Characterisation of fresh extruded rice with added soybean protein isolate

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Abstract

Incorporating proteins into gluten-free foods can often improve their nutritional value. Plant-based proteins are often used as a good source of protein due to their easy absorption in the body and low environmental impact. The utilization of Soy Protein Isolate (SPI) in an extruded food product aimed to examine the impact of SPI on the physicochemical characteristics of Fresh Extruded Rice (FER) in this study. We used rheological techniques and thermal analysis to determine the suitability of the extrusion process and the loss of heating mass. The microstructure, textural properties, sensory evaluation and rice taste analyser scores of FER were determined. A new gluten-free food product was produced and its quality was improved by the addition of SPI. When the content of SPI was 3%, the microstructure and texture properties showed that the FER had medium hardness, good elasticity and cohesion, which was better than paddy rice in food quality analysis. In the extrusion process, SPI has the potential to enhance not only the rheological, thermogravimetric, microstructure, and texture properties of FER, but also serve as a dietary supplement to elevate the sensory experience of FER.

Introduction

Malnutrition falls under the category of food insecurity. The World Health Organization (WHO) and other organizations related to food security and health are both concerned with the implementation of a more balanced, nutritious, and sustainable diet. Exploring food sources abundant in nutrients could be a viable solution to combat food insecurity and guarantee the general public access to nutritious food. Nutrition is a key component of food security. Malnutrition is related to nutritional imbalances in food, lack of food or excessive intake of non-nutritious food[1].

Fresh Extruded Rice (FER), known as gluten-free extruded food, is often supplemented with proteins to enhance its quality[2]. An increasing number of people are becoming aware of the detrimental effects of animal protein on human health, with the World Cancer Research Fund (WCRF) and the World Health Organisation (WHO) advocating for a plant-based diet[3]. Plant-based proteins are seen as having a variety of functions in food production, such as thickening, gelling, emulsification and stabilization, as well as being employed in the making of items like cereal. Nevertheless, the impact of these properties on human health remains unexplored[4]. Soybean protein isolate (SPI) was viewed as a viable substitute for animal-derived proteins due to its advantageous functional and nutritional characteristics. Incorporating SPI into starch could enhance its adhesive viscosity, as well as its ability to form clumps and strengthen its tensile strength[5]. In addition, SPI could also increase viscoelasticity, hardness and chewiness[6]. Jiang et al.[7] found that SPI has better emulsification than other proteins and that heat treatment at 50 °C could promote soy protein hydrolysis. At temperatures above 80 °C, SPI aggregates into a stable strong elastic gel through crosslinking, and the elastic modulus was increased[8]. Moreover, Tang & Ma[9] found that high pressure induced aggregation and conformational changes in SPI.

Nowadays, consumers are keen to know the nutritional value of products and concerned about the use of food additives. Consequently, it is more tolerable for us to incorporate natural ingredients with a high nutritional value into food items[10]. Rice flour was enriched with oat flour, whole potato flour, and pumpkin flour to enhance the nutritional, textural, or organoleptic characteristics of the FER, while SPI was incorporated as both a protein source and a structuring agent to augment texture, rheology, functional properties, and minimize cooking losses in the product. Hence, in this research, the extrusion technique was employed to incorporate SPI as a dietary supplement, thereby augmenting the excellence of FER.

Materials and methods

Raw materials

Xiaozhan Rice flour (77.23% starch, 1.03% lipid, 0.71% dietary fibre, 14.00% moisture) was supplied by Huangzhuang Daoxiang Rice Industry Co., LTD (Tianjin, China). Oat flour (12.29% moisture, 1.69% ash, 63.71% starch, 6.38% lipid), whole potato flour (12.00% moisture, 9.37% protein, 2.30% crude fat, 4.50% ash) and pumpkin flour (14.00% moisture, 5.37% protein, 0.60% crude fat, 6.88% ash, 5.50% crude fiber and 28% amylose) were obtained from Chengnuo Food Co., LTD (Shandong, China). Soybean protein isolate (90.50% protein) was obtained from Kunhua Biotechnology Co., LTD (Henan, China).

