

Use of sake kasu for the production of gluten-free functional pasta: effect of the extrusion process on chemical, cooking and antioxidant properties

Uso de sake kasu para la producción de pasta funcional sin gluten: efecto del proceso de extrusión en las propiedades químicas, de cocción y antioxidantes

Agustin López-Díaz¹ , Carlos Iván Delgado-Nieblas¹ , José Zazueta-Morales¹ , Gabriela López-Angulo¹ , Carlos Alberto Gomez-Aldapa² , Abraham Calderon-Castro¹ , Xochitl Adriana Ruiz-Armenta¹ , Irma Leticia Camacho-Hernandez¹ , Victor Limon-Valenzuela¹  and Ernesto Aguilar-Palazuelos^{1*} 

¹ Posgrado en Ciencia y Tecnología de Alimentos, Universidad Autónoma de Sinaloa, Culiacán, Sinaloa, México.

² Instituto de Ciencias Básicas e Ingeniería, Universidad Autónoma del Estado de Hidalgo, Pachuca, Hidalgo, México.

ABSTRACT

Pasta made from broken rice and sake kasu is safe for individuals with celiac disease due to its composition. The objective of this study was to evaluate the effect of the extrusion process, on pasta made from broken rice and sake kasu and to determine optimal processing conditions. The effects of extrusion temperature (ET, 85-125°C), screw speed (SS, 75-125 rpm), and sake kasu flour (SKF, 25-75 %) on pasta properties were assessed using a rotatable central composite design. It was found that protein content (PRO) increased with SKF, cooking loss (CL) increased with SKF at high ET and SS, phenolic compounds (PC) increased with SKF, maximum antioxidant capacity (AC) was observed at high SKF, and general acceptability (GA) improved with increases in ET and SS and low SKF. The optimal conditions were: SKF=60.83 %, ET=116.89°C, and SS=107.93 rpm. The responses under optimal conditions were: PRO of 13.18±0.28 %, CL of 6.89±0.36 %, PC of 376.11±18.55 mg GAE/100 g d.w., AC of 8691.89±381.13 µmol TE/100 g d.w., and GA of 57.47±1.80. The pasta presented higher protein content than commercial products. Due to its composition and sensory acceptability, sake kasu pasta has potential health benefits and high protein content.

Keywords: Sake lees; gluten-free rice pasta; bioactive compounds; process optimization.

RESUMEN

La pasta elaborada con arroz quebrado y sake kasu es segura para personas celiacas por su composición. El objetivo de este estudio fue evaluar el efecto del proceso de extrusión sobre pastas elaboradas con arroz quebrado y sake kasu y obtener condiciones óptimas. Se evaluaron los efectos de la temperatura de extrusión (TE, 85-125°C), velocidad del tornillo (VT, 75-125 rpm) y harina de sake kasu (HSK, 25-75 %) en propiedades de pastas, utilizando un diseño central compuesto rotatable. El contenido proteico (CP) incrementó con la HSK. La pérdida por cocción (PSC) aumentó con HSK a altas TE y VT. Los compuestos fenólicos (CF) incrementaron con HSK. La máxima capacidad antioxidante (CA) se observó con alto HSK. La aceptabilidad general (AG) aumentó con

incrementos en TE y VT, y baja HSK. Las condiciones óptimas fueron: HSK = 60.83 %, TE = 116.89°C y VT = 107.93 rpm. Las respuestas en condiciones óptimas fueron: CP de 13.18 ± 0.28 %, PSC de 6.89 ± 0.36 %, CF de 376.11 ± 18.55 mg EAG/100 g b.s., CA de 8691.89±381.13 µmol ET/100 g b.s. y AG de 57.47 ± 1.80. La PO presentó mayor proteína que las pastas comerciales. Por su composición y aceptabilidad sensorial, la pasta con sake kasu presentó potenciales efectos benéficos para la salud y alto contenido de proteína.

Palabras clave: Subproducto del sake; pasta de arroz; compuestos bioactivos; optimización.

INTRODUCTION

Celiac disease is an autoimmune disorder affecting a significant proportion of the global population, characterized by gluten intolerance, a protein found in wheat, barley, and rye (Ontiveros *et al.*, 2021). This condition can trigger various gastrointestinal and systemic symptoms that substantially impair patients' quality of life, driving increasing demand for gluten-free food products including pasta made with alternative ingredients (García-Almeida *et al.*, 2012).

The most widely marketed pasta products are made from durum wheat semolina. To meet the needs of consumers with celiac disease, pasta formulations have been developed using various gluten-free raw materials such as legume, rice, and corn flours. These formulations not only satisfy dietary restrictions but also aim to improve the nutritional profile of the products (Calvo-Lerma *et al.*, 2019; Morreale *et al.*, 2019; Trevisan *et al.*, 2019).

Extrusion stands as one of the primary methods for pasta production. This high-temperature, short-time (HTST) process enables both the generation and preservation of beneficial components such as antioxidants. The method has been successfully employed to produce gluten-free pasta using broken rice as raw material, yielding products with acceptable cooking, physicochemical, and phytochemical properties (Delgado-Murillo *et al.*, 2024).

Sake kasu, a by-product of sake production, has emerged as a promising functional ingredient for gluten-free pasta formulations. Rich in proteins, carbohydrates, and bioactive

*Author for correspondence: Ernesto Aguilar Palazuelos
e-mail: eaguilar@uas.edu.mx

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compounds including β -glucans (a type of health-beneficial soluble fiber), sake kasu offers both nutritional value (Izu *et al.*, 2019) and functional property enhancements (Shakibaie *et al.*, 2018; Ishak *et al.*, 2018; Ola *et al.*, 2019; Ashooriha *et al.*, 2022).

Despite these advantageous properties, the application of sake kasu in pasta production remains unexplored. Therefore, this study evaluates its potential as an innovative ingredient in gluten-free food products, specifically examining the effects of sake kasu incorporation on the chemical, physicochemical, nutritional, and functional characteristics of extruded pasta to identify optimal processing conditions that maximize product attributes.

MATERIAL AND METHODS

Raw Materials

The raw materials used in this study consisted of broken rice (Japonica variety Yamada Nishiki) and sake kasu obtained from Junmai-style sake production, provided by Sakecul Company (Culiacán, Sinaloa, Mexico).

