



**UNIVERSITI PUTRA MALAYSIA**

**MODIFICATION OF WHEAT, SAGO AND TAPIOCA STARCHES BY  
IRRADIATION AND ITS EFFECT ON THE PHYSICAL PROPERTIES  
OF FISH CRACKERS (KEROPOK)**

**NORANIZAN BINTI MORD ADZAHAN**

**FSMB 2002 5**

**MODIFICATION OF WHEAT, SAGO AND TAPIOCA STARCHES BY  
IRRADIATION AND ITS EFFECT ON THE PHYSICAL PROPERTIES OF  
FISH CRACKERS (KEROPOK)**

By

**NORANIZAN BINTI MOHD ADZAHAN**

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

**January 2002**

*Specially dedicated to all my family members...*

*...Abah, Ummi, Abang Yuz, Kakak and Zuf*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

**MODIFICATION OF WHEAT, SAGO AND TAPIOCA STARCHES BY IRRADIATION AND ITS EFFECT ON THE PHYSICAL PROPERTIES OF FISH CRACKERS (KEROPOK)**

By

**NORANIZAN BINTI MOHD ADZAHAN**

**January 2002**

**Chairman: Dzulkiily Mat Hashim**

**Faculty: Food Science and Biotechnology**

The effect of starch irradiation on the properties of fish crackers in relation to microstructure of starch in 'keropok' was investigated. Wheat, tapioca and sago starch were used. Linear expansion of 'keropok' was best when the swelling of granules, leaching of amylose and amylopectin were high. Irradiation has been investigated as a means of degrading the starch polymers, which leads to an increase in the amount of soluble materials leached. Microwave, electron beam and gamma ray irradiation were used to degrade the starch polymers. The Brabender Viscograph, Texture Analyser (TAXT2-*i*), Falling Ball Viscometer and Haake Rheometer were used to determine the rheological properties of the starch pastes and gels. Results showed that irradiation caused an increase in leaching, a concomitant drastic reduction in swelling volumes of starch granules, and rate of gelation. It also showed that the strength of starch gels, viscosity, viscoelasticity and intrinsic viscosity decreased as the levels of irradiation was increased, indicating a decrease in the molecular weight of starch polymers. These changes were due to the cleavage of the amylose and amylopectin fractions by radiation energy. Fish crackers made from irradiated wheat starches expanded significantly better than the native starch and

were crispier. However, after a certain level of irradiation, the expansion decreased although the values remained higher than the expansion values for 'keropok' from native starch. The expansion of some of these wheat and sago starches improved greatly as the values exceeded the acceptable level *i.e.*, 77% expansion. 'Keropok' from microwave irradiated tapioca starch expanded significantly better than its native starch. On the other hand, electron beam and gamma irradiated tapioca starches seemed to produce 'keropok' with poor expansion properties and worse than the native starch. Good expansion was found in 'keropok' made from starches with high amounts of leaching and high molecular weight. Irradiated starch fish crackers were found to fracture at lower energy and had better crispiness properties despite that some crackers did not expand well. As a conclusion, irradiation of starch can improve the expansion and crispiness of fish crackers as it increases the leaching of amylose and amylopectin from the starch granules. The amylose and amylopectin can then be involved in the formation of starch-fish network, which allows the entrapment of water and will aid expansion during frying. The presence of higher molecular weight amylose and amylopectin will further contribute to better formation of this network. The ratio of amylose and amylopectin in the leachate would play a role in expansion, where higher amounts of amylopectin would give a better expanded fish crackers. High swelling ability and protein contents in starch are also contributing factors to expansion.

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

**PENGUBAHSUAIAN KANJI GANDUM, SAGU DAN UBI KAYU  
MENGUNAKAN RADIASI DAN KESANNYA KE ATAS CIRI-CIRI  
FIZIKAL KEROPOK IKAN**

