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Research Article

Effects of Blanching and Gamma Irradiation on Jerusalem Artichoke (*Helianthus tuberosus* L.) Powder Properties

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Jerusalem artichoke powder (JAP) is a natural source of inulin but presents limited hydration and adsorption properties, highlighting the need for improved processing methods to enhance functional food applications. This study evaluated the effects of thermal pretreatment (blanching at 100°C for 2 min; B) combined with gamma irradiation (0–10 kGy; IR) on the functional and structural properties of JAP. Samples were assessed for hydration capacity, glucose adsorption, antioxidant activity, carbohydrate content, and molecular structure using FTIR and ^{1}H NMR spectroscopy. The treatment combining blanching and irradiation at 2.5 kGy (B-IR2.5) produced the most significant improvements, with water holding capacity increasing to 11.8 g/g, swelling capacity to 17.8 g/g, and glucose adsorption reaching 148 mmol/g. Antioxidant activity also improved, with total phenolic content rising to 60 mg GAE/g in nonblanched samples irradiated at 7.5 kGy (NB-IR7.5). Protein and total dietary fiber contents increased to 11.94 and 28.6 g/100 g, respectively, while reducing sugar and inulin contents were reduced due to thermal degradation. FTIR analysis revealed stronger signals in hydroxyl and glycosidic bond regions, while ^{1}H NMR spectra of B-IR and NB-IR at 2.5 kGy showed reduced signal complexity and patterns similar to those of commercial short-chain inulin. An optimized combination of blanching and low-dose gamma irradiation enhances key functional and structural attributes of JAP, making it suitable as an alternative dietary fiber source in functional food applications.

Keywords: blanching; gamma irradiation; Jerusalem artichoke; pretreatment

1. Introduction

Jerusalem artichoke (JA) (*Helianthus tuberosus* L.) has gained increasing attention as a functional food due to its high content of dietary fibers, particularly inulin and fructo-oligosaccharides [1]. The tubers contain inulin, which functions as a prebiotic and a soluble dietary fiber (SDF) that supports gut microbiota and contributes to various health benefits. Its consumption is associated with health-promoting effects, including reduced risks of diabetes and colon cancer. Consequently, JA is incorporated into processed foods to enhance nutritional quality [2]. However, several limitations remain when incorporating JA into food formulations. These include enzymatic browning caused by polyphenol oxidase and peroxidase activity, along with the risk of microbial contamination due to its underground cultivation [1, 3]. In addition to these quality concerns, the functional performance of JA also presents challenges. Compared to inulin extracted from chicory root, the powder form of JA tubers shows lower gel-forming capacity, limiting suitability for fat-reduced formulations. In bakery products, the inclusion of JA can lead to a firmer crumb texture and shortened shelf life [4, 5]. Furthermore, the influence on product structure is concentration-dependent, with higher concentrations leading to undesirable textural properties [6].

Pretreatment techniques are considered essential for improving the stability, safety, and functional performance of Jerusalem artichoke powder (JAP). Blanching is widely applied prior to drying due to its ability to inhibit enzymatic browning, reduce microbial load, and preserve bioactive compounds [7]. This thermal pretreatment has also been linked to improvements in raw material quality. Chauhan et al. [8] reported that blanching contributed not only to microbial and enzymatic stability but also enhanced the sensory attributes and overall quality of JA-based food products. Khuenpet et al. [9] demonstrated that blanching unpeeled JA before drying increased inulin content and reduced sugar level, indicating the effectiveness of this pretreatment in improving raw material quality. Similar benefits have been reported in other plant materials. Huang and Hsieh [10] conducted research on the effect of blanching on soybean pod hulls. Their findings indicated that blanching could improve some physical and chemical characteristics including water retention capacity, oil-holding capacity, swelling properties, and solubility.

Although thermal techniques such as blanching have proven effective in enhancing the quality of raw materials, the development of nonthermal alternatives has received growing interest due to their ability to preserve heat-sensitive components while preserving and enhancing functional attributes [11]. Gamma irradiation has been utilized in food processing for preservation purposes. Its effectiveness depends on several factors, including irradiation dose, dose rate, and the physicochemical characteristics of the material being treated [12]. This technique induces structural changes without the use of chemical initiators or the formation of harmful by-products [13].

In polysaccharide-rich food matrices, gamma irradiation can cleave chemical bonds, enhance solubility, reduce viscosity, and modify rheological behavior [14]. It also assists polymer transformations through mechanisms such as cross-linking, grafting, and degradation [15]. Cheng et al. [16] reported that pea fiber irradiated at 2 kGy showed improved oil binding, water retention, and swelling capacity, while Li et al. [15] observed similar enhancements in orange peel dietary fiber irradiated at 3–6 kGy. These structural improvements can contribute to desirable changes in viscosity, texture, and calorie reduction in fiber-enriched food products [17]. Furthermore, gamma irradiation has been shown to affect protein structures by inducing conformational changes and promoting functional improvements in the food matrix [18].

In a recent study, Sudesh et al. [14] demonstrated that inulin extracted from chicory root exhibited increased antioxidant activity, bifidogenic potential, and overall functionality following exposure to 25 kGy of gamma irradiation, highlighting its value as a functional ingredient in synbiotic formulations. As higher doses may provide enhanced biofunctional properties, the current study employed irradiation levels not exceeding 10 kGy, in alignment with international safety standards. Regulatory authorities such as FAO, IAEA, and WHO have confirmed that doses up to 10 kGy do not produce adverse nutritional or toxicological effects and are considered safe for food applications without the need for chemical preservatives [19].

Previous studies on JA have primarily focused on its nutritional composition and general food applications [1, 20]. Few investigations have addressed the effects of processing techniques on the functional, nutritional, and structural characteristics of JA powder. Blanching and gamma irradiation have been commonly applied in food processing to improve product quality and stability [3, 14]. Research on the characterization of JAP remains limited, particularly in relation to its functional and physical properties following gamma irradiation alone or in combination with other treatments such as blanching. Therefore, this study evaluated the impact of these factors on the quality attributes of JAP to support its potential use as a value-added ingredient in food applications.

2. Material and Methods

2.1. Material. JA tubers (KKU Ac 001 variety) were obtained from Kasiwattana Farm, Khon Kaen, Thailand. This cultivar, developed by Khon Kaen University, is known for its high adaptability and yield potential [21, 22]. Selected tubers measured approximately 6.5 cm in length and 3 cm in diameter. Commercial chicory-derived inulin (short-chain, degree of polymerization (DP) < 10; long-chain, DP > 23) was supplied by DPO (Thailand) Co., Ltd.

The overall experimental procedure is outlined in Figure 1, providing a schematic overview of sample preparation, treatment classification, and the scope of quality evaluations conducted in this study.

2.2. Preparation of JAP. Jerusalem artichoke tubers (JATs) were processed into JAP following the method described by Khuenpet et al. [9], with slight modifications (Figure 1). Unpeeled tubers were washed and sliced into 2–3-mm thick pieces using a slicer (FS-Slicer, Fresh Sealer, China). The sliced tubers were immersed in a citric acid solution of 0.5% w/v for 5 min to minimize enzymatic browning, followed by draining. The pretreated samples were then divided into two groups based on thermal processing: non-blanched (NB) and blanched (B). For blanching, the sliced tubers were immersed in boiling water at 100°C for 2 min, immediately cooled, and drained. Both groups were then dried in a tray dryer (PG 9-4, Progress, Thailand) at 65°C for 8 h.

The dried samples were ground and sieved through a 60-mesh screen to obtain powder, which was packed in aluminum foil bags.

