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RESEARCH ARTICLE

Food Processing Technology

Utilization of jackfruit seed flour (*Artocarpus heterophyllus* L.) as a thickening agent in tomato sauce production

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Abstract: Starch-based thickening agents are widely used in the food industry, and corn flour (CF) is the most prominent in tomato sauce manufacturing. Jackfruit seeds which are highly abundant but underutilized source of flour, have very limited industrial applications. Jackfruit seed flour (JSF) which can be acquired from jackfruit seeds is a good option to meet different industrial applications. Hence, this study aims to investigate the thickening capacity of JSF in tomato sauce production. As functional properties of flour change with their drying techniques, two drying techniques: hot-air-drying (HAD-JSF) and freeze-drying (FD-JSF) were tried, and out of them, HAD-JSF was used for the further studies based on its functional properties and potential to be used in commercial level. According to the proximate analysis, ash, fat, crude protein, and crude fiber were significantly higher while moisture and total carbohydrate content were significantly lower in HAD-JSF than CF ($p < 0.05$). HAD-JSF incorporated tomato sauce showed incredible thickening properties with increased viscosity (1083 cP) with lower syneresis than CF- incorporated tomato sauce (1004 cP). During the 8 weeks of storage period, total soluble solids and titratable acidity of JSF- incorporated tomato sauce was significantly consistent ($p > 0.05$) while the pH and the water activity significantly increased ($p < 0.05$). The microbial counts were below the standard limits. JSF incorporated tomato sauce received the highest consumer acceptance on the sensory evaluations. This study proclaims the potential of JSF as a successful thickening agent in tomato sauce.

Keywords: Functional properties, jackfruit seed flour, thickening agent, underutilized source of flour.

INTRODUCTION

Thickening agents are widely used in the food industry to customize the consistencies of foods (Cho & Yoo, 2015). They are food additives that can improve the moisture binding capacity, alter flow properties, and help in structural modifications. Starches, proteins, gums, and seaweed extracts are some of the most used food thickeners in the food industry (Jayakody *et al*., 2023; Wedamulla & Wijesinghe, 2021). Considering starches, corn starch (CF) is the most prominent starch-based food thickener in use, mainly in food products such as sauces, soups, beverages, and purees.

Jackfruit (*Artocarpus heterophyllus* L.) seeds, a highly abundant source in Sri Lanka, are a rich source of starch and nutrients such as fiber, vitamins, minerals, and other phytonutrients (Amadi *et al*., 2018; Pushpakumara & Harris, 2007). It is a potential local food source where value addition is low. Most jackfruit seeds are discarded as waste reinforced by the short shelf life of fresh jackfruit seeds and sporadic uses and applications of jackfruit seeds. Jackfruit seed flour (JSF) which can be produced from jackfruit seeds, is a good option for different applications in the food industry and is also an alternate option to address the short shelf life of jackfruit seeds. Hence, this study was directed to investigate the potential of JSF to be used as a thickening agent.

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Dehydration is a preservation technique used for fresh commodities where microbial and enzymatic activity is inhibited by reducing the water activity (Morais *et al*., 2018). Dehydration is used to procure JSF from jackfruit seeds. There are different drying techniques in use, such as hot-air-drying, freeze-drying, microwave-assisted drying, ultrasound-assisted drying, high electric field drying, heat pump drying, and refractance window drying (Izli *et al*., 2017; Moses *et al*., 2014). The functional properties and physicochemical properties of the flour may be varied with the drying technique. Consequently, the applications of flour can be varied depending on the functional properties affected by the drying techniques. Considering this fact, the study aims to process JSF using two drying techniques: hot-air-drying and freeze-drying and assess the most suitable drying technique to produce JSF as a thickening agent while considering the practical and economical aspects of production.

Tomato (*Solanum lycopersicum*) is a key ingredient in worldwide cuisines where the production is going up day by day. Tomato sauce has been a rooted food product worldwide for many years, becoming the most consumed tomato-processed product in the world. Tomato sauce processing uses thickening agents to achieve the viscosity which is a vital quality parameter of tomato sauce. Traditionally, CF is used as the thickening agent, and in the present study, an effort was taken to replace CF with JSF as the thickening agent for tomato sauce. The physicochemical parameters of tomato sauces made using JSF and CF were investigated to examine the potential of JSF as a replacer for CF in tomato sauce production.

MATERIALS AND METHODS

Jackfruit seeds were collected from mature unripe and mature fully ripened jackfruits purchased from a local market in Pannipitiya, Sri Lanka, on the prior day of seed flour preparation. All other ingredients required for tomato sauce production were purchased from local supermarkets in Sri Lanka. All chemicals and reagents used during the study were of standard analytical grade.

Preparation of JSF

JSF was prepared using two main drying techniques.

Hot-air-dried JSF

Jackfruit seeds from mature, unripe and mature, fully ripe fruits were collected and rinds were removed. Lye peeling was used to remove the seed coat (testa). Jackfruit seeds were soaked in sodium hydroxide (5% w/v) solution for 2 min and then soaked in citric acid (5% w/v) solution for 2 min. Then the seeds were thoroughly washed using tap water until the brown color seed coat was removed. Excess water was drained off. The cleaned seeds were sliced, steam blanched for 4-5 min and immediately dipped in cold water. Blanched seed slices were laid on clean white cloths in a way that cut surfaces were exposed to air. The slices were then dehydrated at 55°C for 20 h in a hot-air dehydrating oven. The dried jackfruit seeds of 8.32±0.09% moisture content were ground using an electric grinder and sieved through a standard 100 μm sieve to get a fine powder. The flour was packed in laminated pouches and stored in a dry place under room temperature (25°C).