Preparation of FER

The optimum ratio of rice flour, oat flour, whole potato flour and pumpkin flour was 3:3:3:1 from pre-experiments, and then 2%, 3% and 4% SPI were added respectively. SPI was added at 0% as the control (CK). The production of FER involved the utilization of a laboratory twin-screw extruder (DSE32-I, Jinan Sheng run Technology Development Co., Ltd., China) equipped with a rice-shaped die. The extruder's screw was partitioned into three distinct zones, each with varying temperatures and speeds, namely the feed zone (80 °C, 17 r/min), screw zone (110 °C, 6 r/min), and cutting zone (90 °C, 32 r/min), correspondingly. The FER samples obtained were left to cool at room temperature for 24 h.

Texture Profile Analysis (TPA)

The texture of FER was analysed by using a Texture analyzer (TA. XT plus, Stable Micro Systems, Godalming, Surrey, UK) equipped with a P/36R probe. In accordance with the techniques employed by Laranjo et al.[11]. The pre-test speed, test speed and post-test were 2, 1 and 1 mm/s, respectively. The application included a trigger value of 5.0 g, a compression degree of 60.0%, and a compression time interval of 5.00 s.

Microstructure analysis

The SEM (SU1510, Hitachi, Japan) was utilized to measure the Microstructure of FER. Briefly, the FER was made into powder by a high-speed mill (FW100, Shanghai, China). After that, the flour particles were sputter-coated (Leica EM ACE200, Shenzhen, China) with gold (20 nm thick) in an ion sputter coater and then monitored at 8,000×.

Molecular docking simulation

Firstly, the two-dimensional structural formula of starch was drawn with Chemibio Ultra14.0 (Sichuan, China), and then it was transformed into three-dimensional structure. The structural formula of soy protein isolate (CAS:9010-10-0) was downloaded from the protein database (https://pubchem.ncbi.nlm.nih.gov/), and finally the molecular docking was carried out by using AutoDock Vina.

Thermal properties: Thermogravimetric (TG) and Derivative Thermogravimetric (DTG)

The TGA apparatus (Q50, New Castle, USA) utilized platinum pans to collect samples (8.0 mg), which were then subjected to scanning between 25 and 600 °C at a heating rate of 10 °C per minute. The apparatus was immersed in a continuous flow of high purity nitrogen (99.99%) at a rate of 100 mL/min[12].

Dough rheological properties

A dynamic temperature sweep was used to study the effect of FER rheological properties. The SPI model doughs were subjected to a temperature range of 25 to 80 °C, with a heating rate of 5 °C/min, while maintaining a constant frequency of 1 Hz and a strain of 0.5%[13].

Electronic nose odour analysis

The commercial PEN 3.5 electronic nose (Win Muster Airsense Analytics Inc., Schwerin, Germany) was used to perform the E-nose analysis. FER (3.00 g) was placed in a 10 mL airtight vial and left to incubate for 30 min at 60 °C. Utilizing tubing, a hollow needle was employed to penetrate the vial's seal and consistently absorb the volatile gases (1,000 μL) from the headspace. The duration of the measurement was 150 s, and the pure air was utilized to purify the chamber until the sensor signals reverted to their original state.

Food quality analysis

A team of 12 experts (male : female = 1:1) from the sensory evaluation room of the Tianjin University of Science and Technology evaluated the appearance, colour, flavour and taste of the FER using a 5-point structured scale (5-liked extremely, 1-disliked extremely), and the total score was determined using the Chen et al.[14] method with a rice taste analyser (STA1A, Hiroshima, Japan).

Statistical analysis

The experiments were carried out in a randomized fashion and carried out with a minimum of three repetitions. ANOVA was employed to examine the disparities among the samples. The significance of treatments was determined by Duncan's multiple range test ($p < 0.05$). The SPSS software (SPSS, Inc., USA) was utilized to conduct a statistical analysis of the data.