2.3. Gamma Irradiation of JAP. JAP samples obtained from NB and B treatments were subjected to gamma irradiation. Gamma irradiation was performed at room temperature using a cobalt-60 source in a carrier-type gamma irradiator (JS 8900 IR-155, MDS Nordion, Canada) at the Thailand Institute of Nuclear Technology (TINT). Irradiation was applied at doses of 2.5, 5.0, 7.5, and 10.0 kGy, with the dose rate controlled according to standard operating procedures. Irradiation dose selection followed the FAO/IAEA/WHO guidelines, which recognize 10 kGy as the maximum safe

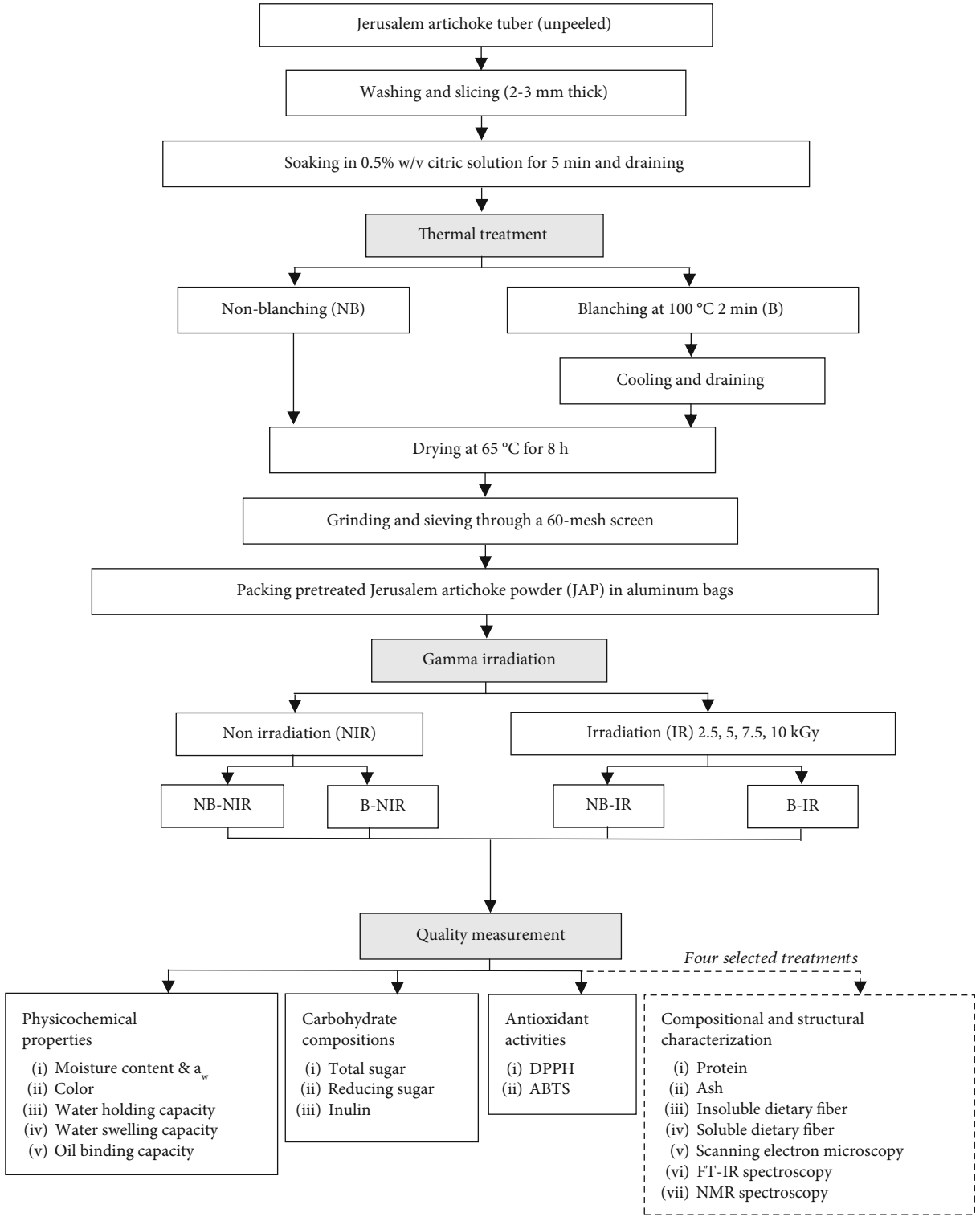


Figure 1: Schematic representation of sample preparation, thermal treatment (nonblanching and blanching), γ-irradiation at various doses, and quality evaluation of treated Jerusalem artichoke powder. Note: Analyses within the dashed box were conducted only on selected treatment groups as defined in the experimental design.

limit for food applications without adverse nutritional or toxicological effects [19].

2.4. Experimental Design and Sample Selection for Analysis. To evaluate the effects of thermal pretreatment and gamma irradiation, a structured experimental design was established, consisting of 10 treatment groups. These included two nonirradiated controls (nonblanched–nonirradiated (NB-NIR) and blanched–nonirradiated (B-NIR)) and eight irradiated samples exposed to four dose levels (2.5, 5.0, 7.5,

and 10.0 kGy) under both NB and B conditions (nonblanched irradiated (NB-IR) and blanched irradiated (B-IR)). The NB-NIR and B-NIR samples, which received no irradiation, were used to represent the visual appearance of the samples after nonblanching and blanching, respectively. Prior to quality evaluation, samples from each treatment group were photographed under consistent lighting and camera settings.

All samples were analyzed in three major categories: physicochemical properties, antioxidant activities, and carbohydrate compositions. In addition, only four specific treatments, namely, the NB-NIR, B-NIR, NB-IR, and B-IR samples treated at the most effective gamma irradiation dose, were further analyzed for protein, ash, insoluble dietary fiber (IDF), and SDF contents. These selected samples were also subjected to scanning electron microscopy (SEM), Fourier-transform infrared (FT-IR) spectroscopy, and nuclear magnetic resonance (NMR) spectroscopy to investigate changes in structural characteristics.

2.5. Quality Determination

2.5.1. Physicochemical Properties

2.5.1.1. Moisture Content and Water Activity. Moisture contents of all JAP samples were determined using the oven-drying method at 105°C, following the AOAC Official Method 925.10 [23]. Water activity (a_w) was measured using a water activity meter (CX2, Aqua Lab, United States).

2.5.1.2. Color Measurement. Color values of JAP samples were determined using a color meter (Hunter Lab, Color Flex CX2687, United States) and expressed in the $L*$, $a*$, and $b*$ scale. $L*$ denotes lightness ($0 \le L* \le 100$) whereas $a*(+)$, $a*(-)$, $b*(+)$, and $b*(-)$ represent redness, greenness, yellowness, and blueness, respectively. The total color difference (ΔE) between two samples was calculated using Equation (1). The control sample used for ΔE comparison was untreated JAP (0 kGy).

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}. \quad (1)$$

2.5.1.3. Water Holding Capacity (WHC). WHC of JAP samples was measured according to the method of Zhu et al. [24]. The 0.5 g of JAP samples was weighed into a test tube, and 10 mL of distilled water was added. The test tube, covered with a lid, was vortexed and stored at 25°C for 18 h. After this period, the mixture was centrifuged at 3000 rpm for 20 min to separate solid from liquid. The residues were weighed (M_1) and then dried in a hot air oven until a constant weight (M_2) was reached. WHC of JAP samples was calculated using Equation (2):

$$\text{Water holding capacity (g/g)} = \frac{(M_1 - M_2)}{M_2}. \quad (2)$$

2.5.1.4. Water Swelling Capacity (WSC). WSC was determined by mixing 0.5 g of JAP samples (M_0) with 10 mL of distilled water in a measuring cylinder. The mixture was left at room temperature for 24 h. Initial volume (V_0) and after swelling volume (V_1) were recorded. The WSC was calculated using the Equation (3):

$$\text{Water swelling capacity (mL/g)} = \frac{(V_1 - V_0)}{M_0}. \quad (3)$$

2.5.1.5. Oil Binding Capacity (OBC). To determine OBC, 1 g of JAP (M_0) was mixed with 10 mL of soybean oil in a centrifuge test tube and allowed to stand at 4°C for 24 h. After that, the mixture was centrifuged at 4000 rpm for 15 min to separate the unabsorbed oil from the powder. The residues, which were the oil-absorbed JAP, were weighed (M_1). The OBC was calculated according to Yin et al. [25] using Equation (4):

$$\text{Oil binding capacity} \left(\frac{\text{g}}{\text{g}}\right) = \frac{(M_1 - M_0)}{M_0}. \quad (4)$$

2.5.1.6. Glucose Adsorption Capacity. Glucose adsorption capacity was measured by adding 100 mL of glucose solution (10, 50, 100, and 200 mmol/L, denoted as C_1) to 0.5 g of JAP in a test tube. The mixture was incubated at 37°C for 6 h with constant shaking. After incubation, the mixture was centrifuged at 4000 rpm for 15 min, and the glucose concentration in the supernatant was determined using the 3,5-dinitrosalicylic acid (DNS) colorimetric method (C_2). The glucose adsorption capacity was calculated using Equation (5).

$$\text{Glucose absorption capacity} \left(\frac{\text{mmol}}{\text{g}}\right) = \frac{((C_1 - C_2) \times V)}{W}, \quad (5)$$

where V is the volume of the glucose solution and W is the initial weight of the JAP sample.

