PHYSICOCHEMICAL CHARACTERIZATION OF GAMMA IRRADIATED SAGO STARCH AND RICE STARCH

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ABSTRACT

In this study, sago and rice starches were subjected to gamma irradiation treatment at 5, 10, 25 and 50 kGy. Effects of irradiation on physicochemical properties of starches were investigated. Cleavage of starch molecules by irradiation induced the formation of carboxylic acid which in turn increased the carboxyl content and reduced pH value of both starches ($p<0.05$). Sago starch showed greater alteration in carboxyl content and pH than rice starch. Severe degradation of amylose fractions by irradiation significantly decreased amylose content at high dosage ($p<0.05$), where greater reduction was showed by rice starch irradiated at 50 kGy. Rice starch (A-type polymorphic) had greater decrease in the degree of ordered structure than sago starch (C-type polymorphic). The reduction of the molecular size due to irradiation also resulting in declination of swelling power and turbidity while increased solubility of starch as irradiation dose increased ($p<0.05$). Sago starch showed greater reduction in swelling power than rice starch at 50 kGy ($p<0.05$). Syneresis was found at high irradiation doses where rice starch irradiated at 50 kGy showed highest percentage of syneresis ($p<0.05$). The major pasting profile parameters decreased drastically with increasing irradiation doses in both starches ($p<0.05$), particularly for rice starch irradiated at 50 kGy. Gelatinization temperature for sago starch increased as irradiation dose increased, while opposite trend was observed in rice starch ($p<0.05$). Irradiation did not affect retrogradation of sago starch ($p>0.05$), whereas it induced retrogradation in rice starch with increasing doses ($p<0.05$). The rheological study showed reduction of viscosity as irradiation doses increased for both starches. Higher irradiation dosage (25 and 50 kGy) was found to damage the gel-forming ability of starch. Microscopic observation under Scanning Electron Microscope (SEM) showed granular size reduction at higher irradiation dosage.

ABSTRAK

PENCIRIAN SIFAT FIZIKOKIMIA KANJI SAGU DAN KANJI BERAS TERIRADIASI GAMA

Dalam kajian ini, kanji sagu dan kanji beras dirawat dengan sinaran gama pada 5, 10, 25 dan 50 kGy. Kesan rawatan iradiasi ke atas ciri-ciri fizikokimia kanji telah dikaji. Pemecahan molekul kanji oleh iradiasi mendorong pembentukan asid karboksilik seterusnya meningkatkan kandungan karboksil dan menurunkan nilai pH kedua-dua jenis kanji ($p<0.05$). Kanji sagu menunjukkan perubahan yang lebih besar dari segi kandungan karboksil dan pH berbanding dengan kanji beras. Kemusnahan pecahan amilosa disebabkan oleh iradiasi mengakibatkan penurunan kandungan amilosa pada dos yang tinggi ($p<0.05$), di mana penurunan yang lebih tinggi telah ditunjukkan pada kanji beras yang teriradiasi pada 50 kGy. Kanji beras (polimofik jenis-A) menunjukkan penurunan keteraturan struktur yang lebih tinggi berbanding dengan kanji sagu (polimofik jenis-C). Pengurangan saiz molekul oleh iradiasi turut mengakibatkan kemerosotan kuasa pembengkakan dan kekeruhan tetapi meningkatkan keterlarutan seiring dengan peningkatan dos iradiasi ($p<0.05$). Kanji sagu menunjukkan penurunan kuasa pembengkakan yang lebih tinggi berbanding dengan kanji beras pada dos 50 kGy ($p<0.05$). Sineresis pada dos sinaran gama yang tinggi diperhatikan di mana kanji beras teriradiasi pada 50 kGy menunjukkan peratusan sineresis yang paling tinggi. Parameter utama profil pempesan bagi kedua-dua jenis kanji menurun secara mendadak dengan peningkatan dos iradiasi ($p<0.05$), terutamanya bagi kanji beras teriradiasi pada 50 kGy. Suhu penggelatinan bagi kanji sagu meningkat seiring dengan peningkatan dos iradiasi, manakala tren yang bertentangan diperhatikan pada kanji beras ($p<0.05$). Iradiasi tidak mempengaruhi retrogradasi kanji sagu ($p>0.05$), namun peningkatan dos iradiasi mendorong retrogradasi kanji beras ($p<0.05$). Kajian reologi bagi kedua-dua jenis kanji menunjukkan pengurangan kelikatan apabila dos iradiasi meningkat. Dos iradiasi yang tinggi (25 dan 50 kGy) didapati mengurangkan kemampuan pembentukan gel kanji. Pemerhatian mikroskopik dengan Mikroskop Imbasan Elektron (SEM) menunjukkan pengurangan saiz kanji pada dos iradiasi yang tinggi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

ANOVA	Analysis Of Variance
AOAC	Association Of Analytical Communities
DMSO	Dimethyl Sulfoxide
DSC	Differential Scanning Calorimetry
KBr	Potassium bromide
KI	Potassium Iodine
NaOH	Sodium Hydroxide
RPM	Revolutions per minute
RVA	Rapid Visco Analyser
RVU	Rapid Visco Unit
SEM	Scanning Electron Microscope
SPSS	Statistical Package For Social Science
rpm	Revolutions per minute

