REVISTA IBEROAMERICANA DE VITICULTURA, AGROINDUSTRIA Y RURALIDAD

Editada por el Instituto de Estudios Avanzados de la Universidad de Santiago de Chile

NOVEL APPROACH TO FRENCH FRIES: FOOD PRODUCTS FROM POTATO AND RICE EXTRUDED

Nuevo enfoque para las papas fritas: Productos alimenticios a partir de la papa y el arroz extruidos

Nova abordagem para as batatas fritas: Produtos alimenticios a partir da batata e o arroz extrudidos

Laura Almendares
Universidad de Santiago de Chile
Santiago, Chile
ORCID 0000-0001-8349-1818
laura.almendares@usach.cl

Emerson Andrés Núñez-Ferrada
Pontificia Universidad Católica de Chile
Santiago, Chile
ORCID 0000-0002-5335-6065
ennunez@uc.cl

Angela Monasterio
Universidad de Santiago de Chile
Santiago, Chile
ORCID 0000-0001-7309-0746
angela.monasterio@usach.cl

Ruth Salinas
Universidad de Santiago de Chile
Santiago, Chile
ORCID 0000-0001-5507-4742
ruth.salinas@usach.cl

José Román
Universidad de Santiago de Chile
Santiago, Chile
ORCID 0000-0002-8426-5756
jose.roman@usach.cl

Vol. 11, N° 32, 276-296, mayo 2024
ISSN 0719-4994

Artículo de investigación
https://doi.org/10.35588/ax8yr664

Recibido
02 de marzo de 2023

Aceptado
26 de julio de 2023

Publicado
Mayo de 2024

Cómo citar
Almendares, L., Núñez-Ferrada, E.A., Monasterio, A., Salinas, R. y Román, J. (2024). Novel Approach yo French Fries: Food Products from Potato and Rice Extruded. *RIVAR, 11*(32), 276-296, https://doi.org/10.35588/ax8yr664

ABSTRACT

This study aimed to craft an extruded product resembling conventional French fries, utilizing rice as the primary ingredient, and incorporating potato blends to enhance physicochemical and sensory attributes during frying. Mashed potatoes, rice flour, and additives were processed using a twin-screw extruder, followed by frying at 160 °C for 2.15 minutes in three stages. In stage I, four formulations were assessed, with the formulation comprising 70% mashed potato, 30% rice flour, and 0.1% salt displaying superior acceptability and minimal oil absorption (8%). Stage II compared vacuum application to non-vacuum conditions, revealing enhanced sensory acceptability with vacuum due to improved texture and firmness. Combining optimal conditions, stage III yielded the best formulation of 70% mashed potatoes, 30% rice flour, 0.1% salt, and 48% moisture. Extrusion conditions result in heightened sensory evaluation across sensorial parameters. This study pioneers a novel avenue for producing healthier rice-based French fry alternatives via extrusion technology, ameliorating frying attributes.

KEYWORDS

Potato, rice, food technology, food processing.

RESUMEN

Este estudio tuvo como objetivo crear un producto extrusionado similar a las papas fritas convencionales, utilizando el arroz como ingrediente principal e incorporando mezclas de papa para mejorar las propiedades fisicoquímicas y sensoriales durante la fritura. Se procesaron papas trituradas, harina de arroz y aditivos mediante una extrusora de doble tornillo, seguido de una fritura a 160 °C durante 2,15 minutos en tres etapas. En la etapa I, se evaluaron cuatro formulaciones, siendo la que contenía 70% de papa triturada, 30% de harina de arroz y 0,1% de sal, la que presentó una aceptabilidad superior y una absorción mínima de aceite (8%). La etapa II comparó la aplicación de vacío con condiciones sin vacío, revelando una mayor aceptabilidad sensorial con vacío debido a una textura y firmeza mejoradas. La combinación de condiciones óptimas en la etapa III produjo la mejor formulación con un 70% de papas trituradas, 30% de harina de arroz, 0,1% de sal y 48% de humedad. Las condiciones de extrusión resultaron en una evaluación sensorial mejorada en parámetros sensoriales. Este estudio pionero abre una nueva vía para producir alternativas más saludables de papas fritas a base de arroz mediante tecnología de extrusión, mejorando las propiedades de fritura.