Broken rice flour (BRF) was produced by grinding the broken rice using a hammer mill (Pulvex Model 200, Mexico City, Mexico) followed by sieving to achieve a particle size < 420 μ m. Sake kasu flour (SKF) was prepared by first drying the sake kasu in a forced convection oven at 65 °C for 3.5 h. The dried material was then ground using the aforementioned mill.

The experimental formulations for different treatments were derived from a preliminary study, with sake kasu flour quantities adjusted according to the experimental design (Table 1).

Extrusion Process

To obtain the pasta, samples with a moisture content of 28 % were fed into a Shandong Light LT32L twin-screw extruder from China. This equipment featured three heating zones: the feeding zone, with a temperature of 60 °C; the mixing/cooking zone, with temperatures ranging from 85 to 125 °C according to the experimental design; and the outlet zone, maintained at constant temperature of 75 °C. The screw speed was varied according to the experimental design, from 75 to 125 rpm, using screws with a 2:1 compression ratio. A 2 mm diameter outlet die was used to obtain the products. The produced pastes were kept at 25 °C at room temperature for 24 h, reaching final humidity levels of 10 to 12 %, and were subsequently stored under refrigeration and ground to a particle size < 420 μ m for subsequent characterization.

Proximate Analysis

The proximate composition of the raw materials (broken rice flour (BRF) and sake kasu flour (SKF)), control pasta (CP), optimal pasta (OP), commercial rice pasta (CRP), and commercial wheat semolina pasta (CWP) were determined in triplicate according to the methodology proposed by the AOAC (2012) for moisture (925.10), ash (923.03), protein (960.52), and lipids (920.39), with carbohydrates determined by the difference from the other components (Bolarinwa and Oyesiji, 2021).

Table 1. Experimental design for the extrusion study.

Tabla 1. Diseño experimental para el estudio de extrusión.

Assay	Coded levels			Actual levels		
	X1	X2	X3	SKF (%)	ET (°C)	SS (rpm)
1	-1	-1	-1	35.13	93.11	85.13
2	1	-1	-1	64.87	93.11	85.13
3	-1	1	-1	35.13	116.89	85.13
4	1	1	-1	64.87	116.89	85.13
5	-1	-1	1	35.13	93.11	114.87
6	1	-1	1	64.87	93.11	114.87
7	-1	1	1	35.13	116.89	114.87
8	1	1	1	64.87	116.89	114.87
9	-1.682	0	0	25	105	100
10	1.682	0	0	75	105	100
11	0	-1.682	0	50	85	100
12	0	1.682	0	50	125	100
13	0	0	-1.682	50	105	75
14	0	0	1.682	50	105	125
15	0	0	0	50	105	100
16	0	0	0	50	105	100
17	0	0	0	50	105	100
18	0	0	0	50	105	100
19	0	0	0	50	105	100
20	0	0	0	50	105	100

SKF= sake kasu flour content; ET= extrusion temperature; SS= screw speed.

The protein content was also determined in the different treatments of the experimental design using the previously reported methodology.

Cooking Loss

Cooking loss was calculated using 50 g of pasta cut into 5 cm lengths, following the methodology described by AACC 16-50 (2000). This measurement indicates the number of solids lost in cooking water and is an indirect measure of the integrity of pasta's polymeric matrix. Measurements were performed in triplicate according to experimental design, with values reported as a percentage.

Extraction of total phenolic compounds

The extraction of total phenolic compounds was performed according to the methodology of Rahaman *et al.* (2017) with modifications. Free and bound phenolic compounds were extracted and quantified separately, and at the end they were added to obtain total phenolic compounds. Free phytochemical extracts were obtained using 80 % ethanol as solvent, the supernatant was recovered and evaporated in a rotary evaporator (model LABOROTA4011, Germany), and at the end it was reconstituted with methanol and stored at - 20 °C until its use in the determination of total phenolic compounds and antioxidant activity.

Bound phenolic compounds were extracted from the free phenolic extraction residue, where the sample reacted with 4 M NaOH for 4 h under stirring. Two mL of concentrated HCl were added, and lipids were subsequently removed with 10 mL of hexane. Upon completion, four washes were performed with 10 mL of ethyl acetate. The supernatant containing the bound phytochemicals was evaporated and reconstituted with 2 mL of methanol, and stored at -20°C until use.

Total phenolic compounds (TPC)

The determination of total phenolic compounds was carried out on the free and bound extracts mentioned above. Quantification was performed using the spectrophotometric method of Folin Ciocalteu, following the methodology of Heimler *et al.* (2006) with modifications. Measurements were performed in triplicate, measuring absorbance at 760 nm, using a spectrophotometer (Model 10, UV GENESYS, Series AQ7-2H7G229001, USA). To obtain the TPC values, the value of free (FPC) and bound (BPC) phenolic compounds were added. The results were reported as mg gallic acid equivalents (GAE)/g d.b.

Total Antioxidant Activity (ABTS)

Total antioxidant activity was obtained from the sum of the antioxidant activity values of free and bound extracts. To measure antioxidant activity by ABTS, a 20 μL aliquot of the extract (free or bound) was taken and mixed with 980 μL of the previously activated ABTS radical. The sample was left to stand for 5 min, and the absorbance at 740 nm was determined using a spectrophotometer (UV-GENESYS model 10, Thermo Electron Scientific Instruments LLC.) (Félix-Medina *et al.* 2020). The assays were run in triplicate and compared with a curve prepared with Trolox.

General Acceptability (GA)

The sensory evaluation of pasta made with sake kasu was conducted with the participation of 30 untrained panelists (Sacchetti *et al.*, 2004) over 18 years of age (both genders), who are regular pasta consumers. GA of all treatments in the experimental design was assessed, as well as that of the optimal treatment for validating the optimal conditions. The evaluation by the panelists was carried out at room temperature, with the pasta cooked until the product presented an "al dente" texture. A bidirectional 100-mm scale called Labeled Affective Magnitude (LAM) was used, with verbal descriptions ranging from - 100 mm (most disliked imaginable) through 0 mm (neither liked nor disliked), and the highest value being + 100 mm (most liked imaginable) (Cardello and Schutz, 2004). The scale was later transformed into a 0 to 100 scale, with 50 representing the midpoint of "neither like nor dislike". A section was also added at the end of each evaluation sheet for evaluators to provide feedback on the product being evaluated.