Freeze-dried JSF

The same initial procedure was followed until steam blanching. Then the blanched seeds were immediately dipped in cold water, put into precleaned and dried petri dishes, and were frozen overnight. The frozen seeds were dried using the freeze drier at -40 ºC for 20 h. The dried seeds of 4.98±0.43% moisture content were ground, sieved through a standard 100 μm sieve, packed in laminated pouches, and stored in a dry place under room temperature (25°C).

Determination of functional and physicochemical properties of JSF and CF

The functional properties and physicochemical properties of hot-air-dried JSF, freeze-dried JSF and CF were determined. The most suitable drying method out of hot-air drying and freeze drying to use JSF as a thickening agent was selected out of hot-air-dried and freeze-dried JSF in comparison to CF based upon their functional properties.

Bulk density

The bulk density was determined according to the method described by Chowdhury *et al*. (2012) with slight changes. A pre-weighed (w1) clean measuring cylinder was taken, and flour was filled up to a 5 mL level while tapping (where Chowdhury *et al*. (2012) had filled up to an unspecified level and recorded the volume). The weight of the measuring cylinder with flour (w2) was weighed and the density was calculated by using the below equation.

$$Bulk\ density\ (gmL^{-1}) = \frac{w2 - w1}{5}$$

Water absorption index (WAI) and water solubility index (WSI)

The WAI and WSI were determined according to Ahmed *et al*. (2016). 1.0 g of fully dried flour was dissolved in 6 mL of distilled water in a pre-weighed centrifuge tube and heated at 80°C for 30 min in the shaking water bath. It was then centrifuged at 2500 rpm for 10 min. After centrifugation, the supernatant was poured into a pre-weighed dry petri dish and oven-dried at 105°C for 10 h. The dried sample was weighed. The weight of the wet sediment was measured. The test was done in triplicates. The WAI and WSI were calculated using the following equations.

$$WAI = \frac{Weight\ of\ wet\ sediment}{Dry\ weight\ of\ flour}$$

$$WSI = \frac{Weight\ of\ dried\ supernatant}{Dry\ weight\ of\ flour} \times 100\%$$

Oil absorption capacity

Oil absorption capacity was determined as per Chowdhury *et al*. (2012) with minor modifications. 1g of JSF was measured into a pre-weighed centrifuge tube, and 25 mL of refined oil (vegetable oil, Marina brand) was added to it. It was vortexed thoroughly for 5 min and centrifuged at 4000 rpm for 30 min. The centrifuged tubes were kept resting for another 30 min at room temperature (25°C). The volume of the supernatant was measured. The oil absorption capacity was calculated as a percentage and expressed as mL of oil absorbed by 1g of flour (v/w).

Swelling power

Swelling power was determined according to Ahmed *et al*. (2016) with slight modifications. 0.5 g of fully dried flour was measured into a pre-weighed centrifuge tube. 15 mL of distilled water was decanted into the centrifuge tube. Then it was heated at 80 °C for 30 min in a shaking water bath. Afterward, the sample was centrifuged at 4000 rpm for 20 min. The supernatant was collected in a pre-weighed dry petri dish and oven-dried at 105°C until a constant weight was acquired. The dried supernatant was weighed. The weight of wet sediment together with the centrifuge tube was measured. The swelling power was calculated by using the below-given equation. The result was taken as the average of triplicates.

$$Swelling\ power = \frac{Weight\ of\ sediment}{Weight\ of\ flour - Weight\ of\ dried\ supernatant}$$

Least gelation capacity

The least gelation capacity was determined as per Aremu *et al*. (2008) and Chowdhury *et al*. (2012). Flour suspensions of 1-15% were prepared in test tubes using distilled water as each test tube contains 10 mL. The test tubes were heated in boiling water until gels were formed. Next, test tubes were cooled immediately to 4 °C under refrigerated conditions (4 °C) and kept for 2 h. Then the test tubes were inverted and checked for the falling or slipping nature of suspensions. The least gelation concentration was determined as the concentration when the sample from the inverted test tube did not fall or slip.

Emulsifying activity and stability

Both emulsifying activity and stability were determined according to Elkhalifa *et al*. (2005) with slight modifications. 1g of flour was measured into a beaker and 50 mL of distilled water at 4 °C and 50 mL of refined oil (vegetable oil, Marina brand) were added into the beaker. The mixer was stirred at high speed for 5 min using the magnetic stirrer. 50 mL of the stirring mixture was pipetted out while stirring and filled into a centrifuge tube. The remaining 50 mL was filled into another centrifuge tube. One centrifuge tube was directly centrifuged at 4000 rpm for 10 min while the other centrifuge tube was heated at 80°C for 30 min, cooled to room temperature (25°C), and then centrifuged under the same conditions. Afterwards, the height of the emulsion layer was measured in centimeters using a graduated transparent ruler and expressed as a percentage of the total height of the material in the centrifuge tube. The height of the emulsion layer of the heated and centrifuged sample was used to determine the emulsion stability while the rest was used to determine the emulsion capacity of the flour. The test was performed in triplicates.

