Acta Sci. Pol. Technol. Aliment. 23(3) 2024, 357–369

www.food.actapol.net pISSN 1644-0730 eISSN 1898-9594 http://doi.org/10.17306/J.AFS.001238

ORIGINAL PAPER

Received: 26.04.2024
Accepted: 18.06.2024

EFFECTS OF ROASTING ON THE QUALITY OF ROASTED JACKFRUIT SEED POWDER

Duong Thi Phuong Lien[1✉], Bui Thi Loan[1], Duong Kim Thanh[1],
Phan Thi Thanh Que[2], Nhan Minh Tri[2]

[1]Food Technology Department, Institute of Food and Biotechnology, Cantho University
Cantho University, 3/2 street, Cantho city, **Vietnam**
[2]Post-Harvest Technology Department, Institute of Food and Biotechnology, Cantho University
Cantho University, 3/2 street, Cantho city, **Vietnam**

ABSTRACT

Background. Roasting is the best choice for seeds to develop flavor, color, texture, and palatability. The roasting process also increases the antioxidant activity in roasted products. All these changes are mainly affected by roasting temperature and time. This research aims to determine the appropriate roasting temperature and time for jackfruit seed to increase the use value of the underutilized waste part of jackfruit.
Material and methods. The jackfruit seeds came from Thai jackfruits harvested from Hau Giang province, Vietnam. Jackfruit seed slides were roasted in a rotary drum roaster at temperatures of 160, 170, and 180°C for 30, 40, and 50 minutes after oven-drying for 90 minutes at 60°C. The functional properties, pasting properties, thermal properties, total phenolic content (TPC), antioxidant activity expressed through 2,2-diphenyl-1-picryl-hydrazyl (DPPH) free radical scavenging, and the sensory attributes of the roasted samples were analyzed.
Results. Roasting temperature and time significantly affected the quality of roasted jackfruit seed powder (RJSP). The high roasting temperature and time decreased bulk density (BD), tapped density (TD), foam capacity (FC), foam stability (FS), and viscosity properties of the powder. On the contrary, TPC, DPPH free radical scavenging, pasting temperature, and enthalpy for gelatinization significantly increased. A notable result was the formation of a chocolate aroma, notably when roasting jackfruit seeds at 170°C for 40 minutes. RJFS then exhibited high TPC (5.54 mg GAE/g) and antioxidant activity (DPPH free radical scavenging of 79.02%).
Conclusion. Temperature and time are important factors for the roasting process. Roasting jackfruit seed at 170°C for 40 minutes enhanced the chocolate aroma, antioxidant activity, and suitable functional properties for chocolate products.

Keywords: antioxidant activity, pasting properties, roasting, sensory attributes, temperature, thermal properties

INTRODUCTION

Jackfruit (*Artocarpus heterophyllus* Lam) is a tropical fruit belonging to the mulberry family (Moraceae) and a native of South and Southeast Asia. Currently, it is cultivated mainly in Thailand, Vietnam, China, the Philippines, Indonesia, Malaysia, Bangladesh, Myanmar, Nepal, and Sri Lanka (Kumari et al., 2018). In Vietnam, jackfruits are grown in the Southeast region (Binh Phuoc and Binh Duong) and the Mekong Delta provinces (Hau Giang, Tien Giang, Vinh Long, Long An, and Ben Tre). The primary part of jackfruit is the pulp used in fresh or processed food products. Along with jackfruit peel and latex, jackfruit seeds are edible

✉dtplien@ctu.edu.vn, https://orcid.org/0000-0002-0369-4656

wastes generated during jackfruit processing. Jackfruit seeds are mainly eaten after boiling or are discarded, which contributes to environmental damage. For this reason, the need to handle amounts of jackfruit seed waste at processing plants is also important to note. There are from 100 to 500 jackfruit seeds in a single jackfruit, accounting for 8% to 15% of the total weight of the fruit. Jackfruit seed contains considerable starch (about 70%) and has the same nutritional value as other seeds and tubers. In addition, jackfruit seeds contain bioactive compounds that bring many health benefits to consumers. Jackfruit seeds are known to reduce constipation, stress, infections, the risk of heart attack, and irritable bowel syndrome, and are therefore of increasing interest to consumers in the Asian region (Akmeemana et al., 2022).

Roasting is a significant step in the food processing industry using dry heat treatment commonly applied to seeds to develop the flavor, color and texture, as well as the overall palatability of the product (Prusak et al., 2014). Moreover, the presence of phenolic compounds in plants can be released into a free form that enhances their antioxidant activity during roasting (Lee et al., 2006). Roasted jackfruit seeds can be eaten like roasted nuts and beans. In addition, roasted jackfruit seed powder is used in composite blends with wheat flour in baked products. Papa-Spada et al. (2018) roasted jackfruit seeds at 171°C for 47 minutes and found a chocolate aroma in the roasted powder. In chocolate products, especially chocolate milk beverages, properties such as low viscosity, high solubility, swelling power, and water absorption are required (Spada et al., 2020). For it to be used in chocolate products, RJSP should have a chocolate aroma and the appropriate functional properties mentioned above. According to Prusak et al. (2014), the time-temperature relationship is a significant characteristic of the roasting process, and each product requires an appropriate roasting temperature. Papa-Spada et al. (2018) did not investigate the effects of temperature and roasting time on the formation of chocolate aroma as well as other properties of RJSP. Furthermore, there are no previous reports concerning the effects of the roasting process on the properties and quality of RJSP. This study aims to determine the effects of roasting temperature and time on the physical and functional properties, antioxidant activity, and sensory quality of RJSP, and then to determine the most appropriate parameters for the process of roasting RJSP products.

MATERIAL AND METHODS

Materials

Sample preparation

Thai jackfruits (*Artocarpus heterophyllus* Lam) were harvested from Hau Giang province, Vietnam (9°47′ to 9°78′N latitude and 105°28′ to 105°47′E longitude, an elevation of 2.81 meters), and transported to the Food Technology Laboratory, Institute of Food and Biotechnology, Can Tho University. After washing, the ripe jackfruits were cut and opened to reveal the jackfruit bulbs and to collect the jackfruit seeds. After removing the thin outer layer and washing, the seeds were sliced into 2 mm-thick slices using a cutting machine. The jackfruit seed slices were dried at 60°C for 90 minutes before being roasted in a rotary drum roaster (Model RH-20, Vinastar, Vietnam) at temperatures of 160, 170, and 180°C for 30, 40, and 50 minutes. The roasted samples were finely ground and passed through 60 mesh sieves to obtain fine roasted powder (< 0.25 mm). The RJSP samples were stored in zip bags at 4ºC and used for analyzing the functional properties, pasting properties, thermal properties, antioxidant activity, and sensory attributes. The RJSP showing the best quality was used to identify the nutritional components such as protein, carbohydrates, lipids, ash, and crude fiber.