Results and discussion

Textural properties of FER

As illustrated in Table 1, the hardness, adhesiveness, cohesiveness, chewiness and resilience of The SPI added group exhibited a lower value in comparison to the CK group. The decrease of hardness and chewiness was due to the emulsifying and water-holding properties of SPI, and most of them were polar groups. According to the principles of similarity and compatibility, water was a polar molecule that was attracted to the polar SPI and attached to the SPI surface, so the hydrodynamic force of the water was reduced, which provided sufficient conditions for starch swelling. The variability of the resilience of FER was not significant ($p > 0.05$), and the elasticity was gradually increased. SPI is combined with starch and lipid to form insoluble complexes with gel properties, enhancing the plasticity of FER. Chen & Xi[15] found that polyphenols in coarse cereals could change the structure and properties of protein through covalent and noncovalent interactions, and thus recombine protein to improve the texture of products. Adhesion is a measure of force holding dissimilar particles/surfaces together, the increase of adhesiveness property was closely related to the rheological property. Cohesion decreased gradually, and the increase of moisture leads to cohesive

Table 1. Effect of soybean protein isolate on the textural properties of FER.

	Hardness (g)	Elasticity (mm)	Adhesiveness (gs)	Cohesiveness (g)	Chewiness (g)	Resilience (gs)
CK	600.53 ± 27.47[a]	0.48 ± 0.08[c]	0.47 ± 0.01[c]	296.60 ± 9.63[a]	155.56 ± 5.39[a]	0.36 ± 0.19[a]
2%	236.35 ± 10.06[b]	0.58 ± 0.02[bc]	0.57 ± 0.01[a]	140.92 ± 2.63[b]	91.23 ± 0.32[b]	0.26 ± 0.01[a]
3%	241.25 ± 4.28[b]	0.54 ± 0.01[bc]	0.52 ± 0.01[b]	120.67 ± 4.25[c]	66.39 ± 1.14[c]	0.21 ± 0.01[a]
4%	169.53 ± 3.95[c]	0.66 ± 0.01[a]	0.52 ± 0.01[b]	89.82 ± 2.39[d]	60.25 ± 1.16[c]	0.18 ± 0.01[a]

The values represent the average value plus or minus the standard deviation (SD). The presence of distinct letters within the identical column signifies a significant disparity at a significance level of $p < 0.05$.

failure. When the SPI content was 4%, FER had the least hardness, cohesiveness, and chewiness (169.53, 89.82 and 60.25 g, respectively).

Microstructure analysis of FER

The extrusion process caused starch to become gelatinous, proteins to become desiccated, and complexes to form between starch and lipids[16]. Despite this, some of the initial components of the extrusion process remained intact. When subjected to intense shear and minimal moisture extrusion, these primary structures have a tendency to fracture and create tiny pieces that can influence the microstructure of the FER and eventually spread out during the cooking process. The electron microscopic observation micrograph of the flour particles is shown in Fig. 1, the incorporation of SPI enhanced the internal structure of FER, resulting in a more compact and smoother product due to the Maillard reaction combining protein and polysaccharide, which improved the solubility, emulsification, and gel characteristics of FER. The starch grains of FER without the addition of SPI (Fig. 1a) were fragmented and angular. the microstructure of FER starch grains added with SPI (Fig. 1b−d) was agglomerated, which may be related to the emulsification and crosslinking of SPI. Through the molecular docking of SPI and starch (Fig. 2b−d), we verified this point, and found that the binding force between SPI and starch was very strong (the maximum binding energy was −3.16), which suggests that SPI has an impact on the thermal characteristics and rheological characteristics of the FER.