LIST OF UNIT

g	Gram
ml	Mililiter
°C	Degree celcius
M	Molarity
cm	Centimeter
kGy	Kilogray
mm	Milimeter
nm	Nanometer
mg	Milligram
Pa	Pascal
S	Second
Min	Minute

LIST OF SYMBOLS

=	Equal to
α	Alpha
×	Multiply
-	Deduct
%	Percentage
P	Significant value
<	Less than
r	Correlation coefficient
W	Weight
V	Volume

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Background

Starch is the main storage reserve carbohydrate and source of energy in plants. It is found in seeds, fruits, tubers and roots (Jobling, 2004; Wilson *et al.*, 2010). Nunez-Santiago *et al.* (2004) reported that starch represents an essential component of a lot of agricultural products such as cereals (corn, wheat and rice), legumes (bean, pea and faba) and tubers (potato, tapioca). Starch can be classified into three types based on the x-ray diffraction patterns, namely type-A which consists of cereal starches, type-B such as tuber starches as well as type-C including pea and bean starch (Pang *et al.*, 2007). In nature, starch exists as granules with various sizes ranging between 1 to 100μm in diameter, various shapes including spherical, lenticular, polyhedral and irregular shape, with uni-modal and bimodal distributions size, as well as in simple or compound forms which characterise their botanical source (Tester *et al.*, 2004; Dhital *et al.*, 2010).

Starch has found widespread application in the food industry due to its usefulness, versatility, cheap, natural resources as well as its ease to be chemically or physically modified to induce physicochemical properties changes (Jobling, 2004). The most important properties to determine the suitability of starches in food application are physicochemical properties such as gelatinization and retrogradation as well as its functional properties (solubility, swelling, water absorption, syneresis, gel formation) (Gani *et al.*, 2012a).

Native starch does not always have the physical and chemical properties which are suitable for certain processing category (Gani *et al.*, 2012a) as it is limited by their instability against thermal processing, shear, pH and cold storage, generally to processed foods application (Srichuwong *et al.*, 2012). Singh *et al.* (2011) also reported the limitation of native starch such as low shear, low thermal resistance and high affinity for retrogradation which limits their wide application and industrial use. Modification maybe required for their adaptability to wide application by improving the physicochemical and functional characteristics of starches.

According to Tester *et al.* (2004), starches may be physically, chemically or enzymatically modified to induce novel characteristics although native starch has a wide variation of granule dimensions and size distributions. Starch modification, which involves the alteration of the physical and chemical characteristics of the native starch to improve its functional characteristics, can be used to alter starch to suit specific food applications. Starch modification is generally achieved through acid or enzymatic hydrolysis, chemically modified by derivatization or conversion as well as physically modified through ionizing radiations, pre-gelatinization and heat–moisture treatment (Singh *et al.*, 2007).

Ionizing radiations such as UV, gamma or accelerated electrons that developed since many years on a large number of polymers are now frequently used on starches (Henry *et al.*, 2010). Irradiation treatment is one of the physical modifications of starch (Gani *et al.*, 2012a) and it can be a convenient tool for modification of polymer materials through cross-linking, grafting, and degradation techniques (Singh *et al.*, 2011). It has also been suggested as a rapid modification technique which breaks large molecules into smaller fragments and is capable of cleaving glycosidic linkages. Chemical bonds of starch can be hydrolysed by gamma irradiation leading to degradation of polymeric chain (Singh *et al.*, 2011). These free radical-generating radiations are able to lower the molecular weight of starches, altering their structure, and creating additional chemical functionalities on the ionized chains. The development of these properties may lead to increased water solubility as well as a decrease in swelling capacity and viscosity depending on botanical origin (Henry *et al.*, 2010). The changes in molecular structure and physicochemical properties of starch during gamma irradiation could help in design of new foods with high resistant starch (RS) content and high nutrient density (Chung *et al.*, 2010a).

Since chemical modification involves the presence of chemicals, there is concern for the safety issues by utilising chemical modification. According to Gani *et al.* (2012b), physical modification can be safely used as a modification process in food products as it does not involve any chemical. Chung *et al.* (2010a) also reported that gamma irradiated foods in the markets have been confirmed to be nutritious and safe for human consumption. Gamma irradiation treatment is essential due to its rapidness, independence on type of catalysts, require minimal sample preparation and do not induce a significant temperature increment (Gani *et al.*, 2012a). This shows the potential and benefits of utilising gamma irradiation in modifying starch properties over chemical modification.

Modified food starches generally show better paste clarity and stability, higher resistance to retrogradation, and freeze–thaw stability compared to its native form. Modified starches have almost unlimited food and nonfood applications which gaining more attention by food producers (Kang *et al.*, 1999). Besides, current market trends also motivating food producers towards natural source of food ingredients and minimising chemical treatments on starch. There is growing interest in discovering improvement of native starches properties without utilising chemical modification (Puncha-arnon *et al.*, 2008). For the time being, there is a great interest in utilising physical modification techniques such as gamma irradiation which are able to modify the physicochemical properties of starch (Jayakody and Hoover, 2008).

