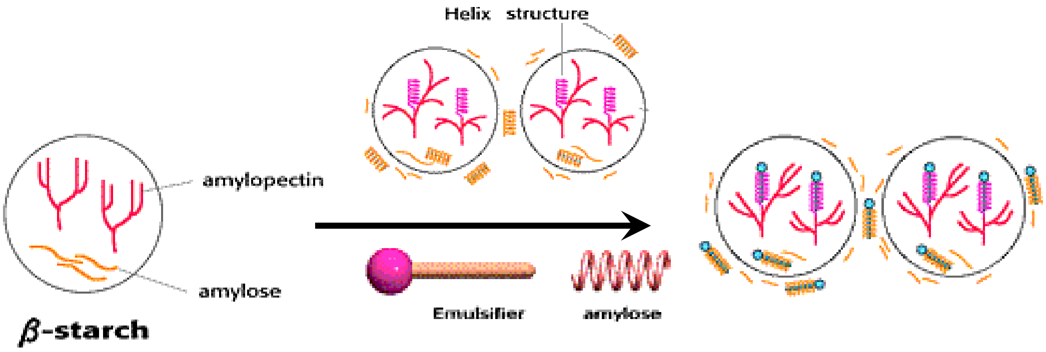


Fig 9 Action of emulsifier on starch

Source: Terry (1984)

The amylose-surfactant complex

The association between AM and surfactants is thought to involve complexed molecules located within single-helical conformations of the AM. There is strong evidence for this picture from X-ray diffraction studies of crystalline complexes in the solid state (Godet et al., 1995) and some complementary support from structural studies in aqueous solution.(Bulpin, Welsh, & Morris, 1982; Bulpin et al., 1987) A molecular modeling representation of the AM-lipid complex is presented in Figure 10 The ability of surfactants to form complexes with amylose is thought to reside in their capacity to satisfy the solvation requirements of the AM helical cavity (ca. 0.5 nm in diameter) which has a hydrophobic character. The helical cavity in AM has characteristics similar to those of cyclodexrins but it has higher flexibility in size and length of the guest binding sites.

The complexed state represents an energetically favourable situation both for the AM and the surfactant molecule, which is reflected by the fact that the formed complexes are difficult to dissociate. The complexes formed between AM and a number of amphiphilic molecules crystallise to give rise to a characteristic V-type X-ray diffraction pattern which arises from the crystallization of AM in the form of single left-handed helices with a hydrophobic inner core and a hydrophilic outer surface.(Zobel, 1988) From studies of crystalline complexes of AM and a variety of organic molecules, it is known that each turn of the AM helix may consist of 6, 7 or 8 glucosyl residues (Takeo et al., 1973) and that the number of residues depends on the size and shape of the guest molecules. Molecular modelling studies have indicated that in complexes of AM with amphiphilic molecules such as monoglycerides and fatty acids, there are on average two or three turns for each ligand molecule and that the polar head group is most likely not included within the helix due to both steric and/or electrostatic repulsions (Godet et al., 1993).

The thermal properties of the complexes of AM with a variety of amphiphilic molecules in the solid state have been extensively characterized by means of calorimetry (Eliasson & Krog, 1985; Tufvesson et al., 2003). From these studies it is known that the thermal stability and the melting enthalpies of crystalline complexes are dependent on the chemical nature of the complexing ligand (chain length, unsaturation, nature of the polar head group), the degree of polymerisation of the amylose and the conditions (temperature, time and solvent) employed during complexation.

Table 3 HLB and Characteristic behavior related to water

Characteristic behaviors related to water	**HLB**	**Ratio**		**functions**	
		hydrophilic part	**Lipophilic part**		
not dispersing	0	0	100		
				anti-foaming agent	
slightly dispersing	2	10	90		
	4	20	80		W/O emulsification
	6	30	70		
				wetting agent	
milky dispersion	8	40	60		O/W emulsification
stable milky dispersion	10	50	50		
transparent dispersion	12	60	40		
				cleaning agent	
colloidal solution	14	70	30		
	16	80	20	solubilizing agent	
	18	90	10		
	20	100	0		

Source: Terry (1984)

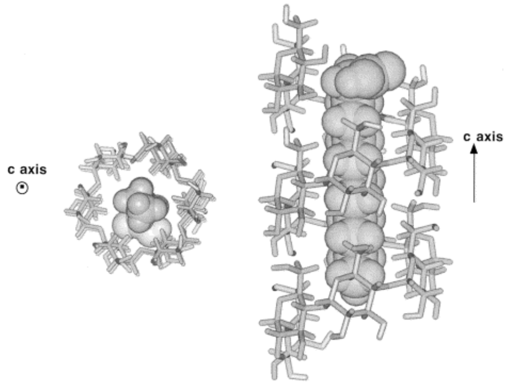


Fig 10. Molecular modelling representation of the amylose-fatty acid complexes showing the inclusion of the hydrophobic part (C12) of the fatty acid inside the hydrophobic cavity of the amylose single helix.
Source: Buléon et al. (1998)

The amylopectin-surfactant complex

It was for long believed that surfactants interacted mainly with AM. However, it is now known that surfactants can also complex with amylopectin (AMP). This view is supported by strong evidence from binding studies of surfactants to AMP in solution as well as some indirect evidence from diverse calorimetric studies of waxy starch varieties in the presence of surfactants (Evan, 1986; Eliasson et al., 1988). Although the nature of this complex has not been completely resolved, the evidence indicates that the binding involves the formation of inclusion complexes with the AMP outer chains (Lundqvist et al., 2002). Amylopectin has been reported to be able to bind similar amounts of surfactant as AM. However, in contrast to AM, the binding of surfactants to AM lacks cooperativity (Lundqvist et al., 2002a) and it is extremely sensitive to small changes in the AMP molecular structure (Lundqvist et al., 2002b).

INTERACTIONS BETWEEN SURFACTANTS AND STARCH DURING GELATINIZATION

Early stages of starch gelatinization and related thermal events

From calorimetric studies it is known that surfactants affect the earlier aspects of the starch gelatinization process. Numerous calorimetric studies of starches gelatinized (in excess water) in the presence of surfactants have shown that surfactants have the ability to alter the onset of the gelatinization transition (T_O GEL) as well as the enthalpy of the process (ΔH GEL) (Biliaderis & Tonogaik, 1991; Ghiasi, Varriano-Marston, & Hoseney, 1982; Eliasson, 1986). The effect of added surfactants on the onset of the gelatinization transition usually involves changes in the order of 1-4°C, the actual magnitude of the effect depending on the type of starch, test conditions (heating rate) and type and concentration of surfactant. In this respect, most surfactants have been found to increase the T_O GEL (i.e. to delay the onset of gelatinization) of wheat and other cereal starches whereas the opposite effect has been found to be produced by sodium dodecyl sulphate (SDS). (Biliaderis & Tonogaik, 1991; Eliasson, 1986) As for the effect of surfactants on ΔHGEL,, gelatinization studies of wheat and other normal cereal starches in the presence of different surfactants have invariably found lower gelatinization enthalpies than in the absence of these (Biliaderis & Tonogaik, 1991; Eliasson, 1986). A similar effect has also been reported for normal tuber, legume and even waxy cereal starches (Biliaderis &Tonogai, 1991).

In the DSC-trace of starches gelatinized in the presence of surfactants, a second endothermic transition is observed beyond the temperature range within which the gelatinization transition occurs. This endotherm, which occurs near 100°C and is also observed in the DSC trace of lipid-containing starches, is ascribed to the order-disorder transition of AM-surfactant (lipid) complexes that are formed simultaneously as the granule gelatinizes (Figure 11). This endothermic event, which is usually attributed to the disordering of the complexes (V-helix → coil transition) rather than to the melting of the crystallites (Raphaelides & Karkalas, 1988) is thought to involve the actual dissociation of the complex into free ligand and AM (Karkalas et al., 1995). No such endothermic transition is observed in the DSC-trace of waxy (i.e. AM-free) starches gelatinized in the presence of surfactants. This has been attributed to the absence of cooperativity of the AMPsurfactant association (and dissociation) process (Evans, 1986).

In most cases, the enthalpy of dissociation of the AM-surfactant complex (ΔHcx) has been found to be comparable in magnitude to the reductions that added surfactants induce on the ΔHGEL of starches (Evans, 1986; Biliaderis & Tonogai, 1991; Eliasson, 1986). The decreasing effect of surfactants on ΔHGEL has therefore been suggested to be the result of an exothermic effect associated with the formation of starch-surfactant complexes occurring simultaneously as the starch granule gelatinizes.

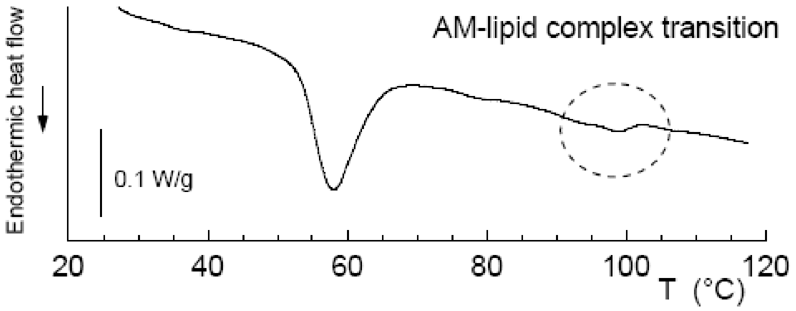


Fig 11 DSC thermogram obtained during the gelatinization of wheat starch showing the endothermic transition attributed to the dissociation of the AM-lipid complex (starch to water ratio of 1:3, scanning rate of 6°C/min).
Source: Raphaelides, & Karkalas (1988)

The dissociation transition of the AM-surfactant complexes is reversible and can be observed, albeit with considerable hysteresis, both during heating and cooling. When this transition corresponds to complexes formed with lipids already present in starch granules the associated enthalpy remains, within experimental error, the same in all heating and cooling runs. On the contrary, when the peak is caused by added surfactants the enthalpy during first heating is only about 50 to 60% of the value observed on subsequent cooling and reheating. It has been suggested that this may be due to the fact that, immediately after gelatinization, only a portion of the amylose is in a suitable state for complexing and that full complexing does not occur until the amylose has been leached from the granule.(Kugimiya, & Donovan, 1981) An alternative view is that, on the first heating, a rather imperfect complex is formed perhaps as a result of steric constraints on the amylose molecules which may initially be non-covalently bonded to amylopectin chains.(Evans, 1986)

Later stages of starch gelatinization: granule swelling and AM-leaching

Surfactants are well-known to have the ability to alter the granule-swelling and AM-leaching processes that take place during the later stages of the starch

gelatinization process. The effect produced by surfactants on these processes causes significant changes in the rheological behavior of starch pastes. In this respect, the extent of the effect produced by surfactants on the swelling/AM-leaching properties of starches is known to be strongly dependent on the test conditions (heating and shearing), the type of starch and the type and concentration of surfactant.
The importance of the surfactant structure for the effect on the swelling properties of starches is indicated by the fact that, even for the same type of starch and under the same test conditions, some surfactants have the ability to restrict the swelling whereas others have the ability to enhance it. For instance, in the case of wheat and other cereal starches, surfactants such as long chain (C14-C18) saturated monoglycerides,(Krong, 1973; Nierle, & El Baya,1990; Roach, & Hoseney, 1995;) esters of sucrose (Deffenbaugh, & Walker,1989) and lactic acid derivatives (sodium and calcium stearoyl lactylate) (Krong,1973; Eliasson,1985) have been reported to restrict the swelling whereas others such as sodium dodecyl sulphate (SDS)(Eliasson,1985; Svensson et al., 1998) and glycerol monocaprate (Roach, & Hoseney, 1995) have been found to have the opposite effect.

The restricted swelling of starch in the presence of surfactants has been proposed to be due to the presence of an insoluble surface layer of AM-surfactant complexes that would form and precipitate readily on the granule surface as AM leaches out during gelatinization.(Eliasson, 1985) It has also been suggested that surfactants may penetrate the granules and complex with AM thereby increasing the internal bonding and leading to a restricted swelling.(Evans, 1986) The swelling-enhancing effect produced by a surfactant such as SDS has been proposed to be related to the increased solubility of the AM-surfactant complex, which would result from the high hydrophilicity of the charged surfactant head group and would favour water uptake by the granule.(Eliasson, 1985) Although plausible, this theory cannot account for the swelling-enhancing effect produced by some nonionic surfactants such as glycerol monocaprate (Roach, & Hoseney, 1995) or the restricted swelling observed in the presence of some anionic, food-grade surfactants such as sodium stearoyl lactylate (Krong,1973; Eliasson,1985), which is an indication that further work is required in order to elucidate the molecular mechanism involved.

ARABIC GUM

Gum Arabic exists in nature as a neutral or slightly acidic salt of complex polysaccharide containing calcium, magnesium and potassium cations. The differences of chemical composition and physical properties of the various Acacia species gums are quite diverse. The essential analytical parameter which allows good identification differentiation are ash content, nitrogen content, methoxyl content, specific rotation, intrinsic viscosity, molecular weight, equivalent weight (uronic acid content), and the balance of the different simple structural sugar.

Basically, gum arabic is composed of six carbohydrate moieties – galactose, arabinopyranose, rhamnose, glucuronic acid, and 4-0-methylglucuronic acid. The presence of any other carbohydrate material indicates that the gum is not pure gum Arabic or that is blended with another material. It is believed that there is a small amount of protein present in the molecule since the protein cannot be removed without degrading the gum.