Oleh

**NORANIZAN BINTI MOHD ADZAHAN**

**Januari 2002**

**Pengerusi: Dzulkiily Mat Hashim**

**Fakulti: Sains Makanan dan Bioteknologi**

Kesan radiasi kanji ke atas ciri-ciri keropok ikan dari segi mikrostruktur kanji dalam keropok telah dikaji. Kanji gandum, ubi kayu dan sagu digunakan. Pengembangan linear keropok adalah paling baik apabila pengembangan granul kanji dan larut lesap amilosa/amilopektin adalah tinggi. Radiasi merupakan suatu cara memendekkan polimer kanji yang akan membawa kepada penambahan amaun bahan terlarut yang telah terkeluar dari granul. Gelombang mikro, pancaran electron dan sinar gamma telah digunakan untuk memendekkan polimer kanji. Brabender Viscograph, Texture Analyser (TAXT2-i), Falling Ball Viscometer dan Rheometer telah digunakan bagi menentukan ciri-ciri aliran pes dan gel kanji. Keputusan yang diperolehi menunjukkan bahawa radiasi telah menyebabkan pertambahan lelehan, pengurangan isipadu pengembangan granul yang ketara serta pengurangan kadar pembentukan gel secara serentak. Keputusan juga telah menunjukkan bahawa kekuatan gel kanji, kelikatan, ciri-ciri viskoelastik dan kelikatan intrinsik berkurang dengan peningkatan paras radiasi. Ini menandakan pengurangan berat molekul polimer kanji. Perubahan-perubahan ini adalah disebabkan pemotongan fraksi amilosa dan amilopektin menerusi tenaga radiasi. Keropok ikan yang diperbuat daripada kanji

gandum yang telah dikenakan radiasi kembang dengan nyata, lebih baik dari pengembangan oleh keropok yang diperbuat dari kanji gandum biasa. Keropok dari kanji gandum teriradiasi ini lebih rangup berbanding kanji gandum biasa. Walaubagaimanapun, selepas paras tertentu semasa radiasi, pengembangan keropok merosot sungguhpun nilainya masih lebih tinggi dari keropok kanji biasa. Pengembangan sesetengah kanji gandum dan sagu meningkat dengan baik sehingga melebihi paras yang boleh diterima iaitu pengembangan 77%. Keropok daripada kanji ubi kayu yang telah dikenakan gelombang mikro didapati kembang lebih baik daripada kanji pengembangan kanji biasa. Sebaliknya, kanji ubi kayu yang dikenakan radiasi elektron dan sinar gamma menghasilkan keropok yang pengembangannya kurang baik berbanding kanji biasa. Pengembangan yang baik didapati disumbangkan oleh kandungan lelehan yang tinggi serta berat molekul yang tinggi. Keropok dari kanji teriradiasi didapati lebih mudah pecah dengan tenaga yang rendah serta rangup. Sebagai kesimpulan, rawatan radiasi ke atas kanji boleh memperbaiki pengembangan dan kerangupan keropok ikan kerana ia meningkatkan lelehan amilosa dan amilopektin dari granul kanji. Amilosa dan amilopektin akan terlibat dengan pembentukan jaringan kanji-ikan yang akan memerangkap air bagi tujuan pengembangan semasa menggoreng. Kehadiran amilosa dan amilopektin yang mempunyai berat molekul yang tinggi akan seterusnya menyumbang kepada pembentukan jaringan yang lebih baik. Nisbah amilosa dan amilopektin di dalam lelehan akan memainkan peranan dari segi pengembangan yang mana mana yang tinggi akan menghasilkan keropok yang baik pengembangannya. Kebolehan untuk granul mengembang dengan baik dan kandungan protein dalam kanji yang tinggi adalah merupakan penyumbang kepada pengembangan keropok.

## ACKNOWLEDGEMENTS

All praise due to Allah, the most gracious and merciful, for giving me the strength, health and determination to complete this research study. I would like to express my deepest appreciation and gratitude to the Chairman of my supervisory committee, En. Dzulkifly Mat Hashim for his patience, invaluable guidance and suggestions throughout the planning and extension of this research. I am eternally grateful to my co-supervisor, Assoc. Prof. Dr. Sharifah Kharidah Syed Muhammad and the coordinator for graduate studies in the faculty, Prof. Hasanah Mohd Ghazali for their attention, support and constant encouragement. I would like to express my sincere gratitude to Assoc. Prof. Dr. Russly Abdul Rahman, Dr. Zulkafli Ghazali and Dr. Kamarudin Hashim for their guidance, suggestions and insightful comments as members of the supervisory committee. I wish to acknowledge with thanks the staff of MINT, Electron Microcopy Unit, and Faculty of Engineering, UPM for the facilities and technical assistance provided. I would also like to thank all my friends especially Liyana, Benchamaporn and Choo Wee Sim for their support and cooperation throughout the whole period of this study. Appreciation is extended to Mr. Kyaw Zay Ya, En. Azman, Pn. Jamaliah, En. Amran, En. Soib, En. Mohd. Noh and En. Mustafa for their assistance in making this project possible. Finally, I would like to express a special note of appreciation to my beloved parents for their help in editing and providing ideas, advice and support throughout the duration of the project.