PALABRAS CLAVE

Papa, arroz, tecnología de alimentos, procesamiento de alimentos.

RESUMO

Este estudo teve como objetivo criar um produto extrudado similar às batatas fritas convencionais, utilizando o arroz como ingrediente principal e incorporando mixturas de batata para melhorar as propiedades fisico quimicas e sensoriais durante a fritura. Processaram-se batatas trituradas, farinha de arroz e aditivos mediante uma extrusora de dobre parafuso, seguido de uma fritura de 160 °C durante 2,15 minutos en três fases. Na fase I, avaliaram-se quatro formulações, sendo a que tinha 70% de batata triturada, 30% de farinha de arroz e 0,1% de sal, a que apresentou uma aceitabilidade superior e uma absorção mínima de óleo (8%). A fase II comparou a aplicação de vazio com condições sem vazio, revelando uma maior aceitabilidade sensorial com vazio devido a uma textura e firmeza melhoradas. A combinação de condições ótimas na fase III produziu a melhor formulação com um 70% de batatas trituradas, 30% de farinha de arroz, 0,1% de sal e 48% de humidade. As condições de extrusão resultaron numa avaluação sensorial melhorada em parâmetros sensoriais. Este estudo pioneiro abre uma nova via para produzir alternativas mais saudáveis de batatas fritas a base de arroz mediante tecnologia de extrusão, melhorando as propriedades de fritura.

PALAVRAS-CHAVE

Batata, arroz, tecnologia de alimentos, processamento de alimentos.

1. Introduction

In recent years, a poor diet has given rise to a series of health problems throughout the world, triggering the appearance of non-communicable chronic diseases such as cardiovascular diseases, type 2 diabetes, obesity, and non-alcoholic fatty liver disease, among others (Gheorghe et al., 2023). These diseases have been mainly linked to the consumption of harmful foods such as sugary drinks, alcohol, fried foods, and fast food. However, it is important to highlight that this trend is not only affecting the global level but also has repercussions at the individual level, which requires urgent attention to address this growing problem at the national level. Chile is among the countries with the highest rate of per capita consumption of calories from processed foods (Csákvári et al., 2023). This alarming trend has aroused concern due to its possible negative implications for the health of the population. The increase in the intake of processed foods, characterized by their high caloric density, saturated fat content, added sugars and, additives, has been associated with the development of non-communicable chronic diseases (Mambrini et al., 2023). Given these data, it is essential to examine and understand the factors that contribute to this high intake of processed foods in Chile, as well as to explore effective strategies to promote healthier eating and reduce the risks associated with this worrying trend.

French fries are widely recognized as a popular and highly consumed food globally. They are defined as a "potato product made by cutting potatoes into thick or thin strips, soaking in cold water, drying and frying in oil" (Mullay, 2010). In addition to the term "fries," this food is also called by different names in different parts of the world, such as "chips" in the United Kingdom, "pommes frites" in French, and "patatas fritas" in some Spanish-speaking countries. French fries are widely consumed due to their crunchy flavor and their versatility as a side to various meals. However, its high consumption has raised health concerns due to its high saturated fat, sodium, and calorie content. This unhealthy nutritional profile has led to a growing interest in understanding the effects of French fries on human health and their potential contribution to the onset of chronic noncommunicable diseases, such as obesity, type 2 diabetes, and cardiovascular disease. Despite the wide availability of information on the potential adverse effects of French fries, their consumption remains significant in many parts of the world (Devaux et al., 2021). Therefore, it is crucial to further investigate both the nutritional aspects and the health impacts associated with its regular consumption. In addition, it is important to examine possible approaches to improve the nutritional quality of French fries and to develop healthier alternatives that can satisfy consumer tastes and preferences.