As shown in fig. 12, the main structural feature of gum arabic is a main chain of β-galactopyranose units through positions 1→ 3, with side chains of 1,6-linked galactopyranose units terminating inglucuronic acid or 4-0-methylglucuronic acid residues. Additional groups are also attached to the C_3 positions on the galactose sidechains.

The gum from Acacia Senegal can best be described as a polymer system having either a variation of monomer (i.e., glactose, arabinose, rhamnose, glucuronic acid, and 4-0-methylglucuronic acid) composition and/or a variatjion in the mode of linking and branching of the monomer units, in addition to a distribution in molecular weight.

Molecular weights for gum Arabic can range from $5x10^4$ to $3.5x10^6$ or $2.6x10^5$ to $1.2x10^6$ depending on the source. Typical molecular weights of $5x10^5$ to $6x10^5$ are observed.

Gum Arabic molecules are suggested to be in the shape of short, stiff spirals, with numerous side chanins, accounting for its low viscosity. The length of the cone varies between 1050 and 2400A depending upon the amount of charge on the molecule.

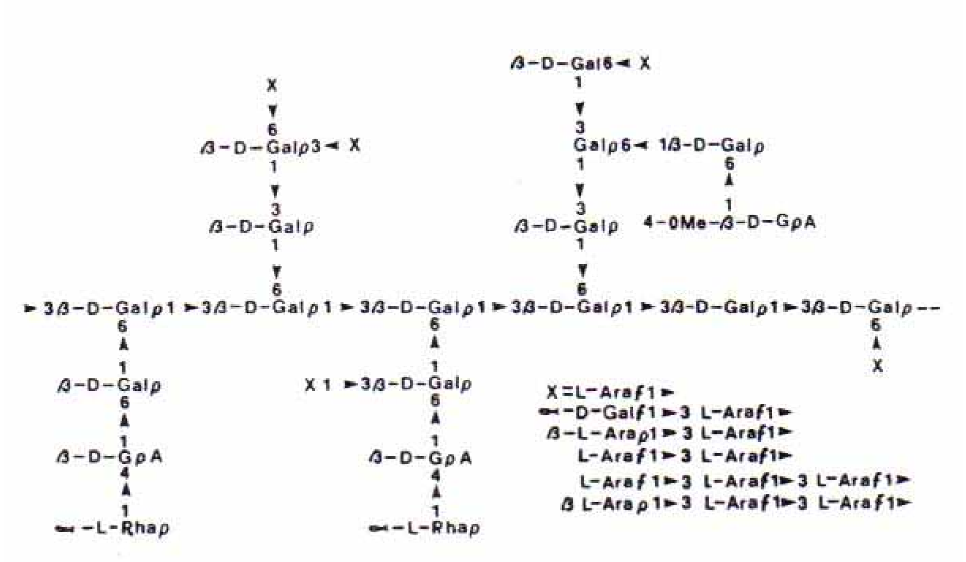


Fig. 12 Schematic representation of the main structural features of the gum arabic molecule. Source: Nussinovitch (1997)

FOOD TEXTURE; DEFINITIONS OF MECHANICAL PROPERTIES

Strain is a pure number, since it compares shape before and after deformation. It is expressed either as the ratio of the dimensional change divided by the starting dimension.

Stress is the outward expression of the restoring force developed by starching the interatomic bonds that hold the material together. It is defined as the force exerted (*F*) divided by the cross-sectional area over which the force is acting (*A*):

$$\sigma = F / A$$

Normal practice is to divide by the original area (A_o) of the sample, but for large deformations, the instantaneous are (A) at any point should be use. Units of stress are newtons per square meter or ($N*m^{-2}$) or pascals (Pa) Various stress states are defined depending on how the force is applied (Fig. 14)

Stiffness is the resistance of an elastic body to deflection or deformation by an applied force. Or how difficult it is to deform the material and is expressed as the ratio between stress and strain (it therefore has the units of stress), or the slope of the linear portion of the stress-strain plot.

Strength is the stress at which the material breaks and must not be confused with stiffness. Like stiffness, strength is affected by time, temperature and other factors, and in the same direction

Toughness

Strength and toughness are often confused, and it is important to differentiate between them. Strength is defined as the maximum stress and object will withstand before it breaks, whereas toughness is the resistance to cracking. In terms of a force-extension relationship (Fig.13), Strength is simply the maximum force divided by the cross-sectional area. Toughness is defined as the energy required to propagate a fracture by given crack area, generally derived from the area under a force-extension curve.

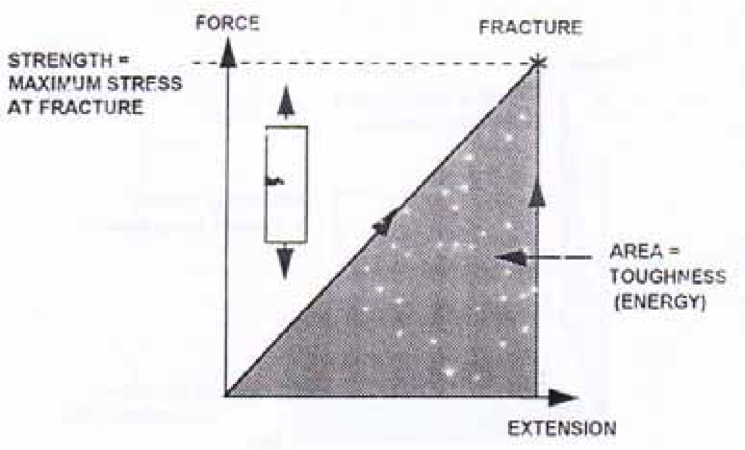
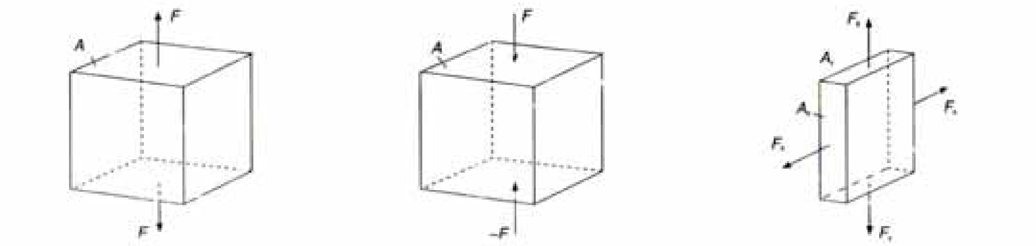
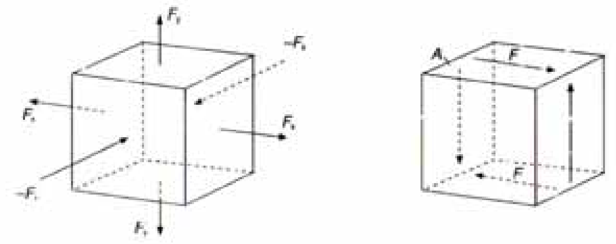


Fig. 13 Nominal Force-Extension Plot Showing Definitions of Strength and Toughness

Source: Rosenthal (2000)



(a) simple uniaxial tension, $\sigma = \frac{F}{A}$ (b) simple compression, $\sigma = \frac{-F}{A}$ (c) biaxial tension: $\sigma_x = \frac{F_x}{A_x}$, $\sigma = \frac{F_z}{A_z}$



(d) triaxial stress, $\sigma_i = \frac{F_i}{A_i}$

hydroctatic pressure: $\sigma_x = \sigma_y = \sigma_z$, $p = \frac{-F_i}{A_i}$

(e) pure shear, $\tau = \frac{F}{A}$

Fig. 14 Common state of stress

Source: Rosenthal (2000)

THE PRINCIPLE OF MICROWAVE HEATING

The electromagnetic spectrum and the electromagnetic wave

Microwaves are part of the electromagnetic spectrum (Fig. 15) and are located between 300 MHz and 300 GHz. Microwave heating is defined as the heating of a substance by electromagnetic energy operating in that frequency range. The high frequency range, which also can be used for heating, is very large and it can be subdivided into kHz high frequency (10 kHz < f £ 1 MHz) and MHz high frequency (1 MHz < f £ 300 MHz). The latter range is used here when speaking about high frequency heating. The term radio frequency is used for high frequency mainly in the United Kingdom (Risman, 1991a). The infrared region is located between microwaves and visible light. Only restricted microwave or high frequencies are freely allowed for heating in industrial, scientific, and medical applications, the so-called ISM frequencies (Buffler, 1993). Of these, only 2450 MHz is commonly used in food processing in Europe, while 915 MHz dominates in America and 896 MHz in the UK. Higher frequencies are not in active use, but Decareau (1985) has suggested that by combining higher frequencies with lower frequencies it would be possible to get surface browning.

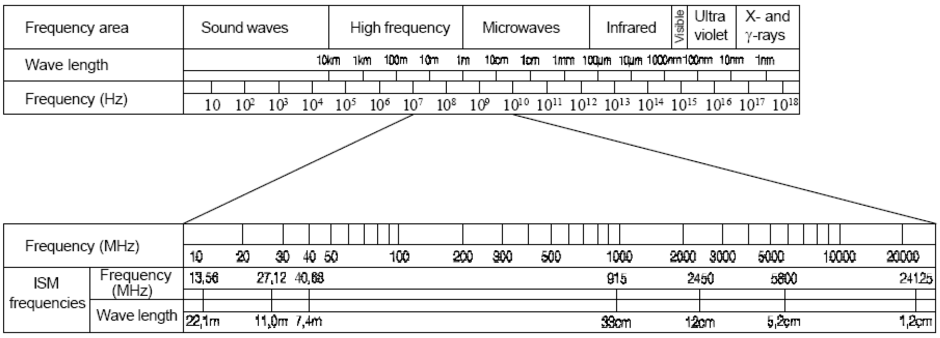


Fig. 15 The electromagnetic spectrum and the ISM frequencies

Source: Peräniitty (1988).

A propagating electromagnetic wave has two components, an electric field (E; unit V/m) and a magnetic field (H; unit A/m). They are vectors and always perpendicular to each other (Fig. 16). In free space the propagating wave has a velocity (c0) of about 3.0 x 108 m/s, and this is the maximum speed at which energy can travel. Frequency (f) and wavelength (l) are linked with the equation:

c = lf

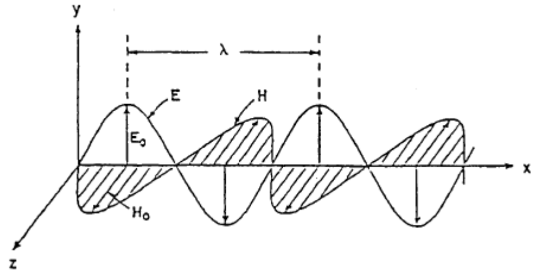


Fig. 16 A propagating electromagnetic wave.

Source: Peräniitty (1988).

The electromagnetic properties of food material

Polarization of dielectrics

When two opposite charges are separated by a distance, they constitute an electric dipole.Molecules with non-zero permanent electric dipole moments are called polar molecules. Nonpolar molecules may obtain a dipole moment in an electric field as a result of the distortion of their electronic distributions and nuclear positions. The relative permittivity e is a measure of the polarising effect from an external field, that is, how easily the medium is polarised. Polarization (P) can be described by an equation:

$$P = \varepsilon_0 E(\varepsilon - 1)$$

Alberty (1987) lists three types of polarization: electronic, atomic, and orientation polarization. An important mechanism at microwave frequencies is also ion conductivity (ionic loss or polarization), where hydrated ions try to move in the direction of the electrical field and transfer energy by this movement. This is strongly temperature dependent (Ohlsson, 1989). Electronic polarization comes from the field-induced displacement of the electrons with respect to the nucleus. This polarization occurs in all substances. In atomic polarization, the atoms can be moved in crystals or molecules. Electronic polarization, together with atomic polarization, gives most dry solids a permittivity of the order of $e' < 10$. When only these two mechanisms are present, the material is almost lossless at microwave frequencies. Atomic polarization, which is also called vibration polarization, is closely related to electronic polarization but, because of the much greater mass to be moved, the resonant frequencies of atomic polarization are lower. Atomic polarization is found in the infrared band while electronic polarization is found in the optical band. They both are practically independent of the temperature (Alberty, 1987; Nyfors & Vainikainen, 1989). Many molecules have a permanent dipole moment, and orientation (dipolar) polarization is due to the partial alignment of these dipoles. Water is a dipole and is usually a major component in biological materials. In a microwave or high frequency field, the dipoles try to follow the rapidly changing field. The dipoles are not completely oriented due to the disorienting effect of thermal motion. This phenomenon is strongly temperature dependent; with rising temperature the thermal agitation becomes more vigorous and fewer dipoles are oriented. The orientation polarization occurs at microwave frequencies due to inertial forces (Alberty, 1987). Of all the possible forms of loss mechanisms, orientation polarization is perhaps the most significant in microwave heating applications at frequencies above 1 GHz. However, this type of polarization does influence the lower frequency bands as well. Ionic loss typically predominates at frequencies below 1 GHz (Nyfors & Vainikainen, 1989). The origin of different types of losses can be seen in Figure 17. With rising temperature, all the phenomena are found at higher frequencies.

Dielectric properties

The dielectric properties describe how materials interact with electromagnetic radiation. Natural biological materials absorb only the electric part of the electromagnetic field. Food materials are practically non-magnetic, as they contain only trace amounts of magnetic material, such as iron and cobalt (Metaxas & Meredith, 1983; Mudgett, 1995).