2.5.2. Carbohydrate Compositions

2.5.2.1. Total Sugar, Reducing Sugar, and Inulin Contents. To prepare samples for carbohydrate analysis, water-soluble carbohydrates were extracted from JAP using a hot water extraction method. Briefly, 10 g of JAP was mixed with 350 mL of distilled water, heated to 85°C, and maintained at this temperature for 30 min with continuous stirring. The mixture was then cooled to room temperature and centrifuged at 3000 rpm for 10–15 min. The resulting supernatant was used for subsequent analyses.

The total sugar content was determined using the phenol–sulfuric acid colorimetric method. One milliliter of extract was mixed with 0.5 mL of 5% phenol solution. The resulting solution was shaken well, and then 2.5 mL of concentrated sulfuric acid (H_2SO_4) was added. The mixture was incubated in a boiling water bath for 10 min and then cooled to room temperature. The absorbance was measured at 350 nm using a spectrophotometer (UV2-100, High Lab, Thailand). Total sugar concentration was estimated using a standard curve generated with known fructose concentrations.

The reducing sugar content was determined using the DNS method. Equal volumes (7.5 mL) of extract and DNS reagent were mixed thoroughly and incubated at room

temperature for 10 min. The absorbance was measured at 490 nm using the same spectrophotometer, and the reducing sugar content was calculated using a fructose standard curve.

The inulin content was calculated by subtracting the reducing sugar from the total sugar, based on the following equation:

$$\text{Inulin content} = \text{Total sugar content} - \text{Reducing sugar content}. \quad (6)$$

This calculation assumes that inulin, a nonreducing fructan, comprises the nonreducing sugar fraction. This approach is supported by previous studies involving inulin quantification from root and tuber sources [26–28].

2.5.3. Antioxidant Activities

2.5.3.1. Total Phenolic Content (TPC). The TPC of JAP was determined using the Folin–Ciocalteu colorimetric method adapted from Amin et al. [29]. A 0.1-g sample was extracted with 10 mL of ethanol using an ultrasonic bath (40 kHz) for 60 min. After sonication, 0.5 mL of the extract was mixed with 0.5 mL of the Folin–Ciocalteu reagent and allowed to stand for 5 min. Subsequently, 2 mL of 7.5% Na_2CO_3 solution was added, and the volume was adjusted to 5 mL with distilled water. The mixture was incubated at room temperature for 2 h, and absorbance was measured at 760 nm using a UV-Vis spectrophotometer. A standard curve was prepared using gallic acid (10–75 μg/mL). TPC was expressed as mg GAE/g dry sample.

2.5.3.2. Radical Scavenging Activity (DPPH and ABTS Assays). For both assays, 1 g of JAP was mixed with 35 mL of distilled water to prepare the sample solution. For the DPPH (1,1-diphenyl-2-picrylhydrazyl) assay, 100 μL of the sample solution was mixed with 2.9 ml of DPPH reagent, and the mixture was incubated in the dark at room temperature for 30 min. Absorbance was measured at 517 nm using a UV–Vis spectrophotometer. The method followed Desgupta and De [30]. For the ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) assay, 100 μL of the same sample solution was mixed with 2.9 mL of ABTS working solution. The absorbance was recorded at 734 nm exactly 1 min after mixing and every minute up to 6 min. The method followed Re et al. [31]. Results from both assays were expressed as Trolox equivalents per gram of dry sample (mg TE/g dry weight).

2.5.4. Compositional and Structural Characterization

2.5.4.1. Compositional Analysis. Composition analysis was conducted on selected JAP samples, including NB-NIR, B-NIR, NB-IR, and B-IR treated at the most effective gamma irradiation dose, as determined in this study. The analyzed parameters included protein, ash, IDF, and SDF. Additionally, moisture, reducing sugar, and inulin values obtained from earlier experimental procedures were incorporated into the composition table to provide a comprehensive comparison across selected treatments.

The composition was determined using standard AOAC methods [23]. Protein content was determined using the Kjeldahl method (AOAC 991.20), with total nitrogen multiplied by a factor of 6.25. Ash content was assessed by dry ashing in a muffle furnace at 500°C (AOAC 930.30). IDF and SDF were analyzed following AOAC Methods 991.42 and 993.19, respectively. All measurements were carried out in triplicate and expressed on a dry weight basis.

2.5.4.2. Structural Characteristics. Structural analyses were performed on selected JAP samples (NB-NIR, B-NIR, NB-IR, and B-IR at the most effective irradiation dose). FT-IR and NMR spectra of these samples were also compared with commercial inulin from chicory root (short- and long-chain types).

SEM. JAP samples were mounted on stubs with double-sided adhesive tape, coated with gold, and examined using a SEM (JSM-5410LV, JEOL, Japan) at 1500× magnification to observe surface morphology under different pretreatments (with and without blanching) and γ-irradiation conditions.

FT-IR spectroscopy. The FT-IR spectra of samples were recorded using an IR spectrophotometer model Nicolet iS50, Thermo Scientific, United States. After mixing the sample with potassium bromide (KBr), the resulting mixture was pressed into tablets. The FT-IR spectra were collected in the range 4000–500 cm^{-1} with a resolution of 4 cm^{-1}. The transmittance (percent) was plotted against wavenumber (cm^{-1}) to identify the characteristic functional groups present in the samples.

NMR spectroscopy. ^1H NMR spectroscopy was applied to identify the chemical structure of inulin in samples. The spectra were recorded using an NMR spectrometer (Ascend TM 600/Avance III HD, Bruker, Switzerland). The obtained chemical shifts were expressed in ppm.

2.6. Statistical Analysis. The experiment was conducted using a completely randomized design (CRD) with three replications per treatment. The quality attribute data of JAP samples were analyzed using analysis of variance (ANOVA), followed by the Duncan multiple range test (DMRT), performed in SPSS software (SPSS, Version 21, Inc., Chicago, Illinois). Mean values and standard deviations were reported. The difference between average values of experimental data were considered significant at a confidence level of 95% ($p < 0.05$).

3. Results and Discussions

The effect of blanching and γ-irradiation on the moisture content and water activity (a_w) of JAP samples are presented in Table 1. For both NB and B JAP samples, the moisture contents were not significantly different ($p > 0.05$) among samples with dissimilar γ-irradiation doses. However, when comparing NB and B JAP samples, the moisture contents of B JAP samples (5.65%–5.86%) were lower than those of NB samples (6.20%–6.30%). The a_w values of the NB samples with different γ-irradiation doses also remained insignificantly different, whereas those of B JAP samples were significantly different, with the water activity showing a significant reduction from 0.365 at 0 kGy to 0.313 at 10 kGy. These

TABLE 1: Moisture content and water activity values of the treated JAP samples.

Pretreatment	γ-Irradiation doses (kGy)	Moisture content (%)	a_w
Nonblanched	0	6.30 ± 0.24^{a}	0.308 ± 0.003^{d}
	2.5	6.22 ± 0.19^{a}	0.304 ± 0.004^{d}
	5	6.27 ± 0.20^{a}	0.303 ± 0.002^{d}
	7.5	6.26 ± 0.19^{a}	0.303 ± 0.004^{d}
	10	6.20 ± 0.16^{a}	0.303 ± 0.007^{d}
Blanched	0	5.86 ± 0.13^{b}	0.365 ± 0.028^{a}
	2.5	5.84 ± 0.12^{b}	0.331 ± 0.014^{b}
	5	5.82 ± 0.27^{b}	0.324 ± 0.017^{bc}
	7.5	5.83 ± 0.13^{b}	0.317 ± 0.018^{bcd}
	10	5.65 ± 0.35^{b}	0.313 ± 0.008^{cd}

Note: Different letters in the same column indicate that values are significantly different ($p < 0.05$).

results indicate that blanching and γ-irradiation have a significant effect on both moisture contents and water activities of JAP samples.