Analysis

Measurement of the physiochemical properties

The water activities (A_w) of samples were measured using the VTS-60A Digital Food Water Activity Tester (China).

The moisture, protein, lipid, and ash contents were determined according to the AOAC (2005). The crude fiber content was analyzed according to the TCVN 4998:1989 standard.

Measurement of the functional properties

Bulk density and tapped density

Bulk density (BD) and tapped density (TD) were determined by the procedure described by Jan et al. (2019). The sample (5 g) was poured separately into a 20 mL measuring cylinder. The volume of powder was noted (bulk volume, mL). The volume of the same samples in measuring cylinders after being tapped 20 times on a plane surface was measured (tapped volume, mL). BD and TD of the RJSP were calculated according to equation (1) and (2), respectively (Jan et al., 2019; Akhila et al., 2022):

$$\text{BD (kg/m}^3\text{)} = \text{(weight of the sample/bulk volume)} \times 1000 \quad (1)$$

$$\text{TD (kg/m}^3\text{)} = \text{(weight of the sample/ tapped volume)} \times 1000 \quad (2)$$

Water absorption index (WAI)

WAI was determined according to the method described by Hatamian et al. (2020), with some modifications. Sample (2 g) was suspended in 20 ml of distilled water. The dispersion was stirred for 30 minutes and centrifuged at 4000 rpm for 30 minutes. The supernatant was removed and the residue was dried at 70°C until the moisture content was about 10% in order to determine the weight. WAI was calculated using equation (3):

$$\text{WAI (g/g)} = \text{weight of sediment/weight of dry solids} \quad (3)$$

Foaming properties

The foaming properties were determined according to the method described by Jan et al. (2019). The sample (5 g) was mixed with 250 mL of distilled water. The suspension was then whipped using a blender (Philips) for 5 minutes at maximum speed. After that, the samples were allowed to stand for an hour at room temperature. The volumes of suspension before whipping (V_o), after whipping (V_1), and after standing for an hour (V_2) were read using a measuring cylinder. The foam capacity (FC) and foam stability (FS) were calculated using equation (4) and (5), respectively:

$$\text{FC (\%)} = [(V_1 - V_0)/V_0] \times 100 \quad (4)$$

$$\text{FS (\%)} = [(V_2 - V_0)/V_0] \times 100 \quad (5)$$

Color

The powders were put into a petri dish and covered with a transparent film before measuring the color attributes (L^*, a^*, and b^* values) with a colorimeter (CR-20, Minolta, Japan). Browning index (BI) was determined using the equation (6) (Hatamian et al., 2020).

$$\text{BI} = [100\,(x - 0.31)]/0.17 \quad (6)$$

where: $x = (a^* + 1.75L^*)/(5.645L^* + a^* - 3.012b^*)$

Pasting properties

The pasting behaviors of RJSP samples were analyzed using a viscometer (RVA 4500, Perten, Australia) following the method described by Akhila et al. (2022). A slurry of sample (4 g) in distilled water (21 g) was made in a canister and thoroughly mixed. The suspension was heated from 30°C to 95°C for 7 minutes and maintained for 7 minutes at the same temperature (95°C). Then the temperature was reduced to 30°C for 7 minutes. The rotating speed was held at 960 rpm for the first 10 seconds and maintained at 160 rpm for the remaining process. The parameters such as peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BDV), final viscosity (FV), setback viscosity (SBV) and pasting temperature (PT) were recorded.

Thermal properties

Thermal properties were measured according to the method described by Jan et al. (2019), with some modifications, using a differential scanning calorimeter (DSC 204 F1 Phoenix, NETZSCH, Germany). The samples were weighed into aluminum DSC pans, and distilled water was added to make suspensions with 70% moisture content. The pans were hermetically sealed. For heating in the DSC, the heating ranged between 30–120°C, at a heating rate of 10°C minutes^{-1}. The thermal parameters such as onset temperature (To), peak temperature (Tp), conclusion temperature (Tc), and enthalpy of denaturation (ΔH) were calculated.

Determination of the total phenolic content (TPC) and antioxidant activity

Sample extraction

A sample (2 g) was extracted in 80% methanol to a volume of 20 mL. After 24 hours at 4°C, the mixture was filtered to receive the extract (Ojwang et al., 2018).

Total phenolic content (TPC) determination

100 μL of the extract was mixed with 500 μL of water and 100 μL of Folin-Ciocalteu reagent. The reaction mixture was left for 6 minutes before adding 1 mL of

7% sodium carbonate and 500 µL of distilled water. Absorbance was recorded at a spectral wavelength of 765 nm after incubating at 90 minutes under room temperature. A gallic acid standard curve was constructed by preparing different dilution concentrations in 80% methanol. From the measured absorbance and the standard curve, TPC in samples was calculated and expressed as mg GAE/g (Ojwang et al., 2018).

Determination of the DPPH free radical scavenging activity

The DPPH free radical scavenging activity of samples was determined using the method described by Ojwang et al. (2018) with slight modifications. A standard sample was prepared by mixing 0.002% DPPH solution in methanol, and the absorbance at 517 nm of the spectrometer was noted (A). The analyzed sample was prepared by mixing 50 µL of the extract into 3 ml of DPPH solution, which was kept in dark conditions for 30 minutes, and the absorbance was read at 517 nm from the spectrometer (B). The DPPH free radical scavenging of the extracted sample was calculated following the equation (7).

$$\text{DPPH free radical scavenging (\%)} = (A-B)/A \times 100\% \quad (7)$$

Evaluation of the sensory attributes

The sensory attributes of RJSP used for the quantitative descriptive analysis method were according to Papa-Spada et al. (2018), with some modifications (Table 1). Eight panelists (TCVN 3215:1979 standard) were selected through basic tests of taste and odor discrimination and trained to recognize the sensory attributes of the product. The panelists described the sensations perceived regarding all the sample attributes using a six-point intensity scale ranging from not appearing (0) and from less intense (1) to more intense (5) for attributes.