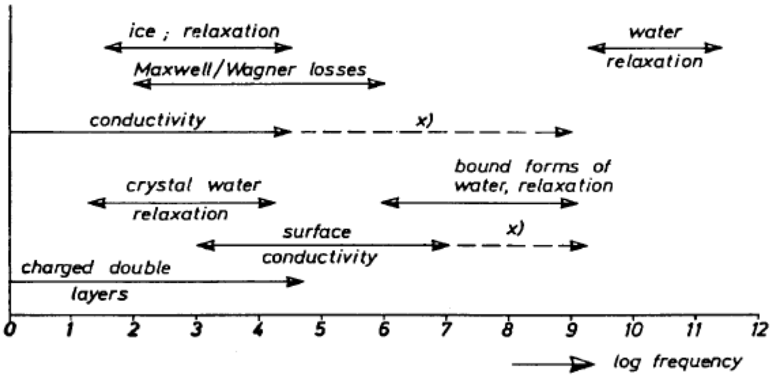


Fig. 17 Origin of different types of losses in heterogeneous mixtures containing water; x is extension for water containing ions
Source: De Loor (1968).

Food materials; the influence of composition, temperature, and frequency

The dielectric properties of food products are primarily determined by their chemical composition and, to a much lesser extent, by their physical structure. The influence of water and salt (or ash) content depends to a large extent on the manner in which they are bound or restricted in their movement by the other food components. This complicates the prediction of the dielectric properties of a mixture, based on data for single ingredients (Mudgett, 1995). There have been some attempts to predict dielectric properties of foods (Calay et al., 1995). They found that although significant data exist in the literature, there was much variability due to different measuring techniques, variations in composition, etc. Calay et al. (1995) could establish predictive equations for selected food types and the agreement was usually within ±15% accuracy but sometimes the discrepancy was over 30%. They could not find any suitable general equation for all foods as the discrepancies could exceed ±40%. The prediction of dielectric data of food mixtures from individual components is very difficult.

There is a positive correlation between e' and water content, and permittivity can be used to quickly determine the moisture content. The correlation for e" is uncertain. A low or moderate salt content does not modify the e' values much. Many frozen products may be viewed as homogeneous mixtures of solids (mostly ice) and aqueous ions. For all substances with a high water content, a sharp increase in e' and e" is observed in the melting zone and, after melting, ε' decreases with further temperature increase. For pure water, ε“decreases rapidly with increasing temperature. At higher microwave frequencies (2800 MHz) only salty foods show an increase in e" with temperature but at lower microwave frequencies there is a general increase in e". The effect of fat on dielectric properties appears to be that of dilution (more fat, less water). At lower frequencies (450 and 900 MHz), the relationships appear to be similar (Bengtsson & Risman, 1971; Ohlsson et al., 1974a).

For pure water, ε' increases slightly with decreasing frequency. At lower microwave frequencies, e' shows a sharper decrease with increasing temperature for salty foods than at higher frequencies. For moist foods, ε" increases with falling frequency as the magnitude of conductivity losses at lower frequencies is greater. Losses due to the dipolar relaxation are more important when moving towards higher frequencies. The net conductivity is usually independent of frequency. The frequency at which the other losses begin to dominate conductivity loss depends on many factors (Bengtsson & Risman, 1971; Nyfors & Vainikainen, 1989).

Heating characteristics vary also with particle size, homogeneity, and distribution. For example, laminated or fibrous structures have higher ε' than do granular ones. The effects of pH are not believed to be significant per se, at the pH levels typical in foods (Ohlsson et al., 1974a; Nyfors & Vainikainen, 1989). The large differences in both dielectric and thermal properties between frozen and thawed foods can cause difficulties in thawing. The effect known as runaway heating, which means that the warm part is rapidly heating while there is still some ice left in the rest of the food, is more complicated than is generally believed. The thawed part of a food has a higher lεl and, thus, lower characteristic impedance than the frozen part. This modifies the current paths during thawing, so that higher currents occur in high lεl parts, resulting in "shorting-out" of the frozen parts with a low lεl (Risman, 1994).

Dielectric properties of foods

The dielectric properties of some foods can be found in the literature (Datta et al., 1995) and in databases. The most common food products have a loss factor of less than 25 and permittivity between 30 and 80, which implies a penetration depth of 0.8 to 1.5 cm. However, literature data is mostly limited to food ingredients and their components. For complex foods, like lasagne, the dielectric properties must be measured or estimated (Ohlsson, 1989; Buffler & Stanford, 1991; Calay et al., 1995). The dielectric properties of some foods as a function of temperature,at 2.8 GHz, are presented in Figure 16 (Bengtsson & Risman, 1971) and Figure 17 presents a “food map” at 2450 MHz and 20-25ºC (Buffler & Stanford, 1991).

The dielectric properties for bread and flour have been measured mostly at high frequencies. Although e' varies with water content, as can be expected, temperature has only a minor effect. Both e' and e" are low also for flours at microwave frequencies as long as water content is low (Kent, 1987). For fats and oils, both e' and e" are very low (Bengtsson & Risman, 1971).

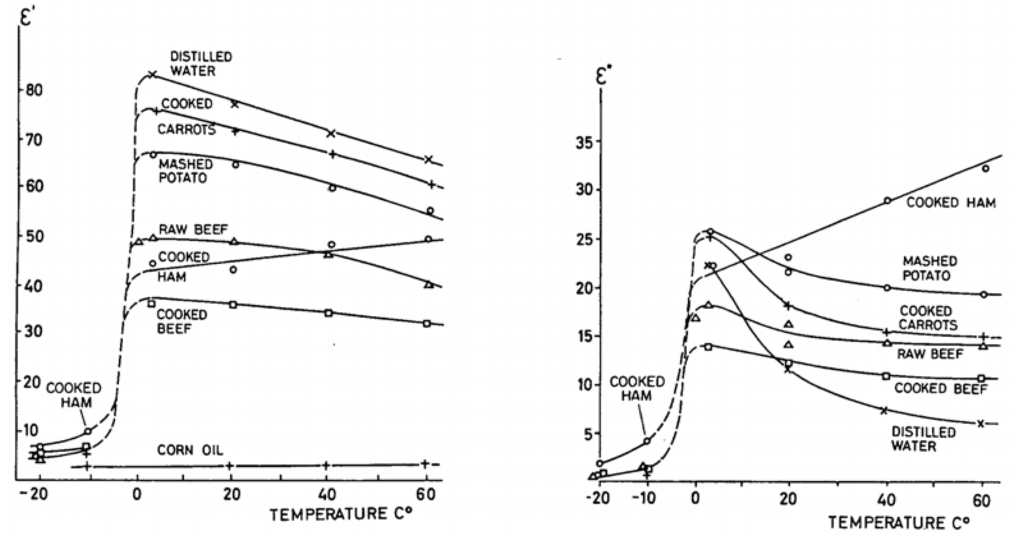


Fig. 18 Temperature dependence of e' (a) and e” (b) for various food substances at 2.8 GHz

Source: Bengtsson & Risman, (1971)

Ohlsson et al. (1974b) studied meat emulsions at 900 and 2800 MHz. They could not find a simple correlation with dielectric data for fat and protein content but they found that for three component systems (water, fat, protein), composition of dielectric data could be determined from triangular diagrams. The triangular diagrams can also be utilized to follow the gradual change in dielectric data and composition in processes where water is removed. To et al. (1974) have measured the dielectric properties for beef and turkey products at 300, 915 and 2450 MHz and they concluded that although moisture content is important, both ash and protein content can also affect dielectric properties. For beef products, both e' and e" increase with decreasing frequency at constant temperature; however e' decreases and e" increases with increasing temperature at constant frequency.

Vegetables have quite high permittivity in accordance with their high water content (Bengtsson & Risman, 1971). For dried vegetables, e' and e" are low as the water content is low. Roebuck et al. (1972) have studied the dielectric properties of potato starch, sucrose, glucose, ethanol and glycerol, at 1 and 3 GHz and 25ºC. They found that, especially in an intermediate water concentration, gelatinized potato starch has higher e' and e" values than starch in granular form. Carbohydrates do not show appreciable dipole polarization at microwave frequencies. Miller et al. (1991) studied the dielectric properties of selected unmodified and chemically modified starches. The type of chemical modification seems to have a strong influence on the dielectric behavior.

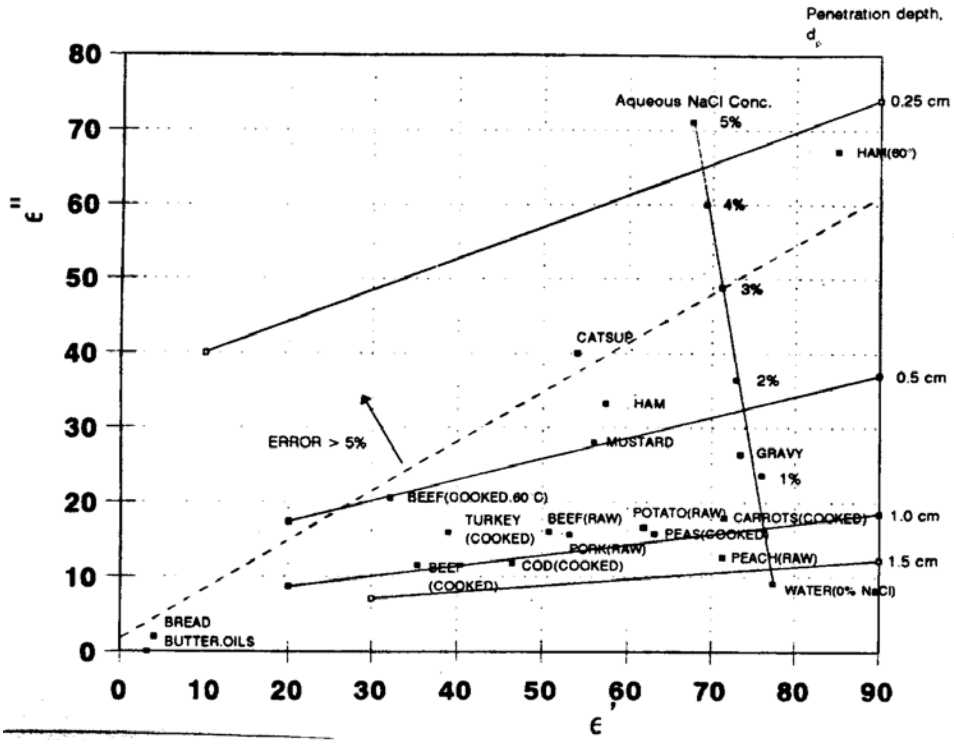


Fig. 19 Dielectric properties food map at 20-25ºC, 2450 MHz

Source: Buffler and Stanford, (1991)

Other factors affecting microwave heating

Besides the electromagnetic properties many other factors affect how foods are heated by microwaves. Among these properties are the thermal properties of foods, the initial temperature of food, size and shape of the product, and size, shape, and position of components within the food, the packaging, and the microwave oven (James, 1993). According to Buffler & Stanford (1991) two major effects influence the heating patterns in microwave heated foods: in some cases the pattern is dominated by the hot and cold spot phenomenon, and under certain circumstances there is a combination of geometry and oven dependence.

The initial temperature of the food influences the heating time. If the food is frozen the needed heating time is much longer than if the food is refrigerated or at ambient temperature. However, the difference in the heating time between refrigerated and ambient temperature food is not obvious. The heating rate of the components in a multicomponent product can be modified by component layout (arrangement). Components can shield each other; foods in close contact need more time to heat than those placed separately. In some experiments component layout could, in the worst cases, result in temperature differences up to 70ºC while in another layout the difference was only 15ºC (Thorsell, 1994). Temperature may affect even the structure of food, e.g. when starch is gelatinized, and this in turn affects the free water content (George & Burnett, 1991).

In contrast to conventional heating methods, in microwave heating the oven and surrounding air are cooler than the products when its cooks. As moisture is vaporated into a cool environment the surface of the food remains below the boiling temperature of water. The surface temperature depends on the rate of evaporative cooling. Microwave heating of itself does not cause any differences in cooling rates compared to conventionally heated foods (Buffler, 1991).

Thermal and mechanical properties

After microwave energy has penetrated the product, two thermal properties (thermal conductivity, k, and specific heat capacity, cp,) and two mechanical properties (density for solid, and viscosity for liquid products) determine how the product will be heated (Buffler, 1993). The heating rate depends on the thermal properties while absorbed power on the dielectric properties. Buffler & Stanford (1991) recommend therefore that in multicomponent products, which may have widely differing dielectric and thermal properties, it is necessary to balance both the thermal and dielectric properties in order to get more even temperature distribution. Usually it is more fruitful to adjust specific heat capacity than the dielectric properties. However, if this is done by for example altering the water content, this will in turn affect the dielectric properties. Viscosity affects how a product will flow and in general, a higher viscosity reduces the rate of heat transfer and hence produces more uneven heat distribution (George, 1993). Thermal diffusivity depends on density, specific heat capacity, and thermal conductivity, and it denotes how rapidly a heat front diffuses through a food product. Foods with high thermal diffusivity tend to equilibrate hot and cold spots. Unfrozen foods have mostly values within a narrow range. Foods will be heated with similar thermal profiles if microwave energy is deposited within them in an identical manner (Buffler, 1993).

Shape and size of the foods

The influence of product geometry is often underestimated compared to the attention given to the dielectric properties. Foods with slab geometry are difficult to heat due to overheating of corners and edges. These affect the energy distribution so that energy concentrates around the corner or edge and the centre area tends to remain cold. The shorter the penetration depth the more pronounced the overheating is. Oval or circular shapes reduce this problem. This edge heating effect, which is also caused by diffraction, is non-resonant and it is stronger in some oven models than in others, and the phenomenon is often the dominant type of uneven heating (Risman et al., 1987; Ohlsson, 1990; Buffler, 1993).

