International Journal of Agricultural Technology 2023 Vol. 19(3):1379-1390
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Effect of electron beam irradiation on the physicochemical properties of Jackfruit seed flour

Vatthanakul, S.[1,2*], Klamsakun, S.[1] and Sajjabut, S.[3]

[1]Department of Food Science and Technology, Faculty of Science and Technology, Thammasat University, Pathumthani 12120, Thailand; [2]Thammasat University Center of Excellence in Food Science and Innovation, Thammasat University, Pathumthani 12120, Thailand; [3]Thailand Institute of Nuclear Technology (Public Organization), Ongkarak, Nakhon Nayok 26120, Thailand.

Vatthanakul, S., Klamsakun, S. and Sajjabut, S. (2023). Effect of electron beam irradiation on the physicochemical properties of Jackfruit seed flour. International Journal of Agricultural Technology 19(3):1379-1390.

Abstract Jackfruit seed flour was applied 4 conditions at doses of 0, 2, 4, and 6 kGy of electron beam, respectively. The result showed that after being exposed to radiation, jackfruit seed flour formed a type C crystal structure. Pasting properties of peak, breakdown, holding, final and set-back viscosities decreased with increasing irradiation dose. The final viscosity of jackfruit seed flour with electron irradiation intensity at 2 KGy, 4 KGy, and 6 KGy was 614, 521, and 348 RVU, respectively. Furthermore, electron irradiated flour showed a decreasing trend in syneresis (%) which observed with increasing irradiation dose in jackfruit seed flour. It may be concluded that food containing election beam radiation flour had a softer texture.

Keywords: Jackfruit Seed flour, Electron beam irradiation, Physicochemical properties, Pasting properties, Syneresis

Introduction

Jackfruit (*Artocarpus heterophyllus*) is a large perennial plant that can be grown all year round and produces continuous production for a long time. It has a unique smell and taste (Akter and Haque, 2018). The inside of the jackfruit consists of jackfruit pulp, jackfruit seeds, and jackfruit meat. Jackfruit seeds are important by-products and are nutritious with a great source of energy (Ocloo *et al.*, 2010). Each 100 g of jackfruit seeds contains 153 kcal of energy, 5.5 g of protein, 32.2 g of carbohydrates, 0.2 g of fat, vitamins B, B1, B2, C, niacin, vitamin A, high phosphorus, and has other properties such as having prebiotics. From the properties of jackfruit seeds with a high amount of amylose content (24-32 percent). It is naturally classified as type II resistant starch; RS2, which helps control blood sugar levels and promote intestinal health when considering

[*]**Corresponding Author:** Vatthanakul, S.; **Email:** emmesuteera@gmail.com

the structural properties and functional properties of jackfruit seed flour. It was found that jackfruit seed flour can be used as a thickener, gelling agents or stabilizers in products Therefore, jackfruit seeds are processed into starch to extend shelf life. It can also increase the value of jackfruit seeds by substituting wheat flour in bakery products and sweets as well.

Irradiation is a food preservation method whereby electron beams, X-rays, or gamma rays are applied to food products. It is a food processing method without heat (non-thermal processing) in which irradiation makes the bond of starch polymer broken. Ionizing and stimulating conditions result in the breaking of chemical bonds into smaller chains. Studies on the reduction of the viscosity of starch using irradiation have also been reported. Electron beam irradiation is also more efficient in reducing the swelling capacity and viscosity of starch (Kerf *et al.*, 2001) Swelling of maize starch decreased significantly, with γ-irradiated doses of 2–50 kGy (Chung and Liu, 2009). However, there is few or no report on the effect of electron beam irradiation on microstructure and physical properties of jackfruit seed flour.

The research aimed to study the properties of polymers, or a change in the structure of the polymer of jackfruit seed starch modified by electron beam irradiation in order to be more effectively used as a component in various culinary items and expanded the potential applications of jackfruit seed flour.

Materials and methods

Materials

The sample of jackfruit seeds was purchased at a local market. The seeds were cleaned for shrivelled and damaged grains. The jackfruit seeds were peeled, mashed to a smaller size, and heated for overnight at 50 ℃ until the moisture content was 5-8 percent. The dried jackfruit seeds were then ground into a fine powder and put through a 50-mesh screen before being put into 500 g airtight food-grade polyethylene pouches, which were bought from registered suppliers. The investigation only employed analytical-grade compounds.