$$Emulsion\ activity\ (\%) = \frac{Height\ of\ the\ emulsion\ layer}{Height\ of\ the\ total\ material\ content} \times 100\%$$

$$Emulsion\ stability\ (\%) = \frac{Height\ of\ the\ emulsion\ layer\ of\ heated\ sample}{Height\ of\ the\ total\ material\ content} \times 100\%$$

Foaming capacity and Foaming stability

The foaming capacity and stability were determined as per Aremu *et al*. (2008) with slight modifications. One gram (1 g) of flour was measured into a calibrated 100 mL measuring cylinder and 50 mL of distilled water was added. The volume was noted. Then the resulting solution was homogenized using a linear shaker at high speed for 5 min. The volume of foam was noted. The total volume of foam remaining over time at intervals of 0.00, 0.5, 1, 2, 3, and 4 up to the 24^{th} was noted to determine the foam stability. The foaming capacity and stability were calculated using the equation given below. The test was done in triplicates.

$$Foaming\ capacity\ (\%) = \frac{Volume\ after\ homogenization - Volume\ before\ homogenization}{Volume\ before\ homogenization} \times 100\%$$

$$Foaming\ stability\ (\%) = \frac{Volume\ of\ foam\ after\ time\ (t)}{Volume\ before\ homogenization} \times 100\%$$

The most preferable drying technique to produce JSF as a thickening agent was selected based on their functional properties and carried forward to determine proximate composition and use as a thickening agent in tomato sauce.

Determination of gelatinization properties using Rapid Viscosity Analyzer (RVA)

The gelatinization properties of the selected HAD-JSF sample were determined by using the RVA (RVA; TechMaster, PerkinElmer Co., Ltd, Austria) according to the pre-described method with increased sample weight (Zhang *et al*., 2023). Three grams (3 g) of flour were filled into the metal canister and 25 mL of deionized water was added. The plastic paddle of the RVA mixed the flour and water rotating at a speed of 960 rpm at the start and then maintained at 160 rpm during the rest of the analysis. The sample was heated at 50 °C for 1 min and then increased to 95°C at a rate of 12 °C/min. The system was maintained at 95°C for 2.5 min and was decreased to 50°C at the rate of 12°C/min which maintained for the next 2 min. The RVA curve was generated by using the data and the peak viscosity (PV), trough viscosity (TV), breakdown (BD = PV – TV), final viscosity (FV), and setback (SB = FV – TV) were calculated. The test was done in triplicates.

Determination of proximate composition of JSF and corn flour

The moisture content, crude ash, crude protein, crude fat, and crude fiber content of JSF and CF were determined as per standard AOAC, 2016 methods (925.10, 900.02, 930.25, 920.39, and 978.10 respectively). The digestible carbohydrate content was determined according to the method described by Akande *et al*. (2020) by using the below equation.

Digestible carbohydrate content (%) = 100 - (% moisture + % ash + % protein + % fat +% fiber content)

Preparation of tomato sauce

Tomato sauce, more specifically ketchup was prepared according to the specifications given by Sri Lanka Standards for tomato sauce (ketchup) (SLS 260:1989). Three sauce samples were prepared using JSF and CF as the thickening agents and the control without any thickening agent. 37.5 g of thickening agents were used for 1 kg of tomato pulp.

The glass bottles were cleaned using detergent and tap water and sterilized by boiling in hot water for 30-40 min for ketchup storage. Fully mature, ripened tomatoes were selected, cleaned using tap water, and blanched for 8-10 min to remove the peel. The tomato pulp was then extracted using a sieve. The pulp was concentrated by heating at medium heat. Garlic, ginger, onion, cardamom, and cinnamon were ground into a paste and a spice bag was prepared. The spice bag was dipped in tomato extract concentrate. Sugar, chilli powder, and salt were added to the pulp and stirred for 10 min while supplying medium heat. The thickening agent and vinegar were added and stirred until the Brix value reached 25-30°Bx. The sauce was then filled into sterilized glass bottles, sealed, and stored for further studies.

Determination of physicochemical properties of tomato sauce

The physicochemical properties given below were determined throughout the storage period of 8 wks.

pH

Five grams of tomato sauce was measured into a beaker (100 mL) and diluted up to 50 mL level by using distilled water. The sample was well mixed using a magnetic stirrer to homogenize the sample. The pH was then measured using a calibrated digital pH meter. Three replicates were determined, and the probe of the digital pH meter was washed with distilled water and wiped with a paper towel prior to each measurement.

Total soluble solids (TSS)

A handheld refractometer was used to determine the TSS of sauce samples. The refractometer was calibrated using distilled water and wiped off. A drop of sauce was placed on the glass plate and the Brix reading was taken. Three replicates were performed for each treatment.

Titratable acidity

One gram of sauce was weighed into a conical flask and diluted with 10 mL of distilled water. 2 to 3 drops of phenolphthalein were added into the conical flask and titrated against 0.1N NaOH solution. The burette reading was taken at the endpoint where the orange color turned into a permanent pink color. Three replicates were done for each sample. The acidity of the sample was calculated based on the volume of 0.1N NaOH used to neutralize the acids available in tomato sauce using the below-given equation.

$$Titratable\ acidity\ (\%) = \frac{V \times N \times 60 \times 100}{W \times 1000}$$

Where,
V = Volume of NaOH required for the titration
W = Weight of the sample
N = Molarity of NaOH ($moldm^{-3}$)
60 = Equivalent weight of the acid

Serum separation

The serum separation of the tomato sauce samples was determined by pipetting out the separated serum and measuring the volume. Serum separation was determined initially for 8 wks with 4-wk intervals.