Edge overheating is a common problem with foods. Sundberg (1998) has studied which factors determine the phenomenon. The overheating is caused by TM (transverse magnetic) polarized fields whereas TE (transverse electric) polarized fields do not create this problem. Increasing permittivity strengthens the overheating. The size of the food does not have any significant effect but the radius of the edge has a strong effect; the power density at the edge decreases with an increasing opening angle. If two blocks of food are near each other (less than 2 cm) the edge overheating may decrease but if the separation gets larger the overheating may exceed that of an isolated block.

In cylindrical and spherical foods the microwaves may concentrate at the centre. This focusing phenomenon does not occur with flat, rectilinear geometries. If the penetration depth (dp) is small compared with the dimensions of food, most of the energy is absorbed near the surface leaving the centre cold. If dp is intermediate, reasonable amounts of energy reach the centre and focusing occurs. Ohlsson & Risman (1978) have demonstrated this with model foods and IR imaging. Figure 20 shows the power level near the centre and surface as a function of diameter. The internal focusing effect is caused by diffraction and this phenomenon is dominant for relatively small food dimensions. Probably the best known example is an egg which "explodes" when heated in a microwave oven. The power density near the centre of the egg is much higher than in other parts and this cause violent shattering as the interior becomes superheated.

Generally, twice the amount of food needs double the heating time in a microwave oven. However, the oven output power is measured with a water load of 1000 g, and the power output is reduced when the load is smaller. The reduction depends of the amount of food, the package, and the oven itself. This also means that up to certain loads, greater amounts of foods are heated more efficiently. The position of the food in the microwave oven influence the power delivered into the product (James, 1993; George & Burnett, 1991).

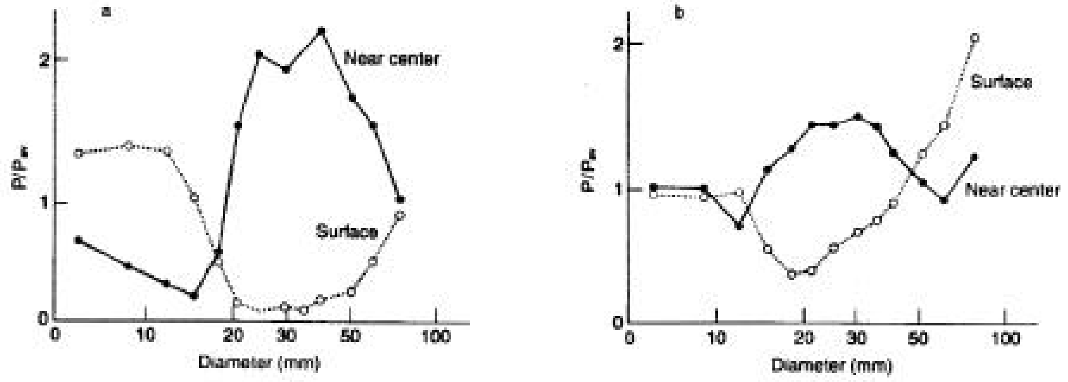


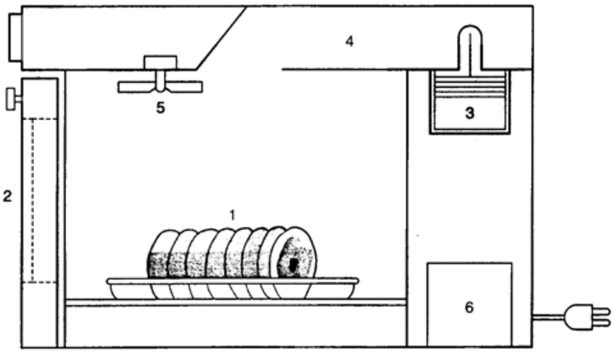
Fig. 20 The effect of the diameter on the relative microwave power levels (P/Pav) near center and at surface of a) spheres and b) cylinders
Source: Ohlsson & Risman, (1978).

Microwave oven and power measurements

Household and institutional microwave ovens operate at the frequency of 2450 MHz. The lower microwave frequency (915 MHz in the America or 896 MHz in the United Kingdom) is currently only used for industrial applications. The principal construction of a household microwave oven is shown in Figure 21. A typical oven requires about 4 kV current which is fed to the microwave generator, called a magnetron. A waveguide leads the generated microwaves either directly into the oven cavity or first into a feedbox with a mode stirrer, which is a metallic fan blade that rotates within the feedbox. The stirrer is used to reduce the effect of hot and cold spots through modifying the field pattern in the oven. Alternatively, a rotating turntable can be used. To further reduce non-uniform heating, most ovens have a microwave transparent shelf, which elevates the food from the metallic bottom (Buffler, 1993; Ohlsson & Bengtsson, 2001). The output power of the household microwave ovens is normally 600-800 W, of which about 90% is absorbed into the food material and 10% is reflected back to magnetron. If the amount of food is smaller than 500 g the reflected part may rise up to 40-50%, especially in low-cost ovens with smaller cavities

In the oven cavity, microwaves are reflected back from walls and standing wave patterns are generated. The field is not evenly distributed but has a pattern with maxima and minima. The pattern in an empty oven depends on the oven dimensions and is modified by a mode stirrer. Typically three to six cavity volume modes exist in microwave ovens with a stirrer and fewer in ovens with a rotating turntable. The modes (electromagnetic fields) have different polarizations and propagation directions and the polarity determines the amount of reflected and transmitted part of energy. For a TM (transverse magnetic field) polarized wave the reflection factor has a minimum at a high angle of incidence while for TE (transverse electric field) polarised the situation is vice versa. Certain TM modes cause much less overheating of horizontal food edges than TE modes and they are common in “well-behaved” microwave ovens. They are also non-resonant, which means that they are not very sensitive to changes in the food dimensions. Heating from below, called under-heating, cannot be achieved by the cavity volume modes. These so-called confined modes (under-heating modes) are of great importance for more uniform heating and smaller waste of energy by evaporation. Better heating of low permittivity foods, such as frozen products, may be obtained by raising them by a couple of centimetres, although this does not work well for high-permittivity foods. (Risman, 1994; Ohlsson & Bengtsson, 2001).

There is considerable variation of electric field inside the microwave oven cavity. In general, more expensive ovens tend to have a well-designed stirrer or a turntable and more uniform field distribution, while low-cost ovens have more hot and cold spots (Buffler, 1993). Analysis of field patterns in a microwave oven and their interaction with typical foods is very complicated. When material is put into the cavity the field distribution will change compared to that of an empty oven depending on the food composition and geometry, the package and the positioning of the food. (Ohlsson & Bengtsson, 2001).



1 = food load
2 = door
3 = magnetron
4 = waveguide
5 = stirrer
6 = power supply

Fig. 21 The household microwave oven (based on Risman, 1989).

Knowledge of all phenomena determining the efficiency and distribution of microwave heating is essential for proper assessment of the performance of ovens and foods (Risman, 1993). Many methods have been proposed for determining both the oven field pattern and measuring the microwave power output. Oven field distribution has been determined by e.g. using layers of homogeneous food materials or model substances and measuring the temperature distribution after a certain heating time. Model substances can visualize the temperature by changing color, or temperature of the product surface can be monitored by IR imaging. Food geometry and composition affect the microwave power distribution, and therefore test loads should be similar when evaluating the heating performance for food products. (Ohlsson & Bengtsson, 2001). The International Electrotechnical Commission (IEC) has worked with microwave oven performance testing and it has issued a standard including cooking, defrosting, and heating tests (IEC International Standard, 1999). It should be noticed that the determinations are carried out in room temperature ovens; within about one minute, the power delivered in the food may be reduced 20-35% due to magnetron and power supply heat-up after only a few minutes of operation. Also the voltage input affects the output power. The variation allowed at the power supply is ± 6% in the UK and this may change the power delivered into the food typically ±10% but may be over 30% (James, 1993; Risman, 2002).

Sensory and Nutritional properties of Microwave heated food

Recent research on microwave heating and sensory properties is focused on drying or other processing of foods, rather than on household applications. Most of the research on sensory properties of microwave heated foods in households has concentrated on comparison between conventional heating and microwave cooking or reheating. The majority of these studies have been on cooking or reheating of meat or vegetables. Comparison between the different studies showed a great variability in experimental designs and the results obtained. Ohlsson & Åström (1982) have reviewed the literature on sensory and nutritional quality in microwave cooking with an emphasis on the proper way of comparing microwave and other cooking methods. Techniques used for sensory evaluation vary from simple difference tests to tests with highly trained panel. Even large consumer panels have been used.

Ohlsson & Åström (1982) noticed that early research indicated an inferior quality of microwave cooked meat but many later, better-controlled studies showed that microwave cooking compares favorably to conventional cooking. The lack of browning in moist cooking methods compared to dry cooking makes an obvious difference; microwave cooking belongs to the first category. There were no differences in tenderness in beef between the different methods if the final internal temperature was the same. Howat et al. (1987) substantiated the results when comparing roasts cooked by different methods. The overall acceptability was the same, except the differences in surface color and appearance. Color, appearance, and flavor of microwave cooked vegetables were judged to be the same or better than in conventionally boiled vegetables, but only very few texture differences have been found.

Comparisons of the sensory quality of prepared foods are very few and the variations in the methods are large. Cipra et al. (1971) evaluated the eating quality and measured some physical characteristics of precooked turkey reheated in microwave and gas ovens. They found that microwave reheating resulted in more intense turkey flavor and less stale flavor compared to turkey reheated in a gas oven. No differences in physical properties (pH, juiciness, color, or tenderness) were found. Barbeau & Schnepf (1988) compared microwave, microwaveconvection, and electric-convection oven in the cooking of chickens. They used both an untrained sensory panel (consumer panel) and a trained laboratory panel. The consumer panel judged the samples cooked by microwave-convection to be more acceptable in terms of juiciness than the microwave cooked samples. The trained panel rated the chicken cooked in the conventional oven as more tender and juicy than the microwave or microwave-convection cooked ones.

Some authors have studied warmed-over flavor (WOF) in meat. WOF, or reheated flavor, in meat products is caused by the oxidation of fatty acids. Johnston & Baldwin (1980) found no difference in WOF when comparing microwave reheated roast beef slices to conventionally reheat. Satyanarayan & Honikel (1992) reported that microwave cooking of pork produced the maximum WOF compared to other methods (pan-frying, grilling, conventional cooking in water) while Albrecht & Baldwin (1982) found that the intensity of warmed-over flavor and aroma increased in reheating but there were no differences between the methods used. Research on sensory properties of microwave heated ready meals and how the serving temperature and temperature uniformity affect these properties or consumer acceptance could not be found in the literature.

Serving temperature is an important factor affecting food acceptability. Cultural learning influences the perception of the most pleasant serving temperature of foods (Zellner et al.,1988). For example, Cardello & Maller (1982) showed that the acceptability varied depending on the food and the serving temperature. If the serving temperature is much over 70ºC acceptability decreases as too high temperatures cause pain sensation. Temperature affects also other sensory properties such as the odour and texture of foods (Kähkönen et al., 1995). Temperature distribution in a microwave heated food can be very uneven which probably affects the pleasantness or acceptability of the food.

Comparisons have been made between microwave and conventionally heating on the nutritional quality of foods, but they have mainly concentrated on cooking or baking. Only a few of them have focused on reheating of products. Higher retention of vitamin C and vitamins of the group B have been reported when microwave heating was compared to conventional methods due to shorter heating time and smaller amount of water used in cooking. Microwave heating seems to aid in the retention of proteins and, in some cases, the quality of protein has been reported to be more favourable (Ohlsson & Åström, 1982). Davies et al. (1993) found that microwave cooked beef burgers contained less bacterial mutagens than traditionally fried ones. Albrecht & Baldwin (1982) compared three methods of reheating but they found no differences in thiamin retention between the methods. It is unlikely that microwave reheating of prepared foods will be a problem from the nutritional viewpoint if the product is not strongly overcooked. Microwave reheating may even offer a better solution compared to warm-holding in catering.

Product development of microwave ready meals

Food scientists developing a microwave product should have a good knowledge of the fundamental mechanisms of microwave heating and the interaction of microwaves with materials. As Schiffmann pointed out already in 1982, the technology is difficult, subtle and often not well understood. He also recommended a close co-operation with packaging materials manufacturers. Buffler (1993) divides the microwave product development into three steps: 1) characterization of the microwave oven, 2) measurement of product parameters, and 3) product testing. He recommends the use of several types (minimum six, recommended nine) of microwave ovens as consumers have a wide variety of ovens. The characteristics of each oven must be known, such as oven power, power versus initial operating time and versus load volume, oven pattern, time base and duty cycle. It is also important to know the line voltage of the laboratory doing the testing.

There is not much literature dealing with the design of dinners for microwave heating but some general guidelines have been published. Component layout can be a useful tool in developing microwaveable food (Ohlsson & Thorsell, 1984). Decareau (1992) recommended strongly a careful review of the literature, especially the earlier literature as a background to product development.

According to George & Burnett (1991) the important factors to be considered in the choice of suitable food components for microwave heated meals are physical, chemical, and sensory properties of foods. Most of the physical properties of major importance have been discussed earlier in this literature review. Chemical composition affects the dielectric properties but also other properties. Fats have very low dielectric properties but still can reach high temperatures. The specific heat capacity of fats is much lower than that of water and therefore fat will heat faster. Carbohydrates and proteins tend to bind water, which leads to depression of dielectric properties and heating rate. Salts and some other food ingredients elevate the loss factor of foods and thus lower the penetration depth and cause more pronounced surface heating (Ohlsson & Bengtsson, 2001).