Gamma irradiation treatment

A 20 kW/10 MeV electron accelerator was utilized as the source irradiator to irradiate the packed jackfruit seeds flour at 23 2 ^{o}C with a dosage rate of 1.08 kGy/h. The doses employed were 0 (unirradiated, used as control), 2, 4, and 6 kGy. The irradiation treatments were performed at Thailand Institute of Nuclear Technology (Public Organization), Ongkarak, Nakhon Nayok.

Scanning electron microscopy

Scanning electron micrograph (SEM) of the jackfruit seeds flour was determined using the specimens (JEOL model JSM7800F, Japan) to observe the surface morphology. the jackfruit seeds flour was placed on a piece of adhesive tape attached to a circular aluminum specimen room and coated with gold- particles. With an accelerating potential of 2 kV, the samples were imaged. The morphological properties of the jackfruit seeds flour were then examined in the SEM micrographs at magnifications of 500, 1000, and 2000.

The crystal structure was tested by X-ray diffractometry

The crystal structure was analyzed by X-ray diffractometer (Bruker AXS Model D8 Advance, Germany). Test conditions were determined as follows: X-ray generator at 40 kV and 40 mA with scan angle 2θ from 4° - 45 °at scan rate of 2◦/min.

Water solubility index and water absorption index

The water absorption index (WAI) measures the volume occupied by the granule or starch polymer after swelling in excess of water followed by method of Yousf *et al.* (2017) with some modifications. The precise weight of a 2.5 g sample of flour was measured, added to a centrifuge tube with a cover, and then the material was weighed again. Mix thoroughly by stirring the glass rod and stirring every 5 minutes for 30 min. Rinse the attached portion of the glass rod into a centrifuge tube using distilled water. 5 ml was placed in a centrifuge at 2200 rpm for 15 min. The clear was poured into a known weight aluminium cup. It was dried at 105 ℃ until a stable weight was obtained. and then weighed to calculate the solubility index. For centrifuge tubes with the remainder in the weigh tubes to calculate the water absorption value as follows.

Solubility index = (dissolved fraction sample weight / initial sample weight) x 100

Water absorption index = (centrifuge tube weight with sludge – centrifuge tube weight) / initial sample weight.

Determination of amylose content

A modified version of Naklaor's method was used to determine the amount of amylose in jackfruit seed flour (2011). Jackfruit seed flour (100 mg) was combined with 95% ethanol (1 ml), 1 N NaOH (9 ml), and let to stand at room temperature for 10 min. After that, it was heated in a water bath (100C) for 10 min., and it was then allowed to cool to room temperature for at least two hours. Using distilled water, the solution was prepared to a volume of 100 ml and vortexed vigorously. The sample solution (5 ml) was incubated with 50 ml of distilled water, 2 ml of 1 N acetic acid, and 2 ml of iodine solution (0.2 g iodine and 2.0 g potassium iodide in 100 mL of aqueous solution), after which the volume was brought to its final value of 100 ml with distilled water. At 620 nm, the absorbance was measured after standing for 10 minutes. Using a standard curve made of potato-derived pure amylose, the amount of amylose was calculated.

Freeze-thaw stability

Samples of jackfruit seed flour (2.5 g) were mixed with distilled water (50.0 mL), heated at 90oC for 10 minutes, and then allowed to cool for 30 minutes. The paste (Ws), weighing around 5.0g, was then placed into a centrifuge tube with a known weight (W1). The tubes were frozen at -20 ℃ for 24 hours in a freezer chest, then they were thawed at 30 ℃ for two hours in a storage chamber. The freeze–thaw cycle was repeated for up to three cycles with a 3-day interval. Four samples were centrifuged at 4600g in a refrigerated centrifuge for 15 min. The supernatant was decanted, and the residue was weighed. The degree of syneresis was calculated by dividing the mass of the decanted supernatant by the mass of the paste before centrifugation and multiplying by 100.

$$\% \text{ syneresis (Freeze -thaw stability)} = (W2 - W1) \times 100 / WS$$

Pasting properties

Rapid Visco Analyzer (RVA) was used to evaluate the pasting properties of starch suspension. The temperature was maintained at 50 ℃ for 1 minute from 95 ℃, stabilized for 2.5 minutes, and then decreased to 50 ℃ for 2 minutes using three grams of flour specimen and 25.0 mL of distilled water. The following viscosity measurements were made: breakdown viscosity (BV=PV-TV), setback viscosity (SV=FV-TV), final viscosity (FV), peak viscosity (PV), and trough viscosity (TV).