Experimental Design

A rotatable central composite design was employed in this study. The independent variables were extrusion temperatu-

re (ET), screw speed (SS), and sake kasu flour (SKF) content, each evaluated at five levels (Box and Behnken, 1960) with an α value of 1.682 (Table 1). Data analysis and process optimization were conducted using Design Expert software (Version 11, Stat-Ease Inc., Minneapolis, MN, USA). For proximate composition analysis, Fisher's least significant difference (LSD) test was applied at $p < 0.05$.

Extrusion Process Optimization

For process optimization, the numerical method was employed using Design-Expert software (version 11, Stat-Ease, Inc., Minneapolis, MN, USA). The response variables considered in the optimization were: protein content (PRO), cooking loss (CL), total phenolic compound (TPC) content, antioxidant activity (ABTS), and general acceptability (GA). The optimization criteria targeted maximum values for PRO, TPC, and ABTS, along with minimum CL values. The use of the numerical method for optimization enabled the calculation of individual and GA values for study factors and response variables used in the optimization, with desirability values ranging from 0 to 1, as described by Myers and Montgomery (1995). A new treatment was performed under optimal processing conditions to validate the values predicted by the mathematical models for the different response variables used in the optimization.

RESULTS AND DISCUSSION

Proximate Composition

The proximate composition of the raw materials, broken rice flour (BRF) and sake kasu flour (SKF), used to make the gluten-free pasta is shown in Table 2. Similarly, the proximate composition of the control pasta (CP), which was made under optimal processing conditions using only BRF as raw material, optimal pasta (OP), commercial rice pasta (CPR), and commercial wheat semolina pasta (CWP) are shown.

The results of the proximate composition of the raw materials used to produce gluten-free pasta showed that SKF presented higher ash, protein, and fat values compared to BRF. This behavior may be due to the fact that SKF yeasts concentrate protein and lipids, and are used for the growth of their biomass. The ash values in SKF were similar to those reported by Ito *et al.* (2022) for Japanese sake kasu; however, the protein and fat values obtained in the present study were lower. This may be due to the different fermentation conditions (temperature, fermentation time, and yeast type). The protein and ash values found in the present study in BRF were lower than those reported by Castro-Montoya *et al.* (2024) and Delgado-Murillo *et al.* (2024), who used BRF to produce gluten-free pasta. This behavior may be due to the different variety of grains used, since the rice used in the present study was of the Japanese variety Yamada nishiki.

Protein content (PRO)

Protein content is a variable of high interest in foods, so in the production of gluten-free pastas, the challenge is to find raw

Tabla 2. Chemical composition of the raw materials broken rice flour (BRF), sake kasu flour (SKF), control pasta (CP), optimal pasta (OP), commercial rice pasta (CRP), and commercial wheat semolina pasta (CWP).**Tabla 1.** Composición química de la harina de arroz quebrado (HAQ), harina de sake kasu (HSK), pasta control (PC), pasta optima (PO), pasta de arroz comercial (PAC) y pasta de semolina de trigo comercial (PSTC).

Sample	Dry weight (%)	Ash (%)	Protein (%)	Fat (%)	Carbohydrates (%)
Raw materials					
BRF	90.71 ± 0.30	0.32 ± 0.02	06.28 ± 0.10	0.45 ± 0.01	92.95 ± 0.75
SKF	90.52 ± 0.60	0.68 ± 0.04	20.13 ± 0.04	0.95 ± 0.01	78.24 ± 0.50
Pasta					
CP	88.60 ± 0.80 ^a	0.30 ± 0.01 ^a	06.13 ± 0.13 ^a	0.42 ± 0.01 ^a	93.15 ± 0.92 ^a
OP	88.21 ± 0.14 ^a	0.78 ± 0.01 ^b	13.44 ± 0.06 ^b	0.50 ± 0.06 ^b	85.28 ± 0.72 ^b
CPR	90.92 ± 0.60 ^b	0.82 ± 0.01 ^b	03.56 ± 0.23 ^c	0.02 ± 0.01 ^c	95.60 ± 0.70 ^c
CWP	90.02 ± 0.10 ^c	0.59 ± 0.06 ^c	10.45 ± 0.02 ^d	0.25 ± 0.01 ^d	88.71 ± 0.23 ^d

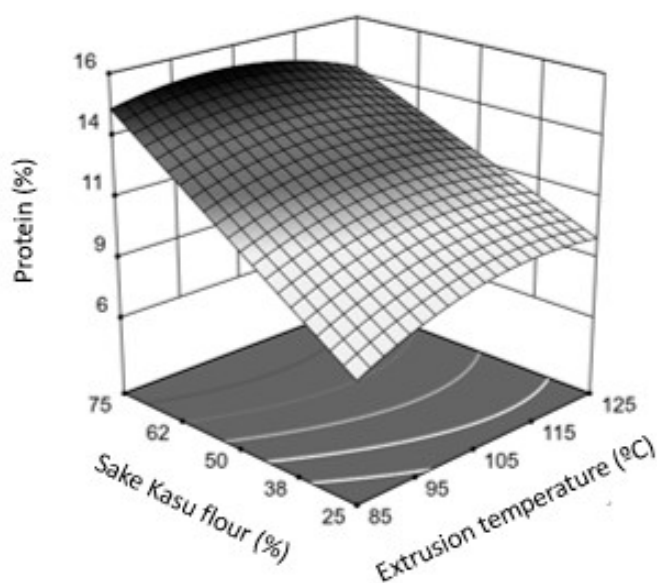
Data are presented as mean ± standard deviation, means with different superscript letters in the same column are significantly different (LSD test; $p < 0.05$).

materials that improve the quantity and quality of protein, in order to provide a better nutritional contribution to the consumer (Soriano-García and Aguirre-Díaz, 2019). In sake kasu, the improvement of the quantity of protein is mainly provided by yeast, since this microorganism concentrates the rice protein for its own growth and reproduction during alcoholic fermentation (Yousif and Tinay, 2000). Figure 1 shows the effect of ET and SKF on the PRO (%) of gluten-free pastas (PGF), at constant SS (100 rpm). It can be observed that the factor that showed the greatest effect on this response variable was SKF, obtaining the highest PRO values (15 %) at high levels of SKF (75 %) throughout the studied range of ET. This trend can be attributed to the fact that yeasts present at high SKF levels showed higher percentages and quality of proteins compared to common rice. Tsutsui *et al.* (1997) evaluated the nutritional content of sake kasu, finding a protein value

of 44.6 %, and a protein quality (C-PER) of 89.6 in comparison with the amino acid requirements for preschool children. Additionally, in the previously mentioned work, the content of limiting amino acids in rice, such as lysine, was enhanced.