One obvious difference compared to conventional heating methods is the lack of surface browning or crisping. In microwave heating the surface temperature usually remains low and more moist compared to conventional heated product, thus the Maillard reactions which create the color and flavor in oven baked products, do not occur or proceed very slowly. One solution is to use a combination oven with hot air or radiation, or to use susceptors. Special food ingredients, which react at lower temperatures and give surface browning, have been developed. (George & Burnett, 1991; Ohlsson & Bengtsson, 2001).

The effect of microwave heating on flavor of foods varies; in some cases the flavor is perceived as stronger or better while sometimes the microwave heated foods are described as flavorless. The flavor industry has even developed special microwave flavors which can mask the warmed-over flavor (Ohlsson & Bengtsson, 2001). As short cooking times and low temperatures do not induce the Maillard reaction, flavor enhancement and retention are great challenges in developing a microwavable product. Conventionally baked or cooked products contain more nutty, brown and caramel-type aromas, whereas microwave heated products are dominated by green vegetable flavors (Yeo & Shibamoto, 1991). Flavor can be encapsulated to ensure a controlled release during the heating period, as flavors are susceptible to steam distillation during heating. The majority of low-boiling flavors may be lost during microwave heating and this causes an imbalance in flavor concentrations compared to conventionally heated products. Complex carbohydrates and flavor carriers can have an essential role in the protection and retention of flavor (Whorton & Reineccius, 1990).

Temperature and time affect both the flavor and texture and as the heating time is short in microwave heating the development of the desired flavor or texture may require special actions. The different time-temperature combination compared to conventional heating results in a different moisture gradient, too. Conventional formulations of prebaked bread and breadlike doughs develop unacceptable textures when heated in microwave oven (Shukla, 1993). In multicomponent products, the bread component becomes soggy and rubbery. If exposure to microwaves lasts too long the result is a tough and rubbery crumb. The reason for toughness is not well understood (Persaud et al., 1990). In coated (battered) products the technical challenges are water migration, too little surface evaporation and lack of browning (Darrington, 1991). Many ingredients affect or are proposed to have an effect on how a food product heats in a microwave oven; these ingredients are starches, sugars and honey, free amino acids and proteins, phosphates, polyols etc. (Shukla, 1998).

Product development should always be combined with package development and the testing in different types of microwave ovens. Bows (2000) has created a classification system based on the applicator type (structure which applies the microwave energy to the food) and so called electrical size of a product. The electrical size compares the characteristic dimensions of a product to the penetration depth. This classification system may help in better understanding of microwave heating or find factors for controlling the heating result. Recent research done on simulation of microwave heating of foods indicate that simulation can be of great help in optimisation of food products and packages, as well as microwave ovens (Wäppling-Raaholt et al. 2001).

The definition of quality consists of several different factors: hygienic quality, nutritional quality, and sensory quality. Also, the definition may be different depending on whether it is defined by an expert or by consumers. In developing food products or finding a suitable package, sensory evaluation is needed as shown by Heiniö et al (1993).

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CHAPTER 3

INFLUENCE OF EMULSIFIER AND ARABIC GUM ADDITION ON TEXTURAL CHARACTERISTICS OF TARO PASTE

ABSTRACT

The effect of emulsifier and arabic gum (AG) addition on the textural characteristics of taro paste was investigated. The results revealed that the addition of glycerol monosterate (GMS) and sodium stearoyl 2 lactylate (SSL) in taro paste caused a decrease in toughness of the formulated taro paste during 8 weeks of storage, in addition, arabic gum addition provided dominantly rubbery characteristic of this product. It was noticed that the higher gum (10% and 15%) usage, the lower shear stress and greater shear strain of the tested samples obtained. According to the textural mapping, an increasing amount of gum usage in taro paste led to a progressive appearance of rubbery characteristic. In addition, GMS and SSL presence directly affected the toughness of the product.

Keywords: taro paste; emulsifier; gum; textural properties

INTRODUCTION

Taro (*Colocasia esculenta* (L.) Schott), belonging to the family Araceae, is an economic tuber crop cultivated in the tropical and subtropical regions of the world (Tatiyakul et al., 2006). According to its edible corms and leaves, it normally can be not only consumed as a staple food and vegetable, but also processed as a food ingredient and animal feed. In Asia, the corms are usually used for the preparation of a sweetened paste via cooking and mashing taro into smooth paste, in which some sweeteners, shortenings and/or seasonings are usually added. Sweetened taro paste traditionally can be used as a filling for some bakery products or desserts because of its unique texture and aroma. However, the quality of sweetened taro paste is easily degraded due to staleness as with other starchy foods and is also readily deteriorated by microorganism contamination (Lai et al., 1998). In addition, traditional paste normally has short period of shelf life however, for shelf-life extension, the paste must keep this product under refrigeration, and consequently the hardening of textural product is unacceptably occurred.

Many researchers found that starch retrogradation was the major phenomena explained for the stale formation in the taro paste during storage. The retrogradation rate of starch component is normally affected by some serious factors, such as the sources, concentration of starch, and temperature of handling and storage. Food emulsifiers are widely used as improving agent for anti-firming and texture of starchy foods including breads and noodles (Ito et al., 2005).

The study of the addition of some polyols and emulsifiers to retard starch retrogradation during storage has been done (Lai et al., 1998). Normally, the food emulsifiers would be adsorbed on the surface of starch granule and amylose sequentially form complexes with some lipids and emulsifiers (Katsuta et al., 2002). As a result of the complexes formation, the depression in the swelling power of starch granules and in the retrogradation of gelatinized starch will be obtained. In addition, amylopectin could form complexes with surfactants and lipids in the exterior molecular chains (Kurakake et al., 2004). As the emulsification properties, long-chain satuated monoglycerides, sucrose esters, and sodium stearol lactylate (SSL) have been used in starchy food to inhibit the swelling of starch granules (Mira et al., 2000). The formation of water-insoluble complexes between monoglyceride and amylase eventually prevented leaching of amylase during gelatiniztion, inhibited swelling of starch granules heated in water, and reduced the water-binding capacity of starch, is thought to result in reduced stickiness (Charutigon et al., 2008).

Food hydrocolloids such as plant-derived polysaccharides (gums) were normally applied in food system not only as functional ingredients to improve the texture, flavor, and shelf-life but also known as the excellent stabilizing and thickening agents (Dickinson, 2003). The use of common food gums, such as locust bean, guar, arabic and xanthan gum, and their interactions with other food materials were well known (Kaur et al., 2008). The addition of gum in starchy food system was capable to modify the rheological properties, increase the viscosity, and alter the rate of the gelatinization and retrogradation of starch (Kim & Yoo, 2006). Many researches have shown in their studies that the interaction between gum and starch such as rice starch-xanthan gum mixtures attain the higher viscosity with the increase in gum concentration (Kim & Yoo, 2006) or increase the apparent viscosity of cake batter by adding the xanthan gum (Turabi et al., 2008). In addition, As the most commonly recognized hydrocolloid emulsifier was arabic gum (Dickinson, 2003), actually, emulsifying activity of arabic gum at the oil–water interface was attributed to a small amount of the protein fraction that was covalently bound to highly branched carbohydrate structures and detected as a high molecular mass. Arabinogalactan-protein complex was largely responsible for the emulsifying capability of the arabic gum (Ikeda et al., 2005).

In this paper, the attention was drawn to investigate the effect of emulsifier and gum addition on the change in textural properties of sweetened taro paste at the different time of storage.

MATERIALS AND METHOD

Raw Materials

Sweet Taro paste was formulated from the raw taro (*Colocasia esculenta* (L.) Schott) medium corm size, weight 0.4 - 0.6 kg which was, 6-month old, harvested in Thailand from July to August 2008 purchased from local market (Foodland supermarket, Bangkok). Sodium steroyl 2 lactylate (SSL) and glycerol monosterate (GMS) were obtained from Oleofine Organic (Thailand) Co.,Ltd. Arabic gum; trade name: INSTANTGUM BA was supplied from Colloides Natural International Co.,Ltd.

Taro paste preparation

The sweet taro paste recipe used in this experiment contained 57.5% cooked taro paste, 24.0% sucrose, 8.0% glucose syrup, 5.0% fat powder, 5.0% glycerin, and 0.5% salt. Raw Taros were peeled, cleaned with fresh water, cut into 6x5x2 cm. chunk, and then steamed at 95°C for 20 min. The cooked taro was mashed by mincer (Powerline, PG12FS, USA). Using the 3-mm of screen diameter finally mixed thoroughly with other ingredients at low speed for 30 s, and at high speed for 1 min. with food mixer (HM400, Kenwood, USA). The mixed taro paste (approximately 1 kg) was then placed into microwavable plastic box (24x15x9 cm.). The paste would be 2.5 cm of height. The taro paste was cooked by microwave heating (M1933N, Samsung, Thailand) at 1000W for 20 min. The cooked paste was finally stirred at low speed for 30 s via food mixer before forming to the uniform size and shape.

The first experiment was conducted to investigate the effect of emulsifier addition on the textural change of sweet taro paste at the different storage time. Thus, the uncooked taro paste was then mixed with the combination between SSL and GMS before heating process. Five different sweet taro pastes were made from the mixture: SSL: GMS ratio 100:0:0 (used as the control), 100:1:1, 100:2:1, 100:1:2, and 100:2:2, respectively. The cooked sweet taro paste was formed the shape of 1.5x1.5x1.5 cm. cubic shape, packaged and stored at room temperature. Three replications were performed in this experiment.

The second experiment was conducted to investigate the effect of gum on textural properties. The taro paste composition contained the mixture: SSL: GMS ratio 100: 1: 2. The mixture was prepared with the same recipe of preliminary experiment which mentioned above. Different INSTANTGUM BA levels were studied by adding 5.0%, 10.0%, and 15.0% of INSTANTGUM BA powder, in addition to studying a sample which did not contain gum.

Texture measurement

The texture analysis of sweetened taro paste was measured with a TA-XT2i texture analyzer.(Stable Micro Systems, Goldaming, UK). All samples that had 1.5 cm^3 cubic shapes and kept at room temperature were measured. The compression test was done by a disc plunger (25 mm diameter) with testing speed 1 mm/s and the pressing depth was 80% of the sample height. The hardness of taro paste was expressed in terms of the maximum compressing force. The shear force was testing with a HDP/BSW blade set with warner bratzler probe was performed. The test speed was 1 mm/s. Each test was performed five replications to measure maximum shear force (N). Shear stress ($10^3 Nm^{-2}$) was calculated as the maximum shear force multiplied by area.

Statistical analysis

Analysis and samples treatment were repeated at least three times. The statistic analyses were performed using analysis of variance (ANOVA) to determine if there were statistically significant ($p \leq 0.05$) differences in each attribute. Least significant difference (LSD) was used to determine which of the samples were significantly different.

RESULTS AND DISCUSSION

Influence of emulsifier addition on textural properties

After heating, the freshly-made taro paste was reached a target yield as about 82% and had total soluble solid about 62°Brix, the pH range of products was 6.21 - 6.40 with the moisture content 28.59 - 29.67%, and all had presented water activity (A_w) less than 0.85 (table 4) and then was formed to cubic shape 1.5x1.5x1.5 cm^3 by sheeting and molding. Textural characteristic of sweetened taro paste was further studied after one week of storage. A texture map, which was a plot of shear stress vs. shear strain, provided a graphical representation of product texture (Truong & Daubert, 2001; Tunick & Hekken, 2002). Maps illustrating the textural changes in the taro paste during 8 weeks storage were shown in figure 23. Foods exhibiting low shear stress (σ_{max}) were termed mushy, if the shear strain (γ_{max}) was low, and rubbery if γmax was high. Food with high σ_{max} could be considered brittle if γ_{max} was low and tough if γ_{max} was high (Truong & Daubert, 2001; Noronha et al., 2008). The obtained results revealed that the addition of GMS and SSL in taro paste caused a decrease in toughness. In the first week of storage, the shear stress and strain values for the emulsifier-free taro paste (control) were 3.02 N and 12.24, respectively. However, all treatment was plotted quite closely together suggesting that they had similar texture profile. After 5 weeks of storage, the emulsifier-free taro paste increased more shear strain. According to the texture map, the taro paste containing emulsifiers were mushier than the control.

Increasing the emulsifier content changed the texture profile of taro paste to tougher. The textural properties of the taro paste containing 1%SSL and 1%GMS did not change to the same extent as the other more emulsifier content during storage, but presented mushier and was the similar texture as the control at initial of storage time. Since the stress value indicated the softness and strain indicated cohesiveness (Swan & Boles, 2006), cohesiveness was further decreased by GMS and SSL (Numfor et al., 1998) through limit both gelatinization of starch and the hydrogen bonding of adjacent starch molecules by causing them to coil about the fatty acid trial (Kite et al., 1963; Swan & Boles, 2006). Furthermore, GMS and SSL inhibited both swelling and solubility below 85^{o}C by preventing amylose exudation with reduced leaching of amylose and the presence of emulsifier, the elastic quality of the paste was diminished because the starch molecule could not establish enough junction zones of adequate size to give and elastic network (Ghiasi et al., 1982).

Influence of arabic gum addition on textural properties

The effect of different concentrations of arabic gum on the textural characteristics of taro paste was studied during storage. The chemical and physical properties of the fresh-made taro paste supplemented with AG were shown in table 5, total soluble solid about 62^{o}Brix, pH range 6.21 - 6.40 and the moisture content 28.59 - 29.67%.