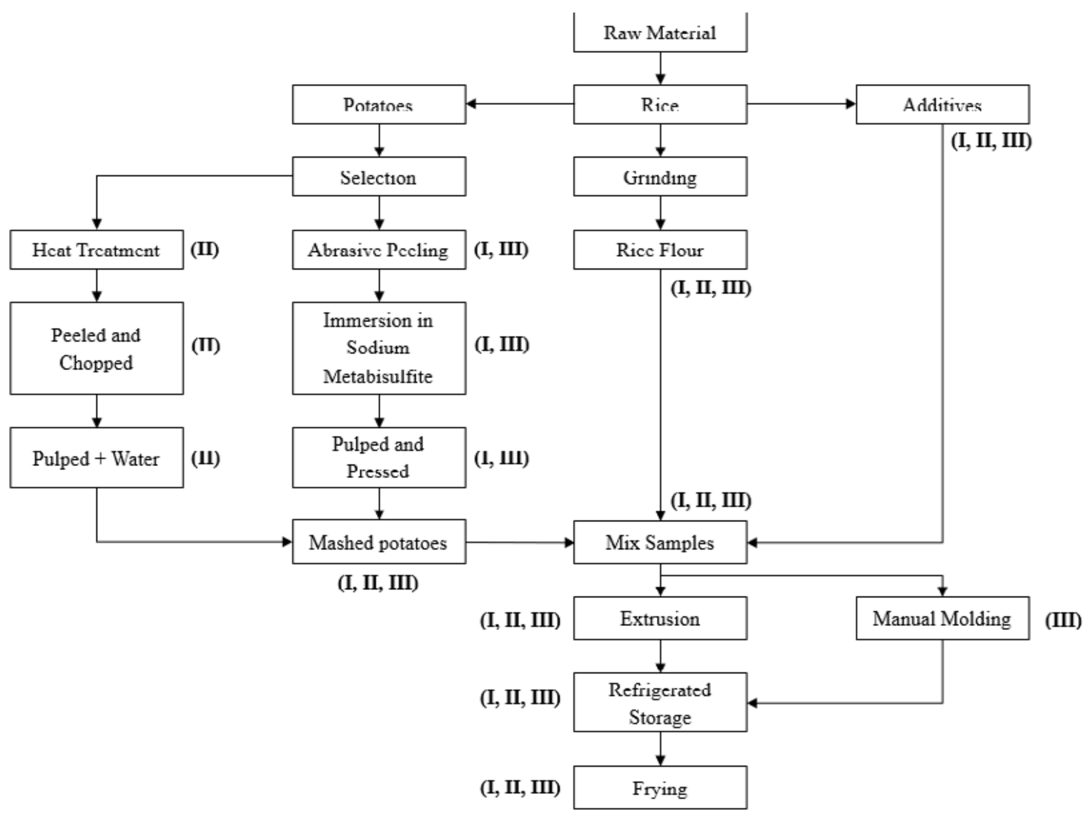
The rice flour has characteristics that make it potentially suitable as a substitute for French fries (Oppong et al., 2022). Rice flour, when subjected to a proper frying process, can acquire a crispy texture similar to that of French fries but with less oil absorption (Kutlu et al., 2022). Compared to traditional French fries, rice flour contains less fat so the saturated fat and calorie content of the final product can be significantly reduced (Weber et al., 2023). Faced with this debatable problem, the proposal has arisen to develop a substitute product for French fries, with the predominant presence of rice flour that presents organoleptic properties similar to traditional French fries, but which has better physical properties such as a decrease in its oil absorption capacity and texture. The extrusion process is a technology widely used in the food industry for the production of a wide variety of products (Choton et al., 2020). It consists of subjecting a mixture of ingredients to high temperatures and pressures in a machine called an extruder. During the extrusion process, the mixture is heated and subjected to intense shear forces and pressure, causing physical and chemical changes in the ingredients (Yadav et al., 2022). In the present study, the process to develop an extruded product similar to French fries using traditional rice as the main raw material and its mixtures with potato through an extrusion process will be addressed in detail to improve the physicochemical and sensory properties of this product to contribute to the elaboration of an alternative of this type of high-consuming product. The development of a similar product, with low oil absorption and good acceptability, could be a healthier alternative to conventional French fries.

2. Materials and methods

2.1. Preparation of mashed potatoes

The raw material was subjected to different treatments for its subsequent use. In the case of the potato, it was subdivided into three stages: I, II, and III for the formation of a mashed potato with different physical characteristics. The best treatment will be used for mixtures with rice flour. Below, Figure 1 shows the general diagram of the three processes used.

Figure 1. General diagram of the processes used in the production of the product
Figura 1. Diagrama general de los procesos empleados en la elaboración del producto



Source: own elaboration. Fuente: elaboración propia.