Cooking Loss (CL)

The loss during pasta cooking may be due to the leaching of compounds into the cooking water, which is undesirable for these products (Delgado-Murillo *et al.*, 2024). Figure 2a shows the effect of ET and SKF on the CL values at constant SS (100 rpm). Higher CL values (9 %) can be observed with increasing SKF levels (from 25 to 75 %). This behavior may be attributed to the proteins in sake kasu which are of microbiological origin (primarily from *Saccharomyces cerevisiae* yeast), unlike wheat proteins (gluten) which form elastic and cohesive networks. These microbial proteins lack the ability to generate a stable viscoelastic matrix. Furthermore, the starch present in the system may have undergone partial hydrolysis due to the enzymes of *Aspergillus oryzae* from the sake kasu. These two phenomena could compromise the structural integrity of the starch-protein matrix, which is critical in traditional wheat pasta. The lowest CL values (5 %) were obtained at SKF levels (37.5 - 40 %) across the entire ET range. Figure 2b shows the effect of ET and SS on the CL values of the pastas at a constant SKF (50 %). The lowest CL values (5.7 %) were obtained at high ET and intermediate SS levels. This behavior may occur because under intermediate SS conditions, there was no high thermomechanical effect, so the properties of the samples were less affected by less friction within the extruder, allowing a reduction in CL in the pastas. The area with the lowest CL value was found at ET of 125 °C and SS between 87.5 and 112.5 rpm (5.7 % CL). This is consistent with that reported by Jalgaonkar *et al.* (2019) and Delgado-Murillo *et al.* (2024), who reported the same behavior for pastas made from wheat semolina and pearl millet and cracked rice and chickpea pastas, respectively.

**Figure 1.** Effect of the sake kasu flour content and extrusion temperature on the protein content of gluten-free pasta.**Figura 1.** Efecto del contenido de harina de sake kasu y la temperatura de extrusión sobre el contenido de proteína de la pasta sin gluten.

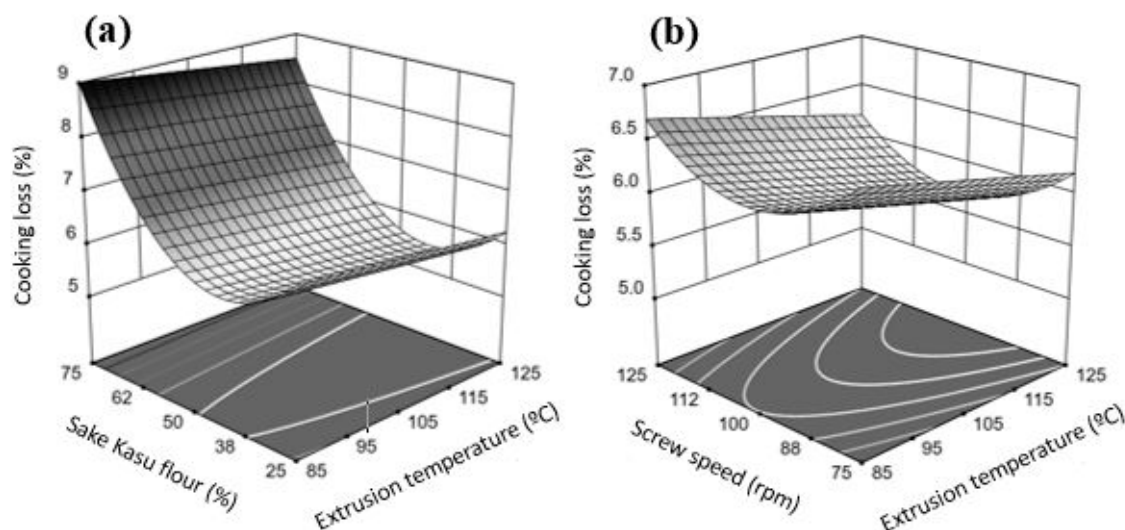


Figure 2. Effect of the sake kasu flour content and extrusion temperature on the cooking loss (a); effect of the screw speed and extrusion temperature on the cooking loss (b) of glu-ten-free pasta.

Figura 2. Efecto del contenido de harina de sake kasu y la temperatura de extrusión sobre la pérdida de cocción (a); efecto de la velocidad del tornillo y la temperatura de extrusión sobre la pérdida de cocción (b) de pasta sin gluten.

Total Phenolic Compounds (TPC)

Figure 3 shows the effect of ET and SKF on the TPC content at constant SS (100 rpm). It can be observed that as SKF increased throughout the ET range, TPC values increased, reaching their maximum value at 75 % SKF (397.55 mg GAE/100 g d.b.). This behavior may be related to the higher TPC content found in sake kasu (780.72 ± 58.31 mg GAE/100 g d.b.) compared to BRF (37.03 ± 2.52 mg GAE/100 g d.b.), which was the other raw material used for PLG production. This effect may occur because sake kasu is a byproduct of fermentation. Ramírez-Esparza *et al.* (2024) reported that fermentation can produce the release of phenolic compounds, since microorganisms generate enzymes that can release these types of

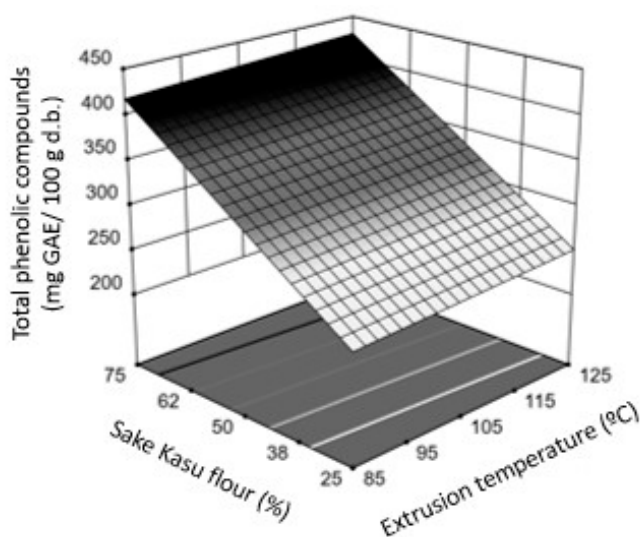


Figure 3. Effect of the sake kasu flour content and extrusion temperature on total phenolic compounds.