As the gum concentration increased, the compression force decreased significantly (table 6). The presence of AG decreased the compression force at first week of storage over the control value from 29.33 N to 17.98 – 27.34 N. Among different gum concentrations, at 15% gum showed the lowest compression force at 17.98 N followed by 10% gum (22.46 N) and 5% gum (27.34 N). During storage of taro paste, textural hardening was observed, as evidenced by increasing compression force values ($p<0.05$) with increasing storage time. As showed in table 6, an increase in compression force value with storage time was observed in all samples. However, the supplemented with AG notably increased the hardness of taro paste less than control. After 8 weeks of storage, 15% AG supplemented sample leading compression force to 34.18% of hardness reduction as compare to the control followed by 12.16% and 8.17% of the 10 and 5% AG added sample, respectively.

Figure 24 illustrating the texture map of torsion data (shear stress vs. shear strain) taro paste containing gum (AG) and emulsifier (SSL, GMS) during storage. The obtained results revealed that the addition of AG in taro paste caused an increase in rubbery characteristic. According to the texture map, the taro pastes containing AG were more rubbery than the control at one week storage and remained that character through 8 weeks of storage. Since, the highest shear strain exhibited the most elastic character and the highest shear stress exhibited the hardest texture in previous experiments (Gwartney et al., 2002; Park, 2007). The AG addition at 15, 10 and 5% brought higher 6.42, 6.33 and 31.48% elastic character than the control at an initial and then extended to 21.71, 21.98 and 22.06%, respectively, after 7 week of storage time. However, an increasing of toughness was observed in week 7 by increasing AG content. It was remarkable that 15% AG content presented tougher than 10, and 5% AG content, respectively.

The changes of textural properties of taro paste when added the gum explained by the properties of gums that were added to the food product mainly for their thickening properties. In addition, they were used to improve mouth feel and to change the viscosity of solutions due to their high polymeric nature and the interactions between polymer chain when they were dissolved or dispersed (Turabi et al., 2008). INSTANTGUM BA produced from arabic gum, its low viscosity and adhesive properties, meanwhile, made this gum an excellent ingredient for binding the water as humectant or readily soluble to give relatively low viscosity newtonian solutions even at high concentrations (Dickinson, 2003) together with two important functions of gum arabic, one to retard or prevent sugar crystallization and to emulsify the fat and keep it evenly distributed throughout the product (Ikeda et al., 2005), that perhaps gave results in higher shear strain of AG content taro paste.

CONCLUSION

Information from a texture map such as this study was useful to food scientists who wish to relate parameter such as storage and composition to stress and strain of the product at fracture. These mechanical properties were important to consumer perception, and torsion gelometry provided a systematic method of measuring them. For this study obtained that the addition of SSL and GMS provided taro paste less cohesive and exhibited mushier character than emulsifier-free taro paste during 8 weeks of storage. On the contrary, the supplemented with arabic gum provided taro paste notably elastic character improvement.

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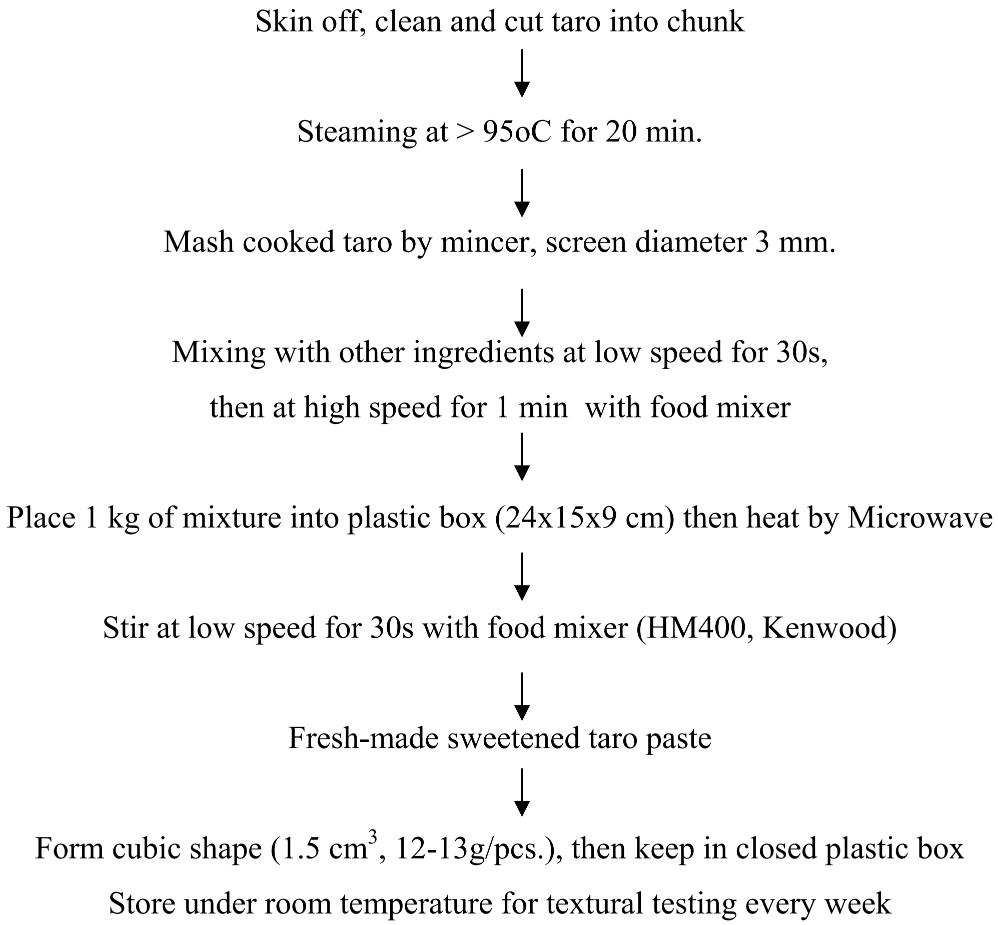

Skin off, clean and cut taro into chunk

Steaming at > 95oC for 20 min.

Mash cooked taro by mincer, screen diameter 3 mm.

Mixing with other ingredients at low speed for 30s,
then at high speed for 1 min with food mixer

Place 1 kg of mixture into plastic box (24x15x9 cm) then heat by Microwave

Stir at low speed for 30s with food mixer (HM400, Kenwood)

Fresh-made sweetened taro paste

Form cubic shape (1.5 cm^3, 12-13g/pcs.), then keep in closed plastic box
Store under room temperature for textural testing every week

Fig. 22 Flowchart of the preparation of sweetened taro paste

Table 4 The chemical analysis of fresh-made taro paste with different emulsifier proportions

TRT	Emulsifier	%Yeild	TSS (°Brix)	A_w	pH	%MC
control	Without emulsifier	81.95	62	0.823	6.21	29.67
1	SSL 1%, GMS 1%	81.96	62	0.835	6.32	29.13
2	SSL 2%, GMS 1%	81.39	62	0.838	6.4	28.66
3	SSL 1%, GMS 2%	81.99	62	0.834	6.38	28.87
4	SSL 2%, GMS 2%	81.94	62	0.821	6.33	28.59

Table 5 The chemical analysis of fresh-made taro paste with different gum concentrations

TRT	% Yield	TSS (°Brix)	A_w	pH	%MC
Control	82	62	0.838	6.4	28.87
5% INSTANTGUM BA	82	62	0.810	6.28	28.61
10% INSTANTGUM BA	82	62	0.802	6.32	28.10
15% INSTANTGUM BA	82	62	0.800	6.30	27.61

Table 6 The compression force of taro paste in different storage times

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
No gum	29.33aD (0.55)	32.10aC (1.49)	34.29aC (3.79)	31.42aCD (0.59)	34.71aC (1.89)	47.01aA (1.89)	42.42aB (2.23)	44.58aAB (3.57)
Gum 5%	27.34bE (0.53)	29.79aD (1.98)	29.20bDE (1.27)	30.60aCD (1.18)	32.50aC (0.62)	38.04bB (2.55)	39.20bAB (1.57)	40.94bA (2.56)
Gum 10%	22.76cDE (0.24)	22.30bE (1.55)	25.13bD (1.85)	25.03bD (0.51)	28.92bC (1.74)	31.86cB (0.22)	32.11cB (1.78)	39.16cA (2.15)
Gum 15%	17.98dC (0.51)	17.93cC (0.70)	19.81cC (2.04)	19.38cC (1.54)	20.25cC (0.68)	23.66dB (2.91)	23.50dB (0.22)	29.34dA (1.86)

a, b, c,… compared in row (effect of various treatment)

A, B, C,…compared in column (effect of storage time)

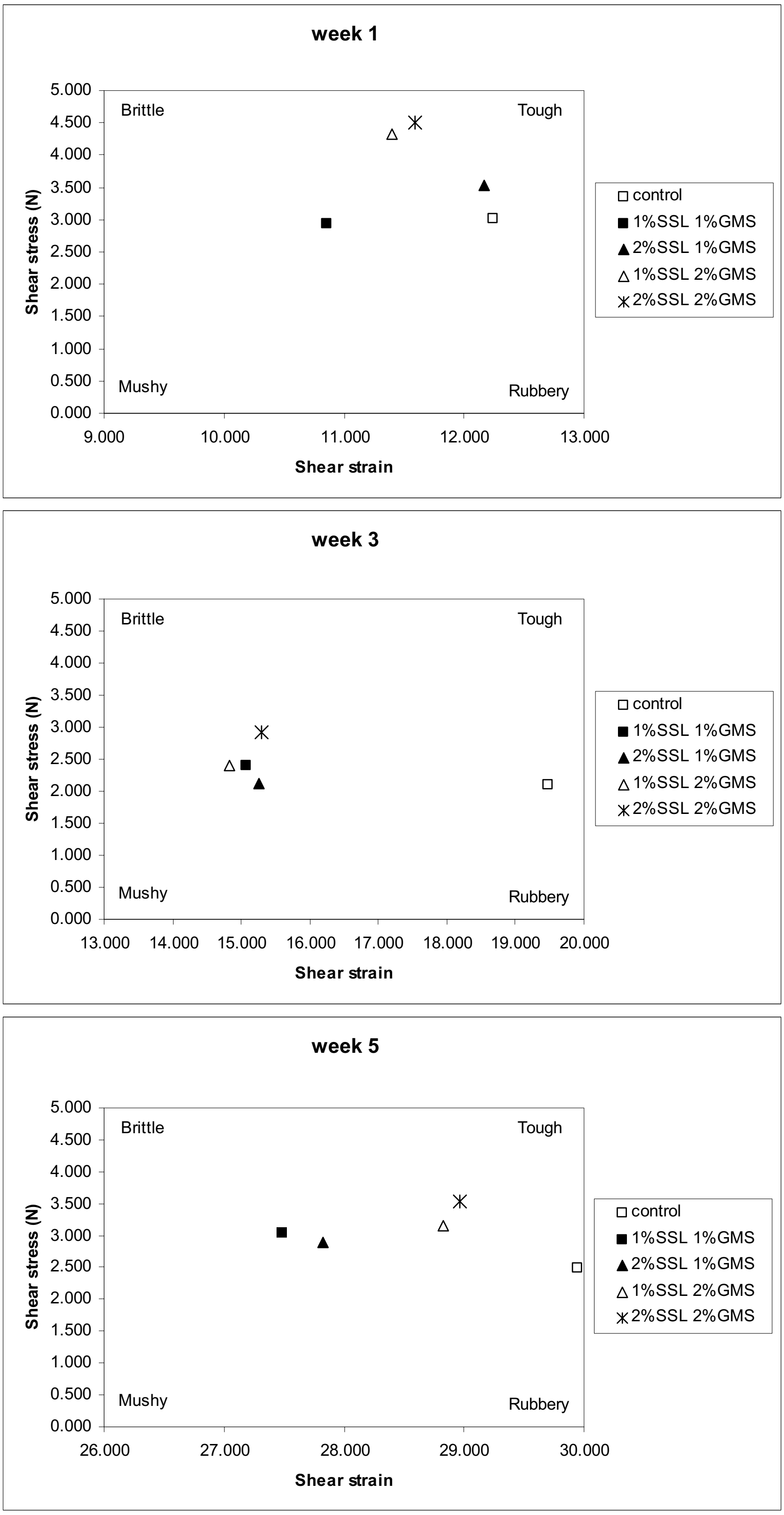

Figure 23 Texture map of taro paste containing emulsifier during storage.