1.2 Objective

The objective of this study is to investigate the effect of gamma irradiation on physicochemical properties of rice and sago starch including thermal, pasting, rheological as well as morphological properties under various gamma irradiation doses (0, 5, 10, 25, and 50 kGy).

1.3 Importance of Study

Commercial starches including rice and sago starch have been chosen in this study to investigate the effect of gamma irradiation on physicochemical properties of starches. This is due to their wide application in food industry and from different botanical origins with distinct granular size. Physicochemical properties of starch have found to be affected by granular size, type of crystalline polymorphic and botanical origin (Chung and Liu, 2009). Therefore, a thorough comparison between effect of gamma irradiation on physicochemical properties against granular size and botanical sources can be determined. This study may provide helpful information in understanding the suitability of gamma irradiated starch in different food applications.

There are extensive researches being conducted to study the structural and physicochemical properties of gamma irradiated starches (Chung and Liu, 2009) such as corn (Chung and Liu, 2009; Chung *et al.*, 2010a), rice (Wu *et al.*, 2002), sago (Singhal *et al.*, 2008) and potato starch (singh *et al.*, 2011) respectively. Chung *et al.* (2010) reported that at higher dosage during irradiation could cause more resistant starch content in normal corn starch. Rombo *et al.* (2004) reported that higher irradiation doses will lead to a reduction in the molecular size of amylopectin in both bean and corn starches. In addition, more short and straight chain molecules (amylose-like molecules) are produced when irradiation doses increased. According to Bao *et al.* (2005), crystallinity of irradiated wheat and rice starches increases but decreases in potato starch with increasing irradiation dose. In addition, elevation of irradiation dosage increases water solubility and acidity of starches but decreases starches viscosity.

However, there are limited studies conducted to compare the physicochemical properties between rice starch and sago starch under same irradiation condition. This study provides an insight into the physicochemical properties of these two types of starches in a more systematic manner under the influence of similar conditions. This study will be able to determine the changes of physicochemical properties of different gamma irradiated food starches which in turn may be useful to investigate the potential and suitability of gamma irradiated starch in food applications.

Malaysia is one of the world's leading sago producers where Sarawak is the world's biggest exporter of sago to peninsular Malaysia and other countries. Sago starch is also the main carbohydrate source in Malaysia which has a low production cost and high yields as compared to other starches such as maize and cassava. Since sago is an excellent resource of starch with possible applications in food, polymer, pharmaceutical and textile industries, modification is needed to overcome the unstable properties of native sago starch as well as improving its quality and physical properties during processing (Singhal *et al.*, 2008). Therefore, the research findings on the effect of gamma irradiation on physicochemical properties of sago starch may be able to overcome the instability of its properties and possibly aid in widespread the application of sago starch in food industry and expand both domestic and global market.

CHAPTER 2

LITERATURE REVIEW

2.1 Starch

Starch is the most common storage carbohydrate in plants and also the largest source of carbohydrates in human food (Singh *et al.*, 2010). Starches from different botanical origin, growing conditions, mutations or maturity may be differed in chemical structures and physicochemical properties. Starch is deposited as insoluble, semi-crystalline granules in storage tissues such as grains, tubers and roots. Size of starch granules can vary from 1 to 100mm diameter and with various shapes such as polygonal, spherical and lenticular. Starch granule can be greatly different in relation to content, structure and organization of the amylose and amylopectin molecules, branching architecture of amylopectin as well as degree of crystallinity. In addition, granules can occur in uni-modal or bi-modal size distributions and in the form of individual or compound granules (Tester *et al.*, 2004; Copeland *et al.*, 2009). Form and functionality of starch varies greatly between botanical sources as well as same plant cultivar under different growing conditions. This variability provides starches with different functionality and diverse properties (Copeland *et al.*, 2009). Besides, starch is made up of two polymers of D-glucose, namely amylose, and amylopectin. Amylose and amylopectin make up 98–99% of the dry weight of native granules, with the remainder consisting of minor components such as lipids, minerals, and phosphorus (Copeland *et al.*, 2009).

Amylose is a relatively long, linear α–glucan containing around 99% of α-1,4 and α-1,6 linkages. Amylose varies in term of size and structure depending on the botanical source (Tester *et al.*, 2004). The molecular weight range of amylose is approximately 10^5 to 10^6, corresponding to a degree of polymerization (DP) of 1000–10,000 glucose units. In amylose, there are less than 0.5% of glucoses in α-1,6 linkages, causing in low degree of branching and a structure with 3–11 chains of around 200–700 glucose residues per molecule. Dissolved amylose has a tendency to form insoluble semi-crystalline aggregates due to low degree of branching, where it is very much depending on the position of branches in the structure (Tester *et al.*, 2004; Copeland *et al.*, 2009).