Viscosity

The viscosity of the samples was determined using a Brookfield DVDTLV TJO viscometer fitted with model LV spindles. LV-2 (62), LV-3 (63), and LV-4 (64) spindles were used to measure the viscosity of control, CF-added tomato sauce, and JSF-added tomato sauce samples, respectively. The sauce samples were stirred well before measuring the viscosity. All measurements were done in triplicates.

Determination of microbial properties

The total plate count and the yeast and mold count of prepared tomato samples were determined according to the SLS 516: Part 1 and SLS 516: Part 2 with slight modifications. During the total plate count determination, the incubation period was extended (24 h) as no colonies appeared after the recommended incubation period (72 h). Both the tests were carried out after one month and two months of preparation. Tomato sauces were stored in sealed glass bottles under room temperature (25 °C) during the period. All the microbial analyses were performed in triplicates.

Sensory evaluation

The consumer acceptability and sensory perception were evaluated using a sensory evaluation. Color, aroma, flavor, mouthfeel, and overall acceptability of sauce samples were evaluated using the 9-point hedonic scale, where 9 represents extremely like and 1 represents extremely dislike. Fifty untrained panelists equally representing males and females in the age of 20-40 years, with no deprivations in sensory functions, were chosen. All the sensory evaluations were done on the next day of tomato sauce preparation and samples coded using a 3-digit code were presented at room temperature (25°C) under normal lighting conditions. Potato chips were provided as the carrier for the tomato sauce and cream crackers were provided to remove lingering tastes in the mouth. A cup of potable water was provided for oral rinsing between sensory attribute evaluations (Jayamali *et al*., 2022).

Statistical analysis

Data on the functional properties of JSF were analyzed using Excel 2018. Proximate analysis of JSF and CF, physicochemical properties, microbial properties, and sensory properties of sauce samples were analyzed using MINITAB 16 statistical software.

RESULTS AND DISCUSSION

Physicochemical and functional properties of JSF and CF

The physicochemical properties and the functional properties of hot air-dried JSF (HAD-FSF), freeze-dried JSF (FD-JSF), and CF were determined. The functional properties of flours vary with their drying techniques. Hence, the functional properties of HAD-JSF and FD-JSF were compared with the functional properties of CF to select the most suitable drying technique to use JSF as a thickening agent. The results are presented in Table 1.

Table 1: Physicochemical and functional properties of JSF and CF

Property	HAD-JSF	FD-JSF	CF
Moisture content (%)	8.77 ± 0.12^b	5.17 ± 0.59^c	12.95 ± 0.15^a
Bulk density (gcm^{-3})	0.95 ± 0.03^a	0.85 ± 0.04^b	0.57 ± 0.02^c
Water absorption capacity (mLg^{-1})	2.05 ± 0.05^b	2.52 ± 0.13^a	1.53 ± 0.15^c
Water solubility index (%)	22.68 ± 4.04^b	3.84 ± 1.03^c	43.54 ± 0.88^a
Oil absorption capacity (mLg^{-1})	0.24 ± 0.05^c	2.51 ± 0.13^a	1.43 ± 0.11^b
Swelling power	5.09 ± 0.18^c	6.37 ± 0.34^b	12.63 ± 0.63^a
Least gelation capacity (%)	2.0 ± 0.0^b	2.0 ± 0.0^b	7.0 ± 0.0^a
Emulsifying capacity (%)	1.49 ± 0.01^b	0.49 ± 0.00^c	3.20 ± 0.36^a
Emulsifying stability (%)	1.9 ± 0.1^a	1 ± 0.01^c	1.36 ± 0.24^b
Foaming capacity (%)	20.3 ± 2^a	7.17 ± 1.04^b	0.00 ± 0.00^c
Foaming stability (%)	20.2 ± 2^a	0.00 ± 0.00^b	0.00 ± 0.00^b

Values are average of triplicate analysis ± standard deviation. $^{a-c}$ Values in rows with different letters are significantly different at $p < 0.05$.

Moisture content is a crucial parameter of flour that ensures its storability and marketability. The moisture content of flour should lie within the admissible limits recommended by the WHO, which is 15% to ensure a longer shelf-life (Kaushalya & Wijesinghe, 2024). The moisture levels of all studied flour types were below the recommended level. The moisture content of FD-JSF was significantly lower than the moisture content of HAD-JSF ($p < 0.05$) after drying for an equal time. The moisture content of the CF purchased had the highest moisture content.

Bulk density is defined as the heaviness of flour, which is specifically the mass of particles per unit volume (Alam *et al*., 2023; Sasanka *et al*., 2024). In comparison, HAD-JSF had an aggregated granule-like nature and had the highest bulk density. FD-JSF had a small, individual, and uniform granule-like nature with a bulk density lower than HAD-JSF. However, the bulk densities of both HAD-JSF and FD-JSF were significantly higher than that of CF ($p < 0.05$). The lower the bulk density of flour, the flour absorbs water more efficiently. In regards to FD-JSF, it can be identified as more appealing than HAD-

JSF with its lower bulk density value and neither of them were appealing than CF with higher bulk densities.