The decrease in moisture content in B samples can be explained by the thermal impact of blanching. This process causes the weakening of cellular membranes and the breakdown of cell walls, resulting in water leakage [32]. The studies conducted by Rittirut and Siripatana [33] revealed that B samples exhibited a greater degree of water loss in comparison to NB samples. Ciurzynska et al. [34] found that B pumpkin had reduced moisture content during freeze-drying because of damage to the cell walls caused by blanching. This damage made it easier for water to be removed.

The observed reduction in water activity in B samples as the γ-irradiation dose increases may be because of irradiation on dietary fibers. Dietary fiber could retain water by both adsorption and absorption. Additionally, some water is kept separately from the fiber structure as free water [35]. The application of γ-irradiation leads to the degradation of hemicellulose and lignin within the fiber matrix [16], perhaps resulting in a decrease in the quantity of unbound water. Based on our results, the combination of blanching and γ-irradiation appeared to reduce both moisture content and water activity more than either treatment alone. This may suggest that the two treatments interact to enhance the reduction of available water in the product. This may lead to improved drying rates and color retention, as well as modifications in structural components that affect its capacity to retain moisture. This can be seen in the reduced moisture content reported in B JAP samples.

Figure 2 shows the appearance of JAP after being treated under two pretreatment conditions: nonblanching (NB) and blanching (B), followed by various γ-irradiation doses at 0, 2.5, 5, 7.5, and 10 kGy. Blanching significantly affected the color of JAP. The B samples (Figures 2f, 2g, 2h, 2i, and 2j) appeared darker than NB samples (Figures 2a, 2b, 2c, 2d, and 2e). This darkening in B samples was due to the formation of Fe^{2+} and *o*-diphenolic acid complexes during blanching, which oxidized to Fe^{3+}-*o*-diphenolic acid complexes, exposing a bluish-grey color when exposed to air [36]. The

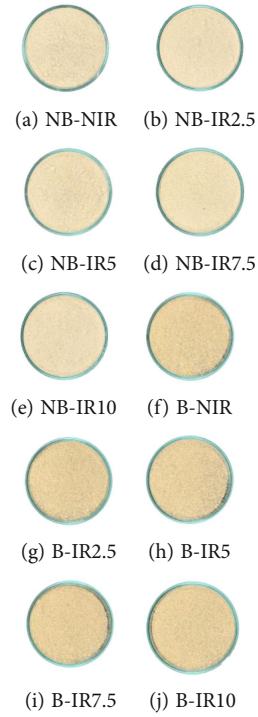


Figure 2: Appearance of JAP under two different pretreatments: (a–e) nonblanching (NB) and (f–j) blanching (B) under different γ-irradiation doses (NIR: nonirradiated; IR: irradiated) from 0 to 10 kGy.

effect of increased γ-irradiation doses on color change was not clearly visible in the images.

Figure 3 shows the color values ($L*$, $a*$, $b*$,and ΔE) of JAP samples. The lightness ($L*$) values declined as the irradiation doses increased. The decrease was greater in NB samples, indicating more significant darkening when exposed to irradiation. The redness ($a*$) and yellowness ($b*$) values exhibited more significant variation in NB samples in comparison to B samples. This indicates that irradiation influenced the color stability of NB samples.

When compared to B samples, NB samples had greater ΔE values, especially at higher irradiation doses. ΔE values in NB samples were approximately 1.4–2.1 times higher than those in B samples, with the greatest difference observed at 10 kGy. This suggests that blanching assists in minimizing the color changes caused by irradiation. Blanching appears to stabilize pigments and potentially inhibit enzymatic and nonenzymatic browning reactions that could be accelerated by irradiation [37]. The more stable color profile of B samples across different irradiation doses suggests that blanching may protect certain compounds or structures within the JAP that are sensitive to irradiation-induced changes. The results indicated the important role of blanching as a pretreatment technique for maintaining the color of JAP during irradiation.

Blanching combined with irradiation (B-IR) significantly improved the hydrophilic properties of JAP, specifically its WHC and WSC, as shown in Figure 4a,b. B samples showed a significant increase in WHC (Figure 4a), reaching a peak of 11.8 g/g at 2.5 kGy, compared to 2.9 g/g in NB samples at the

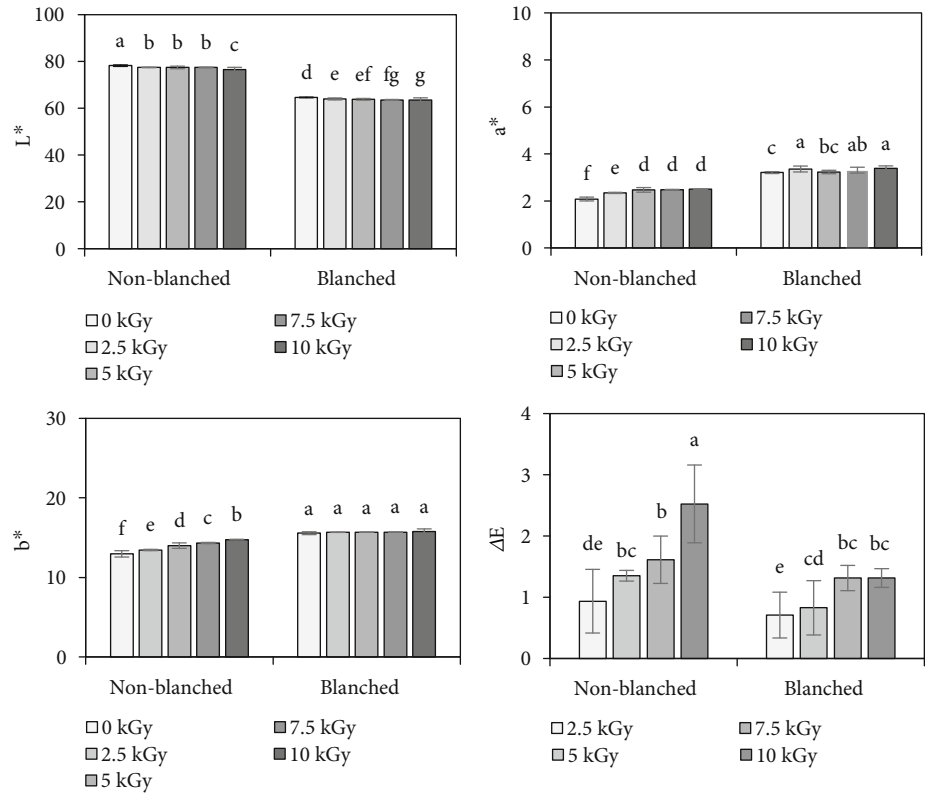


Figure 3: Color values (L, a, $b*$, and ΔE) of JAP samples pretreated by blanching or nonblanching, followed by different γ-irradiation doses.

same dose. The WHC of the B sample was approximately 4 times higher than that of the NB sample. This indicates that B samples were able to absorb water more effectively due to changes in cell wall composition. Similarly, WSC (Figure 4b) also followed a similar trend, as B samples revealed higher swelling capacities at all irradiation levels. At 2.5 kGy, WSC of B JAP was 17.8 g/g, while the value for the NB sample was 8.3 g/g. The WSC of the B sample was more than twice the value of the NB sample. These differences point out the effectiveness of blanching in improving water interaction properties. The improvement is a result of the presence of hydrophilic groups, such as hydroxyl groups in inulin, which improve the ability of powder to form hydrogen bonds with water molecules [38]. JAP is not only a great source of dietary fiber and inulin but also contains proteins that contribute to its functional properties in water interaction and binding [39, 40]. Likewise, heat causes the major proteins to break into subunits with more water-binding sites, increasing water absorption compared to native proteins [41]. Heat treatment modifies functional groups, increasing the availability of sites for water interaction and thus improving water absorption and retention during rehydration [42].

Irradiation involves exposing JAP to ionizing radiation. This process breaks down complex molecules and creates more hydrophilic sites within the food matrix [43]. It enhances the water absorption capacity of the powder by forming free radicals and other reactive species that interact with water molecules [44]. Additionally, irradiation disrupts the cell walls and creates microchannels [16, 45]. These changes accelerate better water penetration and retention, significantly improving the swelling capacity of the powder [46]. The formation of free radicals and reactive oxygen species during irradiation can lead to the modification of food components, including proteins and carbohydrates, which may contribute to increased hydrophilicity [47]. Nevertheless, excessive radiation doses often lead to a decrease in WHC due to the destruction of the network structure of fiber [16]. However, the OBC of JAP did not show significant changes by reason of either blanching or irradiation. This suggests that these treatments have a minimal impact on their oil absorption capabilities.