Thermal properties of FER

As shown in Fig. 3, the TG curves have a similar trend: the main weight loss occurred in three phases in consecutive reactions (25~250 ℃, 250~350 ℃ and 350~600 ℃ in Fig. 3a). Simultaneously, the characteristic decomposition temperature
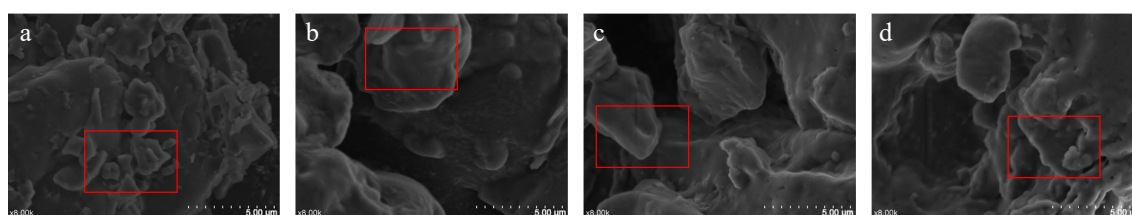

Fig. 1   Electron microscopic observation: (a) represents CK, (b) represents SPI 2%, (c) represents SPI 3%, and (d) represents SPI 4%.
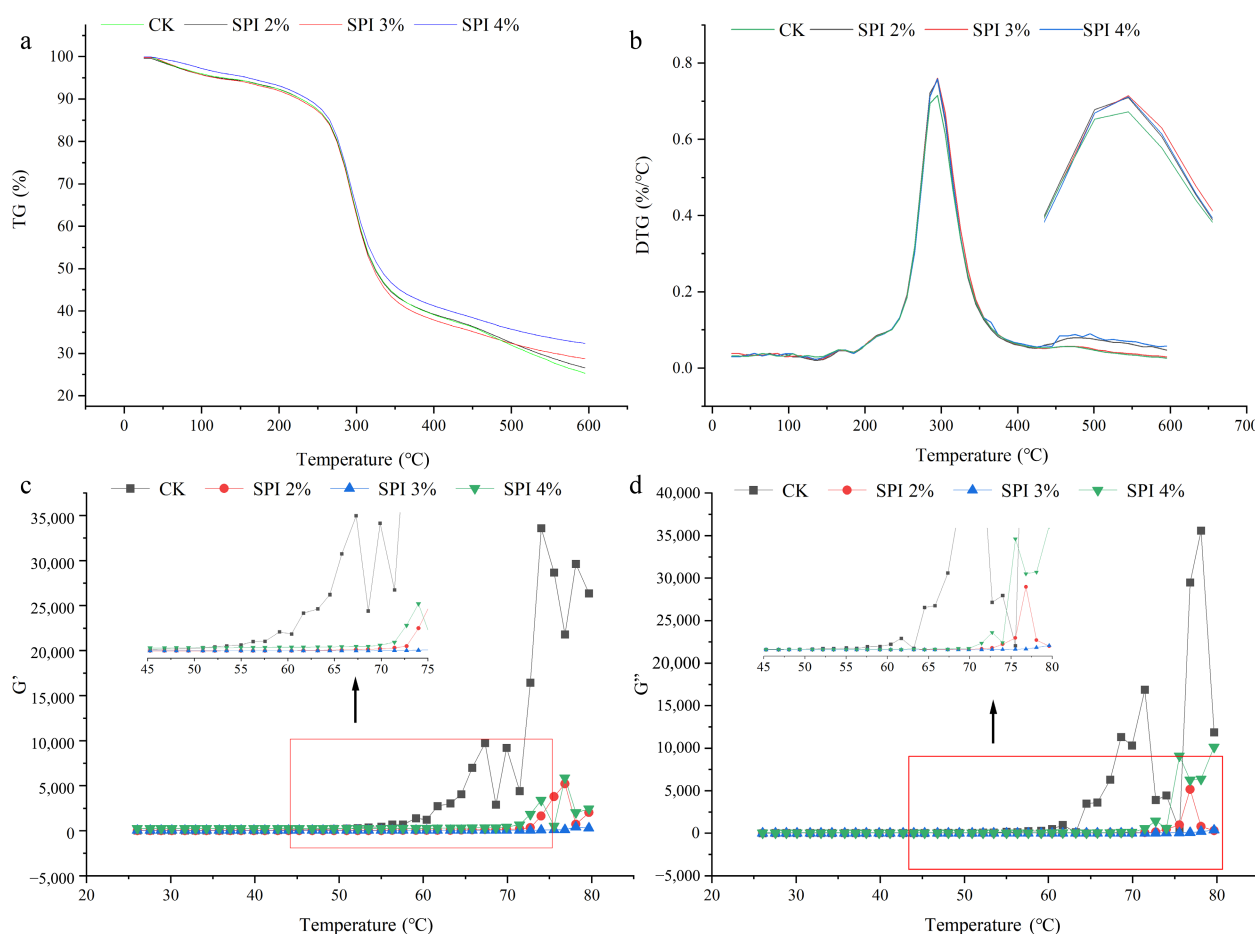