Statistical analysis

All data were calculated from the average of three replicate measurements. Data were analyzed for analysis of variance (ANOVA) and the significance of their variations was verified by means of Duncan's multiple range test ($p < 0.05$).

Results

Scanning electron microscopy (SEM)

The morphology and surface characteristics of the jackfruit seed flour at different doses of electron beam irradiation are shown in Figure 1. The SEM results showed that the granules of jackfruit seed flour were composed of polygonal or irregularly shaped granules of uneven size. After the flour was irradiated, fractures started to form on the surface.

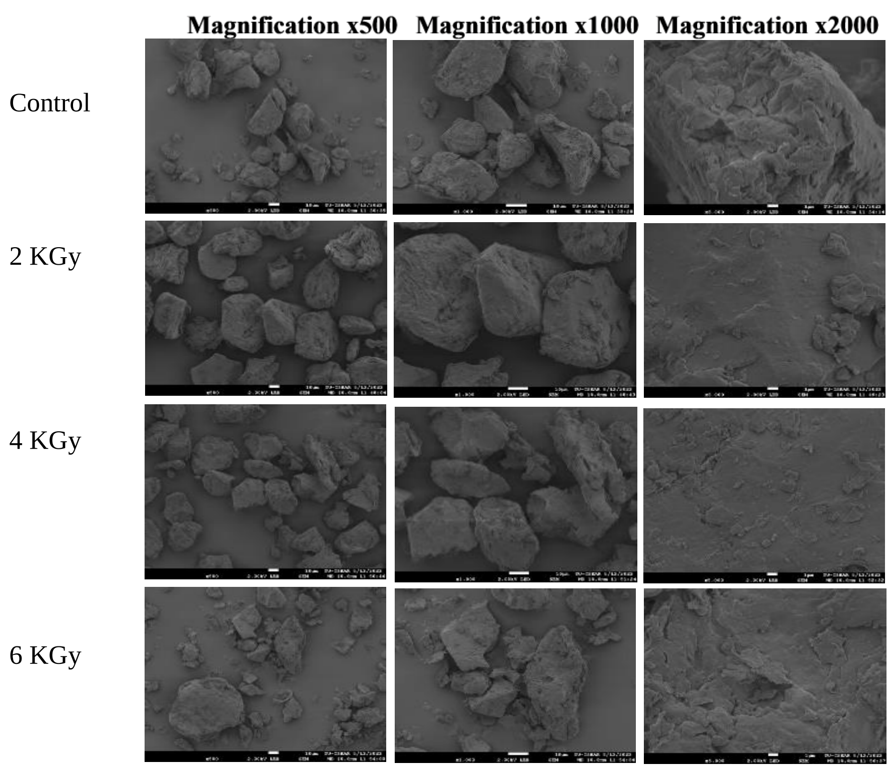

Figure 1. Structure of jackfruit seed flour at various conditions observed under scanning electron microscopy (SEM) at 500x, 1000x and 2000x magnifications)

The jackfruit seed flour particles totally ruptured and created pits when exposed to the highest electron beam irradiation dose as seen in Figure 1.

The crystal structure was tested by X-ray diffractometry

The X-ray diffraction patterns of the irradiated jackfruit seed flour and controlled jackfruit seed flour showed that from the X-ray diffraction pattern of the control flour and the flour that undergoes electron irradiation at 2 KGy, a main peak at 2θ = 17°, a double peak at 22° and 24°. This is a characteristic of starch with a type B crystal structure. When modified with higher intensity electron irradiation, the X-ray diffraction pattern of starch was found at the main peak at 2θ = 14.5° and 17° and the doublet peaks at 22 ° and 24 ° tend to merge into a single peak. Therefore, starch undergoing electron irradiation at 4 and 6 KGy can be classified as having a C (A+B) crystal structure since type B crystals are hexagonal with approximately 36 water molecules in one cell. Therefore, the double helix of crystals when heated or electron-ionized with water as a plasticizer moves more easily than type A crystals, causing some type B crystals to change to type A, resulting in a C crystal structure.