2.1.1 Process I

The Pukará potato variety was selected through a size calibration because it presents good availability, it is small and for this reason, it has a lower consumption and commercial value (Haros et al., 2023). To remove the peel from 150 kg of potatoes through an abrasive mechanism, a HOBART mechanical peeler was used, with a capacity of 80 kg h^{-1}, model 60 with 25 HP 1/3 motor 1450 rpm that has a coupled water current that facilitates the extraction of the shells. Minor irregularities were removed manually. Then, the potatoes were submerged in a solution of sodium metabisulfite ($Na_2O_5S_2$) at a concentration of 6 g L^{-1}. This additive stops enzymatic browning during the entire process, preventing the generation of dark or brown areas. In said solution, the potatoes were cut into sticks of 10 mm to favor the contact surface with the antioxidant solution. The chopped potatoes were deposited in a semi-industrial blender (SKYMSEN, LAR / MB models, with a 4 L capacity). Finally, the obtained pulp was pressed.

2.1.2 Process II

For this second treatment, the same potato variety was used, with the same size. High-temperature heat treatment was applied at 120 °C for 7 minutes at a pressure of 15 psi in a stainless-steel autoclave as a replacement for the treatment with an antioxidant solution described in stage I. After this process, the removal of peel and chop the potatoes manually to finally make the mashed potatoes in a semi-industrial blender.

2.1.3 Process III

In this procedure, the same methodology was used as in stage I with a small modification. After the immersion and chopping of the potatoes in the antioxidant solution, grinding was carried out to generate a decrease in the caliber of the potato pulp, which was later complemented with the use of a semi-industrial blender. For the three treatments, a maximum value of pulp moisture was established at 65%.

2.2. Preparation of rice flour

For the elaboration of the rice flour, grade 2 white rice with polished ends was used. The grinding process was carried out with a mill (BRABENDER Quadromat Junior, with a capacity of 100 g min^{-1}).

2.3. Formulation of the extruded product

The mashed potatoes, rice flour, and food additives such as salt and emulsifier Prinalux 90 (PRINAL, Chile; Monoglycerides from vegetable fats) were mixed in a semi-industrial mixer (MAIGAS, model SM-25, 3HP), obtaining an adhesive, malleable and homogeneous mixture. The proportions of each component for different extrusion processes (without vacuum and with vacuum) are detailed in Table 1.

RIVAR I Volumen 11, n° 32, 2024: 276-296 • ISSN online 0719-4994
Instituto de Estudios Avanzados, Universidad de Santiago de Chile

Table 1. Base formulations developed with and without the application of vacuum in the extrusion process

Tabla 1. Formulaciones base desarrolladas con y sin la aplicación de vacío en el proceso de extrusión

	With vacuum				Without vacuum			
Treatment	Mashed potatoes (%)	Rice flour (%)	Salt (%)	Emulsifying (%)	Mashed potatoes (%)	Rice flour (%)	Salt (%)	Emulsifying (%)
Control	70	30	-	-	70	30	-	-
1	70	30	0.1	-	70	30	0.1	-
2	70	30	0.1	0.7	70	30	-	0.5
3	70	30	0.1	1	70	30	-	1

Fuente: elaboración propia. Source: own elaboration.

2.4. Extrusion process

A BUHLER twin screw extruder was used to carry out the extrusion tests. The mixed raw material was fed into one end of the extruder and withdrawn from the other under high pressure and temperature conditions. Subsequently, the resulting mixture at the exit of the extruder was molded through a nozzle and cut into strips of approximately 12 cm in length.

The optimal extrusion conditions for each formulation were determined by previous research, which allowed the establishment of specific work parameters. A global range was defined for the parameters of temperature, pressure, and speed of the screw, which included all the formulations. The extruder outlet temperature was maintained between 50-60 °C, the screw speed rang

To further improve the process, vacuum-generating equipment was used to reduce the pressure inside the transport cavity due to the extruder in the CEUS plant facility (Llanquihue, Chile). This made it possible to partially extract the moisture generated during the extrusion process, resulting in a decrease in the moisture content of the final product.