Amylose molecules tend to arrange themselves in a parallel form and come close to each other to allow hydrogen bonding between adjacent chains. This is due to their linear structure, mobility as well as many hydroxyl groups present along the polymer chains. Consequently, the water affinity for polymer is lowered and the solution turns into opaque. The interaction between amylose and iodine causes the formation of amylose-iodine complex with characteristic colour which varies according to amylose chain length. Besides, physicochemical properties of starch are greatly influenced by the botanical origins, its fractionation and purification conditions, molecular weight and molecular weight distribution of amylose. More stable complexes can be formed by long and saturated monoacyl chains whereas unsaturated monoglycerides have a poor complex-forming ability (Liu, 2005).

The iodine reaction is most commonly used for amylose content determination due to its specificity, sensitivity and easy to analyze qualitatively and quantitatively. Blue value method, potentiometric and amperometric titration method have been used for over 50 years. These procedures are based on the complex-forming ability of amylose with iodine, which exhibit a blue value colour determined by a maximum absorption wavelength above 620nm. All of the procedures based on iodine complex formation for amylose content determination might be measured as apparent amylose content. However, if the sample is defatted before potentiometric titration, the amylose content determined can be considered as absolute amylose content (Liu, 2005).

The amylose content determination may be influenced by many factors such as botanical origin, sample preparation and molecular structure of starch. The presence of intermediate materials, lipid, and long linear chains in amylopectin could affect the measurement of amylose content. The presence of monoacyl lipids in starch will form complexes with amylose during gelatinization which competes with iodine binding and hence lower the apparent amylose content (Liu, 2005). Figure 2.1 below shows the structure of amylose.

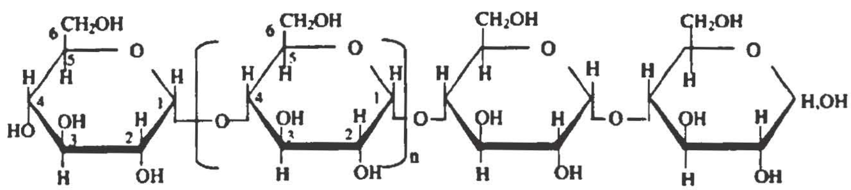

Figure 2.1: Structure of amylose.
Source: Tester *et al.*, 2004

Amylopectin is a much larger polymer compare to amylose with molecular weight of approximately 10^8 and a degree of polymerization (DP) that may exceed one million. The molecular size, shape, structure of the molecule varies with botanical origin (Tester *et al.*, 2004). Most starches contain about 60% to 90% of amylopectin, except for high-amylose starches with as little as 30% amylopectin and waxy starches with almost 100% amylopectin. Amylopectin has about 5% of its glucoses in α-1,6 linkages and about 95% in α-1,4 linkages, giving it a highly branched and tree-like structure. A complex molecular architecture can vary significantly between different starches depending on the placement and length of branches in the structure (Copeland *et al.*, 2009).

Amylopectin which is larger in size and with branched characteristic decrease its mobility in solution and eliminate the possibility of significant levels of inter-chain hydrogen bonding. Typically, amylopectin has one branch point every 20 to 25 residues where the branch points are not located at random (Liu, 2005). The amylopectin chains can be classified into three types according to their length and branching points or pattern of substitution. A-chains are defined as un-substituted or not carry any branch points while B-chains are substituted by other chains and a single C-chain carries the reducing glucose (Copeland *et al.*, 2009).

The presence of covalently linked phosphate monoesters is one of the unique features of amylopectin. They can be linked to the C3 or C6 position of the glucose monomers and it take place to a greater extent in tuber starch, particularly in potato starch. As the degree of phosphorylation at the C6 position increases, the gelatinization enthalpy decreases. Electrostatic repulsion between molecules increases as a result of the charged nature of phosphate monoesters, which causes changes in gelatinization and pasting properties of starch (Liu, 2005). The structure of amylopectin is showed in Figure 2.2.

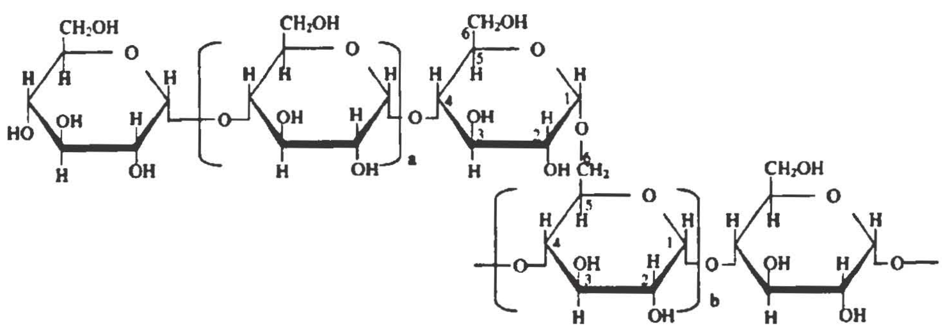

Figure 2.2: Structure of amylopectin.
Source: Tester *et al.*, 2004

2.1.1 Starch Structure

Starch granules are composed of two types of alphaglucan, amylose and amylopectin, which represent approximately 98–99% of the dry weight. The ratio of the two polysaccharides varies according to the botanical origin of the starch. The waxy starches contain less than 15% of amylose and normal starches contain about 20–35% amylose while the amylose content in high amylose starches are greater than 40% (Tester *et al.*, 2004).