High water absorption capacity of a flour characterizes its potential of thickening (Nwosu, 2012). The water absorption capacities of both HAD-JSF and FD-JSF were significantly higher than the water absorption capacity of CF ($p < 0.05$). FD-JSF marked the highest water holding capacity. Water absorption capacity of flour is regulated by the structural properties of starch polymers. The small, individual granule-like nature of FD-JSF starch may offer a great surface for hydration, rooting for the higher water absorption capacity. Freeze-drying as a technique that operates at very low temperatures supports more protein retention where higher amounts of proteins offer rich hydrophilic properties to the flour (Alam *et al*., 2023). The higher fiber content of JSF (Table 3) may act as one possible reason for higher water binding capacity than CF where the fiber content is very low (Jakobek & Matić, 2019).

The water solubility index of CF was significantly higher than JSF ($p < 0.05$) while HAD-JSF had significantly higher water solubility index than FD-JSF ($p < 0.05$). A higher water solubility index is an indicator of lower water absorption capacity and swelling power (Alam *et al*., 2023). Accordingly, FD-JSF marks a perk of being an efficient thickening agent over HAD-JSF.

Oil absorption capacity is a crucial property in the bakery industry that is regulated by the hydrophilic or hydrophobic properties of proteins (Godswill *et al*., 2019). The oil absorption capacities of three flour samples were significantly different ($p < 0.05$) and that of FD-JSF was significantly higher than HAD-JSF and CF ($p < 0.05$). The low temperature and high vacuum used during the production of FD-JSF prevent the collapse of protein molecules which can be considered as the most plausible cause.

Swelling power is the ability to absorb water where a rigid structure is given through water retention (Ulfa *et al*., 2020). The swelling power of CF was significantly higher than JSF and that of FD-JSF was significantly higher than HAD-JSF ($p < 0.05$). Consistency and cohesiveness of the microstructural network of uniform granules with larger amounts of carbohydrates and proteins in FD-JSF allow more absorption and expansion.

The lowest concentration of starch at which gel develops and does not migrate in an inverted manner down the test tube walls is called the least gelation concentration (Maria, 2017). The least gelation concentrations of JSF and CF were significantly different, whereas the least gelation concentration of CF was significantly higher than that of JSF ($p < 0.05$). However, the least gelation concentrations of HAD-JSF and FD-JSF were similar ($p > 0.05$).

Emulsion activity and emulsion stability are functions of proteins that are regulated by their hydrophobic properties (Godswill *et al*., 2019). CF was found to possess the highest emulsion activity and stability over JSF at 95% significance level ($p < 0.05$). HAD-JSF possessed a significantly higher emulsion activity and stability than FD-JSF ($p < 0.05$).

The amount of interfacial area that can be created by proteins when shaken with water is the foaming capacity, and the stability of those interfacial areas over time is measured as foaming stability. These properties are regulated by the amount of protein and are influenced by starch. Both foaming capacity and foaming stability were significantly higher in HAD-JSF than FD-JSF and CF. CF didn't show any foaming properties while FD-JSF reported no foaming stability.

Based upon the above findings, both drying techniques (hot air-drying and freeze-drying) share their own advantages and disadvantages in producing JSF as a thickening agent. In comparison, FD-JSF shares the most favorable functional properties as a thickening agent over HAD-JSF, such as lower bulk density, higher water absorption capacity, and lower water solubility index. However, HAD-JSF also shared advantageous properties such as higher emulsifying ability and stability over FD-JSF. Freeze-drying, being an expensive technique restricts its commercial applications in the food industry while challenging commercial application of FD-JSF as a thickening agent in tomato sauce. Hence, hot-air drying was selected to proceed with the study as commercial application of the findings is crucial.

Gelatinization properties of JSF

The RVA parameters, including peak viscosity (PV), trough viscosity (TV), breakdown (BD), final viscosity (FV) and setback viscosity (SB) of JSF are as in Table 2.

Upon the increase of temperature from 50°C to 95°C, the viscosity of JSF increased and reached the PV, which is characterized by the gelatinization of starch. During the time, starch granules swell, and amylose chains leach out due to rupturing of starch granules. The pasting temperature was reported to be 92.95±1.12°C. The TV shows how intact starch granules are following significant swelling and how resistant the starch is to being harmed by high temperatures and shearing pressures. With the resultant TV, JSF indicates a higher integrity of starch granules under the pre mentioned conditions. JSF reported a lower BD (16.00±1.16 cP) which indicates a lesser degree of damage to starch granules and steadiness of the starch paste after heating. During the cooling process, the viscosity increased reaching FV (1463.00±9.58 cP), resulted from the retrogradation phenomenon of starch.