Fig. 2   Thermal properties and rheological properties of soybean protein isolate on FER: (a) TG curve; (b) DTG curve; (c) Storage modulus (G') curve; (d) Loss modulus (G") curve.

(250~350 °C) of FER was shown in Fig. 3b. At the outset, the majority of the weight loss was attributed to water loss, with a 15% reduction in weight. The breakdown of the C-C-H, C-O, and C-C bonds during the second phase of weight loss was mainly attributed to the decomposition of cellulose, lignin, and starch, resulting in a weight loss ratio of around 45%. The weight loss in the third stage was mainly caused by the carbonization of materials, and the weight loss ratio was about 15%.

Maximum mass loss rate temperature (T_m), maximum mass loss rate (R_m) and total weight loss (TML) were commonly used parameters in the thermogravimetric analysis. As shown in Table 2, the decomposition rate of FER was the maximum at about 270 °C. A decrease in T_m leads to a decrease in the thermal stability of the sample. The greater the R_m and TML, the poorer the thermal stability of the raw material[17]. The SPI experimental group exhibited higher T_m, R_m, and TML values compared to the CK group, suggesting that SPI had the ability to elevate Tm levels to 270.79 °C, yet failed to decrease R_m and TML. The T_m exhibited an initial increase followed by a subsequent decrease as the SPI rose. R_m and TML showed an increasing trend, and the mass loss rate increased from 0.7275%/°C to

0.7648%/°C. This was due to the emulsification and dissolution of SPI, and the molecular migration velocity of the bio-based components dissolved in FER was completely accelerated at the high temperature (above 250 °C), which finally led to the increase in mass loss rate.

Rheological properties of FER

The storage modulus (G') was a measure of the energy held back during each cycle of dynamic oscillation and could be indicative of the elasticity of the FER[18]. The FER's viscous properties can be inferred from the loss modulus (G). The FER gels

Table 2. Effect of soybean protein isolate on the thermogravimetric properties of FER.

Samples	T_m (°C)	R_m (%/°C)	TML (%)
CK	262.54 ± 0.80[b]	0.7252 ± 0.0073[b]	67.70 ± 0.16[d]
2%	269.74 ± 1.04[a]	0.7625 ± 0.0022[a]	71.30 ± 0.27[c]
3%	270.79 ± 0.66[a]	0.7643 ± 0.0009[a]	73.48 ± 0.42[a]
4%	269.25 ± 0.16[a]	0.7648 ± 0.0024[a]	74.60 ± 0.09[a]