Experimental design and data analysis

The experiment was full factorial, designed to determine the effect of roasting temperature and time on the quality of RJSP. All results were obtained in triplicate and presented as means ± standard deviation. An analysis of variance was carried out to analyze the data of the functional properties, pasting properties, thermal properties and antioxidant activity of samples. The treatments were compared using the LSD test ($p < 0.05$). The sensory results were submitted to principal component analysis and displayed by a bi-plot graph. Statgraphics Centurion software (version XV.I) was used to analyze the data.

Table 1. Sensory attributes and definition

Sensory criteria	Attribute	Definition
Appearance	brown	intensity of color, from pale to dark
	uniform color	the degree of variation in particle color ranges from extremely abundant to absent
Aroma	chocolate	intensity of chocolate odor
	roasted	intensity of roasted odor
	burnt	intensity of burnt odor
	foreign	intensity of strange flavor, that is not suitable for the product
Taste	chocolate	intensity of chocolate flavor
	roasted	intensity of roasted flavor
	burnt	intensity of burnt flavor
	sour	intensity of sour taste
	foreign	intensity of strange flavor, that is not suitable for the product
Texture-Mouthfeel	gritty	the presence of small, hard particles
Overall impression		global perception

RESULTS AND DISCUSSION

The functional properties

The moisture content and water activity

The moisture content of RJSP ranged from 2.08% to 5.09% (Table 2). This result is consistent with the results of Eke-Ejiofor et al. (2014), namely, that the moisture content of roasted jackfruit seed powder is 4.44 ±3.5%. The moisture content and water activity of RJSP significantly decreased when the roasting temperature and time increased because the jackfruit seeds lost water during dry heat treatment at high temperatures. The water activities (A_w) of RJSP ranged from 0.33 to 0.44 (Table 2), which was in accordance with a_w of lightly roasted brown rice powder (0.2–0.4) (Fukui et al., 2022). Because of low A_w, RJSP can be stored at ambient temperature.

Bulk density and Tapped density

The BD and TD of powder are useful attributes used to calculate the suitable facilities for powder transportation, packaging, and marketing (Jan et al., 2019). The BD and TD of RJSP were in the ranges of 463.8–551.5 kg/m^3 and 555.8–672.5 kg/m^3, respectively. From the results found by Nabubuya et al. (2022), the BD of RJSP was 500 kg/m^3. The DB of RJSP statistically significantly decreased as the roasting temperature and time increased (Table 2). The roasting process could cause a pyrolysis reaction that releases CO_2, water, and volatile substances and increases the pressure of the internal gases. Then, the porosity in the grain structure increased, leading to increased grain volume and reduced BD value of powder (Odžaković et al., 2019). The higher the temperature and the longer the time, the higher the increase in volume. Odžaković et al. (2019) found that the volume of coffee beans increased by 55–57% when the roasting temperature increased from 100°C to 175°C. Similar results were reported for palm date seeds and green coffee roasted at different temperatures and time (Fikry et al., 2019; Odžaković et al., 2019). Because of the increase in grain volume after roasting, the TD of the roasted flour also increased.

Foaming properties

RJSP samples had low FC and FS. These values ranged from 0.27 to 0.73% and 0.07–0.25%, respectively (Table 2). FC and FS decreased significantly with the increase in roasting temperature and time. Proteins are often responsible for foaming properties. Treatment

Table 2. The effects of roasting temperature and time on the functional properties of roasted jackfruit seed powders

Roasting temperature °C	Roasting time minutes	Moisture content %	Water activity A_w	Bulk density (BD) kg/m^3	Tapped density (TD) kg/m^3	Foam capacity (FC) %	Foam stability (FS) %	Water absorption index (WAI) g/g
160	30	5.09 ±0.05^a	0.44 ±0.01^a	551.5 ±14.2^a	672.5 ±13.4^a	0.74 ±0.05^a	0.25 ±0.02^a	3.64 ±0.09^c
160	40	4.37 ±0.14^b	0.42 ±0.02^{ab}	522.6 ±10.2^{bc}	642.9 ±9.7^b	0.37 ±0.04^c	0.17 ±0.03^b	3.67 ±0.09^c
160	50	3.75 ±0.09^c	0.39 ±0.01^{bc}	511.9 ±12.4^{bc}	614.9 ±12.3^c	0.27 ±0.03^d	0.07 ±0.02^d	3.80 ±0.11^c
170	30	4.56 ±0.13^b	0.40 ±0.02^{bc}	530.9 ±10.3^{ab}	650.6 ±12.9^b	0.45 ±0.05^b	0.16 ±0.02^b	3.74 ±0.08^c
170	40	3.78 ±0.10^c	0.38 ±0.02^{cd}	514.7 ±11.2^{bc}	615.7 ±11.7^c	0.36 ±0.04^c	0.14 ±0.02^{bc}	3.73 ±0.11^c
170	50	3.20 ±0.17^d	0.34 ±0.01^e	506.0 ±14.2^c	589.5 ±11.6^{de}	0.27 ±0.03^d	0.07 ±0.02^d	3.78 ±0.11^c
180	30	3.33 ±0.11^d	0.36 ±0.01^{de}	516.3 ±10.6^{bc}	601.6 ±13.7^{cd}	0.32 ±0.07^{cd}	0.12 ±0.01^c	3.82 ±0.09^{bc}
180	40	2.51 ±0.21^e	0.35 ±0.02^e	470.1 ±12.7^d	575.6 ±9.8^{de}	0.27 ±0.03^d	0.07 ±0.01^d	4.02 ±0.15^{ab}
180	50	2.08 ±0.10^f	0.33 ±0.02^e	463.8 ±16.1^d	555.8 ±10.5^e	0.27 ±0.03^d	0.07 ±0.01^d	4.04 ±0.20^a

Results are expressed as the mean of three replicates ±SD. Values in the same column with different superscript letters represent statistically significant differences $p \leq 0.05$.

of samples at high temperatures reduced the solubility of proteins leading to a decrease in FC and FS of the sample (Eke and Akobundu, 1993). Jackfruit seed samples roasted for a long time (50 minutes) or roasted at a high temperature (180°C) for 40–50 minutes showed very low FC and FS (0.27 and 0.07%, respectively). They may be of limited use in food products that require high foaming capacity.