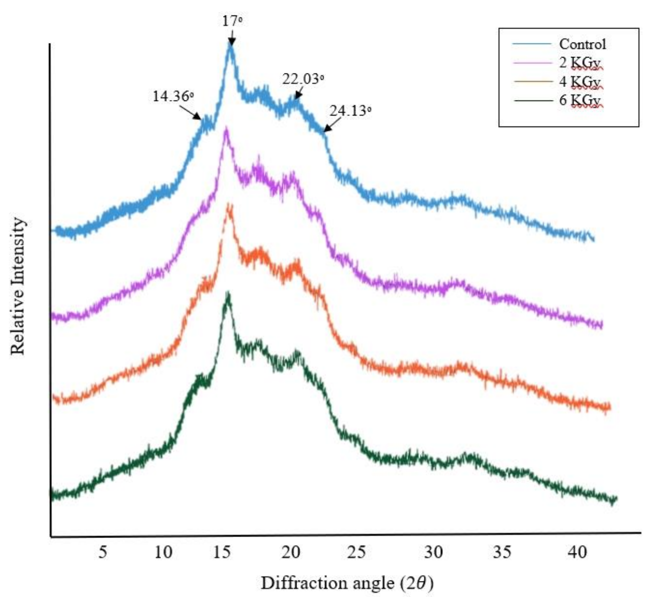

Figure 2. X-ray diffraction pattern of jackfruit granules under various conditions

Water solubility index and water absorption index

The results showed that of the analysis of the water solubility and water absorption index of jackfruit seed flour (control sample and irradiated flour) as seen in Table 1. There was no significant difference in the water absorption index between unirradiated and irradiated jackfruit seed flour, but it was still unchanged when being irradiated from 0 kGy to 6 kGy. It was found to be a higher water absorption was observed for jackfruit seed flour that had been irradiated at 2 KGy compared to the control sample. The irradiation of jackfruit seed flour causes an increase in the solubility in water. The water solubility of the jackfruit seed flour decreased from 9.80 to 10.76 as the irradiation dose increased from 0 kGy to 6 kGy.

Table 1. Types of jackfruit seed flour on water solubility index and water absorption index of jackfruit seed starch

Types of jackfruit seed flour	Water solubility index	water absorption index
Control	$9.80^{a} \pm 0.37$	$3.94^{a} \pm 0.09$
2 Kgy	$10.28^{a} \pm 0.72$	$4.20^{b} \pm 0.06$
4 Kgy	$10.78^{a} \pm 0.66$	$3.90^{a} \pm 0.05$
6 Kgy	$10.61^{a} \pm 0.25$	$3.90^{a} \pm 0.02$

$^{a-b}$ Means within the same column followed by the different letters are significantly different ($p < 0.05$).

Amylose content

The amylose content of all four samples of jackfruit seed flour was determined as shown in Table 2. The amylose content varied from 26.07 to 27.17%. It is classified as a flour with high amylose content.

Table 2. Amylose content of jackfruit seed starch under various conditions

Types of jackfruit seed flour	Amylose content
Control	26.07%
2 Kgy	27.17%
4 Kgy	26.28%
6 Kgy	26.26%

Freeze-thaw stability

The stability of freezing and thawing stability was determined (Figure 3), which was measured by the amount of liquid separated from the freeze-thawed starch gel for 5 cycles. Low syneresis indicates good freeze-thaw stability. It was found that the un-irradiated flour had a higher syneresis than the irradiated flour. As a result, irradiated flour was resistant to freezing and defrosting. Irradiated starch at 2 KGy had the best freezing and thawing stability, followed by 6 KGy and 4 KGy respectively.

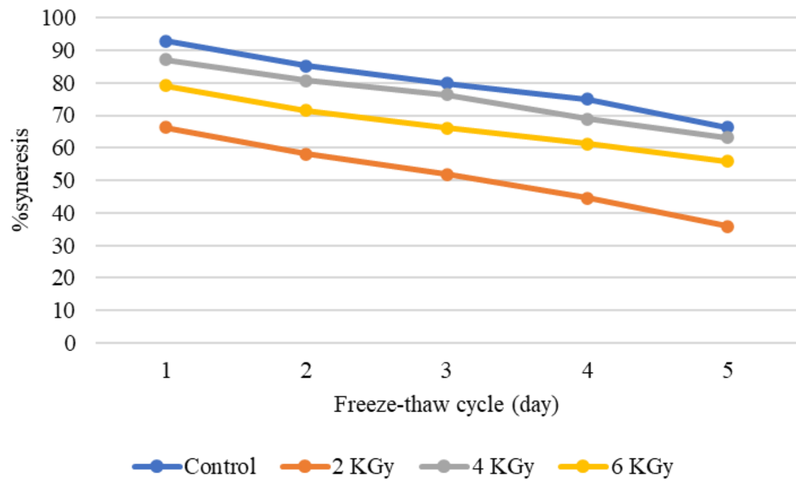

Figure 3. Freezing and thawing stability of jackfruit seed flour at various conditions