## TABLE OF CONTENTS

	<b>Page</b>
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiv
LIST OF FIGURES	xvi
LIST OF PLATES	xix
LIST OF SYMBOLS AND ABBREVIATIONS	xxii
 <b>CHAPTER</b>	
1 GENERAL INTRODUCTION	1
2 LITERATURE REVIEW	5
Starch	5
Starch Granules	6
Structure and Morphology	6
Starch Components	9
Composition of Starches	14
Starch Cooking Phenomena	15
Factors Affecting Starch Gelatinization	17
Physico-Chemical Properties of Starches	19
Starch Swelling and Solubility	19
Leaching of Amylose	23
Starch Retrogradation	26
Relationship Between Gelation, Chain Length and Molecular Weight of Starch	28
Starch Modification	31
Irradiation and Safety of Irradiated Food	33
Types of Radiation	35
Starch Irradiation	38
Mechanisms of Radiolysis	42
Degradation of Starches	43
Rheological Behaviour of Starches	45
Dilute Solutions	47
Starch Gels	48
Factors Affecting the Viscoelastic Properties of Starch Gels	50
Half-Product Expanded Snacks	51
Functionality of Starch in Expanded Snacks	52
Processing of Fish Cracker	54

	Traditional Method	54
	Improved Method	54
	Linear Expansion and Crispiness of Fish Cracker	57
	Structure of Expanded Products by Scanning Electron Microscopy (SEM)	59
3	EFFECTS OF IRRADIATION ON THE PHYSICO-CHEMICAL PROPERTIES OF STARCH	60
	Introduction	60
	Experimental	62
	Raw Materials	62
	Microwave Irradiation	62
	Electron Beam Irradiation	62
	Gamma Ray Irradiation	63
	Moisture Content	63
	Pasting Profile	64
	Swelling Volume	64
	Leaching of Carbohydrates	65
	Leaching of Amylose	65
	Granule Morphology	66
	Statistical Analysis	66
	Results and Discussion	67
	Conversion of Units	67
	Moisture Content	68
	Pasting Characteristics	70
	Swelling Volume	82
	Leaching Properties	86
	Amylose-Amylopectin Ratio	93
	Granule Morphology	96
	Conclusion	104
4	RHEOLOGICAL CHARACTERIZATION OF IRRADIATED STARCHES	105
	Introduction	105
	Experimental	107
	Raw Materials	107
	Gel Strength	107
	Determination of Intrinsic Viscosity	108
	Viscoelastic Measurements of Starch Gels	110
	Viscoelastic Measurements During Ageing of Concentrated Starch Pastes	110
	Statistical Analysis	111
	Results and Discussion	112
	Gel Strength	112
	Relationship Between Gel Strength and Amylose to Amylopectin Ratio	118

	Viscoelastic Behaviour of Starch Gels	125
	Correlation Between $\tan \delta$ and Gel Strength	130
	Rate of Retrogradation	130
	Degree of Polymerization (DP)	136
	Relationship Between the Gelling Properties and Amylose-Amylopectin Ratio	138
	Conclusion	141
5	EFFECTS OF IRRADIATED STARCHES ON THE PROPERTIES OF FISH CRACKERS ('KEROPOK')	142
	Introduction	142
	Experimental	145
	Raw Materials	145
	Preparation of Fish Crackers	145
	Linear Expansion of Fish Crackers	146
	Texture Analyses	146
	Morphology of Fried Fish Crackers	147
	Statistical Analysis	147
	Results and Discussion	148
	Textural Properties of Fish Crackers	148
	Morphology of Fried Fish Cracker	153
	Relationship Between Hardness, Linear Expansion and Toughness	168
	Leaching of Amylose and Amylopectin and Its Relations to the Properties of Fish Crackers	174
	Conclusion	183
6	SUMMARY, GENERAL CONCLUSIONS AND RECOMMENDATIONS	184
	Summary	184
	Conclusions	187
	Recommendations for Further Research	187
	REFERENCES	189
	APPENDIX A	207
	APPENDIX B	209
	BIOGRAPHICAL SKETCH	222