The improved WHC and WSC of JAP following B-IR treatment suggest its potential use in bakery products, such as bread, where moisture retention and texture enhancement are desired [48]. Additionally, JAP demonstrated potential in processed foods requiring thickening or a gel-like consistency. For instance, incorporating JAP into glass noodles improved their hardness, cohesiveness, and fiber content, resulting in a more nutritious and appealing product [49]. The OBC of JAP remained stable after irradiation, showing no negative impacts on structural or functional properties. These characteristics made treated JAP suitable for various applications in food formulations.

The effect of nonblanching and blanching prior to drying and varying γ-irradiation doses on the glucose absorption capacity (GAC) of JAP samples at different glucose concentrations (10, 50, 100, and 200 mmol) is shown in

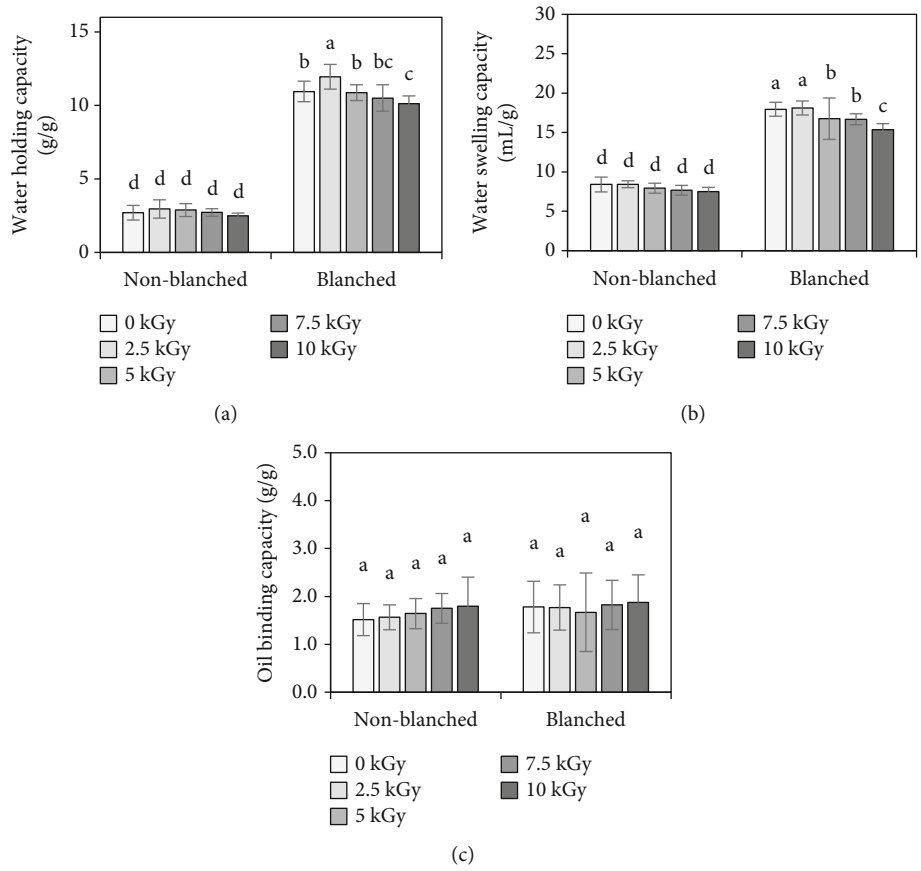


Figure 4: (a) Water holding capacity, (b) water swelling capacity, and (c) oil binding capacity of JAP samples processed with or without blanching, followed by γ-irradiation.

Figure 5. The results indicate that GAC increases with higher glucose concentrations for all treatment conditions. NB samples exhibit a steady increase in GAC with increasing irradiation doses. On the other hand, B samples show higher GAC than their NB counterparts at the same irradiation dose.

At 100 mmol glucose concentration, GAC increased from 48 mmol/g in NB-NIR to 78 mmol/g in B-NIR, and further to 96 mmol/g in B-IR at 10 kGy, representing a two-fold increase overall. At 200 mmol, GAC increased from 78 mmol/g in NB-NIR to 148 mmol/g in B-IR at 10 kGy, corresponding to an 89.7% increase. Blanching and gamma irradiation (B-IR) both improved the ability of food to absorb glucose by increasing surface area and porosity. Blanching disrupts cell walls and denatures proteins, which expose more glucose-binding sites. Gamma irradiation breaks down molecules and forms free radicals. This significantly changes the physicochemical properties of food materials and increases their GAC [50].

The combined effects of blanching and gamma irradiation (B-IR) significantly enhanced the GAC of JAP. This enhancement is beneficial for health, offering potential improvements in blood glucose regulation. The increased GAC of JAP can help manage blood glucose levels by reducing the amount of glucose available for absorption in the gastrointestinal tract. This property is especially useful for those with diabetes or those at risk of developing diabetes, as it may help control postprandial blood sugar increases [51, 52].

Table 2 indicates the effect of blanching and γ-irradiation on the total sugar, reducing sugar, and inulin content of JAP. For NB samples, the total sugar and reducing sugar content increased significantly with higher doses of γ-irradiation. The inulin content increased from 58.92 g/100 g in NB-NIR to a maximum of 64.44 g/100 g in NB-IR at 7.5 kGy, representing the highest value observed among all treatments, and then slightly decreased at 10 kGy. Farkas [50] reported the effects of γ-irradiation on food components and emphasized that γ-irradiation can cause the breakdown of polysaccharides into simpler sugars, which supports the observed increase in total and reducing sugars in JAP samples.

In B samples, the total sugar content increased from 50.01 g/100 g in B-IR at 5 kGy to 63.44 g/100 g at 10 kGy. The highest reducing sugar content was also observed at 10 kGy, reaching 4.02 g/100 g. The reducing sugar content was generally lower compared to NB samples. Inulin content was also lower in B samples. Blanching appeared to reduce the total sugar, reducing sugar, and inulin content in JAP samples. This reduction could be due to leaching of soluble sugars and inulin into blanching water or the thermal degradation of these components during the blanching process [53]. At higher irradiation doses, γ-irradiation may lead to the formation of new sugars from other components, such as

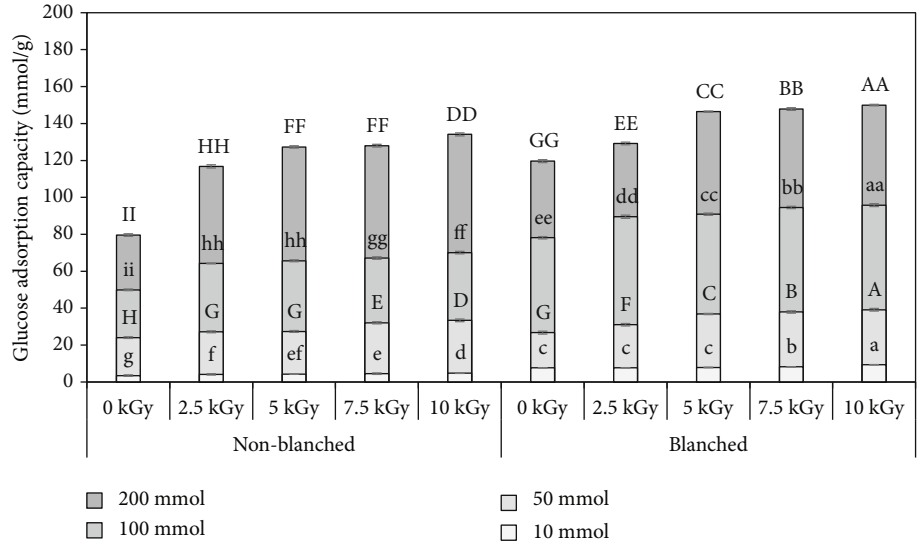


Figure 5: Glucose absorption capacity of JAP samples under blanching and nonblanching conditions, subjected to different γ-irradiation doses. Note: The superscripts on the bars present a statistically significant difference ($p < 0.05$) between treatments for the same glucose concentration.

cellulose and hemicellulose [16], which could explain the increase observed at 10 kGy. Additionally, the breakdown and depolymerization of polysaccharides by radiolysis might induce the production of low molecular weight fragments, leading to an increase in solubility [54]. JAP is a rich source of inulin, a prebiotic fiber that promotes gut health, enhances food texture, and serves as a low-calorie fat or sugar substitute. Gamma-irradiation improves the solubility and functionality of inulin, making it suitable for synbiotic and processed foods [1, 14].