2.5. Conservation process

Once the extruded products were tempered, they were temporarily stored in a refrigeration chamber at 4 °C to continue production. Once the extrusion process was finished, the samples were stored frozen at -18 °C until their characterization.

2.6. Frying process

To apply the heat treatment to all the samples, a VENTUS CORP brand VFS-102 electric fryer was used, equipped with an adjustable thermostat. 100% wonder oil was chosen as the immersion medium due to its good behavior at high temperatures. The frying conditions were established at 160 °C ± 2 °C, with a frying time of two minutes and fifteen seconds. These conditions were kept constant for all the samples processed.

2.7. Physicochemical properties

2.7.1. Proximal analysis

The proximal analysis of the extruded products contemplated the determination of the moisture content through the AOAC 925.45, the protein content using the Kjeldahl method proposed by the AOAC 990.03, the fat or lipid content using the AOAC 996.06 from alkaline hydrolysis, the total ash content of the samples was determined according to the AOAC 923.03. Crude fiber with the method based on AOAC 962.09 and carbohydrates calculated by difference with previously obtained data, expressed as a percentage (AOAC, 2016).

2.7.2. Total oil absorption

The oil absorption in the fried samples was determined using the method described by Liu et al. (2021). To carry out the analysis, the fried potato sticks were ground to obtain a homogeneous sample. Approximately 5 grams of sample was weighed and transferred to an extraction thimble. Previously, a 250 ml flask was dried and weighed, to which 130 ml of petroleum ether was added. The extraction was carried out for four hours using a Soxhlet apparatus. A rotary steamer removed the solvent. The ball containing the extracted oil was dried to constant weight by heating it in an air oven at 105 °C. Duplicates of each sample were made and the results were expressed a as percentage of oil on a dry basis. The total oil content was determined by solvent extraction using the Soxhlet technique. The results obtained were expressed a as percentage of oil on a dry basis.

2.7.3. Texture analysis

Texture is considered an important quality attribute in food formulation. In this study, texture analysis was carried out on the final extruded product with a food texturometer (Agrosta® Texturometer Version 2). The parameter used was fracturability as it is one of the most important quality indicators in French fries (Saini et al., 2023).

2.8. Sensory properties

In the present study, a sensory analysis was carried out based on the UNE-ISO 6658:2019 standard. Twenty-five potential consumer panelists were used for each trial at the laboratory level. The attributes chosen to assess the similarity of the extruded product with traditional potato chips were aroma, color, stick firmness, flavor, and residual oiliness. To determine sensory acceptability in hedonic terms, unstructured scales from 0 to 15 cm long were used, where 0: dislike extremely, 15: like extremely, with fixed ends according to UNE-ISO 4121:2006.

2.9. Statistical analysis

All assays were performed in triplicate and the experimental data obtained were expressed as mean ± standard deviation. Differences between three or more groups were assessed

RIVAR I Volumen 11, n° 32, 2024: 276-296 • ISSN online 0719-4994
Instituto de Estudios Avanzados, Universidad de Santiago de Chile

using ANOVA tests, followed by Duncan's multiple comparison tests at the 95% confidence level ($p < 0.05$) to determine statistical significance. If the data were found to be out of normality, the Kruskal-Wallis Test was added. All the statistical analyses were performed with the STATGRAPHICS Centurion XVI software, v.16.1.03.

3. Results and discussion

The results were presented in different stages, according to processes I, II, and III. Reference is made to the process used, the data obtained and the variables to improve the product, in each of the stages.

3.1. Process I

3.1.1. Moisture of the fresh and fried extruded product

The base formulation is constituted by previous research, which is defined from a formula composed of 70% mashed potatoes and 30% rice flour (Almendares et al., 2020). Among the modifications made to the base formulation is the incorporation of additives to overcome these deficiencies, for which table salt (sodium chloride) and an emulsifier (vegetable fat monoglyceride) were used. Each one of these additives was mixed and then moisture samples were taken to analyze their behavior, compared to the proportion of water contained in the food, to obtain an approximation of the behavior of the mixture, in the development of the extruded product. Table 2 shows that the addition of additives did not generate statistically significant differences for the moisture parameter concerning the control, this is because the concentration of the additives does not interfere with the water retention capacity of the mixture. Then, Figure 2 shows the developed formulations.