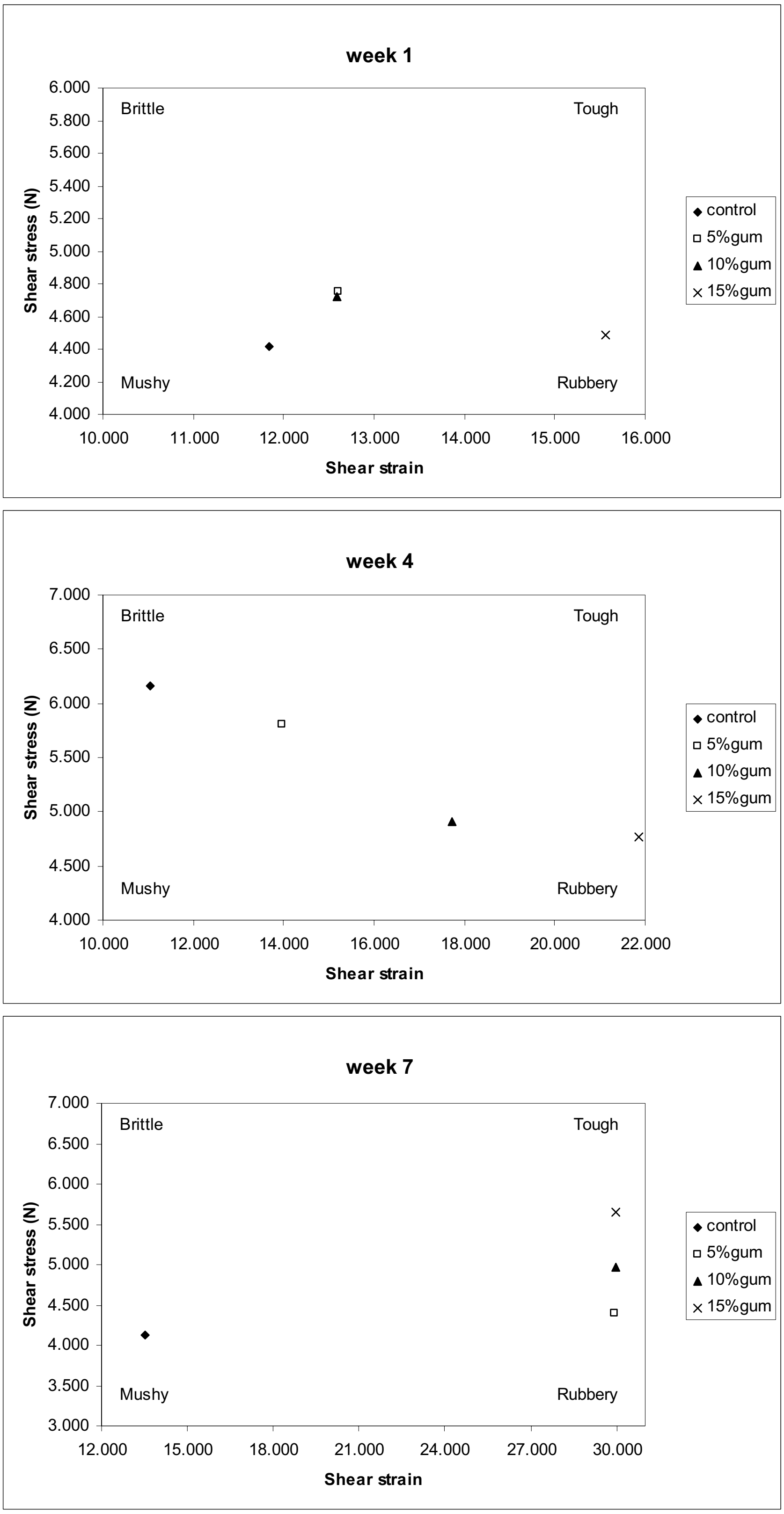

Figure 24 Texture map of taro paste containing gum and emulsifier during storage.

CHAPTER 4

EFFECTS OF MICROWAVE HEATING ON COLOR AND TEXTURAL CHARACTERISTIC OF TARO PASTE

ABSTRACT

The effects of microwave treatment on taro paste were studied. The different powers of microwave (450, 600, 850 and 1,000 watts) were applied to prepare the taro pastes. The result was noticed that taro paste which was treated by microwave heating at 1,000 watts for 20 minutes could rapidly decrease the water activity to less than 0.85 without degradation in color compared the others and did not present more toughness development during 8 weeks of storage. On the contrary, 450 W-treated taro pastes resulted the longest time as 54 minutes to achieve and exhibited the hardest textural characteristic. Less compression force was resulted in 600 watts / 38 minutes treated taro paste and at this condition, less toughness development during storage was presented.

Keywords: taro paste, microwave, textural properties

INTRODUCTION

The term food quality includes three principal areas: nutritional value, acceptability and safety. Almost any method of processing raw food will have an adverse effect on some of its nutrients. Acceptability includes large array of attributes like visual appeal, aroma, flavor and texture. The overall quality of a product is judged by a number of parameters. Good quality is judged by freshness, expected appearance, flavor and texture. The quality changes that can happen in any product during process are changes in optical properties (color, appearance), sensory properties (odor, taste, and flavor), structural properties (density, porosity, specific volume), nutritional characteristics and textural properties (Warchalewski et al., 1998; Vadivambal & Jayas, 2007).

Microwave heating (MW) is a thermal process that offers many advantages in food processing including less startup time, faster heating, energy efficiency, space savings, precise process control, selective heating and final products with improved nutritive quality (Sumnu, 2001; Palav & Seetharaman, 2007). Since it is quite competitive in cost compared with other methods of heating, it has been applied in various food processing operations such as tempering, thawing, pasteurization, drying, expansion and cooking (Palav & Seetharaman, 2006; Lewandowicz et al., 1997; Decareau & Peterson, 1986). However, although microwaves have many advantages, several products produced by microwave heating has been limited due to poor final product quality compared to products processed by using traditional process (Palav & Seetharaman, 2007). The causes for these differences in the quality are not fully understood as yet but generally thought that are a reflection of the differences in the mechanism of heat and mass transfer or due to the interactions between microwave energy and the individual polar molecules (Sakonidou et al., 2003; Goebel et al., 1984).

In previous research reported that microwaves substantially affected physico-chemical properties of the irradiated tuber starch, caused a rise in the starch pasting temperature, a reduction of solubility, and changes in the crystalline structure exemplify form the B-pattern to the A-pattern (Lewandowicz et al., 2000). In addition, even less thermal damage to the test material than general heating methods, it causes biochemical reaction and changes the molecular conformation of starch, protein, and texture of food products (Zhao et al., 2007).

However, few studies have attempted to explain how microwaves influence the storage quality of taro paste. In this study, we treated taro paste with different microwave energy condition. The objective was to investigate the effect of microwave treatment on the color and textural properties of taro paste during storage, and to provide optimal process conditions for the industrial application.

MATERIALS AND METHOD

Raw Materials

Sweetened Taro paste was formulated from the raw taro (*Colocasia esculenta* (L.) Schott) medium corm size, weight 0.4 - 0.6 kg which was, 6-month old, harvested in Thailand from July to August 2008 purchased from local market (Foodland supermarket, Bangkok). Sodium steroyl 2 lactylate (SSL) and glycerol monosterate (GMS) were obtained from Oleofine Organic (Thailand) Co.,Ltd. Arabic gum; trade name :INSTANTGUM BA was supplied from Colloides Natural International Co.,Ltd.

Taro paste preparation

The sweetened taro paste was prepared according to the flow chart shown in Figure 25. Taros were peeled, cleaned and cut in to chunk, then were steamed at> 95°C for 20 min. The cooked taros was mashed by mincer (Powerline, PG12FS, USA), at screen diameter 3 mm, after that were mixed thoroughly with other ingredients at low speed for 30 seconds, and then at high speed for 1 minute with food mixer (HM400, Kenwood). Place 1 kg of the mixture into plastic box (24x15x9 cm.), paste height 2.5 cm from bottom, then heating by microwave (M1933N, Samsung, Thailand) and then stirred at low speed for 30 seconds with food mixer(HM400, Kenwood, USA). The experiment was conducted to investigate the effect of microwave heating at different level 450, 600, 850 and 1,000W, the ingredients including 58.0% cooked taro paste, 24.0% sucrose, 8.0% glucose syrup, 5.0% fat powder, 5.0% glycerin, 1% SSL, 2% GMS and 5.0% arabic gum. The fresh-made taro paste was formed cubic shape, packaged and stored at room temperature.

Texture measurement

The texture analysis of sweetened taro paste was measured with a TA-XT2i texture analyzer (Stable Micro Systems, Goldaming, UK). All samples that had 1.5 cm3 cubic shapes and kept at room temperature were measured. The compression test was done by a disc plunger (25 mm diameter) with testing speed 1 mm/s and the pressing depth was 80% of the sample height. The hardness of taro paste was expressed in terms of the maximum compressing force. The shear force was testing with a HDP/BSW blade set with warner bratzler probe was performed. The test speed was 1 mm/s. Each test was performed five replications to measure maximum shear force (N). Shear stress ($10^3 Nm^{-2}$) was calculated as the maximum shear force multiplied by area.

Statistical analysis

Analysis and samples treatment were repeated at least three times. The statistic analyses were performed using analysis of variance (ANOVA) to determine if there were statistically significant ($p \leq 0.05$) differences in each attribute. Least significant difference (LSD) was used to determine which of the samples were significantly different.

RESULTS AND DISCUSSION

Effect of microwave heating process on textural properties

The microwave cooking process of taro paste was terminated after reached the target yield as about 82% w/w. The chemical and physical properties of taro paste were showed in table 7, their total soluble solid about 62^{o}Brix, pH range 6.35 - 6.42, with the moisture content range from 28.61-28.94% and all had water activity (A_w) less than 0.85. By microwave heating (MW) at 1,000 W, taro paste was achieved after 20 min, at 850 W after 25 min, at 600 W after 38 min and at 450 W after 54 min. It could be seen that as the level of MW increased, there was a decrease in cooking time.

Among different MW treatments, MW at 450 W showed the highest compression force about 39.25 N as compared to 35.61, 32.38 and 26.17 N of MW at 1,000, 850 and 600 W, respectively after storage for one week. During storage, the textural hardening was observed as showed in table 8. After 8 week of storage, 600 W-treated sample leading hardness to 70.34% increase from the first week of storage and followed by 850 W and 450 W-treated at 20.94 and 17.04%, respectively. While the 1,000 W-treated sample seemed to be barely changed (Fig 26).

Figure 27 illustrating the texture map of torsion data (shear stress vs. shear strain) of taro paste treated by different MW conditions. Foods exhibiting low shear stress (σ_{max}) were termed mushy, if the shear strain (γ_{max}) was low, and rubbery if γ_{max} was high. Food with high σ_{max} could be considered brittle if γ_{max} was low and tough if γ_{max} was high (Truong & Daubert, 2001; Noronha et al., 2008). The highest shear strain exhibited the most elastic character and highest shear stress exhibited the hardest texture (Gwartney et al., 2002; Park, 2007). For the first week of storage, tougher character was presented by 450W-treated taro and followed by 1,000 and 850W-treated, respectively. While the 600 W-treated showed significant characters, the softest texture. And there always was presented during storage. The obtained results revealed that 450 W-treated taro pastes, the slowest process time, notably exhibited tougher character followed by 1,000, 850 and 650 W, respectively. MW-treated taro paste at 850 W and 1,000 W presented quite similar shear stress and was plotted quite closely together suggesting that they got the similarity texture profile. While 600 W-treated taro pastes was noticeable softer texture than the others during storage.

Effect of microwave heating process on color

The color of food is important for its acceptability. The L*, a*, b* value of taro paste during storage were evaluated and compared in table 9a-c. The results showed that L* and b* value of taro paste were not quite difference in each condition but found slightly increased with time. The value a*, red ness or greenness, were found variously.

CONCLUSION

Greater microwave energy treated in taro paste resulted in shorter cooking time and rapidly removed the moisture from the taro paste without any discoloration. The lowest energy of MW as 450W resulted in longest processing time and led textural character to tougher than the others.

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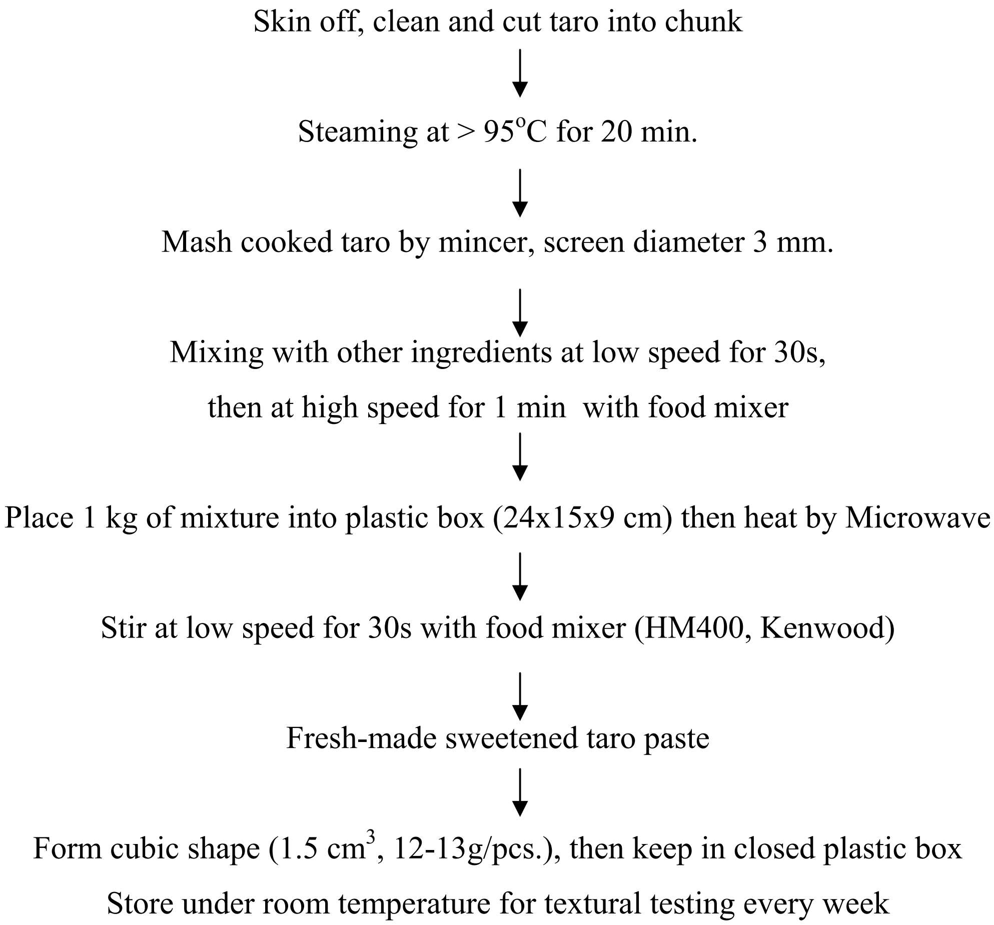

Skin off, clean and cut taro into chunk

↓

Steaming at > 95°C for 20 min.