Table 2: RVA parameters of JSF

	PV (cP)	TV (cP)	BD (cP) (BD = PV – TV)	FV (cP)	SB (cP) (SB = FV – TV)
JSF	951.00 ± 6.04	935.00 ± 5.24	16.00 ± 1.16	1463.00 ± 9.58	528.00 ± 3.23

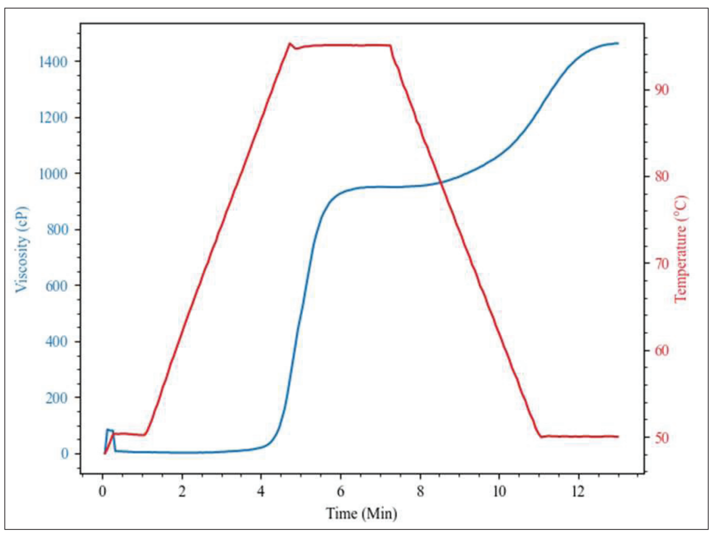

Figure 1: RVA curve for JSF

Table 3: Proximate composition of JSF and CF

Constituent	HAD-JSF	CF
Moisture content (%)	8.53 ± 0.19[b]	12.94 ± 0.15[a]
Crude ash (%)	2.39 ± 0.37[a]	0.44 ± 0.04[b]
Crude protein (%)	13.4 ± 0.09[a]	0.53 ± 0.00[b]
Fat (%)	2.77 ± 0.05[a]	0.22 ± 0.01[b]
Crude fiber (%)	2.93 ± 0.15[a]	0.02 ± 0.00[b]
Total carbohydrate (%)	69.96 ± 0.31[b]	85.83 ± 0.11[a]

Values are average of triplicate analysis ± standard deviation. [a – b] Values in rows with different letters are significantly different at $p < 0.05$.

Proximate composition of JSF and corn flour

The proximate composition of HAD-JSF and CF are as in Table 3. JSF holds significantly ($p > 0.05$) higher amounts of crude ash, crude protein, fat, and crude fiber than CF, while the moisture content and the total carbohydrate content were significantly ($p > 0.05$) higher in CF than JSF. The moisture content of both JSF and CF was within the admissible limits as mentioned before. The higher ash content of JSF indicates higher contents of inorganic constituents such as minerals than CF (Lawal *et al*., 2022). The higher protein content of JSF can impart the functional properties of JSF, such as water absorption capacity, swelling power, emulsifying activity, and foaming capacity. The potential of JSF as a food thickening agent is supported by its higher protein content and its total carbohydrate content. The significantly higher total carbohydrate content of CF proves its mastery as a starch-based thickening agent (Carcelli *et al*., 2020).