Water absorption index (WAI)

WAI of RJSP ranged from 3.64 to 4.04 g/g, which was similar to the findings of Nabubuya et al. (2022) on RJSP with a WAI of 3.74 g/g. WAI increased significantly for roasting at high temperatures and prolonged time (Table 2). As mentioned above, the increase in the porous structure of the powder during high-temperature roasting increased the water absorption capacity. In addition, according to Hatamian et al. (2020), roasting at high temperatures caused the starch to be more damaged and converted into smaller molecular weight molecules (dextrin), thus absorbing more water and the WAI increased.

The color and BI

*L**, *a**, and *b** values of RJSP were in the range of 65.0–83.5, 7.1–11.3, and 16.4–22.4, respectively (Table 3). The *L** value in the samples significantly decreased with the increase in roasting temperature and time, while the values of *a** and *b** gave the opposite result. The non-enzymatic browning reactions during roasting darkened the product color and reduced the *L** value. The heat treatment temperature and time are important factors affecting these reactions (Azeez et al., 2015). Moreover, the appearance of a yellow-brown color increased the *b** value, and the red-brown color increased the *a** value. The BI indicates the degree of color change to brown. The BI of RJSP ranged from 27.8 to 51.7, and this value significantly increased when jackfruit seeds were roasted at high temperatures and for a long time ($p < 0.05$). This result was due to the non-enzymatic browning reactions that occur during roasting. A similar trend of BI change was also found in defatted palm date seed powder and chia seeds after roasting (Fikry et al., 2019; Hatamian et al., 2020). Natural cocoa powder has a lower *L** value (43.14 ±0.03) but similar values of *a** (13.32 ±0.04) and *b** (18.33 ±0.08) compared to roasted jackfruit seed powder (Ondo and Ryu, 2013). The color change and the increase in BI during roasting resulted in RJSP products having a suitable brown color for chocolate products.

Pasting properties

Peak viscosity (PV) of the samples ranged from 361 cP (sample roasted at 180°C for 50 minutes) to 2456 cP

Table 3. The color values of roasted jackfruit seed powders affected by roasting temperature and time

Roasting temperature °C	Roasting time minutes	*L**	*a**	*b**	BI
160	30	83.5 ±0.9[a]	7.1 ±0.7[d]	16.4 ±0.7[d]	27.8 ±1.1[e]
160	40	74.7 ±0.5[b]	9.9 ±1.0[c]	22.0 ±1.3[a]	44.2 ±1.2[bc]
160	50	71.6 ±0.7[c]	10.2 ±0.5[bc]	21.7 ±1.0[a]	46.0 ±1.1[b]
170	30	73.9 ±1.0[b]	9.4 ±1.0[c]	17.3 ±1.1[bc]	35.6 ±1.5[d]
170	40	68.0 ±0.5[d]	10.0 ±0.5[bc]	18.5 ±1.4[b]	42.0 ±2.9[c]
170	50	65.8 ±0.3[e]	11.3 ±0.5[ab]	20.7 ±0.8[a]	49.7 ±2.2[a]
180	30	71.7 ±0.8[c]	9.1 ±0.8[c]	18.2 ±0.8[bc]	38.0 ±0.4[d]
180	40	67.7 ±0.3[d]	11.5 ±0.7[a]	22.2 ±0.8[a]	51.7 ±1.3[a]
180	50	65.0 ±1.6[e]	11.3 ±1.0[ab]	21.3 ±1.1[a]	51.8 ±0.8[a]

Results are expressed as the mean of three replicates ±SD. Values in the same column with different superscript letters represent statistically significant differences $p \leq 0.05$.

(sample roasted at 160°C for 30 minutes). The PV is the maximum viscosity attained by gelatinized starch in water during heating (Kumar et al., 2020). The PV decreased significantly when the roasting temperature and time increased (Table 4). According to Jogihalli et al. (2017), the change in the gelatinization temperature of starch granules after roasting at high temperatures caused them to rupture, which reduced the degree of polymerization during gelatinization and reduced PV. A similar result was reported for roasted common bean flour (Byarugaba et al., 2023).

The trough viscosity (TV) of the samples ranged from 18.5 to 48 cP (Table 4). TV indicates hot paste stability (Kaur et al., 2007). The smaller the TV was, the higher the stability of the paste got. In this study, TV tended to decrease when the roasting temperature and time increased, with a few exceptions. The decrease in TV expressed increased stability for roasted jackfruit seed powder during cooking at high temperatures.

Breakdown viscosity (BDV) indicates the ease with which swollen starch granules can be disintegrated by shear stress (Kaur et al., 2007). Low BDV indicates high paste stability to resist shear stress during cooking (Ragaee and Abdel-Aal, 2006). BDV of samples ranged from 342 to 2408 cP. BDV tended to decrease with the increase in temperature and time, which expressed high paste stability in jackfruit seed powder roasted at high temperature and time.

Final viscosity (FV) indicates the ability of starch to form a viscous paste after cooking and cooling. FV of samples ranged from 4047 to 4954 cP. FV decreased when the roasting temperature and time increased. Increasing heat caused a high degree of starch dextrinization combined with a possible high level of starch retrogradation, resulting in a gradual reduction in FV. A similar result was reported by Kumar et al. (2020) for roasted black chickpeas.

Setback viscosity (SBV) is the difference between FV and TV. The SBV of samples ranged from 4028 to 4920 cP. The SBV decreased with an increase in roasting temperature and time. These results agreed with the observed result of the common bean (Byarugaba et al., 2023).

Pasting temperature (PT) is the temperature at which the viscosity of starch paste begins to extend during the heating treatment. PT is also an indicator of the minimum temperature required for cooking starch in the sample (Pongsawatmanit et al., 2002). The PT of the samples ranged from 89.3°C to 92.4°C and tended to increase when roasted at high temperatures for long times. Roasting at high temperatures and for a long time destroyed a lot of the starch, mainly the

Table 4. Pasting properties of roasted jackfruit seed powders affected by roasting temperature and time