## LIST OF TABLES

<b>Tables</b>		<b>Page</b>
1	Properties of starch components	13
2	Chemical composition of starches	14
3	Amylose and amylopectin contents	14
4	Physical and chemical properties of common starches	24
5	Characteristics of gelatinized and cooled starch dispersions	25
6	Effects of chain length and number of helical turns on the colour produced by starch	30
7	Effect of irradiation on viscosity and degree of polymerization of potato amylose	42
8	Organoleptic evaluation of steamed fish cracker gels	58
9	Effect of protein content of flour on the linear expansion of 'keropok'	58
10	Absorbed energy of irradiated starches	68
11	Moisture content of native and irradiated starches	69
12	Pasting characteristics of native and irradiated tapioca starch	79
13	Pasting characteristics of native and irradiated sago starch	80
14	Pasting characteristics of native and irradiated wheat starch	81
15	Swelling volume of starches exposed to various irradiation conditions	83
16	Leaching properties of starches exposed to irradiation	89
17	Amylose content and maximum leaching of amylose for irradiated starches	90
18	Leaching of amylose and amylopectin exposed to various conditions of irradiation	95
19	Strength of gels for starches exposed to exposed to various conditions of irradiation	115
20	Effect of irradiation on the intrinsic viscosity and molecular weight of starches	123
21	The $\tan \delta$ and gel strength of starch gels (measured at a frequency of 1 Hz) irradiated under different modes of irradiation	129
22	Rate of retrogradation for native and irradiated starches	135

23	Degree of polymerization of native and irradiated starches	136
24	Textural properties of fish crackers from native and irradiated starches	150
25	Physical properties of native and irradiated tapioca starch fish crackers	157
26	Physical properties of native and irradiated wheat starch fish crackers	162
27	Physical properties of native and irradiated sago starch fish crackers	167
28	Factors influencing the linear expansion of fish crackers made from native and irradiated wheat starches	178
29	Factors influencing the linear expansion of fish crackers made from native and irradiated sago starches	179
30	Factors influencing the linear expansion of fish crackers made from native and irradiated tapioca starch fish crackers	180
31	Characteristics of Ball No. 2	208

## LIST OF FIGURES

<b>Figures</b>		<b>Page</b>
1	Starch structure	7
2	Mechanism of cooking and retrogradation of starch	16
3	Electromagnetic spectrum	35
4	Traditional method for fish cracker processing	55
5	Improved method for fish cracker processing	56
6(a)	Brabender viscograms of native and microwave irradiated sago starch treated at various time of exposure	72
6(b)	Brabender viscograms of native and microwave irradiated tapioca starch treated at various time of exposure	73
6(c)	Brabender viscograms of native and microwave irradiated wheat starch treated at various time of exposure	73
6(d)	Brabender viscograms of native and electron beam irradiated sago starch treated at various irradiation doses	74
6(e)	Brabender viscograms of native and electron beam irradiated tapioca starch treated at various irradiation doses	74
6(f)	Brabender viscograms of native and electron beam irradiated wheat starch treated at various irradiation doses	75
6(g)	Brabender viscograms of native and gamma ray irradiated sago starch treated at various irradiation doses	75
6(h)	Brabender viscograms of native and electron beam irradiated tapioca starch treated at various irradiation doses	76
7	Swelling volume of starches exposed to energy levels of various irradiation sources	84
8(a)	Leaching properties of sago starches exposed to various irradiation conditions	86
8(b)	Leaching properties of tapioca starches exposed to various irradiation conditions	87

8(c)	Leaching properties of wheat starches exposed to various irradiation conditions	87
9(a)	Leaching of amylose (AML) and amylopectin (APL) in sago starches exposed to different conditions of irradiation	91
9(b)	Leaching of amylose (AML) and amylopectin (APL) in tapioca starches exposed to different conditions of irradiation	92
9(c)	Leaching of amylose (AML) and amylopectin (APL) in wheat starches exposed to different conditions of irradiation	92
10	Gel strength of starches exposed to various conditions of irradiation	117
11	Effects of amylose to amylopectin ratio on the gel strength of starches that has been subjected to different irradiation treatments	118
12(a)	Mechanical spectrum of native and irradiated sago starch gels	126
12(b)	Mechanical spectrum of native and irradiated tapioca starch gels	126
12(c)	Mechanical spectrum of native and irradiated wheat starch gels	127
13(a)	Tan $\delta$ as a function of frequency for native and irradiated sago starches	127
13(b)	Tan $\delta$ as a function of frequency for native and irradiated tapioca starches	128
13(c)	Tan $\delta$ as a function of frequency for native and irradiated wheat starches	128
14	Effect of different modes of irradiation on tan $\delta$ (1Hz) of starch gels	131
15	Correlation between tan $\delta$ at 1 Hz and strength of starch gels	131
16(a)	Storage modulus as a function of time for native and irradiated sago starches at 25°C	133
16(b)	Storage modulus as a function of time for native and irradiated tapioca starches at 25°C	133
16(c)	Storage modulus as a function of time for native and irradiated wheat starches at 25°C	134
17	Force-extension curve showing definition of strength and toughness	148