Values are the mean ± standard deviation (SD). Different letters within the same column indicate significantly different at $p < 0.05$.
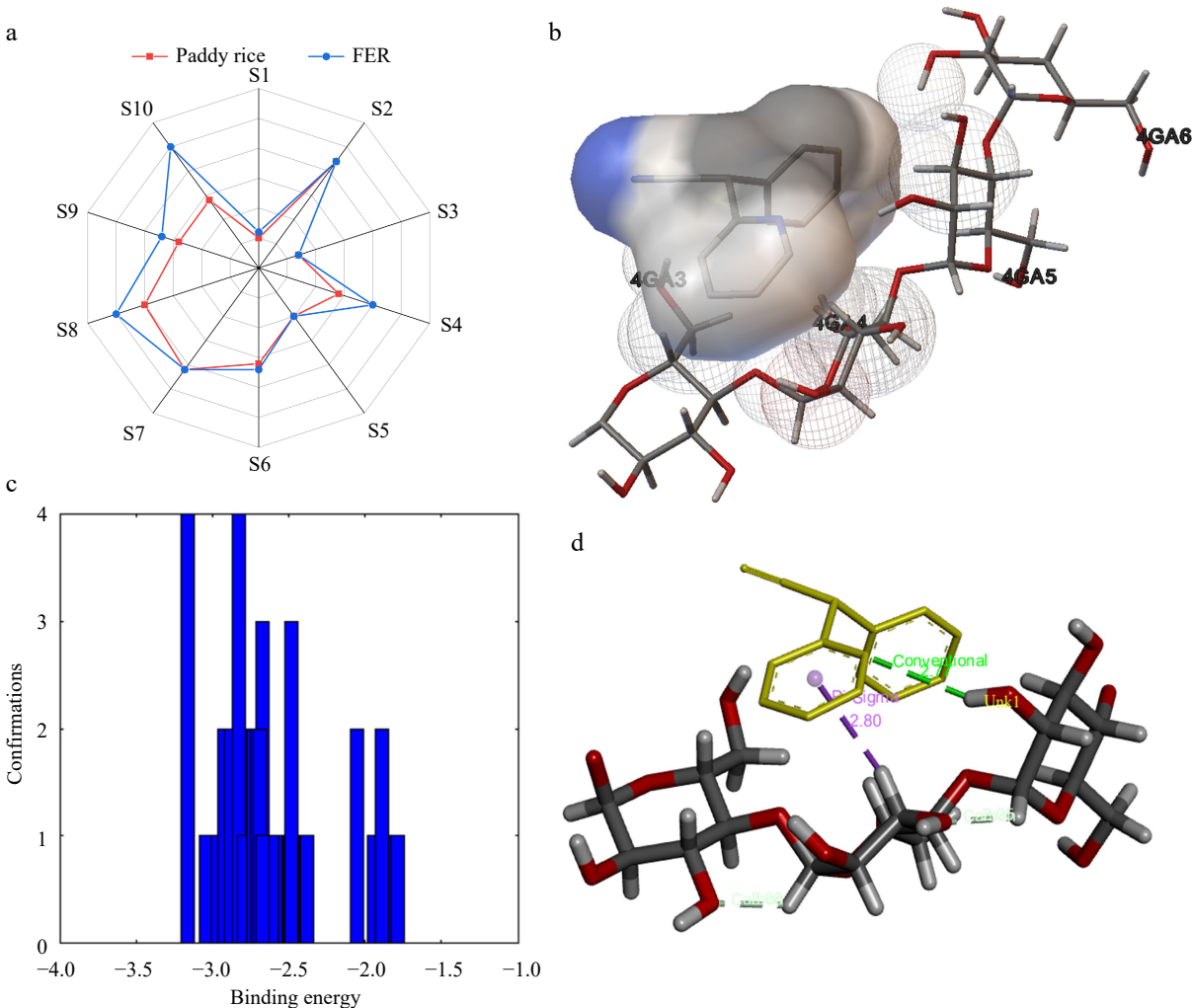

Fig. 3 (a) Food quality analysis radar chart. (b) The schematic diagram of the surface static electricity in the docking of starch and soy protein isolate molecules. (c) Diagram of the binding energy in all docking times, where the binding energy is less than 0, demonstrated that docking can be achieved, and the higher the value, the more powerful the binding. (d) Indicated that they were combined by hydrogen bond and hydrophobic force, and the bond position and length were shown in the figure.