Roasting temperature °C	Roasting time minutes	Peak viscosity PV cP	Trough viscosity TV cP	Breakdown viscosity BDV cP	Final viscosity FV cP	Setback viscosity SBV cP	Pasting temperature PT °C
160	30	2 456 ±18[a]	48.0 ±2.8[a]	2 408 ±15.6[a]	4 954 ±28[a]	4 906 ±26[a]	89.3 ±0.3[d]
160	40	1 195 ±7[b]	24.0 ±2.8[b]	1 171 ±9.9[b]	4 944 ±38[a]	4 920 ±40[a]	91.2 ±0.2[bc]
160	50	638 ±21[d]	19.5 ±2.1[c]	619 ±19.1[d]	4 324 ±76[c]	4 304 ±74[c]	91.8 ±0.3[ab]
170	30	1 189 ±28[b]	21.5 ±0.7[bc]	1 168 ±27.6[b]	4 561 ±50[b]	4 540 ±49[b]	90.6 ±0.1[c]
170	40	1 151 ±84[b]	24.5 ±0.7[b]	1 126 ±83.4[b]	4 633 ±86[b]	4 608 ±85[b]	91.3 ±1.0[bc]
170	50	822 ±29[c]	24.0 ±1.4[b]	798 ±31.1[c]	4 295 ±25[c]	4 271 ±26[c]	91.5 ±0.5[bc]
180	30	870 ±35[c]	18.5 ±2.1[c]	852 ±33.2[c]	4 233 ±55[c]	4 215 ±57[c]	91.2 ±0.1[bc]
180	40	845 ±49[c]	19.0 ±1.4[c]	826 ±48.1[c]	4 315 ±63[c]	4 296 ±64[c]	91.1 ±0.3[bc]
180	50	361 ±14[e]	19.0 ±1.4[c]	342 ±15.6[e]	4 047 ±71[d]	4 028 ±72[d]	92.4 ±0.2[a]

Results are expressed as the mean of three replicates ±SD. Values in the same column with different superscript letters represent statistically significant differences $p \leq 0.05$.

form that remained heat-stable and resistant to rupture, so PT increased.

The decrease in PV and FV when the roasting temperature and time increased showed that roasted jackfruit seed powder met the requirements for processing into chocolate products, as mentioned above (Spada et al., 2020). However, in roasting for a long time (50 minutes), especially at 180°C, PT increased, and the destruction of starch proved to be greater.

Thermal properties

The thermal properties of the samples are presented in Table 5. T_o denotes the initial peak temperature where starch granules begin to swell. The temperature where the starch granules gelatinization is completed is T_p. The enthalpy of gelatinization ΔH reflects the energy consumption of starch during the gelatinization process (Chinnasamy et al., 2022). The T_o, T_p, and T_c values of samples were in the ranges of 85.7–86.6°C, 89.6–90.8°C, and 95.2–97.00°C, respectively. In this study, the variation of T_o was not significant. T_p and T_c tended to increase during roasting at high temperatures (180°C) and for a long time (50 minutes). The remaining samples were not significantly different. Roasting at a higher temperature and for a longer time (180°C, 40-50 minutes) significantly increased the ΔH value (Table 5). After roasting at high temperatures and long times, the roasted powder became more difficult to thermally decompose and more heat-stable, leading to increased heat absorbed or released per gram sample during thermal decomposition after roasting. Yang et al. (2023) confirmed that the thermal stability of rice samples significantly improved after roasting.

Correlation analysis

Table 6 shows the results of the correlation analysis for the functional properties of RJSP. Most of the correlations between properties were statistically significant, except for the correlation between WAI with FC and FS. In addition, the correlation between T_o and the remaining properties was not statistically significant. The correlation coefficients ranged from 0.415 to 0.952, showing a medium-to-strong correlation.

Total phenolic content and antioxidant activity

Table 7 showed that the TPC of RJSP ranged from 2.72 to 6.04 mg GAE/g. TPC increased with increasing roasting time and temperature. During roasting at high temperatures, the bonds between phenolic compounds and proteins were broken, thereby increasing the total phenolic content in the sample. Another reason for the increase in TPC may be the Maillard reaction

Table 5. Thermal properties of roasted jackfruit seed powders affected by roasting temperature and time

Roasting temperature °C	Roasting time minutes	Onset temperature T_o °C	Peak temperature T_p °C	Conclusion temperature T_c °C	Enthalpy ΔH J/g
160	30	86.1 ±0.8^{ns}	89.6 ±0.2^{b}	95.5 ±0.1^{ab}	9.06 ±0.07^{cd}
160	40	85.7 ±0.4^{ns}	90.2 ±0.5^{ab}	95.2 ±1.4^{b}	8.94 ±0.43^{cd}
160	50	85.8 ±1.2^{ns}	89.6 ±0.7^{b}	95.9 ±0.4^{ab}	8.95 ±0.05^{cd}
170	30	86.0 ±0.3^{ns}	89.7 ±0.6^{ab}	96.5 ±0.4^{ab}	8.57 ±0.29^{d}
170	40	86.3 ±0.2^{ns}	90.0 ±0.3^{ab}	96.1 ±0.6^{ab}	9.75 ±0.12^{bc}
170	50	86.6 ±0.2^{ns}	90.3 ±0.4^{ab}	96.4 ±0.2^{ab}	9.95 ±0.11^{b}
180	30	85.2 ±1.1^{ns}	89.8 ±0.4^{ab}	95.5 ±0.2^{ab}	9.76 ±0.28^{bc}
180	40	86.4 ±0.1^{ns}	90.8 ±0.8^{a}	97.0 ±0.9^{a}	10.04 ±0.67^{ab}
180	50	86.0 ±0.3^{ns}	89.9 ±0.2^{ab}	97.0 ±1.4^{a}	10.81 ±0.63^{a}

Results are expressed as the mean of three replicates ±SD. Values in the same column with different superscript letters represent statistically significant differences $p \le 0.05$; ns: not significant.

Table 6. Pearson's correlation matrix of the functional properties of roasted jackfruit seed powder

Properties	Moisture content MC	A_w	Bulk density BD	Tapped density TD	Foaming capacity FC	Foaming stability FS	Water absorption index WAI	Peak viscosity PV	Onset temperature T_o
MC	1	0.886***	0.891***	0.952***	0.753***	0.825***	–0.733***	0.591**	–0.137
Aw		1	0.743***	0.875***	0.715***	0.765***	–0.551***	0.543**	–0.147
BD			1	0.900***	0.681***	0.748***	–0.729***	0.415*	–0.107
TD				1	0.740***	0.829***	–0.735***	0.564**	–0.099
FC					1	0.883***	–0.3492	0.590**	0.001
FS						1	–0.5781	0.525**	–0.094
WAI							1	–0.476*	0.106
PV								1	0.144
T_o									1

*: *p*-value < 0.05; **: *p*-value < 0.01 and ***: *p*-value < 0.001.