Figure 6 shows the effects of blanching, nonblanching, and γ-irradiation on TPC (Figure 6a), DPPH radical scavenging activity (Figure 6b), and ABTS radical scavenging activity (Figure 6c) in JAP. In NB samples, TPC increased significantly with the γ-irradiation dose ($p < 0.05$), reaching a maximum of approximately 60 mg GAE/g dry weight at 7.5 kGy (NB-IR7.5). This suggests that γ-irradiation may enhance the release or formation of phenolic compounds due to cell wall breakdown and structural disruption. Harrison and Were [55] reported that γ-irradiation can release phenolic compounds from glycosidic components and degrade larger phenolic compounds into smaller ones. Ashouri et al. [56] further explained that radiolysis generates reactive species such as hydroxyl and hydroperoxide radicals, contributing to depolymerization and structural breakdown. These changes contribute to increased phenolic and flavonoid content in irradiated plant materials. Similar observations were reported by Behgar et al. [57] in pistachio hulls.

As shown in Figure 6b,c, DPPH and ABTS radical scavenging activities also increased significantly in NB samples with irradiation ($p < 0.05$), peaking at 10 kGy (NB-IR10) at approximately 45 and 85 mg TE/g dry weight, respectively. This trend is consistent with the findings of Sudesh et al. [14], who demonstrated that chicory inulin irradiated at 25 kGy exhibited improved DPPH and ABTS radical scavenging capacities due to the formation of low-molecular-weight fragments. Yin et al. [58] reported a similar enhancement in antioxidant activity of mushroom-derived polysaccharides following γ-irradiation, which was attributed to a reduction in molecular size and greater accessibility of active sites.

In contrast, B JAP samples showed lower TPC, DPPH, and ABTS values across all irradiation doses. The highest TPC in B samples was observed at 10 kGy (B-IR10), approximately 39 mg GAE/g), which was significantly lower than the corresponding NB group ($p < 0.05$). This reduction may be due to leaching or thermal degradation of phenolic compounds during blanching.

A dose of 2.5 kGy was chosen for its ability to enhance important properties, such as WHC, WSC, and glucose adsorption, in both B (B-IR2.5) and NB (NB-IR 2.5) JAP. This low dose caused minimal changes in ΔE values, maintaining color stability, unlike higher doses that resulted in noticeable color shifts and reduced WHC and WSC due to fiber breakdown. To better understand structural changes, the study analyzed the composition of the samples and applied advanced methods such as SEM, FT-IR spectroscopy, and NMR.

Table 3 presents the composition of JAP samples under different pretreatment and γ-irradiation conditions. The samples were either NB or B, and subjected to either no irradiation (NIR) or γ-irradiation at 2.5 kGy (IR 2.5). The results showed that blanching generally increased protein, SDF, and IDF content while decreasing moisture, ash, reducing sugar, and inulin content. The increase in protein content in B samples (B-NIR) (11.94 ± 0.01 g/100 g) compared to NB samples (NB-NIR) (8.90 ± 0.01 g/100 g) can be attributed to the decrease of sugar content by leaching, denaturation, and subsequent exposure of protein molecules, making them more detectable. The rise in dietary fiber content, both soluble and insoluble, was due to the breakdown of complex carbohydrates and cell wall

TABLE 2: Total sugar, reducing sugar, and inulin content of JAP samples under different blanching and γ-irradiation conditions.

Pretreatment	γ-Irradiation doses (kGy)	Total sugar (g/100 g)	Reducing sugar (g/100 g)	Inulin content (g/100 g)
Nonblanched	0	64.97 ± 0.67^{d}	6.05 ± 0.06^{d}	58.92 ± 0.64^{d}
	2.5	68.15 ± 1.00^{c}	6.50 ± 0.06^{c}	61.64 ± 0.94^{bc}
	5	68.81 ± 0.55^{bc}	6.70 ± 0.08^{b}	62.11 ± 0.62^{ab}
	7.5	70.98 ± 0.89^{ab}	6.54 ± 0.07^{c}	64.44 ± 0.82^{a}
	10	71.90 ± 0.24^{a}	7.54 ± 0.16^{a}	64.36 ± 0.35^{a}
Blanched	0	53.20 ± 1.73^{f}	3.47 ± 0.05^{g}	49.72 ± 1.78^{e}
	2.5	54.24 ± 2.04^{f}	3.48 ± 0.05^{g}	50.75 ± 2.10^{e}
	5	50.01 ± 4.61^{g}	3.32 ± 0.06^{h}	46.69 ± 4.55^{f}
	7.5	60.88 ± 2.47^{e}	3.79 ± 0.02^{f}	57.09 ± 2.45^{d}
	10	63.44 ± 1.85^{d}	4.02 ± 0.12^{e}	59.42 ± 1.74^{cd}

Note: Different letters in the same column indicate that values are significantly different ($p < 0.05$).

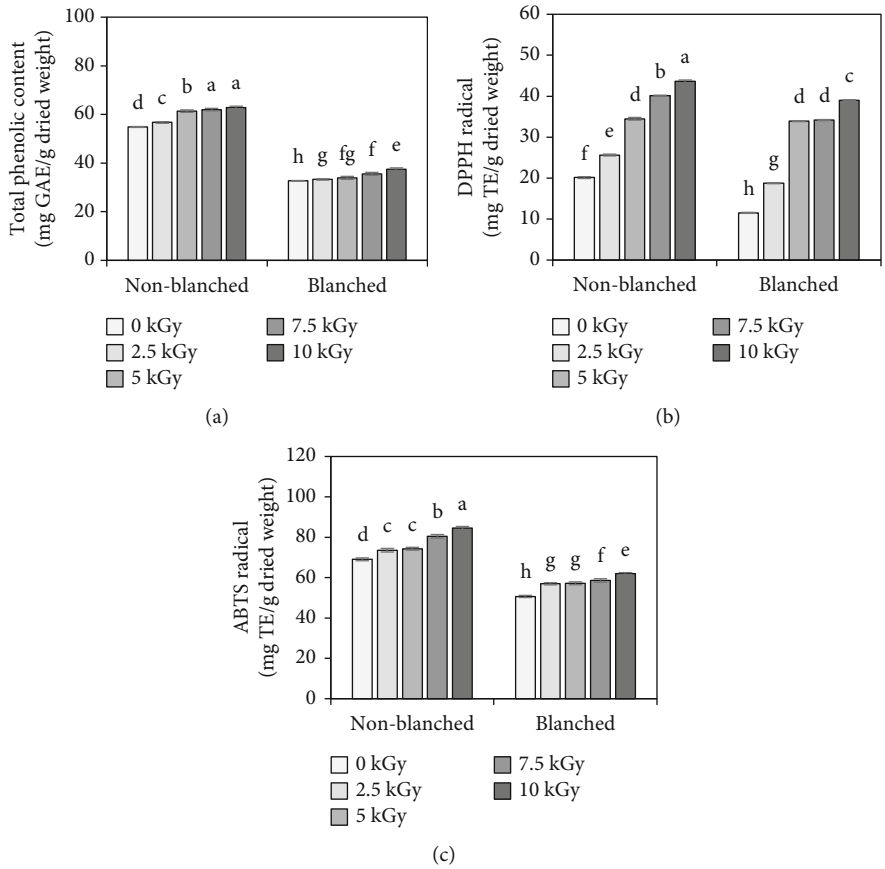


Figure 6: (a) Total phenolic content, (b) DPPH radical scavenging activity, and (c) ABTS radical scavenging activity of JAP subjected to blanching and γ-irradiation.

components during blanching, which released more fibers. This observation supports previous studies reporting that blanching increases dietary fiber content by leaching low-molecular-weight components such as minerals, vitamins, and sugars into blanching water, resulting in a relative increase in total dietary fiber and crude fiber content [1, 7, 14]. These structural changes also contribute to the reduction of reducing sugars and inulin, as both compounds are partially hydrolyzed during blanching.