Figura 3. Efecto del contenido de harina de sake kasu y la temperatura de extrusión sobre los compuestos fenólicos totales.

compounds, causing them to be bioavailable. Hatanaka *et al.* (2015) mention that sake kasu protein has a high content of compounds such as phenylalanine, increasing the TPC value. In addition, it is mentioned that thermal processes generate denaturation and the breakdown of proteins into dipeptides with high TPC, which also have antioxidant activity.

Antioxidant Activity by the ABTS Method (ABTS)

Figure 4a shows the effect of SKF and ET on ABTS at constant SS (100 rpm). A peak is observed at high SKF conditions and ET at 105 °C (8824.80 μ mol ET/100 g d.b.). It is observed that, as SKF increases, the ABTS value increases, providing evidence that the antioxidant potential is provided by SKF. Similarly, it is observed that as the temperature increases, the ABTS value increases, reaching its peak, and subsequently decreases. The initial increase in antioxidant activity may be attributed to the thermal release of phenolic compounds and other antioxidants from sake kasu, facilitated by an adequate residence time in the extruder. However, when temperatures exceed 105 °C, this activity decreases significantly due to the combined effect of two factors: (1) thermal degradation of thermolabile compounds, and (2) reduced residence time, which limits their availability, ultimately resulting in an overall negative effect on the total antioxidant capacity of the product. In addition, compounds that are already free can lose their antioxidant properties. Figure 4b shows the effect of ET and SS on ABTS content at a constant SKF (50 %). As in the previous figure, a peak in ABTS is observed at 105 °C for ET and 110 rpm for SS. This behavior coincides with the effect of ET presented in Figure 2a. Likewise, the increase in ABTS with increasing SS could be due to the thermomechanical effect produced by shear at intermediate levels of SS, releasing phenolic compounds (refer to the effect of SS). However, higher levels of SS could have caused degradation due to greater thermomechanical damage.

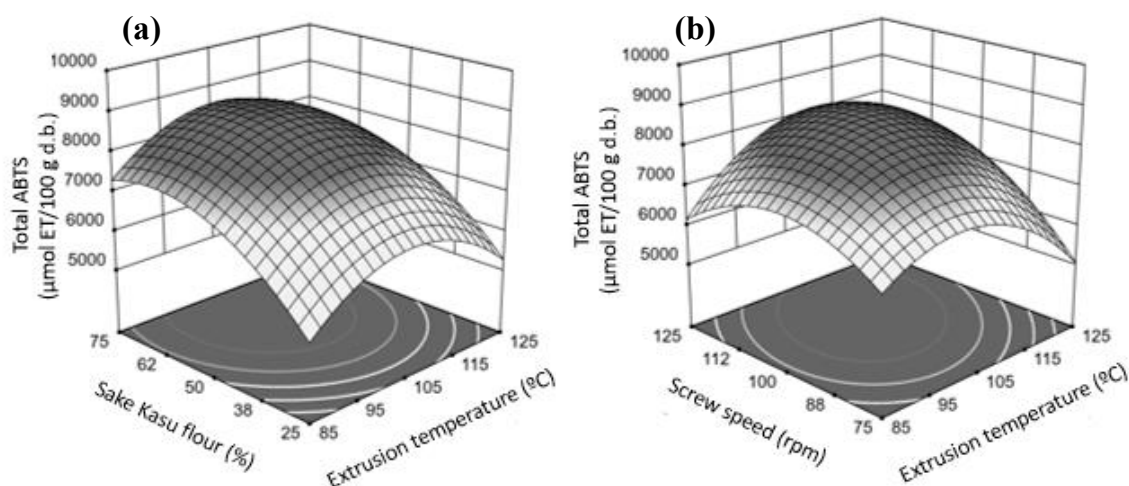


Figure 4. Effect of the sake kasu flour content and extrusion temperature on the total ABTS antioxidant activity (a); effect of the screw speed and extrusion temperature on the total ABTS antioxidant activity (b) of gluten-free pasta.

Figura 4. Efecto del contenido de harina de sake kasu y la temperatura de extrusión sobre la actividad antioxidante total ABTS (a); efecto de la velocidad del tornillo y la temperatura de extrusión sobre la actividad antioxidante total ABTS (b) en pasta sin gluten

General Acceptability Total (GAT)

The sensory acceptability of mass-produced foods produced from new ingredients is of utmost importance, allowing consumers to understand their opinions on the properties of the products (Zegarra *et al.*, 2019). Figure 5a shows the effect of SKF and ET on GA at constant SS (100 rpm). A decrease in GA can be observed at low ET and high SKF. The decrease in GA at high SKF may be due to the bitter taste of sake kasu, which is related to its protein content. Some reports show that proteins can generate a bitter taste in their native form, which decreases when subjected to high temperatures, causing their denaturation (Davis and Williams, 1998). In addition, increasing the sake kasu content in the mixture could generate

a decrease in the severity of the extrusion process, reducing the residence time and cooking of the material (Marti *et al.*, 2010).

Figure 5b shows the effect of ET and SS on the GA of gluten-free pasta (GFP), at constant SKF (50 %), where the highest values (put values) can be observed combining high ET and VT. This could be because high ET combined with high SS could improve the texture and gelatinization of starch, making it more pleasant for the consumer. Likewise, at high ET and VT, the proteins in the material could be denatured, losing their bitter taste in this process (Padalino *et al.*, 2015).