Table 7. Effect of roasting temperature and time on TPC and DPPH radical scavenging activity of roasted jackfruit seed powders

Roasting temperature °C	Roasting time minutes	TPC mg GAE/g	DPPH radical scavenging activity %
160	30	2.72 ±0.11^{f}	60.61 ±0.36^{e}
160	40	4.88 ±0.16^{c}	74.01 ±0.45^{c}
160	50	4.77 ±0.18^{c}	75.78 ±0.47^{b}
170	30	3.85 ±0.13^{e}	65.89 ±0.27^{d}
170	40	5.54 ±0.11^{b}	79.02 ±0.97^{a}
170	50	5.65 ±0.11^{b}	78.97 ±0.32^{a}
180	30	4.23 ±0.15^{d}	74.82 ±0.32^{c}
180	40	5.63 ±0.18^{b}	78.47 ±0.33^{a}
180	50	6.04 ±0.45^{a}	79.17 ±0.55^{a}

Results are expressed as the mean of three replicates ±SD. Values in the same column with different superscript letters represent statistically significant differences $p \leq 0.05$.

occurring during roasting to form phenolic-type structural products such as proanthocyanidins and gallic acid (Şahin et al., 2009). The increase in TPC with increasing roasting temperature and time was also noted in roasted chia seeds (Hatamian et al., 2020) and palm date seeds (Fikry et al., 2019). The resulting significant increase in TPC and antioxidant activity during roasting at high temperatures (170–180°C) for 40–50 minutes is an essential advantage of RJSP because it is related to consumer health.

The DPPH free radicals scavenging activity of the samples indicated their antioxidant activity. After roasting, the DPPH free radicals scavenging activity of samples ranged from 60.61% to 79.17% (Table 7).

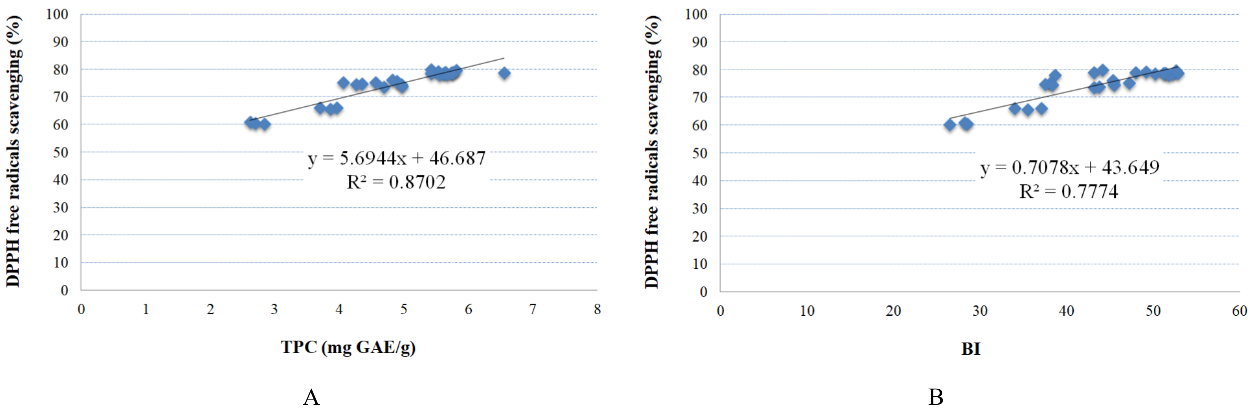

Fig. 1. The significant correlation ($p < 0.05$) between DPPH free radicals scavenging activity with TPC (A) and BI (B)

The DPPH free radical scavenging of the samples significantly increased when increasing the roasting temperature and time. The antioxidant activity of the samples mainly depends on the amount of phenolic compounds from the raw material and other phenolic compounds formed from non-enzymatic browning reactions during heat treatment (Sacchetti et al., 2009). Therefore, with the result of increased TPC, the DPPH free radicals scavenging also increased. To make this result clear, a statistically significant correlation ($p < 0.05$) between DPPH free radicals scavenging with TPC ($R^2 = 0.87$) and BI ($R^2 = 0.78$) was detected and shown in Figure 1. Similar findings for defatted palm date seeds and carob powder have also been reported (Şahin et al., 2009; Fikry et al., 2019).

Quantitative descriptive analysis of the sensory attributes

Principle component analysis conclusively visualized the effect of roasting temperature and time on all the sensory attributes of samples. A biplot (Fig. 2) represented 78.82% (PC1: 55.68% and PC2: 23.15%)

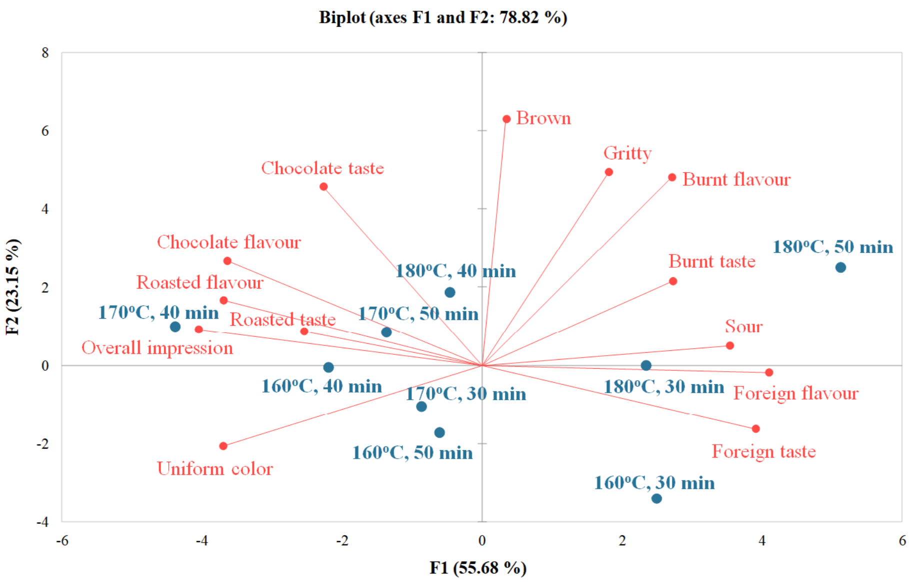

Fig. 2. Biplot of principle component analysis for roasted jackfruit seed powders

variations. The biplot showed the information of both samples and all the sensory attributes from the data matrix. Therefore, it simultaneously provided the effect of roasting temperature and time on the sensory attributes of products.