Table 3. Food quality analysis of FER.

Samples	Taste	Flavour	Colour	Appearance	Taste analyser score
FER	4.46 ± 0.27^a	4.03 ± 0.19^b	4.48 ± 0.25^a	4.85 ± 0.08^a	86.50 ± 1.08^b
Paddy rice	4.63 ± 0.18^a	4.65 ± 0.33^a	3.67 ± 0.42^b	4.89 ± 0.05^a	92.00 ± 1.31^a

The values represent the average value plus or minus the standard deviation (standard deviation). The presence of distinct letters within the identical column signifies a significant disparity at a significance level of $p < 0.05$.

formation temperature was observed to be between 55 ℃ and 60 ℃, as demonstrated in Fig. 3c & d, with G' and G" increasing as the temperature rose to 55 ℃ and 60 ℃. Nevertheless, the experimental groups (SPI 2%, SPI 3%, SPI 4%) displayed significant variation ranging from 70 to 75 ℃, as compared with CK (55~60 ℃). The presence of hysteresis in the SPI-induced gel's gel point demonstrated its thermal stability and its ability to amplify the heat-sensitive active components, which was in agreement with the experimental findings of Zhang et al.[19]. The G' and G" declined at the temperature of 75~80 ℃. Podlena et al.[20] found that the thermal analysis transition temperature of unmodified SPI was 73.8 ℃. Therefore, it could be preliminarily speculated that the rheological properties of FER may be caused by the denaturation of SPI. The rheological profile of FER was flattest when SPI was added at 3%, indicating that it is more suitable for extrusion processing.

Food quality analysis of FER

From the rheological properties, thermal properties and microstructure, it was concluded that SPI with 3% was more suitable for extrusion food production and therefore a quality analysis of FER was required before entering the consumer market. The sensory evaluation and taste analyser score method was used to judge the quality of FER as shown in Table 3. Although there was no significant difference in taste and appearance ($p > 0.05$), the score of FER was high (4.63, 4.89, respectively). The artificial sensory test could be prone to mistakes due to its reliance on the assessment of a variety of sensory traits, such as age, taste sensitivity, taste preference, and other elements[21]. The rice taste analyser was used to determine the quality of rice consumption.The score of the FER taste analyser was higher than paddy rice and that variability was significant ($p < 0.05$) in Table 3, this indicated that the consumer quality of FER was better. Due to the significant variability ($p < 0.05$) between FER and paddy rice flavour, E-nose was used to test odour sensitivity to exclude subjective human preference. The sensitivity of each sensor to FER was greater than paddy rice as shown in Fig. 2a, indicating that FER had a higher response, which was consistent with the conclusion obtained from the sensory evaluation (Table 3, flavour). S8 and S10 were the most sensitive, that is, the odour components contain more alcohols, aldehydes, ketones and long-chain alkanes.

Conclusions

FER was produced by an extrusion process and was safe, nutritious and efficient. Incorporating SPI into the composition of FER has the potential to emulsify and dissolve starch granules, thereby alleviating the impact of temperature on the rheological characteristics of G' and G". By forming a homogeneous and dense gel network structure, SPI reduces the mass loss caused by high temperature and increase thermal stability. SPI could improve the microstructure of FER and reduce rice

steam boiling losses, and it could increase FER elasticity and cohesion and reduce hardness. With a 3% SPI, the FER taste, flavour, and appearance of this rice surpassed that of paddy rice in terms of being edible.

Ethical statement

This article does not contain any studies with human or animal subjects.

Author contributions

The authors confirm contribution to the paper as follows: conceptualization, investigation, software, writing-original draft: Li L; writing-review and editing, data curation: Li D; funding acquisition: Li X. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that they have no conflict of interest.

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