Natural starches occur in different polymorphic forms as classified by X-ray diffraction pattern such as A-, B- and C-types. X-ray diffraction studies showed that most cereal starches, normal maize, rice, wheat and oats exhibited A-type diffraction pattern. Potato, lily, canna, and tulip starches show the B-type while several rhizome and legume starches belong to the C-type, which is a mixture of A- and B-types in different proportions (Chung and Liu, 2010). However, different classification of sago starch has been found in different studies. According to Srichuwong *et al.* (2005), sago starches were classified into A-type starches even

REFERENCE

Abdorreza, M.N., Robal, M., Cheng, L.H., Tajul, A.Y. and Karim, A.A. 2012. Physicochemical, thermal, and rheological properties of acid-hydrolyzed sago (Metroxylon sagu) starch. *LWT-Food Science and Technology.* **46**: 135-141.

Ackar, Đ., Babic, J., Šubaric, D., Kopjar, M. and Milicevic, B. 2010. Isolation of starch from two wheat varieties and their modification with epichlorohydrin. *Carbohydrate Polymers.* **81**: 76–82.

Adawiyah, D. R., Sasaki, T. and Kohyama, K. 2013. Characterization of arenga starch in comparison with sago starch. *Carbohydrate Polymers.* **92**: 2306–2313.

Adebowale, K. O. and Lawal, O. S. 2003. Microstructure, physicochemical properties and retrogradation behaviour of Mucuna bean (Mucuna pruriens) starch on heat moisture treatments. *Food Hydrocolloids.* **17**: 265–272.

Ahmad, F. B., Williams, P. A., Doublier, J.L., Durand, S. and Buleon, A. 1999. Physico-chemical characterisation of sago starch. *Carbohydrate Polymers.* **38**: 361–370.

Alvani, K., Qi, X., Tester, R. F. and Snape, C. E. 2011. Physico-chemical properties of potato starches. *Food Chemistry.* **125**: 958–965.

AOAC. 1990. Official methods of analysis (2000). 15th Edition, Virginia: Association of official analytical chemists, Inc.

Arvanitoyannis, I.S. 2010. Consumer behaviour towards irradiated food. *In* Arvanitoyannis, I.S. (ed.). *Irradiation of Food Commodities: Technique, Applications, Detection, Legislation, Safety and Consumer Opinion*, pp.673-698. United States of America: Academic Press.

Ashogbon, A.O. and Akintayo, E.T. 2012. Morphological, functional and pasting properties of starches separated from rice cultivars grown in Nigeria. *International Food Research Journal.* **19**(2): 665-671.

Ashley, B. C., Birchfield, P.T., Chamberlain, B.V., Kotwal, R.S., Mccellan, F.S., Moynihan, S., Patni, S.B., Salmon, S.A. and Au, W.W. 2004. Health concerns regarding consumption of irradiated food. *International Journal of Hygiene and Environmental Health*. **207**: 493-504.

Bao, J. And Corke, H. 2002. Pasting properties of ç-irradiated rice starches as affected by pH. *Journal of Agricultural and Food Chemistry*. **50**: 336-341.

Bao, J., Ao, Z. and Jane, J.-l. 2005. Characterization of physical properties of flour and starch obtained from gamma-irradiated white rice. *Starch/Stärke*. **57**: 480–487.

Bernabé, A. M., Srikaeo, K. & Schlüter, M. 2011. Resistant starch content, starch digestibility and the fermentation of some tropical starches in vitro. *Food Digestion*. **2**:37–42.

Bertolini, A. C. 2010. Trends in starch applications. *In* Bertolini, A. C. (ed.). *Starches: Characterization, Properties, and Applications*, pp. 6-15. United States of America: CRC Press.

Bhatti, I. A., Zia, K. M., Ali, Z., Zuber, M. and Rehman, F. 2012. Modification of cellulosic fibers to enhance their dyeability using UV-irradiation. *Carbohydrate Polymers*. **89**: 783– 787.

Blazek, J. and Gilbert, E. P. 2011. Application of small-angle X-ray and neutron scattering techniques to the characterisation of starch structure: A review. *Carbohydrate Polymers*. **85**: 281–293.

Byun, E.H., Kim, J. H., Sung, N.Y., Choi, J.I., Lim, S.T., Kim, K.H., Yook, H.S., Byun, M.W. and Lee, J.W. 2008. Effects of gamma irradiation on the physical and structural properties of ß-glucan. *Radiation Physics and Chemistry*. **77**: 781–786.

Chung, H.J. and Liu, Q. 2009. Effect of gamma irradiation on molecular structure and physicochemical properties of corn starch. *Journal of Food Science*. **74**(5): 353-361.

Chung, H.J. and Liu, Q. 2010. Molecular structure and physicochemical properties of potato and bean starches as affected by gamma-irradiation. *International Journal of Biological Macromolecules*. **47**: 214–222.

Chung, H.J., Lee, S.Y., Kim, J.H., Lee, J.W., Byun, M.W. and Lima, S.T. 2010a. Pasting characteristics and in vitro digestibility of γ-irradiated RS4 waxy maize starches. *Journal of Cereal Science.* **52**:53-58.