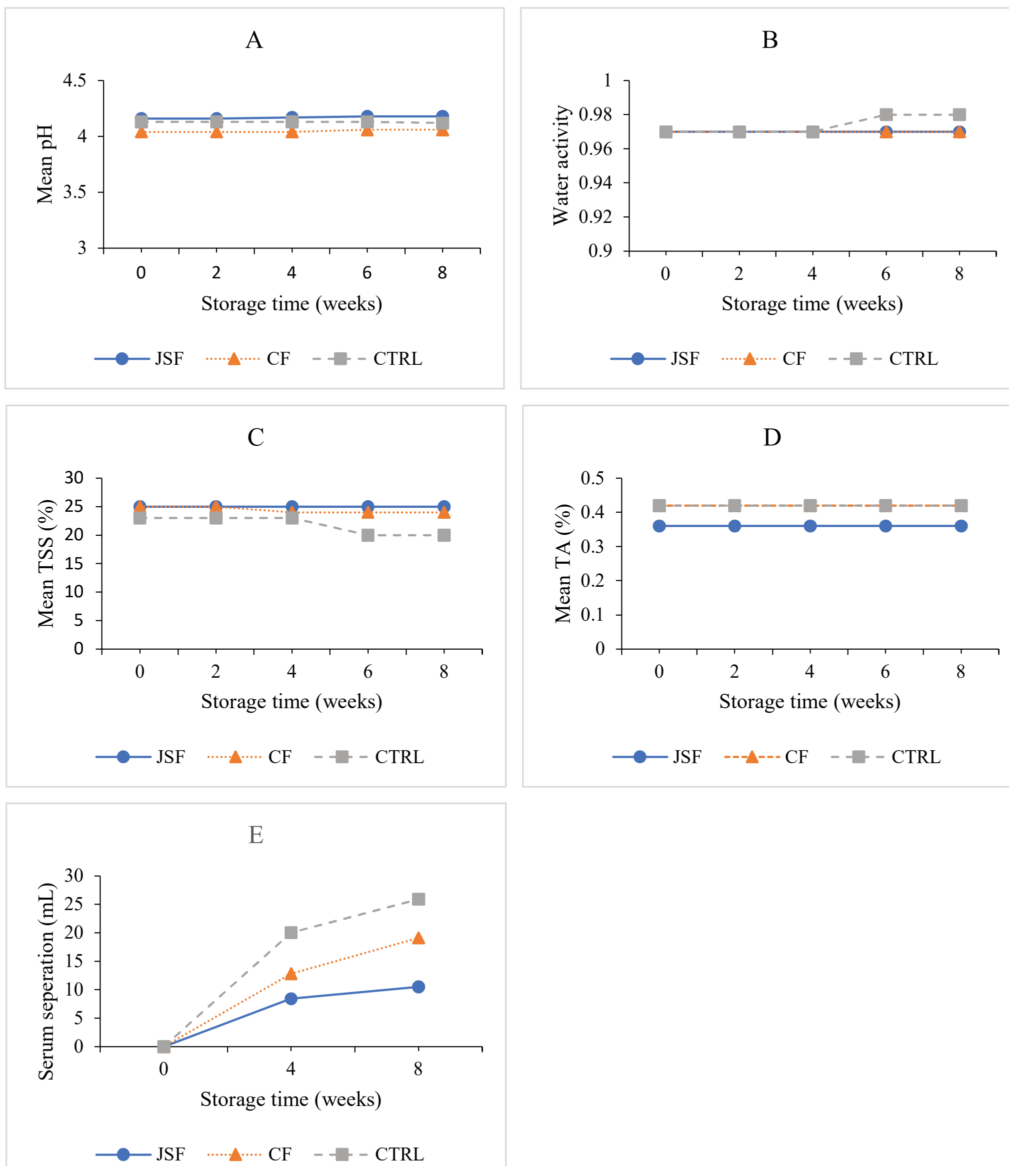

Figure 2: Variation of physicochemical properties of tomato sauce during storage period; A: Variation of mean pH, B: Variation of water activity, C: Variation of mean total soluble solids (TSS), D: Variation of titratable acidity (TA), E: Serum separation; JSF: Jackfruit seed flour, CF: Corn flour, CTRL: Control

Physicochemical properties of tomato sauce

pH

pH is one crucial factor influencing the quality of tomato sauce. Acetic acid in vinegar supports to attain the acidic pH values of tomato sauces along with the original acidity of tomato. The change of pH of tomato sauce over 8-week storage period is as illustrated in Figure 2A. The pH values of the three treatments were not significantly ($p < 0.05$) different at all time periods. The tomato sauce with JSF had the highest pH value followed by the control sample continuously. However, tomato sauce with CF reported the lowest pH value out of the three treatments over the whole storage period. Although the pH of all tomato sauces did not change significantly ($p < 0.05$) over time, an increasing trend of pH of JSF and CF- added tomato sauces could be observed.

Water activity (a_w)

The variation of water activity of tomato sauce over 8-week storage period is in Figure 2B. There was not any significant change in water activity among JSF and CF-added tomato sauces and the control tomato sauce during the first four weeks of storage time which reported a value of 0.97 continuously in all samples. Although tomato sauces with JSF and CF continued to be the same (a_w=0.97) up until the 8th week, the control tomato sauce showed an increased water activity after the 4th week (a_w=0.9).

Total soluble solids (TSS)

TSS is an important parameter in tomato sauce production where TSS affects the final quality of tomato sauce. Other than TSS from the tomato pulp, the addition of other ingredients such as sugar, vinegar, thickening agents and spices acts on the final TSS of tomato sauces. The initial TSS percentages of both JSF and CF added tomato sauces were 25% which had reached the minimum permissible level (25%) defined by Sri Lanka Standards 260:2008 – Specification for tomato sauce (Sri Lanka Standards Institution). Figure 2C presents the variation of TSS over the 8-week storage period.

JSF incorporated tomato sauce didn't show any change of TSS during the 8 weeks of storage. A decreasing trend was observed for TSS in CF-added tomato sauce and the control sample. TSS of CF-added tomato sauce remained the same at 25% until the 2nd week and slightly decreased afterwards. The control sample kept its TSS % constant until the 4th week, decreased by the 6th week, and remained unchanged by the 8th week. Regardless, the TSS of JSF and CF added tomato sauces were always significantly higher than the control sample.

Titratable acidity (TA)

The TA was expressed as a percentage of acetic acid. TA of tomato sauce samples are presented in Figure 2D. TA of tomato sauce with JSF was significantly ($p > 0.05$) lower than that of CF-added tomato sauce and the control tomato sauce. Both CF-added tomato sauce, and the control sample shared the same TA value (0.42%). However, none of the treatments reported any deviation of TA throughout the storage time.

Serum separation

Serum separation or syneresis indicates the inability of tomato sauce to hold the water during storage time (Román *et al*., 2018). JSF-added tomato sauce showed the least serum separation along 8 weeks of storage, and this proved the potential of JSF as a better thickening agent than CF. The highest serum separation was observed in the control sample where no thickening agent is used. The variations of serum separation are shown in Figure 2E.

Viscosity

The texture is one of the most outstanding parameters of foods that determine their quality, and viscosity is the measure of the texture of sauces (Wang *et al*., 2016). The use of a thickening agent remarkably affects the viscosity of the tomato sauce. The general viscosity of tomato sauce is 1000 cP. The highest viscosity was reported by JSF-added tomato sauce (1086 cP) followed by the CF-added tomato sauce (1004 cP). The least was reported by the control sample (142.5 cP) which had a watery consistency. The increase of viscosity of tomato sauce demonstrates the thickening potential of JSF evenly matching with CF in tomato sauce. The viscosities of the three treatments are presented in Table 4.

The physicochemical stability of JSF-incorporated tomato sauce, together with the lowest syneresis and highest viscosity, makes it a competing viable thickening agent.