Pasting properties

Flour granules swelled and their molecules were broken as a result of additional heat from the electron beam (depolymerisation). When the amylose is small, it breaks down more easily and disperses from the flour grains, thereby reducing the viscosity. The pasting properties of the flour are presented in Table 3. The pasting properties (peak, trough, breakdown, final and setback viscosities) of the flour were significantly affected by the electron beam irradiation dose ($p \leq 0.05$). The peak viscosity ranged from 231 to 690 cP, trough viscosity ranged from 218 to 621 cP, final viscosity ranged from 348 to 967 cP, setback viscosity ranged from 130 to 346 cP and breakdown viscosity ranged from 13 to 69 cP.

Table 3. Viscosity change of jackfruit seed flour at various conditions by RVA

Types of jackfruit seed flour	Peak viscosity	Trough viscosity	Break down	Final viscosity	Setback from hold	Setback from Peak
Control	690	621	69	967	346	277
2 KGy	402	368	34	614	246	212
4 KGy	371	350	21	521	171	150
6 KGy	231	218	13	348	130	117

Discussion

The SEM results showed that the radiation damage of jackfruit seed flour may only exist in the form of changes in the molecular structure. The deformation of the granular structure appeared to be dose dependent. As the dose increased, the damage caused by the impact of these highly energetic electron beams to the components of jackfruit seed flour was also increasingly obvious same the result as Xue *et al.* (2017). Chung and Liu (2010) suggested that the irradiation dose causes a significant surface damage, but it appears to depend on the source of the starch. Deformation in starch granules has also been reported by Ashwar *et al.* (2014) and Gani *et al*. (2014). They discovered found that pinholes and cracks were produced by c-irradiation. However, Gani *et al.* (2012) observed that the surface of irradiation bean starch granules had cracks in proportion to the applied dose (up to 20 kGy).

All the experimental results can be concluded that jackfruit seed flour contained a Type B crystal structure when electron beamed. The crystal structure and viscosity of cooked starch tended to change to a C (A+B) crystal structure. The crystal structure of amylopectin was not only factor affecting the change in starch properties. The important properties of flour must be considered. The behavior of viscosity changes when heated. It was found that jackfruit seed flour upon electron irradiation had a lower viscosity. Also, the flour was shown to be more difficult to ripen than the non-irradiated control formula. However, electron irradiated starch showed more stability to freezing and defrosting than control starch (Chatpaphasmon *et al.,* 2016). According to Atrous *et al.* (2017), A- and B-type starch underwent changes in their molecular and physicochemical properties after being treated with gamma radiation. Other parameters that can affect crystallinity include crystal size, the number of crystal regions, the amount of amylopectin present, the average length of amylopectin chains, and the order in which the amylopectin double helix is oriented (Zou *et al.*, 2020).

The ability of starch molecules to hydrogen-bond together and incorporate water in their structure was found to be crucial to swelling, as described by Wang *et al.* (2022). When irradiation causes starch degradation, the combined water ability of the starch decreases. A similar decrease in swelling index was noted by Ashwar *et al.* (2014); this may be due to a high reduction in amylopectin with irradiation, as the amylopectin fraction is predominantly responsible for swelling. When the amorphous area of the starch was degraded as a result of the peak viscosity decline, yam starch's ability to bind water was also reduced (Gani *et al.,* 2016). Moreover, Wang *et al.* (2022) found that the irradiation-induced starch degradation was the cause of the lower pasting characteristics following irradiation. It may be concluded that food containing Election beam radiation flour had a softer texture.