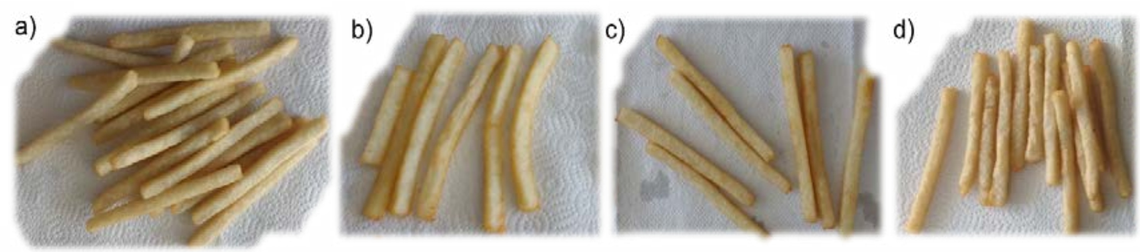
Table 2. Moisture data for the 70/30 fresh mixture
Tabla 2. Datos de humedad para la mezcla fresca 70/30

Sample	Moisture (%)*
Mashed potatoes	66.22 ± 0.20^{a}
Control	49.20 ± 0.38^{b}
1% Emulsifier	49.29 ± 0.30^{b}
0.5% Emulsifier	49.44 ± 0.12^{b}
0.1% Salt	50.05 ± 0.02^{b}

*Moisture values correspond to the Mean ± Standard Deviation of three repetitions. Different letters in the superscripts indicate significant differences ($p < 0.05$). Source: own elaboration. *Los valores de humedad corresponden a la Media ± Desviación estándar de tres repeticiones. Letras distintas en los superíndices indican diferencias significaticas ($p < 0.05$). Fuente: elaboración propia.

Figure 2. Formulations developed through an artisanal process: (a) without additives, (b) 0.5% emulsifier, (c) 0.1% salt, and (d) 1.0% emulsifier

Figura 2. Formulaciones desarrolladas mediante proceso artesanal: (a) sin aditivos, (b) 0,5% de emulsificante, (c) 0,1% de sal y (d) 1,0% de emulsificante



Fuente: elaboración propia. Source: own elaboration.

The product, when subjected to the frying process, changes its structure and, with it, its behavior against the moisture contained within it. Table 3 shows an increase in moisture in the presence of the emulsifier but, in the case of salt, no changes in moisture are observed due to its low concentration within the formulation. It is important to highlight that, within the formulation, a concentration of salt is established that is almost imperceptible to the consumer but, as it is a flavor enhancer, it generates an increase in the organoleptic value of the product.

Table 3. Moisture data for the samples of French fries by manual molding

Tabla 3. Datos de humedad de las muestras de papas fritas por moldeo manual

Sample	Moisture (%)*
Control	29.00 ± 0.14^{a}
1% Emulsifier	31.45 ± 0.35^{b}
0.5% Emulsifier	34.50 ± 0.28^{c}
0.1% Salt	29.50 ± 0.71^{a}

*Moisture values correspond to the Mean ± Standard Deviation of three repetitions. Different letters in the superscripts indicate significant differences ($p < 0.05$). Source: own elaboration. *Los valores de humedad corresponden a la Media ± Desviación estándar de tres repeticiones. Letras distintas en los superíndices indican diferencias significaticas ($p < 0.05$). Fuente: elaboración propia.

3.1.2. Oil absorption

Oil absorption in fried products is influenced by various factors and co-factors, which can either increase or decrease its values. The mechanisms of oil absorption in fried products are not well-established and remain largely speculative. However, for products like French fries, it is known that the majority of oil retention occurs on the surface and within voids or capillaries within the crust (Zhang et al., 2020). Since the product studied in this research is similar to French fries, surface imperfections that occur during the extrusion and molding process are expected to influence oil retention on the product's surface during frying.

Analyzing the results presented in Table 4, it can be observed that the formulation containing 0.1% salt shows a 65% decrease in oil absorption compared to the other formulations. This can be attributed to mass transfer involves the loss of moisture and the gain of oil, which occurs against the flow (Heydari et al., 2021). Salt, or sodium chloride, being a hygroscopic compound, retains water particles, leading to the participation of water molecules in the solvation of salt ions and a decrease in water activity (Aw) within the formulation (Mathlouthi, 2001). As a result, with a decrease in moisture loss, there is also a decrease in oil absorption. This finding is highly significant as it directly influences the desired characteristics of the product. On the other hand, the addition of monoglycerides as an emulsifier does not generate significant changes compared to the control formulation.