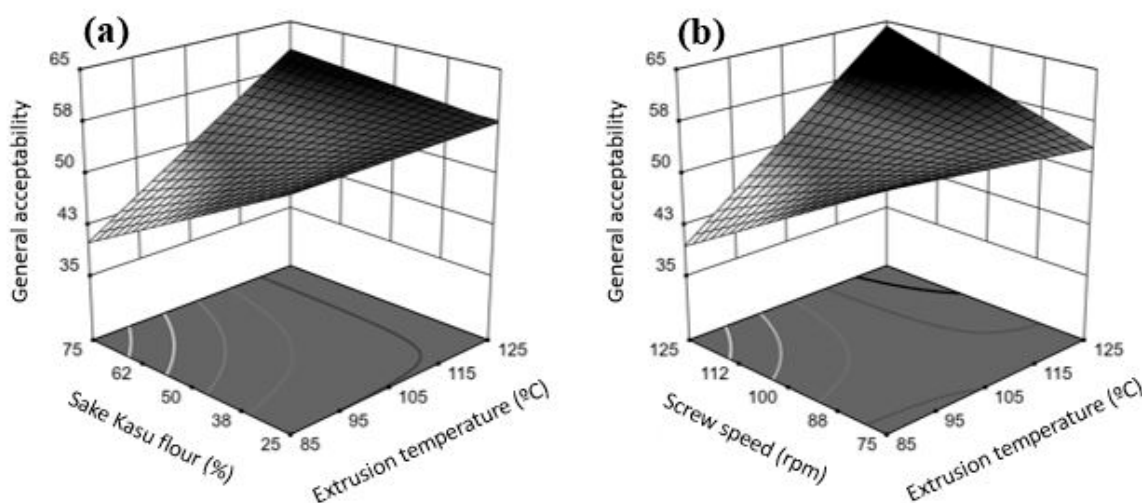


Figure 5. Effect of the sake kasu flour content and extrusion temperature and sake kasu flour content on the general acceptability (a); effect of the screw speed and extrusion temperature on the general acceptability (b) of gluten-free pasta.

Figura 5. Efecto del contenido de harina de sake kasu y la temperatura de extrusión sobre la aceptabilidad general (a); efecto de la velocidad del tornillo y la temperatura de extrusión sobre la aceptabilidad general (b) de pasta sin gluten.

Optimization

The optimization process was carried out to find the ideal processing conditions that would allow obtaining pasta with the best physicochemical, nutritional, functional, and sensory properties. To achieve this, the criteria used were to obtain the highest PRO, TPC, ABTS, and GA values, and the lowest CL values. Higher PRO values are desired because pasta with better nutritional value is sought. Likewise, high TPC and ABTS values are related to the reduction of different diseases (Martins *et al.*, 2016), while high GA values are desired since it is important for mass consumption products such as pasta to have good consumer acceptability. Likewise, low CL values are desired, since pasta should maintain its integrity during the cooking process (Delgado-Murillo *et al.*, 2024). The optimal processing conditions generated by the model

were: SKF of 60.83 %, ET of 116.89 °C and SS of 107.93 rpm. The values predicted by the experimental design were: PRO of 13.18 ± 0.28 %, CL of 6.89 ± 0.36 %, TPC of 376.11 ± 18.55 mg EAG/100 g d.b., ABTS of 8691.89 ± 381.13 $\mu\text{mol TE}/100$ g d.b. and GA of 57.47 (Table 3). These values were experimentally validated, finding for PRO of 13.76 ± 0.60 %, TPC of 380.83 ± 14.40 mg EAG/100 g d.b. of dry base sample, ABTS of 7631.70 ± 721.13 $\mu\text{mol ET}/100$ g d.b. of dry base sample, GA of 59.39 ± 4.61 and CL of 7.15 ± 0.17 %, presenting values very similar to those predicted by the models, demonstrating that the models obtained by the experimental design were adequate. Figure 6 shows the value of individual desirability for each of the response variables, as well as the combined desirability which was 0.707, this being an acceptable value for optimization (Fabila-Carrera, 1998).

Table 3. Regression coefficients of the models, significance levels, analysis of variance, and predicted/ true values, in the optimization process of pasta with addition of broken rice and sake kasu flour.

Tabla 3. Coeficientes de regresión de los modelos, niveles de significancia, análisis de varianza y valores predichos/reales, en el proceso de optimización de pasta con adición de harina de arroz quebrado y sake kasu.

Intercept	PRO	CL	TPC	ABTS	GA
	12.2	5.96	334.49	8479.46	53.82
Linear					
SKF	1.72 (< 0.0001)	0.6725 (< 0.0001)	53.11 (< 0.0001)	607.12 (< 0.0001)	-2.08 (0.0008)
ET	0.3548 (0.0609)	-0.1481 (0.1481)	3.60 (0.4835)	--	3.13 (< 0.0001)
SS	--	--	-1.32 (0.7955)	331.39 (0.0074)	-1.17 (0.0306)
Quadratic					
SKF ²	--	0.5904 (< 0.0001)	--	-330.23 (0.0065)	--
ET ²	-0.3121 (0.0009)	--	--	-445.26 (0.0008)	--
SS ²	-0.2596 (0.0035)	0.1732 (0.0858)	--	-355.96 (0.0040)	--
Interactions					
SKF*ET	-0.2306 (0.0359)	--	--	--	1.79 (0.0136)
SKF*SS	--	0.5863 (0.0004)	--	512.53 (0.0025)	--
ET*SS	0.2621 (0.0197)	--	--	216.44 (0.1342)	2.53 (0.0014)
SKF*ET*SS	--	--	--	--	--
SKF ² *ET	--	--	--	--	--
SKF ² *SS	--	--	--	--	--
R ² adj	0.9774	0.8510	0.8521	0.8275	0.8160
CV (%)	2.36	5.52	5.55	4.95	3.34
p de F (model)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Lack of fit	0.2173	0.4091	0.1735	0.2761	0.3999
Optimization					
Predicted values	13.18 ± 0.28	6.89 ± 0.36	376.11 ± 18.55	8691.89 ± 381.13	57.47 ± 1.80
True values	13.76 ± 0.60	7.15 ± 0.17	380.83 ± 14.40	7631.70 ± 721.13	59.39 ± 4.61

SKF= sake kasu flour content; ET= extrusion temperature; SS= screw speed.