γ-irradiation at 2.5 kGy significantly increased both reducing sugar and inulin contents in NB samples. Specifically, reducing sugar content increased from 6.05 ± 0.06 g/100 g (NB-NIR) to 6.50 ± 0.06 g/100 g (NB-IR2.5), while inulin increased from 58.92 ± 0.64 g/100 g to 61.64 ± 0.94 g /100 g ($p < 0.05$). Singh and Sharma [59] demonstrated that low-dose γ-irradiation improves the solubility and stability of polysaccharides and helps maintain their structure to stabilize food components.

TABLE 3: Composition of JAP samples under blanching and nonblanching conditions, with or without γ-irradiation at 2.5 kGy.

Composition (g/100 g)	NB-NIR	NB-IR2.5	B-NIR	B-IR2.5
Moisture	6.30 ± 0.24^{a}	6.22 ± 0.19^{a}	5.86 ± 0.13^{b}	5.84 ± 0.12^{b}
Protein	8.90 ± 0.01^{c}	8.94 ± 0.01^{b}	11.94 ± 0.01^{a}	11.94 ± 0.01^{a}
Ash	4.27 ± 0.01^{a}	4.08 ± 0.01^{b}	3.10 ± 0.01^{c}	3.05 ± 0.01^{d}
Reducing sugar	6.05 ± 0.06^{b}	6.50 ± 0.06^{a}	3.47 ± 0.05^{c}	3.48 ± 0.05^{c}
Inulin	58.92 ± 0.64^{b}	61.64 ± 0.94^{a}	49.72 ± 1.78^{d}	50.75 ± 2.10^{cd}
Soluble dietary fiber	5.77 ± 0.27^{b}	5.84 ± 0.06^{b}	11.88 ± 0.13^{a}	11.50 ± 0.32^{a}
Insoluble dietary fiber	7.36 ± 0.16^{b}	7.42 ± 0.12^{b}	18.37 ± 0.08^{a}	19.04 ± 0.74^{a}

Note: Values in the same row followed by different superscript letters are significantly different ($p < 0.05$).
Abbreviations: B: blanched, IR2.5: irradiation at 2.5 kGy, NB: nonblanched, NIR: nonirradiated.

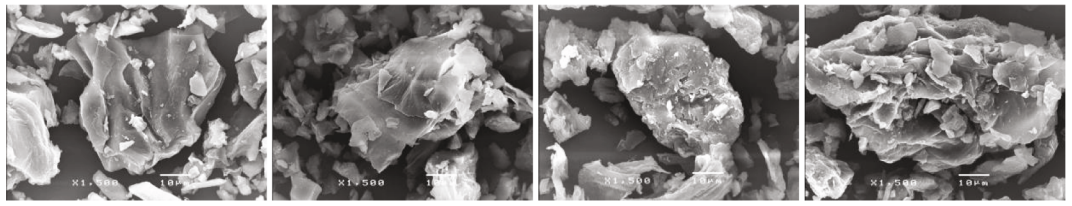


FIGURE 7: Scanning electron microscope (SEM) images of Jerusalem artichoke powder (JAP) at 1500× magnification under blanching and nonblanching conditions combined with γ-irradiation: NB-NIR (nonblanched, nonirradiated), NB-IR2.5 (nonblanched, irradiated at 2.5 kGy), B-NIR (blanched, nonirradiated), and B-IR2.5 (blanched, irradiated at 2.5 kGy).

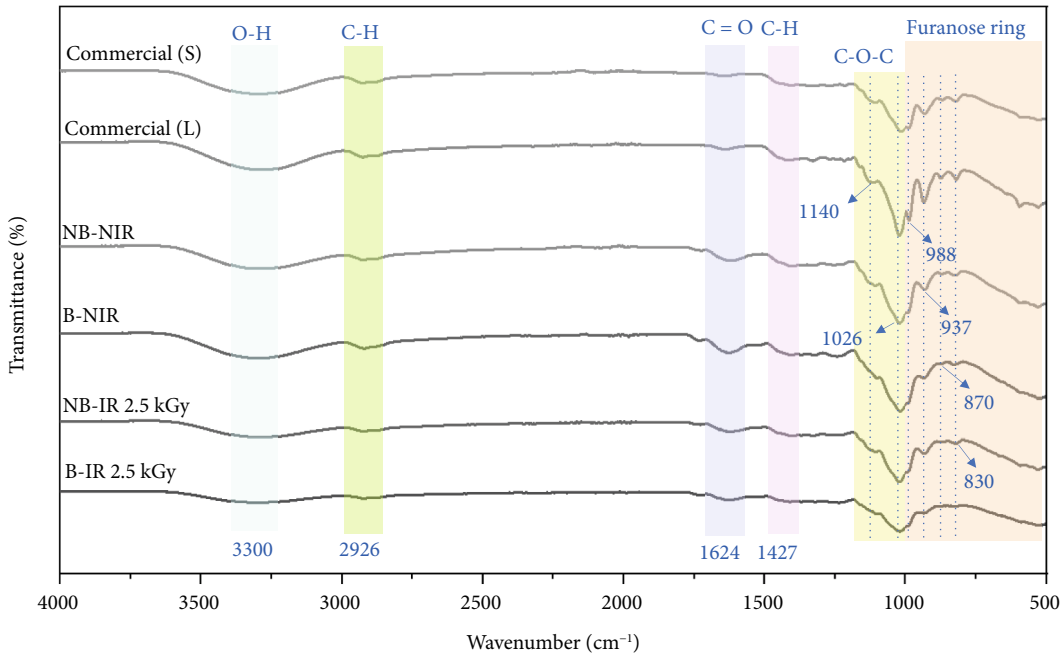


FIGURE 8: FTIR spectra of Jerusalem artichoke powder (JAP) under blanching and nonblanching conditions, combined with γ-irradiation at 2.5 kGy: NB-NIR (nonblanched, nonirradiated), NB-IR2.5 (nonblanched, irradiated), B-NIR (blanched, nonirradiated), and B-IR2.5 (blanched, irradiated), compared to commercial inulin (S: short chain, DP < 10; L: long chain, DP > 23).

The SEM images revealed distinct morphological differences between the samples (Figure 7). The NB-NIR sample showed an intact structure, suggesting minimal cellular damage. In contrast, the NB-IR2.5 sample exhibited increased surface porosity and fragmentation, indicating that irradiation at 2.5 kGy (NB-IR2.5) induced moderate structure breakdown. Although the increase in porosity was apparent, this structural change did not result in a significant improvement in