18	Effect of irradiation on linear expansion of 'keropok'	152
19	Effect of irradiation on the hardness of 'keropok'	152
20	Effect of linear expansion on the strength of 'keropok'	169
21	Relationship between energy to fracture and strength of 'keropok'	169
22	Effect of linear expansion on energy to fracture 'keropok'	170
23	Force-deformation curve of native starch 'keropok'	173
24	Force-deformation curve of native and irradiated wheat starch 'keropok'	173
25	The effect of amylose leaching on the linear expansion of 'keropok'	176
26	The effect of amylopectin leaching on the expansion of 'keropok'	176



## LIST OF PLATES

<b>Plates</b>	<b>Page</b>
1 (a) Native wheat starch	98
1 (b) Microwave irradiated wheat starch - 10 minutes	98
1 (c) Electron beam irradiated wheat starch - 30 kGy	99
1 (d) Gamma ray irradiated wheat starch - 20 kGy	99
2 (a) Native sago starch	100
2 (b) Microwave irradiated sago starch - 10 minutes	100
2 (c) Electron beam irradiated sago starch - 30 kGy	101
2 (d) Gamma ray irradiated sago starch - 20 kGy	101
3 (a) Native tapioca starch	102
3 (b) Microwave irradiated tapioca starch - 10 minutes	102
3 (c) Electron beam irradiated tapioca starch - 30 kGy	103
3 (d) Gamma ray irradiated tapioca starch - 20 kGy	103
4 (a) Haake Falling Ball Viscometer (Model KF 10)	122
4 (b) Ring marks to measure flow time	122
5 (a) SEM photomicrographs of 'keropok' made from native tapioca starch	154
5 (b) SEM photomicrographs of 'keropok' made from tapioca starch that was microwaved for 10 minutes	154
5 (c) SEM photomicrographs of 'keropok' made from tapioca starch that was irradiated by electron beam at 15kGy	155
5 (d) SEM photomicrographs of 'keropok' made from tapioca starch that was irradiated by electron beam at 30kGy	155
5 (e) SEM photomicrographs of 'keropok' made from tapioca starch that was irradiated by gamma ray at 20kGy	156
6 (a) SEM photomicrographs of 'keropok' made from native wheat starch	159
6 (b) SEM photomicrographs of 'keropok' made from wheat starch that was microwaved for 10 minutes	159
6 (c) SEM photomicrographs of 'keropok' made from wheat starch that was irradiated by electron beam at 5kGy	160
6 (d) SEM photomicrographs of 'keropok' made from wheat starch that was irradiated by electron beam at 20kGy	160

6 (e)	SEM photomicrographs of 'keropok' made from wheat starch that was irradiated by electron beam at 30kGy	161
6 (f)	SEM photomicrographs of 'keropok' made from wheat starch that was irradiated by gamma ray at 15kGy	161
7 (a)	SEM photomicrographs of 'keropok' made from native sago starch	164
7 (b)	SEM photomicrographs of 'keropok' made from sago starch that was irradiated by electron beam at 5kGy	164
7 (c)	SEM photomicrographs of 'keropok' made from sago starch that was irradiated by electron beam at 30kGy	165
7 (d)	SEM photomicrographs of 'keropok' made from sago starch that was irradiated by gamma ray at 5kGy	165
7 (e)	SEM photomicrographs of 'keropok' made from sago starch that was irradiated by gamma ray at 15kGy	166
7 (f)	SEM photomicrographs of 'keropok' made from sago starch that was irradiated by gamma ray at 5kGy	166
8 (a)	Microwave irradiated wheat starch – 6 minutes	209
8 (b)	Electron beam irradiated wheat starch – 5kGy	209
8 (c)	Gamma ray irradiated wheat starch – 15kGy	210
8 (d)	Gamma ray irradiated wheat starch – 20kGy	210
8 (e)	Electron beam irradiated sago starch – 30kGy	211
8 (f)	Gamma ray irradiated sago starch – 10kGy	211
8 (g)	Gamma ray irradiated sago starch – 20kGy	212
8 (h)	Gamma ray irradiated sago starch – 20kGy	212
8 (i)	Gamma ray irradiated sago starch – 20kGy	213
8 (j)	Microwave irradiated tapioca starch – 6 minutes	213
9	Microwave oven	214
10	Electron beam machine	214
11	Gamma chamber	215
12	Brabender Amylograph	215
13	Texture Analyser	216
14	Scanning Electron Microscope	216
15	Haake Rheometer	217
16	Deboner	217
17	Sausage stuffer	218