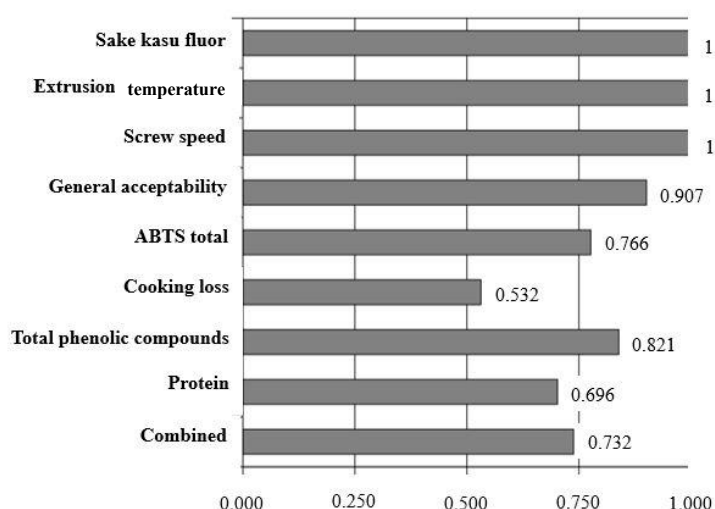


Figure 6. Individual and combined desirability values for the response variables evaluated in pasta during optimization of the extrusion process.

Figura 6. Valores individuales y combinados de deseabilidad para las variables de respuesta evaluadas en la pasta durante la optimización del proceso de extrusión.

CONCLUSIONS

Extruded gluten-free pastas with adequate chemical, physicochemical, and functional properties were obtained using broken rice and sake kasu as raw materials. The addition of sake kasu flour to the pasta formulation improved their nutritional properties (protein) and nutraceutical potential (TPC and ABTS). Furthermore, the pasta obtained under optimal processing conditions presented adequate sensory properties when evaluated by consumers. The production of these products could contribute to increasing the utilization of two potential by-products (broken rice and sake kasu), providing added value and reducing product waste. Likewise, the consumption of these gluten-free pasta could be an alternative for the diet of people with celiac disease, and their consumption could have a positive impact on human health as an important source of protein, bioactive compounds, and antioxidant capacity.

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CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

- AACC. 2000. Method 16-50. Approved methods of the American Association of Cereal Chemists (10th ed.). St. Paul, MN.
- Adom, K.K. and Liu, R.H. 2002. Antioxidant activity of grains. *Journal of Agricultural and Food Chemistry*, 50(21), 6182-6187.
- AOAC International. 2012. Official methods of analysis of AOAC International (19th ed.). Gaithersburg, MD.
- Ashooriha, M., Ahmadi, R., Ahadi, H. and Emami, S. 2022. Application of kojic acid scaffold in the design of non-tyrosinase enzyme inhibitors. *Chemical Biology & Drug Design*. Advance online publication.
- Bolarinwa, I.F. and Oyesiji, O.O. 2021. Gluten-free rice-soy pasta: Proximate composition, textural and sensory attributes. *Heliyon*, 7(1), e06052.
- Box, G.E.P. and Behnken, D.W. 1960. Some new three-level designs for the study of quantitative variables. *Technometrics*, 2(4), 455-475.
- Calvo-Lerma, J., Crespo-Escobar, P., Martínez-Barona, S., Fornés-Ferrer, V. and Donat, E. 2019. Differences in the macronutrient and dietary fibre profile of gluten-free products as compared to their gluten-containing counterparts. *European Journal of Clinical Nutrition*, 73(6), 930-936.
- Cardello, A.V. and Schutz, H.G. 2004. Numerical scale point locations for constructing the LAM (labeled affective magnitude) scale. *Journal of Sensory Studies*, 19(4), 341-346.
- Castro-Montoya, Y.A., Jacobo-Valenzuela, N., Delgado-Nieblas, C.I., Ruiz-Armenta, X.A., Heredia, J.B., Delgado-Murillo, S.A. and Zazueta-Morales, J.J. 2024. Effect of the extrusion process on phytochemical, antioxidant, and cooking properties of gluten-free pasta made from broken rice and nopal. *Revista Mexicana de Ingeniería Química*, 23(1), 2395-8472.
- Codex Alimentarius. 2024. List of standards. Food and Agriculture Organization of the United Nations. <https://www.fao.org/fao-who-codexalimentarius/codex-texts/list-standards/en/>
- Davis, P.J. and Williams, S.C. 1998. Protein modification by thermal processing. *Allergy*, 53 (Suppl. 46), 102-105.
- Delgado-Murillo, S.A., Castro-Montoya, Y.A., Zazueta-Morales, J.J., Quintero-Ramos, A., Ruiz-Armenta, X.A., Limón-Valenzuela, V. and Delgado-Nieblas, C.I. 2024. Effect of the extrusion process on the physicochemical, phytochemical, and cooking properties of gluten-free pasta made from broken rice and chickpea flours. *Journal of Biological and Health Sciences*, 26, 12-121.