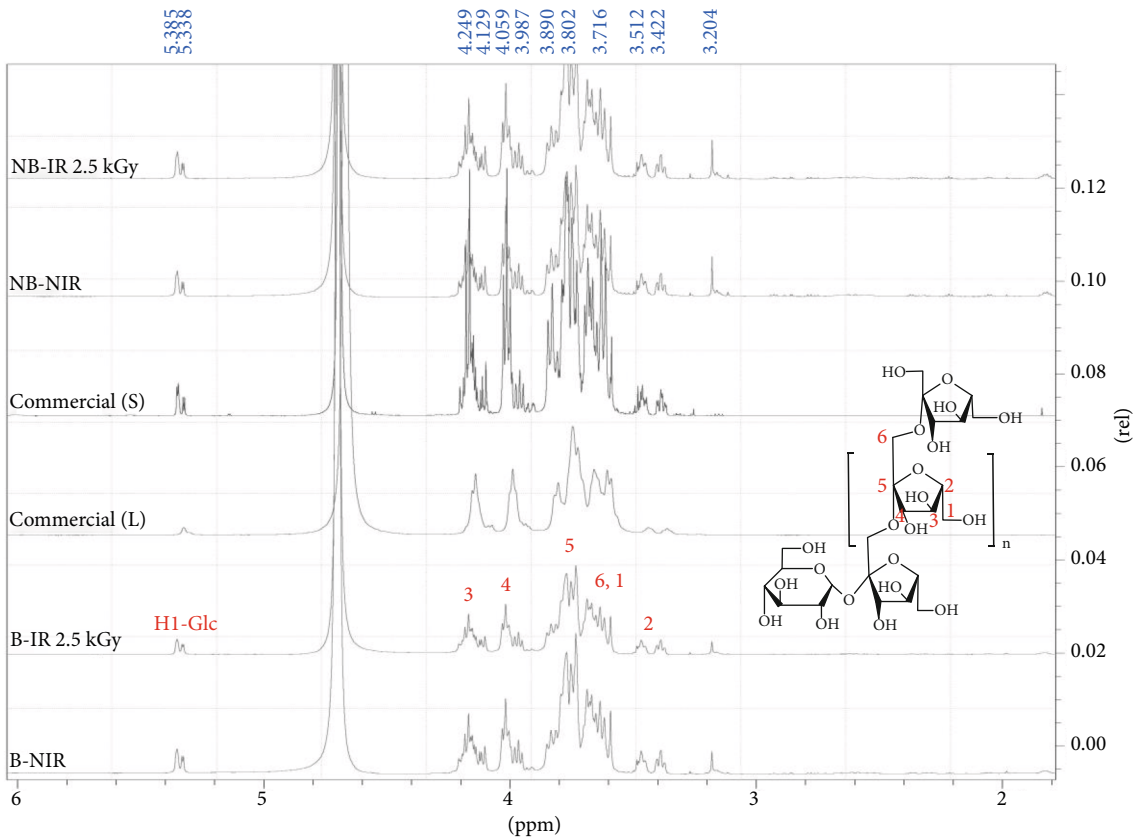


FIGURE 9: NMR spectra of Jerusalem artichoke powder (JAP) under blanching and nonblanching conditions, combined with γ-irradiation at 2.5 kGy: NB-NIR (nonblanched, nonirradiated), NB-IR2.5 (nonblanched, irradiated), B-NIR (blanched, nonirradiated), and B-IR2.5 (blanched, irradiated), compared to commercial inulin (S: short chain, DP < 10; L: long chain, DP > 23).

functional properties such as WHC or WSC, as previously determined in Figure 4.

Blanching alone (B-NIR) induced significant structural modification, considered by a more fragmented and porous surface. This disruption was due to thermal softening of the cell wall matrix, which facilitated the exposure of intracellular components such as proteins and fibers (refer to Table 3). These observations are reliable with the findings of Kaseke et al. [60], who reported that blanching disrupts hemicellulose, cellulose, and pectin networks, thereby enhancing porosity and solvent penetration. The combined treatment (B-IR2.5) resulted in the most noticeable structural breakdown among all conditions. The synergy between blanching and γ-irradiation at 2.5 kGy led to a highly porous structure, which correlated with significantly improved WHC and WSC (Figure 4). These structural changes may be beneficial for food applications that require enhanced hydration capacity and modified texture.

The FTIR spectra of JAP subjected to different pretreatments and γ-irradiation (NB-NIR, B-NIR, NB-IR 2.5 kGy, and B-IR 2.5 kGy) were compared with commercial inulin derived from chicory root, including short-chain (S; DP < 10) and long-chain (L; DP > 23) samples (Figure 8). All spectra exhibited characteristic absorption bands of fructan-type polysaccharides, consistent with previous reports [61].

A broad adsorption band centered around 3300 cm^{-1} was observed in all samples, corresponding to O–H stretching associated with hydrogen bonding and water interaction. Irradiated JAP samples (NB-IR 2.5 kGy and B-IR 2.5 kGy) showed reduced transmittance in this region, suggesting a decrease in hydrogen bonding due to structural modifications from γ-irradiation [62]. A band at approximately 2926 cm^{-1}, assigned to C–H stretching vibrations of methylene groups, was detected in all JAP and commercial inulin samples. At 1624 cm^{-1}, a band related to C=O stretching of bound water or N–H bending from residual proteins was observed in JAP samples but appeared weaker in commercial inulin, indicating compositional differences [63]. A peak around 1427 cm^{-1}, likely corresponding to CH_2 bending or C–H deformation, was detected in all samples and is commonly linked to polysaccharide structures [64].

In the spectral region between 1000 and 1200 cm^{-1}, a strong absorption band around 1026 cm^{-1} was assigned to C–O–C stretching vibrations of glycosidic linkages in the inulin backbone. The intensity of this band decreased in irradiated JAP samples, indicating partial disruption of glycosidic bonds, as previously described in γ-irradiated chicory inulin [15]. Additional absorption bands were found at 1140, 988, 937, 870, and 830 cm^{-1}. The band at 1140 cm^{-1} corresponds to asymmetric C–O–C stretching, while those from 988 to 937 cm^{-1} are related to ring vibrations of the fructo-furanose structure. The bands at 870 and 830 cm^{-1} are characteristic of β-(2→1) glycosidic linkages, a key feature of inulin-type fructans [64]. Blanching and γ-irradiation affected the

intensities of bands associated with hydrogen bonding and glycosidic linkages in JAP. However, no new absorption peaks were observed, confirming that the core structure of inulin-type fructans was preserved throughout processing.

^{1}H NMR spectroscopy was used to characterize structural changes in JAP resulting from blanching and γ-irradiation. Spectra exhibited distinct chemical shift signals in the δ 3.0–5.5 ppm region, corresponding to protons of glucopyranosyl and fructofuranosyl units in inulin-type fructans. This pattern is consistent with previously reported spectra of native inulin molecules [65, 66].

Figure 9 presents the molecular structure of inulin, showing a terminal α-D-glucopyranosyl unit and repeating β-(2→1)-linked D-fructofuranosyl residues. Proton positions are numbered to facilitate assignment of the spectral peaks. The signal at approximately δ 5.38 ppm was assigned to the anomeric proton (H1) of glucose (H1-Glc). Signals between δ 4.05 and 4.24 ppm were attributed to the H3 and H4 protons of fructose (H3-Fru; H4-Fru), and the multiplet region spanning δ 3.70–3.90 ppm corresponds to overlapping resonances from H1-Fru, H5-Fru, and H6-Fru. These results are also in agreement with the ^{1}H NMR data described in the literature [67–69].

Among the JAP samples, the spectrum of the NB-NIR group showed numerous sharp peaks with high intensity, reflecting a complex mixture of inulin chains with varying degrees of polymerization, along with possible low molecular weight sugars. In the B sample (B-NIR), peak intensities were generally lower, especially in regions corresponding to internal fructose protons. This reduction may be related to partial hydrolysis of glycosidic linkages during heat exposure.

In the sample treated with γ-irradiation at 2.5 kGy without blanching (NB-IR2.5), peak intensity continued to decline. The combination of blanching and irradiation (B-IR2.5) led to a more substantial loss of signal intensity, with several peaks becoming less defined or nearly absent. These changes suggest that irradiation caused fragmentation of the inulin structure, and the effect was more pronounced when preceded by thermal treatment. Similar patterns have been reported in other plant-derived fructans, where γ-irradiation disrupted glycosidic linkages but left the primary sugar structures largely intact [70]. The sharper and more limited set of peaks observed in JAP suggests shorter polymer chains and less molecular diversity, similar to the characteristics of short-chain inulin.

4. Conclusion

Blanching followed by gamma irradiation at 2.5 kGy (B-IR2.5) improved the functional quality of JAP. WHC increased from 2.9 to 11.8 g/g (4-fold), and swelling capacity rose from 8.3 to 17.8 g/g (over 2-fold). Glucose adsorption increased by 90%, from 78 to 148 mmol/g. Protein and total dietary fiber contents reached 11.94 and 28.6 g/100 g, respectively. Antioxidant properties improved with γ-irradiation, especially at 7.5 −10 kGy. FTIR spectra showed stronger absorption in hydroxyl and glycosidic regions, and ^{1}H NMR profiles of B-IR2.5 and NB-IR2.5 were similar to those of commercial short-chain inulin. Its structural similarity to short-chain inulin supports its use in products requiring high solubility and fast dispersion, such as fiber-enriched beverages or nutritional supplements. The treated powder has good potential for use as a dietary fiber ingredient in bakery products, beverages, and functional snacks. The selected processing conditions were based on proven effectiveness and safety standards, but further studies are encouraged to explore a wider range of blanching and irradiation parameters, assess product safety and consumer acceptance, and confirm the applicability of the results across different JAT varieties and growing conditions.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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