Chung, H.J., Liu, Q. and Hoover, R. 2010b. Effect of single and dual hydrothermal treatments on the crystalline structure, thermal properties, and nutritional fractions of pea, lentil, and navy bean starches. *Food Research International.* **43**: 501–508.

Ciesla, K. and Eliasson, A. C. 2002. Influence of gamma radiation on potato starch gelatinization studied by Differential Scanning Calorimetry. *Radiation Physics and Chemistry.* **64**: 137–148.

Copeland, L., Blazek, J., Salman, H. and Tang, M. C. 2009. Form and functionality of starch. *Food Hydrocolloids.* **23**: 1527–1534.

Crawford, L. M. and Ruff, E.H. 1996. A review of the safety of cold pasteurization through irradiation. *Food Control.* **7**(2): 87-97.

Darfour, B., Wilson, D.D., Ofosu, D.O. and Ocloo, F.C.K. 2012. Physical, proximate, functional and pasting properties of flour produced from gamma irradiated cowpea (Vigna unguiculata, L. Walp). *Radiation Physics and Chemistry.* **81**: 450–457.

Dhital, S., Shrestha, A. K. and Gidley, M. J. 2010. Relationship between granule size and in vitro digestibility of maize and potato starches. *Carbohydrate Polymers.* **82**: 480–488.

Dias, A. R. G., Zavareze, E. R., Spier, F., Castro, L. A. S. and Gutkoski, L. C. 2010. Effects of annealing on the physicochemical properties and enzymatic susceptibility of rice starches with different amylose contents. *Food Chemistry.* **123**: 711–719.

Dogan, M., Kayacier, A. and Erhan, I. 2007. Rheological characteristics of some food hydrocolloids processed with gamma irradiation. *Food Hydrocolloids.* **21**: 392–396.

Ezekiel, R., Rana, G., Singh, N. and Singh, S. 2007. Physicochemical, thermal and pasting properties of starch separated from gamma irradiated and stored potatoes. *Food Chemistry.* **105**: 1420–1429.

Farkasa, J. and Mohacsi-Farkas, C. 2011. History and future of food irradiation. *Trends in Food Science and Technology*. **22**: 121-126.

Gani, A., Bashir, M., Wani, S.M. and Masoodi, F.A. 2012a. Modification of bean starch by g-irradiation: Effect on functional and morphological properties. *LWT-Food Science and Technology*. **49**: 162-169.

Gani, A., Gazanfar, T., Jan, R., Wani, S.M. and Masoodi, F.A. 2012b. Effect of gamma irradiation on the physicochemical and morphological properties of starch extracted from lotus stem harvested from Dal lake of Jammu and Kashmir, India. *Journal of the Saudi Society of Agricultural Sciences*. **12**: 109-115.

Ghali, Y., Ibrahim, N. and Aziz, H. 1979. Modification of corn starch and fine flour by acid and gamma irradiation. Part 1. Chemical investigation of the modified product. *Starch/Starke*. **31**: 325–328.

Henry, F., Costa, L.C. and Aymes-Chodur, C. 2010. Influence of ionizing radiation on physical properties of native and chemically modified starches. *Radiation Physics and Chemistry*. **79**: 75–82.

Jayakody, L. and Hoover, R. 2008. Effect of annealing on the molecular structure and physicochemical properties of starches from different botanical origins – A review. *Carbohydrate Polymers*. **74**: 691–703.

Jobling, S. 2004. Improving starch for food and industrial applications. *Current Opinion in Plant Biology*. **7**:210–218.

Kang, I. J., Byun, M.W., Yook, H.S., Bae, C.H., Lee, H. S., Kwon, J., H. and Chung, C.K. 1999. Production of modified starches by gamma irradiation. *Radiation Physics and Chemistry*. **54**: 425-430.

Karim, A. A., Tie, A. P. L., Manan, D.M.A. and Zaidul, I.S.M. 2008. Starch from the Sago (Metroxylon sagu) Palm Tree—properties, prospects, and challenges as a new industrial source for food and other uses. *Comprehensive Reviews in Food Science and Food Safety*. **7**: 215-228.

Kaur, A., Singh, N., Ezekiel, R. and Guraya, H. S. 2007. Physicochemical, thermal and pasting properties of starches separated from different potato cultivars grown at different locations. *Food Chemistry*. **101**: 643–651.

Kaur, B., Ariffin, F., Bhat, R. and Karim, A. A. 2012. Progress in starch modification in the last decade. *Food Hydrocolloids*. **26**: 398-404.

Kaur, M., Singh, N., Sandhu, K. S. and Guraya, H. S. 2004. Physicochemical, morphological, thermal and rheological properties of starches separated from kernels of some Indian mango cultivars (Mangifera indica L.). *Food Chemistry*. **85**: 131–140.

Kong, X., Kasapis, S., Bao, J. and Corke, H. 2009. Effect of gamma irradiation on the thermal and rheological properties of grain amaranth starch. *Radiation Physics and Chemistry*. **78**: 954–960.

Koo, S. H., Lee, K. Y. and. Lee, H. G 2010. Effect of cross-linking on the physicochemical and physiological properties of corn starch. *Food Hydrocolloids*. **24**: 619-625.