According to Spada et al. (2021), the roasting of jackfruit seeds created a pleasant chocolate aroma. Figure 2 shows that many good sensory attributes (chocolate odor, chocolate taste, roasted odor, roasted taste, uniform color, and overall impression) were highly grouped around the sample roasted at 170°C for 40 minutes, whereas the samples roasted at higher temperature (180°C) expressed most the poor sensory attributes (gritty, burnt odor, burnt taste, foreign odor, foreign taste, sour). The remaining samples showed intermediate levels of sensory attributes. Figure 2 concludes that in order to gain good sensory quality, especially the high-intensity chocolate flavor in the product, jackfruit seeds should be roasted at 170°C with a time of 40 minutes. This research results in similar roasting temperatures, but the roasting time is shorter than the roasting time that Papa-Spada et al. (2018) applied (171°C for 47 minutes).

Nutritional compositions

The nutritional compositions of fresh jackfruit seeds and jackfruit seed powder roasted at 170°C for 40 minutes are presented in Table 8. Due to the reduced water content after roasting, all components are displayed as percentages based on a dry basis. There are differences in the carbohydrate, lipid, fiber, and mineral components between fresh jackfruit seeds and roasted jackfruit seed powder. For example, lipid content decreased due to hydrolysis. Sieving into a fine powder may result in nutritional component changes. Eke-Ejiofor et al. (2014) announced the contents of carbohydrate, protein, lipid, fiber, and ash of roasted jackfruit seed powder to be 72.16%, 18.80%, 0.27%, 3.38%, and 2.45%, respectively. The differences in the research results are due to the species, growing conditions, and harvest maturity that affect the components of jackfruit seeds and the different processing conditions of roasted jackfruit seeds.

CONCLUSION

Roasting temperature and time are both factors that significantly affect the functional properties, sensory attributes, and antioxidant activity of roasted jackfruit seed powders. Valuable changes include the formation of chocolate aroma when roasting jackfruit seeds at 170°C for 40 minutes. In addition, the total phenolic content and antioxidant activity increased during roasting at high temperatures (170–180°C) for 40–50 minutes. However, poor changes can occur when roasting at higher temperatures (180°C) for a long time (50 minutes). Specifically, starch is ruptured, leading to reduced foaming capacity and stability, reduced pasting properties, and the formation of burnt flavor and odors for roasted flour. Then, the powder has a higher pasting temperature and higher thermal stability. A roasting temperature of 170°C for 40 minutes can be applied to process RJSP products with high sensory quality and antioxidant activity and can be used in chocolate products.

ACKNOWLEDGEMENTS

We sincerely thank for the support of the Department of Science and Technology of Hau Giang province through the project “Researching on the procedures to diversify the products from jackfruit in Hau Giang province”.

Table 8. Nutritional composition of fresh jackfruit seeds and roasted jackfruit seed powder

Nutritional compositions %, dry basic	Carbohydrate	Protein	Lipid	Fiber	Ash
Fresh jackfruit seeds	80.85 ±1.09[b]	13.29 ±0.46[a]	1.20 ±0.13[a]	2.06 ±0.21[a]	1.96 ±0.28[a]
RJSP	84.10 ±0.34[a]	12.39 ±0.16[b]	0.86 ±0.07[b]	1.32 ±0.06[b]	1.14 ±0.05[b]

Results are expressed as the mean of three replicates ±SD. Values in the same column with different superscript letters represent statistically significant differences $p \leq 0.05$.

DECLARATIONS

Data statement

All data supporting this study has been included in this manuscript.

Ethical Approval

Not applicable.

Competing Interests

The authors declare that they have no conflicts of interest.

OPEN ACCESS

REFERENCES

Akhila, P. P., Sunooj, K. V., Aaliya, B., Navaf, M., Sudheesh, C., …, George, J. (2022). Morphological, physicochemical, functional, pasting, thermal properties and digestibility of hausa potato (*Plectranthus rotundifolius*) flour and starch. Appl. Food Res., 2(2), 100193. https://doi.org/10.1016/j.afres.2022.100193

Akmeemana, C., Wickramasinghe, I., Wanniarachchi, P. C., Vithanage, T. (2022). Effect of drying and frying pretreatments on nutrient profile, antioxidant capacity, cooking time, and sensory acceptability of easy to cook jackfruit seeds. Appl. Food Res., 2(2), 1–6. https://doi.org/10.1016/j.afres.2022.100234

AOAC (2005). Determination of moisture, ash, protein and fat. Official Method of Analysis of the Association of Analytical Chemists, 18th Edition. Washington DC: AOAC.

Azeez, S., Lasekan, O., Jinap, S., Sulaiman, R. (2015). Effect of roasting conditions on the browning intensity and structural changes in jackfruit (*Artocarpus hetrophyllus*) seeds. J. Food Sci. Technol., 52(12), 8050–8058. https://doi.org/10.1007/s13197-015-1900-6

Byarugaba, R., Nabubuya, A., Muyonga, J., Mwakha, A. (2023). Effects of roasting conditions on the proximate composition and functional properties of common bean (*Phaseolus vulgaris*) flours. Tanzan. J. Sci., 49(2), 546–558. https://dx.doi.org/10.4314/tjs.v49i2.23

Chinnasamy, G., Dekeba, K., Sundramurthy, V. P., Dereje, B. (2022). Physicochemical properties of tef starch: morphological, thermal, thermogravimetric, and pasting properties. Int. J. Food Prop., 25(1), 1668–1682. https://doi.org/10.1080/10942912.2022.2098973

Eke-Ejiofor, J., Beleya, E., Onyenorah, N. (2014). The effect of processing methods on the functional and compositional properties of jackfruit seed flour. Int. J. Nutr. Food Sci., 3(3), 166–173. DOI: 10.11648/j.ijnfs.20140303.15

Eke, O., Akobundu, E. (1993). Functional properties of African yam bean (*Sphenostylis stenocarpa*) seed flour as affected by processing. Food Chem., 48(4), 337–340. https://doi.org/10.1016/0308-8146(93)90314-6

Fikry, M., Yusof, Y. A., Al-Awaadh, A. M., Rahman, R. A., Chin, N. L., …, Chang, L. S. (2019). Effect of the roasting conditions on the physicochemical, quality and sensory attributes of coffee-like powder and brew from defatted palm date seeds. Foods, 8(61), 1–19. https://doi.org/10.3390/foods8020061