Table 4: Viscosities of tomato sauce samples

Tomato sauce sample	Viscosity (cP)	Torque (%)	Spindle speed (rpm)
JSF	1086	18.1	100
CF	1004	17.9	100
CTRL	142.5	47.5	100

Table 5: Microbial properties of tomato sauce during storage

Weeks	Test	JSF	CF	CTRL
2	Total plate count	Not detected	Not detected	Not detected
	Yeast and mold count	Not detected	Not detected	Not detected
4	Total plate count	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$
	Yeast and mold count	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$
6	Total plate count	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$
	Yeast and mold count	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$
8	Total plate count	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$
	Yeast and mold count	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$	< 1 $CFUg^{-1}$

Microbial properties

Total plate count and yeast and mold count were determined by standard methods (SLS 516: Part 1 and SLS 516: Part 2) throughout the storage period of 8 weeks and the results are presented in Table 5. Microbial counts of both tests at every instance were below the standard maximum limits described by the Sri Lanka Standards 260:2008 – Specification for tomato sauce (Sri Lanka Standards Institution).

The above microbial counts manifested the microbial stability of all the tomato sauces along with their storage stability and safety of the tomato sauces. Several causes of lower microbial counts can be identified. Antimicrobial properties of acetic acid are another underlying reason for lower total plate counts (Kadhum Wali & Mohammed Abed, 2019). Heating during the processing of tomato sauce destroys the microbes in the product itself and the use of sterilized bottles for storage minimizes external contaminations. Hot filling of sterilized glass bottles which subsequently sealed minimized them further.

Sensory evaluations

Two sensory evaluations were held. Sensory evaluation 1 analyzed the organoleptic acceptability of JSF-added tomato sauce in comparison to CF-added and control tomato sauces. There was no significant difference in color and aroma of three tomato sauce samples at the 95% significance level ($p > 0.05$). The JSF added tomato sauce scored the highest for flavor, mouthfeel, and overall acceptability with an estimated median of 8.0 for every parameter while the control sample scored the lowest. The web diagram for the respective sensory evaluation is as in Figure 3A.

Another sensory evaluation (Sensory evaluation 2) was done to compare JSF-added tomato sauce with a commercially available tomato sauce where CF is used as the thickening agent. In regard to color of the tomato sauce, the majority liked the color of the commercial tomato sauce over JSF-added tomato sauce with an estimated median of 8.0 at a 95% significance level ($p < 0.05$). There was a significant difference between flavor and mouthfeel where the JSF-added tomato sauce had scored over commercial tomato sauce with an 8.0 estimated median ($p < 0.05$). No significant difference was noted among the two samples with respect to the aroma ($p > 0.05$). However, the overall acceptability for the JSF incorporated tomato sauce was higher than the commercial product at a 95% significance level ($p < 0.05$) with the highest estimated median (8.0) and the highest sum of rank. Figure 3B presents the web diagram for the second sensory evaluation.

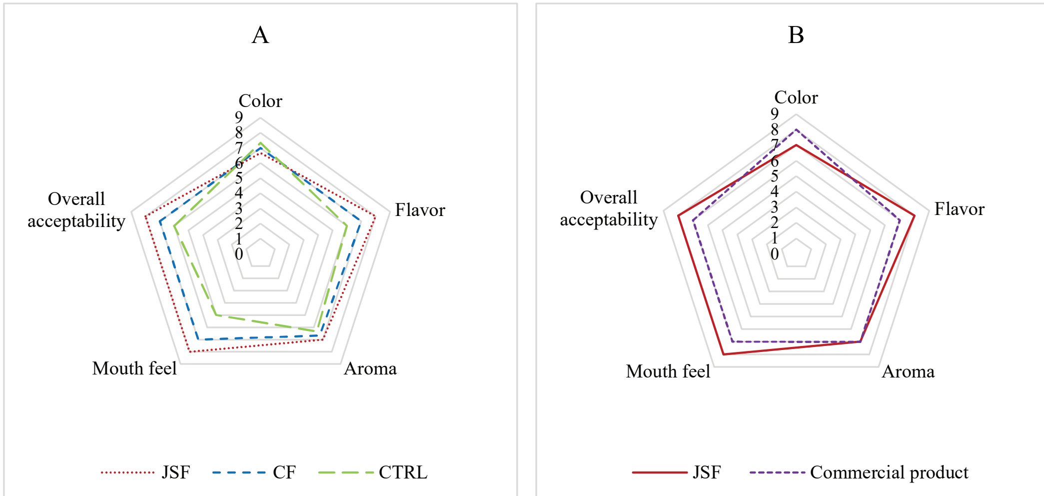

Figure 3: Web diagrams of sensory evaluations; A: Web diagram for sensory evaluation 1 conducted to evaluate three treatments of tomato sauce; B: Web diagram for sensory evaluation 2 conducted to compare JSF incorporated tomato sauce and a commercial product; JSF: Jackfruit seed flour, CF: Corn flour, CTRL: Control

CONCLUSION

The present study investigated the potential of using JSF as a thickening agent in tomato sauce as a replacer for CF. JSF produced using two drying techniques: hot-air drying (HAD-JSF) and freeze-drying (FD-JSF) shared favorable functional properties more or less to be used as a thickening agent. Considering the practical aspects, such as cost and constraints of commercial-level production of freeze-drying technique, HAD-JSF was selected to continue with further investigations. Analysis of physicochemical and sensory properties of hot air dried JSF-added tomato sauce during the 8-week storage, showed impressive results compared to CF-added tomato sauce. The study proved that JSF is a great thickening agent and a viable replacer for CF in tomato sauce production.

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