Lawal, O. S., Lapasin, R., Bellich, B., Olayiwola, T. O., Cesàro, A., Yoshimura, M. and Nishinari, K. 2011. Rheology and functional properties of starches isolated from five improved rice varieties from West Africa. *Food Hydrocolloids*. **25**: 1785-1792.

Lawal, O.S. 2004a. Composition, physicochemical properties and retrogradation characteristics of native, oxidised, acetylated and acid-thinned new cocoyam (Xanthosoma sagittifolium) starch. *Food Chemistry*. **87**: 205–218.

Lawal, O.S. 2004b. Succinyl and acetyl starch derivatives of a hybrid maize: physicochemical characteristics and retrogradation properties monitored by Differential Scanning Calorimetry. *Carbohydrate Research*. **339**: 2673–2682.

Lee, Y-J., Kim, S. Y., Lim, S-T., Han, S-M., Kim, H-M. and Kang, I-J. 2006. Physicochemical properties of gamma-irradiated corn starch. *International Journal of Food Sciences and Nutrition*. **11**: 146-154.

Liu, Q. 2005. Understanding starches and their role in foods. In Cui, S.W. (ed.). *Food Carbohydrates: Chemistry, Physical Properties and Applications*, pp. 309-355. United States of America: CRC Press.

Lu, Z-H., Donner, E., Yada, R. Y. and Liu, Q. 2012. Rheological and structural properties of starches from γ-irradiated and stored potatoes. *Carbohydrate Polymers*. **87**: 69–75.

Maaruf, A. G., Cheman, Y.B., Asbi, B.A., Junainah, A.H. and Kennedy, J.F. 2001. Effect of water content on the gelatinization temperature of sago starch. *Carbohydrate Polymers*. **46**: 331-337.

Mitchell, C.R. 2009. Rice starches: production and properties. In BeMiller, J. and Whistler, R. (ed.). *Starch: Chemistry and Technology*, pp. 569-578. United States of America: Academic Press.

Mohamed, A., Jamilah, B. Abbas, K.A. Rahman, R. A. and Roselina, K. 2008. A Review on Physicochemical and Thermorheological Properties of Sago Starch. *American Journal of Agricultural and Biological Sciences*. **3**(4): 639-646.

Mukisa, I. M., Muyanja, C.M.B.K., Byaruhanga, Y.B., Schuller, R. B., Langsrud, T. and Narvhus, J. A. 2012. Gamma irradiation of sorghum flour: Effects on microbial inactivation, amylase activity, fermentability, viscosity and starch granule structure. *Radiation Physics and Chemistry*. **81**: 345–351.

Nadiha, M.Z. Fazilah, A., Bhat, R. and Karim, A. A. 2010. Comparative susceptibilities of sago, potato and corn starches to alkali treatment. *Food Chemistry*. **121**: 1053–1059.

Nunez-Santiago, M.C., Bello-Perez, L.A. and Tecante, A. 2004. Swelling-solubility characteristics, granule size distribution and rheological behaviour of banana (Musa paradisiaca) starch. *Carbohydrate Polymers*. **56**:65–75.

Nwokocha, L. M. and Williams, P. A. 2011. Structure and properties of Treculia africana, (Decne) seed starch. *Carbohydrate Polymers*. **84**: 395–401.

Pang, J., Wang, S., Yu, J., Liu, H., Yu, J. and Gao, W. 2007. Comparative studies on morphological and crystalline properties of B-type and C-type starches by acid hydrolysis. *Food Chemistry*. **105**: 989–995.

Pimpa, B., Muhammad, S.K.S., Hassan, M.A., Ghazali, Z., Hashim, K. and Kanjanasopa, D. 2007. Effect of electron beam irradiation on physicochemical properties of sago starch. *The Songklanakarin Journal of Science and Technology*. **29**(3): 759-768.

Puncha-arnon, S., Pathipanawat, W., Puttanlek, C., Rungsardthong, V. and Uttapap, D. 2008. Effects of relative granule size and gelatinization temperature on paste and gel properties of starch blends. *Food Research International.* **41**(5): 552–561.

Rombo, G. O., Taylor, J.R. and Minnaar, A. 2004. Irradiation of maize and bean flours: effects on starch physicochemical properties. *Journal of the Science of Food and Agriculture.* **84**: 350–356.

Sandhu, K. S., Singh, N. and Kaur, M. 2004. Characteristics of the different corn types and their grain fractions: physicochemical, thermal, morphological, and rheological properties of starches. *Journal of Food Engineering.* **64**: 119–127.

Schoch, T.J. 1964. Swelling power and solubility of granular starches. In Whistler, R.L. (Ed.). *Methods in Carbohydrate Chemistry 4*, pp. 106–108. New York: Academic Press.

Sequeira, S., Cabrita, E.J. and Macedo, M.F. 2012. Antifungals on paper conservation: An overview. *International Biodeterioration and Biodegradation.* **74**: 67-86.

Singh, J., Dartois, A. and Kaur, L. 2010. Starch digestibility in food matrix: a review. *Trends in Food Science and Technology.* **21**: 168-180.