18	Fish crackers from native and irradiated sago starch	219
19	Fish crackers from native and irradiated tapioca starch	220
20	Fish crackers from native and irradiated wheat starch	221

## LIST OF SYMBOLS AND ABBREVIATIONS

### Symbols

$\alpha$	alpha
$\gamma$	Gamma
$\mu\text{m}$	micrometer
kGy	kiloGray
Co	Cobalt

### Abbreviations

AM	Amylose
AML	Amylose leaching
AP	Amulopectin
APL	Amylopectin leaching
BU	Brabender Units
CHO	Carbohydrate
CHOL	Carbohydrate leaching
EB	Electron beam
G'	Elastic Modulus
G''	Loss Modulus
SAS	Statistical Analysis System
SEM	Scanning Electron Microscope

## CHAPTER 1

### GENERAL INTRODUCTION

Fish crackers or 'keropok' is a high-protein snack food popular in ASEAN countries. In Malaysia, its production was reported as the third largest industry (12%) that was listed under the processed marine fish products with 12,801.43 weight in tonnes (Department of Fisheries Malaysia, 1998). 'Keropok' is made from gelatinised starch pastes, which are dried and then puffed by frying in hot oil (Siaw *et al.*, 1985). The type of starch used is normally sago or tapioca starch and the type of fish used should contain more than 200g/kg protein (Malaysian Food Act, 1985). The quality of fish crackers is judged from their crispiness, which can be determined mechanically or through sensory evaluation. In this study, mechanical determination is used to measure crispiness. Linear expansion of 'keropok' is also a measure of crispiness. The type of starch used in the system mainly influences expansion and crispiness. Different types of starch give different properties to the 'keropok'.

In the processing of fish crackers, sago or tapioca starch is often used. These starches give the cracker its good expansion property. Wheat starch has never been used due to its poor expansion property. The main differences between sago or tapioca starch with wheat starch are the leaching and swelling ability during cooking. In wheat starch, the naturally existing amylose-lipid complex inhibits swelling of the granules. This leads to inhibition of leaching of the starch polymers: amylose and amylopectin.

Wheat starch is among the most abundant starch. The world production in 1999 was reported to be 597.8 million tonnes, about 12% of the overall starch production (FAO, 1999). It has been widely utilized in the baking industry and is a by-product of the paper industry. Wheat starch has the A-type starch properties such as low swelling and leaching ability, opaque and moderate gel strength, and high in lipid and protein contents. The swelling ability was inhibited by the high lipid and protein contents. When swelling is inhibited, granules could not imbibe water and leaching of the starch polymers was limited. In wheat starch, most of the amylose will be solubilized before leaching of amylopectin begins but in oat starch co-leaching of amylose and amylopectin; or amylose and intermediate material occurred (Doublier et al, 1987). However, not all amylose leaches out during cooking. Some of it remains in the granules (“ghost” structure), that consist of mainly amylopectin (not in crystalline order).

The ratio of amylose to amylopectin leaching in starch greatly influences starch expansion and in the end affects the extent of puffing and texture of fried or extruded starch-based products. Besides amylose and amylopectin ratio in the granule, lipid content is also a factor influencing the swelling and leaching property of starch. Lipid forms complexes with amylose to inhibit swelling and leaching. This would affect the end product of a particular food. The consequence has been proven in fish crackers made from wheat, sago and tapioca starches. The amount of leaching varies for different types of starch and follows the order: sago (29.23%) > tapioca (26.83%) > wheat (16.43%) (Kyaw, 1999). The subdued leaching is attributed to the amylose-lipid complex in wheat starch that inhibits swelling. Sago and tapioca starches contain very small amount of lipid, therefore no inhibition to swelling and leaching occurred. Sago, wheat and tapioca starches contain 27%, 25% and 17% amylose,