↓

Mash cooked taro by mincer, screen diameter 3 mm.

↓

Mixing with other ingredients at low speed for 30s,
then at high speed for 1 min with food mixer

↓

Place 1 kg of mixture into plastic box (24x15x9 cm) then heat by Microwave

↓

Stir at low speed for 30s with food mixer (HM400, Kenwood)

↓

Fresh-made sweetened taro paste

↓

Form cubic shape (1.5 cm^3, 12-13g/pcs.), then keep in closed plastic box
Store under room temperature for textural testing every week

Fig. 25 Flowchart of the preparation of sweetened taro paste

Table 7 The chemical analysis of fresh-made taro paste with various microwave heatings

TRT	Time (min.)	TSS (^{o}Brix)	%Yield	A_w	pH	%MC
450 w	54	62	82.0	0.815	6.42	28.61
600 w	38	62	82.4	0.837	6.35	28.94
850 w	25	62	82.0	0.828	6.40	28.61
1,000 w	20	62	82.0	0.823	6.38	28.61

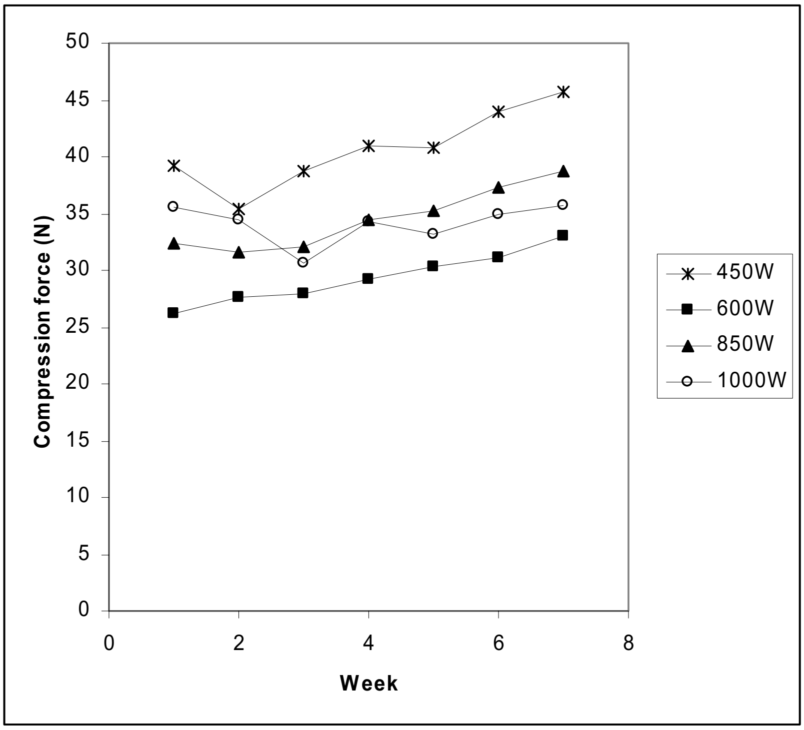

Fig 26 Compression force value of MW-treated taro paste during storage.

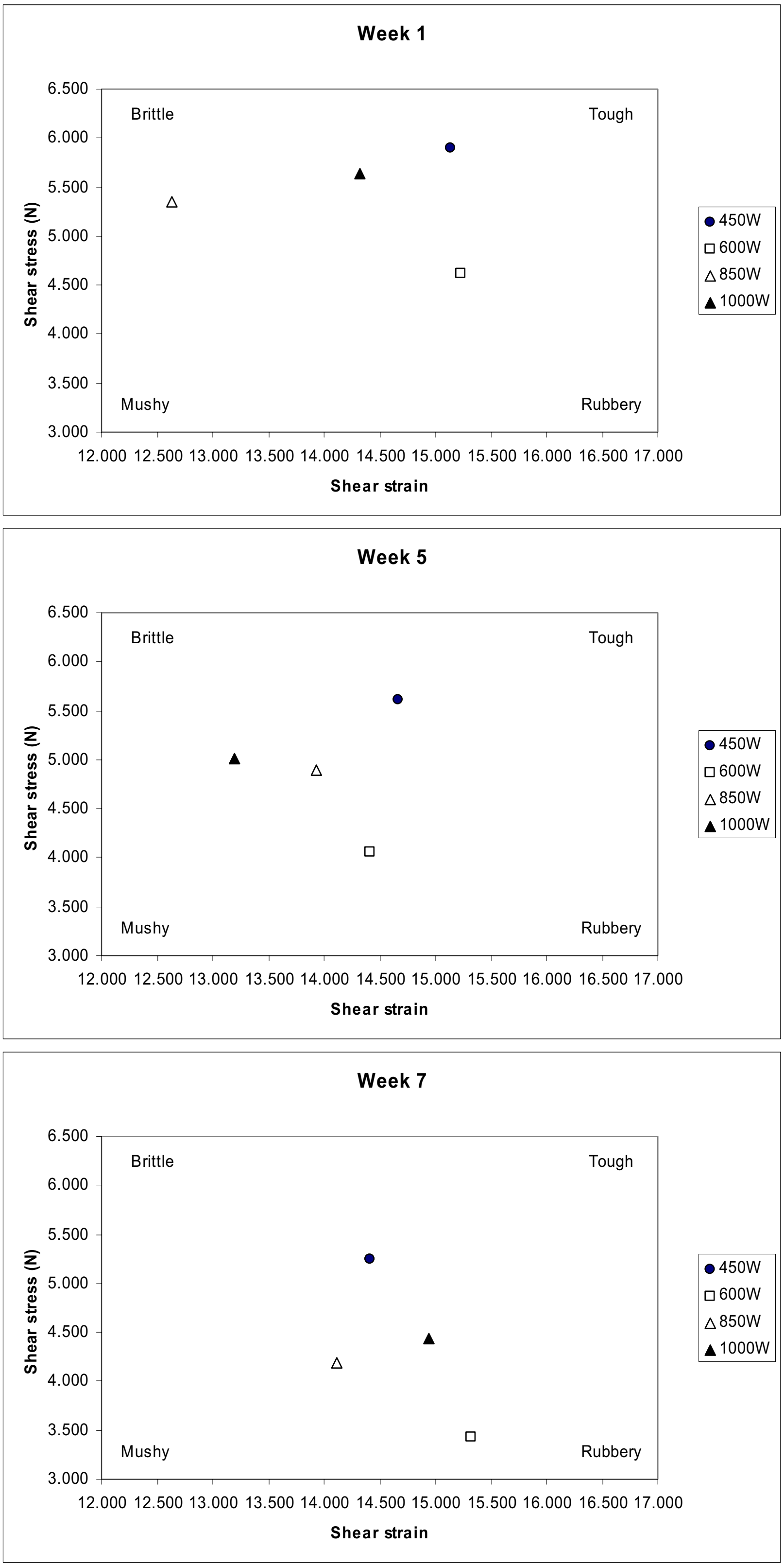

Fig 27 Texture map of MW-treated taro paste during storage.

Table 8 The variation of compression force of taro paste in different storage times

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
450 W	39.25aBC (1.12)	35.37aD (2.14)	38.72aC (0.71)	41.00aB (1.74)	40.78aB (0.69)	43.94aAB (3.06)	45.74aA (2.24)	45.94aA (2.18)
600 W	26.17dD (0.94)	27.54cC (1.00)	27.95dC (0.71)	29.18cBC (0.55)	30.35dBC (1.49)	31.17dB (2.17)	32.94cB (3.46)	44.58bA (1.30)
850 W	32.38cC (1.21)	31.51bD (1.58)	31.99bC (0.16)	34.45bBC (1.73)	35.23bB (0.68)	37.25bAB (1.95)	38.67bA (2.43)	39.16cA (2.71)
1,000 W	35.61bA (0.49)	34.40abAB (1.89)	30.61cC (0.94)	34.26bB (2.13)	33.16cBC (0.42)	34.99cAB (1.35)	35.64bcA (0.77)	35.34dA (1.86)

a, b, c,… compared in row (effect of various treatment)

A, B, C,…compared in column (effect of storage time)

Table 9a The changes of color (L*) of sweetened taro paste during 8 weeks of storage time

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
450 W	74.04C	84.71b	84.94c	84.69c	85.14a	84.05b	82.63c	83.60a
600 W	79.38a	89.48a	89.50a	89.13a	89.83b	88.87a	88.53a	88.84b
850 W	78.51ab	89.35a	88.46ab	88.53a	88.46c	87.59a	86.54b	87.45c
1,000 W	77.99b	88.75a	87.65b	87.08b	87.28d	85.70b	86.22b	86.34d

Table 9b The changes of color (a*) of sweetened taro paste during 8 weeks of storage time

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
450 W	8.79a	6.39a	1.03a	2.59a	-0.57a	3.49a	1.52a	-0.48a
600 W	0.78c	-1.65b	-3.54c	-3.07c	-5.00b	-2.19c	2.97b	-5.47c
850 W	3.19b	-2.43bc	-1.55b	-0.82b	-2.18a	1.52b	0.55a	-2.79b
1,000 W	2.51bc	-3.86c	-0.16ab	0.14b	-0.68a	0.57b	0.11a	-2.35b

Table 9c The changes of color (b*) of sweetened taro paste during 8 weeks of storage time

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
450 W	29.40a	40.99c	42.49b	42.14b	42.88b	42.82b	43.90b	42.25b
600 W	29.06a	42.75b	44.10a	44.36a	44.93a	45.06a	44.88a	44.74a
850 W	29.97a	44.10a	44.64a	45.01a	45.88a	45.66a	45.90a	45.81a
1,000 W	29.54a	43.46ab	44.70a	44.54a	45.06a	45.06a	44.71a	46.42a

a, b, c,… compared in row (effect of various treatment)

CHAPTER 5
SUMMARY

In this study, the attention was drawn to examine the addition of emulsifier and arabic gum to the sweetened taro paste and investigated the changes in textural properties of the products at a period of storage time. Moreover, the further experiment was focused on the investigation of microwave treatment at different energy powers and how much it could not only reduce the moisture content of the sweetened taro paste but also impact on the product color and textural properties during 8 weeks of storage. As expected, the study could provide an optimal process condition for the future industrial application.

The information as shown in the texture maps was so useful to the food scientists who wished to relate parameters such shear stress and shear strain of the product at fracture to its textural characteristics. These mechanical properties were important to consumer perception. This could provide a systematic method to evaluate the texture of taro paste.

According to this study, the experiment found that the addition of SSL and GMS into the sweetened taro paste contributed much less cohesive paste and also exhibited mushier characteristics than the emulsifier-free taro paste during 8 weeks of storage. On the contrary, the supplementation with arabic gum provided taro paste notably elastic characteristic improvement. The higher application of microwave energy power, the shorter taro paste cooking time obtained, and the faster to remove the moisture from the taro paste without any problem of discoloration. The lowest energy applied microwave heating at 450 W resulted in the longest processing time and led to change the textural characteristics to be tougher than the utilization of higher energy power.

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APPENDIX

Raw Material Specification

1. Glycerol mono stearate (GMS SE)

Manufacturer Oleofine Organics (Thailand) Co.,Ltd

Specification

Appearance	White or off white powder
Acid Value	3.0 Max
Iodine Value	2.0 Max
Melting point	55 – 61°C
Monoester content	40 – 45%

2. Sodium Stearoyl 2 Lactylate (SSL)

Manufacturer Oleofine Organics (Thailand) Co.,Ltd

Specification

Appearance	Creamish powder
Ester Value	115 - 140
Acid Value	75 - 100
Melting point	45 – 55°C
Moisture	2.0% Max

3. INSTANTGUM BA

Manufacturer Colloides Naturels International (France) Co., Ltd

Specification

Content	Acacia gum purified and instantised
Moisture	10% Max
Ash @ 600 °C	4% Max
pH (25% sol. @ 20°C)	4.1 – 5.0
Mesh size powder through 75 µm	15% Max
Viscosity (25% Brookfield LVF 60 rpm @ 20°C)	60 – 100 mPa.s

4. Fat Powder (80% palm)

Manufacturer MOLDA AG (Germany)

Specification

Description	Spray dried powder of vegetable fat and carrier
Ingredients	Hydrogenated vegetable fat, glucose syrup, lactoprotein
Appearance	White color, compact, fine powder
Moisture	2.0% Max
Peroxide value	1.0 meqO_2/kg Max
Fat content	75.0 – 81.0%
Sieve > 0.5 mm	1.0% Max

BIOGRAPHY

Researcher	Mr. Suphachai Raksaphol
Address	367 Sathupradij Rd., Bangpongpang Yannawa, Bangkok 10120. Thailand

Education

2000	B. Sc. (Product Development Technology) Agro-industry faculty, Chiang Mai University
2006	Studying for Master’s degree (Food Technology) at Silpakorn university
2008	MBA. (Manangment) Ramkhumhaeng University

Work Experience

2000 – 2001	R&D Supervisor Food & Drink Public Company Limited
2001 – 2005	Researcher Thai President Food Public Company Limited
2005 – Present	R&D Manager Food Blessing (1988) Company Limited