Singh, J., Kaur, L. and McCarthy, O.J. 2007. Factors influencing the physicochemical, morphological, thermal and rheological properties of some chemically modified starches for food applications—A review. *Food Hydrocolloids.* **21**:1–22.

Singh, N. Chawla, D. and Singh, J. 2004. Influence of acetic anhydride on physicochemical, morphological and thermal properties of corn and potato starch. *Food Chemistry.* **86**: 601–608.

Singh, S., Singh, N., Ezekiel, R. and Kaur, A. 2011. Effects of gamma-irradiation on the morphological, structural, thermal and rheological properties of potato starches. *Carbohydrate Polymers.* **83**:*1521–1528.*

Singhal, R. S., Kennedy, J. F., Gopalakrishnan, S. M., Kaczmarek, A., Knill, C. J. and Akmar, P. F. 2008. Industrial production, processing, and utilization of sago palm-derived products. *Carbohydrate Polymers.* **72**:1–20.

Sodhi, N. S. and Singh, N. 2003. Morphological, thermal and rheological properties of starches separated from rice cultivars grown in India. *Food Chemistry.* **80**: 99–108.

Sofi, B. A., Wani, I. A., Masoodi, F. A., Saba, I. and Muzaffar, S. 2013. Effect of gamma irradiation on physicochemical properties of broad bean (Vicia faba L.) starch. *LWT-Food Science and Technology.* **54**: 63-72.

Srichuwong, S., Isono, N., Jiang, H., Mishima, T. and Hisamatsu, M. 2012. Freeze–thaw stability of starches from different botanical sources: Correlation with structural features. *Carbohydrate Polymers.* **87**: 1275– 1279.

Srichuwong, S., Sunarti, T. C., Mishima, T., Isono, N., and Hisamatsu, M. 2005. Starches from different botanical sources I: Contribution of amylopectin fine structure to thermal properties and enzyme digestibility. *Carbohydrate Polymers.* **60**: 529–538.

Svihus, B., Uhlen, A.K. and Harstad, O.M. 2005. Effect of starch granule structure, associated components and processing on nutritive value of cereal starch: A review. *Animal Feed Science and Technology.* **122**:303–320.

Teng, L.Y., Chin, N.L. and Yusof, Y.A. 2013. Rheological and textural studies of fresh and freeze-thawed native sago starch-sugar gels. II. Comparisons with other starch sources and reheating effects. *Food Hydrocolloids.* **31**: 156-165.

Tester, R.F., Karkalas, J. and Qi, X. 2004. Starch—composition, fine structure and architecture: Review. *Journal of Cereal Science.* **39**:151–165.

Thitipraphunkul, K., Uttapap, D., Piyachomkwan, K. and Takeda, Y. 2003. A comparative study of edible canna (Canna edulis) starch from different cultivars. Part I. Chemical composition and physicochemical properties. *Carbohydrate Polymers.* **53**: 317–324.

Tian, Y., Xu, X., Xie, Z., Zhao, J. and Jin, Z. 2011. Starch retrogradation determined by differential thermal analysis (DTA). *Food Hydrocolloids.* **25**: 1637-1639.

Waliszewski, K. N., Aparicio, M. A., Bello, L. A. and Monroy, J. A. 2003. Changes of banana starch by chemical and physical modification. *Carbohydrate Polymers.* **52**: 237–242.

Wang, S., Yu, J., Gao W., Pang J., Yu J., and Xiao P. 2007. Characterization of starch isolated from Fritillaria traditional chinese medicine (TCM). *Journal of Food Engineering.* **80**: 727–734.

Wani, I.A., Jabeen, M., Geelani, H., Masoodi, F.A., Muzaffar, S. and Saba, I. 2013. Effect of gamma irradiation on physicochemical properties of Indian Horse Chestnut (Aesculus indica) starch. *Food Hydrocolloids.* 1-11

Wilson, J., Hardy, K., Allen, R., Copeland, L., Wrangham, R. and Collins, M. 2010. Automated classification of starch granules using supervised pattern recognition of morphological properties. *Journal of Archaeological Science.* **37**: 594–604.

Wu, D.,Q. Shu, Wang, Z. and Xia, Y. 2002. Effect of gamma irradiation on starch viscosity and physicochemical properties of different rice. *Radiation Physics and Chemistry.* **65**:79–86.

Xie, S. X., Liu, Q. and Cui, S. W. 2005. Starch Modification and Applications. In Cui, S.W. (ed.). *Food Carbohydrates: Chemistry, Physical Properties and Applications*, pp. 357-401. United States of America: CRC Press.

Yu, Y. and Wang, J. 2007. Effect of γ-ray irradiation on starch granule structure and physicochemical properties of rice. *Food Research International.* **40**: 297–303.

Zavareze, E.R. and Dias, A. R. G. 2011. Impact of heat-moisture treatment and annealing in starches: A review. *Carbohydrate Polymers.* **83**: 317–328.

Zhou, X. and Lim, S.T. 2012. Pasting viscosity and in vitro digestibility of retrograded waxy and normal corn starch powders. *Carbohydrate Polymers.* **87**: 235– 239.