Fukui, M., Islam, M. Z., Lai, H.-M., Kitamura, Y., Kokawa, M. (2022). Effects of roasting on storage degradability and processing suitability of brown rice powder. LWT Food Sci. Technol., 161, 113277. https://doi.org/10.1016/j.lwt.2022.113277

Hatamian, M., Noshad, M., Abdanan-Mehdizadeh, S., Barzegar, H. (2020). Effect of roasting treatment on functional and antioxidant properties of chia seed flours. NFS J., 21, 1–8. https://doi.org/10.1016/j.nfs.2020.07.004

Jan, K., Ahmad, M., Rehman, S., Gani, A., Khaqan, K. (2019). Effect of roasting on physicochemical and antioxidant properties of kalonji (*Nigella sativa*) seed flour. J. Food Meas. Charact., 13, 1364–1372. https://doi.org/10.1007/s11694-019-00052-4

Jogihalli, P., Singh, L., Sharanagat, V. S. (2017). Effect of microwave roasting parameters on functional and antioxidant properties of chickpea (*Cicer arietinum*). LWT Food Sci. Technol., 79, 223–233. https://doi.org/10.1016/j.lwt.2017.01.047

Kaur, A., Singh, N., Ezekiel, R., Guraya, H. S. (2007). Physicochemical, thermal and pasting properties of starches separated from different potato cultivars grown at different locations. Food Chem., 101(2), 643–651. https://doi.org/10.1016/j.foodchem.2006.01.054

Kumar, Y., Sharanagat, V. S., Singh, L., Mani, S. (2020). Effect of germination and roasting on the proximate composition, total phenolics, and functional properties of black chickpea (*Cicer arietinum*). Legume Sci., 2(1), 1–7. https://doi.org/10.1002/leg3.20

Kumari, S., Prasad, R., Gupta, A. (2018). Processing and utilization of jackfruit seeds, pearl millet and soybean flour for value addition. J. Pharmacogn. Phytochem., 7(6), 569–572.

Lee, S.-C., Jeong, S.-M., Kim, S.-Y., Park, H.-R., Nam, K. C., …, Ahn, D.U. (2006). Effect of far-infrared radiation and heat treatment on the antioxidant activity of water extracts from peanut hulls. Food Chem., 94(4), 489–493. https://doi.org/10.1016/j.foodchem.2004.12.001

Nabubuya, A., Mugabi, R., Kaggwa, A., Ainebyona, P., Nalugya, R. (2022). Influence of roasting on the proximate, functional and sensory properties of Jackfruit seeds and amaranth grain composite complementary flours. Tanzan. J. Sci., 48(1), 156–169. DOI: 10.4314/tjs.v48i1.15

Odžaković, B., Džinić, N., Jokanović, M., Grujić, S. (2019). The influence of roasting temperature on the physical properties of Arabica and Robusta coffee. Acta Period. Technol., 50, 172–178. https://doi.org/10.2298/APT1950172O

Ojwang, R. A., Muge, E. K., Mbatia, B., Mwanza, B., Ogoyi, D. O. (2018). Compositional, elemental, phytochemical and antioxidant characterization of Jackfruit (*Artocarpus heterophyllus*) Pulps and Seeds from Selected Regions in Kenya and Uganda. Eur. J. Med. Plants., 23(3), 1–12. http://dx.doi.org/10.9734/EJMP/2018/40967

Ondo, S. E., Ryu, G.-H. (2013). Physicochemical and antioxidant properties of extruded cornmeal with natural cocoa powder. Food Sci. Biotechnol., 22, 167–175. https://doi.org/10.1007/s10068-013-0063-3

Papa-Spada, F., da Silva, P. P. M., Mandro, G. F., Margiotta, G. B., Spoto, M. H. F., Canniatti-Brazaca, S. G. (2018). Physicochemical characteristics and high sensory acceptability in cappuccinos made with jackfruit seeds replacing cocoa powder. PLoS One, 13(8), e0197654. https://doi.org/10.1371/journal.pone.0197654

Pongsawatmanit, R., Thanasukarn, P., Ikeda, S. (2002). Effect of sucrose on RVA viscosity parameters, water activity and freezable water fraction of cassava starch suspensions. Sci. Asia, 28(2), 129–134. DOI: 10.2306/scienceasia1513-1874.2002.28.129

Prusak, A., Schlegel-Zawadzka, M., Boulay, A., Rowe, G. (2014). Characteristics of the peanut chain in Europe: implications for peanut allergy. Acta Sci. Pol. Technol. Aliment., 13(3), 321–333. https://doi.org/10.17306/J.AFS.2014.3.10

Ragaee, S., Abdel-Aal, E.-S. M. (2006). Pasting properties of starch and protein in selected cereals and quality of their food products. Food Chem., 95(1), 9–18. https://doi.org/10.1016/j.foodchem.2004.12.012

Sacchetti, G., Di Mattia, C., Pittia, P., Mastrocola, D. (2009). Effect of roasting degree, equivalent thermal effect and coffee type on the radical scavenging activity of coffee brews and their phenolic fraction. J. Food Eng., 90(1), 74–80.

Şahin, H., Topuz, A., Pischetsrieder, M., Özdemir, F. (2009). Effect of roasting process on phenolic, antioxidant and browning properties of carob powder. Eur. Food Res. Technol., 230, 155–161. https://doi.org/10.1007/s00217-009-1152-7

Spada, F. P., Balagiannis, D. P., Purgatto, E., do Alencar, S. M., Canniatti-Brazaca, S. G., …, Parker, J. K. (2021). Characterisation of the chocolate aroma in roast jackfruit seeds. Food Chem., 354, 129537. https://doi.org/10.1016/j.foodchem.2021.129537

Spada, F. P., Mandro, G. F., da Matta Junior, M. D., Canniatti-Brazaca, S. G. (2020). Functional properties and sensory aroma of roasted jackfruit seed flours compared to cocoa and commercial chocolate powder. Food Biosci., 37, 100683. https://doi.org/10.1016/j.fbio.2020.100683

Yang, R., Tang, J., Zhao, Q., Piao, Z., Lee, G., …, Bai, I. (2023). Starch Properties of Roasting Rice from Naturally High-Resistant Starch Rice Varieties. Mol., 28(17), 1–15. https://doi.org/10.3390/molecules28176408