The water absorption index was significantly higher than the other samples ($p<0.05$) because the flour granules normally have a semi-crystalline structure that contains amylose and amylopectin formed along the radial line of the starch granule from the hilum point to the boundary of the starch granule. The inside consists of the crystal layer (crystalline) interspersed with the amorphous layer (amorphous). The amorphous form is formed by the molecular segments of amylopectin with high α-1, 6 bonds. As for the crystal region, it is formed by the merging of parallel branching lines along the structure. Amylopectin cluster with amylose inserted in amylopectin, an orderly arrangement of amylopectin molecules radially within the starch granules with alternating layers of crystalline and amorphous parts. This makes it possible to see the phenomenon of birefringence, or birefringence of the starch granules. This phenomenon is caused by the orderly arrangement of molecules within the starch granules (Tunyathan, 2006). Whenever jackfruit seed flour is irradiated with electrons, it breaks the starch's intermolecular hydrogen bonds, starting at the amorphous region first. More water enters the granules and when the electrons continue to be projected for a longer period of time or the level used increases. It would be resulted to change in the crystalline area within the powder granules. The flour granules absorb more water, hence the 2 KGy electron flour is more water soluble and absorbent than the jackfruit seed unheated starch. When there is a greater change in the crystalline region within the flour granules, the absorption and solubility of water decrease due to the change in structure. However, the solubility indices from the experiments were not statistically different ($p>0.05$).

Acknowledgements

This research was supported by research from Thailand Institute of Nuclear Technology in the field of electron projection in samples and Thammasat University Center of Excellence in Food Science and Innovation.

References

Akter, B. and Haque, M. A. (2018). Utilization of Jackfruit (Artocarpus heterophyllus) Seed's Flour in Food Processing: A Review. The Agriculturists, 16:131-142.

Ashwar, B. A., Shah, A., Gani, A., Rather, S. A., Wani, S. M., Wani, I. A. and *et al.* (2014). Effect of gamma irradiation on the physicochemical properties of alkali extracted rice starch. Radiation Physics and Chemistry, 99:37-44.

Atrous, H., Benbettaieb, N., Chouaibi, M., Attia, H. and Ghorbel, D. (2017). Changes in wheat and potato starches induced by gamma irradiation: A comparative macro and microscopic study. International Journal of Food Properties, 20:1532-1546.

Chatpaphasmon, C., Panja-anon, S. and Utaphap, D. (2016). Properties and structure of starch with crystal structure A and B. KMUTT Research and Development Journal, 39:257-270.

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:C353-C361.

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.

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

Gani, A., Nazia, S., Rather, S. A., Wani, S. M., Shah, A., Bashir, M. and *et al.* (2014). Effect of c-irradiation on granule structure and physicochemical properties of starch extracted from two types of potatoes grown in Jammu & Kashmir, India. LWT – Food Science and Technology, 58:239-246.

Gani, A., Jan, A., Shah, A., Masoodi, F. A., Ahmad, M., Ashwar, B. A. and Wani, I. A. (2016). Physico-chemical, functional and structural properties of RS3/RS4 from kidney bean (*Phaseolus vulgaris*) cultivars. International Journal of Biological Macromolecules, 87: 514-521.

Kerf, M. D., Mondelaers, W., Lahorte, P., Vervaet, C. and Remon, J. P. (2001). Characterization and disintegration properties of irradiated starch. International Journal of Pharmaceutics, 221:69-76.

Naklaor, D., Saengnak, A. and Limrungruangrat, K. (2011). Quality improvement of jackfruit seed starch by Pregelatinization method. Science Journal Burapha, 16:12-21.

Ocloo, F. C. K., Bansa, D., Boatin, R., Adom, T. and Agbemavor, W. S. (2010). Physicochemical, functional and pasting characteristics of flour produced from Jackfruits (*Artocarpus heterophyllus*) seeds. Agriculture and Biology Journal of North America, 1:903-908.

Tunyathan, W. (2006). Food chemistry of carbohydrates. Bangkok: Chulalongkorn University.

Xue, P., Zhao. Y., Wen, C., Cheng, S. and Lin, S. (2017). Effects of electron beam irradiation on physicochemical properties of corn flour and improvement of the gelatinization inhibition. Food Chemistry, 233:467-475.

Wang, G., Wang, D., Qing, C., Chen, L., Gao, P. and Huang, M. (2022). Impacts of electron-beam-irradiation on microstructure and physical properties of yam (*Dioscorea opposita* Thunb.) flour. LWT– Food Science and Technology, 163:113531.

Yousf, N., Nazir, F., Salim, R., Ahsan, h. and Sirwal, A. (2017). Water solubility index and water absorption index of extruded product from rice and carrot blend. Journal of Pharmacognosy and Phytochemistry, 6:2165-2168.

Zou, J., Xu, M., Zou, Y. and Yang, B. (2020). Physicochemical properties and microstructure of Chinese yam (*Dioscorea opposita* Thunb.) flour. Food Hydrocolloids, 113:1064.

(Received: 12 September 2022, accepted: 30 April 2023)