- Delgado-Murillo, S.A., Zazueta-Morales, J.J., Quintero-Ramos, A., Castro-Montoya, Y.A., Ruiz-Armenta, X.A., Limón-Valenzuela, V. and Delgado-Nieblas, C.I. 2024. Effect of the extrusion process on the physicochemical, phytochemical, and cooking properties of gluten-free pasta made from broken rice and chickpea flours. *Biotecnia*, 26, 112-121.
- Fabila-Carrera, G. 1998. Design and analysis of industrial experiments (pp. 19–29). Universidad Iberoamericana.
- Félix-Medina, J.V., Montes-Ávila, J., Reyes-Moreno, C., Perales-Sánchez, J.X.K., Gómez-Favela, M.A., Aguilar-Palazuelos, E. and Gutiérrez-Dorado, R. 2020. Second-generation snacks with high nutritional and antioxidant value produced by an optimized extrusion process from corn/common bean flours mixtures. *LWT*, 124, 109172.
- García-Almeida, J., García-Alemán, J., Martínez-Alfaro, B., Vilchez López, F.J. and Maraver-Selfa, S. 2012. Celiac disease: Gluten-controlled diet. In *Dietoterapia, nutrición clínica y metabolismo* (16th ed.). Díaz de Santos.
- Hatanaka, T., Uraji, M., Fujita, A. and Kawakami, K. 2015. Anti-oxidation activities of rice-derived peptides and their inhibitory effects on dipeptidylpeptidase-IV. *International Journal of Peptide Research and Therapeutics*, 21, 479-485.
- Heimler, D., Vignolini, P., Dini, M.G., Vincieri, F.F. and Romani, A. 2006. Antiradical activity and polyphenol composition of local Brassicaceae edible varieties. *Food Chemistry*, 99(3), 464-469.
- Ishak, N., Ahmad, F.B.L., Rosfarizan, M., Arbakariya, B.A., Mohd, S.M., Murni, H. and Helmi, W. 2018. Kinetics and optimization of lipophilic kojic acid derivative synthesis in polar aprotic solvent using lipozyme RMIM and its rheological study. *Molecules*, 23(2), 501.
- Ito, K.R., Sato, T., Goto, H., Sato, K., Watanabe, J. and Yokoo, M. 2022. Utilization of sake lees as broiler feedstuff and its effects on growth performance and intestinal immunity. *The Journal of Poultry Science*, 59(3), 247-259.
- Izu, H., Yamashita, S., Arima, H. and Fujii, T. 2019. Nutritional characterization of sake cake (sake-kasu) after heat-drying and freeze-drying. *Bioscience, Biotechnology, and Biochemistry*, 83(8), 1477-1483.
- Jalgaonkar, K., Jha, S.K., Mahawar, M.K. and Yadav, D.N. 2019. Pearl millet-based pasta: Optimization of extrusion process through response surface methodology. *Journal of Food Science and Technology*, 56(3), 1134-1144.
- Marti, A., Seetharaman, K. and Pagani, M.A. 2010. Rice-based pasta: A comparison between conventional pasta-making and extrusion cooking. *Journal of Cereal Science*, 52(3), 404-409.
- Martins, N., Barros, L. and Ferreira, I.C.F.R. 2016. In vivo antioxidant activity of phenolic compounds: Facts and gaps. *Trends in Food Science & Technology*, 48, 1-12.
- Morreale, F., Boukid, F., Carini, E., Federici, E., Vittadini, E. and Pellegrini, N. 2019. Cooking quality and nutritional value of gluten-free pasta: An overview of the Italian market for 2015. *International Journal of Food Science & Technology*, 54(3), 780-786.
- Myers, R.H. and Montgomery, D.C. 1995. Response surface methodology: Process and product optimization using designed experiments. Wiley.
- Ola, A.R.B., Metboki, G., Lay, C.S., Sugi, Y., De Rozari, P., Darmakusuma, D. and Hakim, E.H. 2019. Single production of kojic acid by *Aspergillus flavus* and the revision of flufuran. *Molecules*, 24(23), 4200.
- Ontiveros, N., Real-Delor, R.E., Mora-Melgem, J.A., Beltrán-Cárdenas, C.E., Figueroa-Salcido, O.G., Vergara-Jiménez, M.D.J., Cardenas-Torres, F.I., Flores-Mendoza, L.K., Arámburo-Gálvez, J.G. and Cabrera-Chávez, F. 2021. Prevalence of wheat/gluten-related disorders and gluten-free diet in Paraguay: An online survey-based study. *Nutrients*, 13(2), 396.
- Padalino, L., Mastromatteo, M., Lecce, L., Spinelli, S., Conte, A. and Del Nobile, M.A. 2015. Optimization and characterization of gluten-free spaghetti enriched with chickpea flour. *International Journal of Food Sciences and Nutrition*, 66(2), 148-158.
- Rahman, M.J., Costa de Camargo, A. and Shahidi, F. 2017. Phenolic and polyphenolic profiles of chia seeds and their in vitro biological activities. *Journal of Functional Foods*, 35, 622-634.
- Ramírez-Esparza, U., Ochoa-Reyes, E., Baeza-Jiménez, R. and Buenrostro-Figueroa, J. J. 2024. Effect of solid-state fermentation on total phenol content and antioxidant capacity of corn. *CienciaUAT*, 18(2), 136-144.
- Sacchetti, G., Pinnavaia, G.G., Guidolin, E. and Dalla Rosa, M. 2004. Effects of extrusion temperature and feed composition on the functional, physical and sensory properties of chestnut and rice flour-based snack-like products. *Food Research International*, 37(5), 527-534.
- Shakibaie, M., Ameri, A., Ghazanfari, R., Adeli-Sardou, M., Amirpour-Rostami, S., Torkzadeh-Mahani, M., Imanif, M. and Forootanfar, H. 2018. Statistical optimization of kojic acid production by a UV-induced mutant strain of *Aspergillus terreus*. *Biotechnology and Industrial Microbiology*, 4(9), 865-871.
- Soriano-García, M. and Aguirre-Díaz, I. S. 2019. Nutritional functional value and therapeutic utilization of amaranth. In *Nutritional value of amaranth*. IntechOpen.
- Trevisan, S., Pasini, G. and Simonato, B. 2019. An overview of expected glycaemic response of one ingredient commercial gluten-free pasta. *LWT*, 109, 13-16.
- Tsutsui, N., Yamamoto, Y. and Iwami, K. 1998. Protein-nutritive assessment of sake lees obtained by brewing from liquefied rice. *Journal of Nutritional Science and Vitaminology*, 44(1), 177-186.
- Yousif, N.E. and El Tinay, A.H. 2000. Effect of fermentation on protein fractions and in vitro protein digestibility of maize. *Food Chemistry*, 70(2), 181-184.
- Zegarra, S., Muñoz, A.M. and Ramos-Escudero, F. 2019. Production of a gluten-free bread based on cañihua flour (*Chenopodium pallidicaule* Aellen) and evaluation of sensory acceptability. *Chilean Journal of Nutrition*, 46(5), 561-570.