Table 4 provides the values of oil absorption for the prototypes developed through extrusion. The percentages are expressed based on different measurement bases: wet basis (WB), degreased moisture base (DMB), dry basis (DB), and degreased dry basis (DDB). The control formulation shows higher oil absorption percentages across all measurement bases compared to the formulations with the addition of an emulsifier or salt. The formulation with 0.1% salt exhibits the lowest oil absorption percentages, indicating its effectiveness in reducing oil uptake.

Table 4. Oil absorption for prototypes developed by extrusion

Tabla 4. Absorción de aceite para prototipos desarrollados por extrusión

Sample	% oil_{WB}	% oil_{DMB}	% oil_{DB}	% oil_{DDB}
Control	20.58[a]	25.91[a]	20.58[a]	22.03[a]
1% Emulsifier	18.64[a]	22.91[a]	18.64[a]	20.95[a]
0.5% Emulsifier	19.75[a]	24.61[a]	19.75[a]	22.52[a]
0.1% Salt	7.09[b]	7.64[b]	7.20[b]	7.76[b]

*WB: wet basis; DMB: degrease moisture base; DB: dry basis; DDB: degrease dry basis. Different letters in the superscripts indicate significant differences ($p < 0.05$). Source: own elaboration. *WB: base húmeda; DMB: desengrase de base húmeda; DB: base seca; DDB: desengrase de base seca. Letras distintas en los superíndices indican diferencias significaticas ($p < 0.05$). Fuente: elaboración propia.

3.1.3. Proximal analysis

The collected data shown in Table 5 confirm that salt, being a hygroscopic compound, captures water particles, which leads to the highest moisture values among the developed formulations. The detected lipid values are only from the emulsifier since it is a vegetable fat monoglyceride (Arslan et al., 2018). However, the non-nitrogenous extract, which represents the soluble carbohydrate fraction, shows a decrease in the formulation with salt. This value could be attributed to water activity (Aw) and osmotic pressure.

Table 5. Proximal analysis of extruded potato chips
Tabla 5. Análisis proximal de papas fritas extruidas

Analysis	Control	1.0% Emulsifier	0.5% Emulsifier	0.1% Salt
Moisture (g/100g)	45.8[a]	46.3[a]	47.7[b]	51.3[c]
Proteins (%N x 6.25)	4.0[a]	4.1[a]	4.0[a]	4.3[a]
Lipids (g/100g)*	ND	0.6[a]	0.6[a]	ND
Ashes (g/100g)	0.6[a]	0.7[a]	0.6[a]	0.8[b]
Crude fiber (g/100g)**	ND	ND	ND	ND
NNE (g/100g)	49.6[a]	48.3[b]	47.1[b]	43.6[c]
Energy (Kcal/100g)	214[a]	215[a]	210[b]	192[c]

*NNE: non-nitrogenous extracts. ND: non-detected. **Detection limit < 0.59g/100g. Different letters in the superscripts in a row indicate significant differences ($p < 0.05$). Source: own elaboration. *NNE: extractos no nitrogenados. ND: no detectado. **Límite de detección < 0.59g/100g. Letras distintas en los superíndices seguidos indican diferencias significativas ($p < 0.05$). Fuente: elaboración propia.

3.1.4. Sensory analysis

The sensory evaluation of the developed food represents the acceptability of the evaluators expressed through the attributes of aroma, stick length, color, flavor, and residual oiliness. The average values of each descriptor are presented in Table 6. The acceptability of the extruded product, according to an unstructured guideline, was defined by ranges, measured in centimeters. The rejection zone is 0-6.99 cm, the indifference zone is 7-7.99 cm, and the acceptability zone is 8-15 cm. The stick firmness is a textural characteristic that is related to starch content and cell structure (Eliasson, 2004). No significant differences ($p < 0.05$) in firmness were observed between treatments. No significant differences were observed between treatments for residual oiliness and flavor. However, significant differences were observed ($p < 0.05$) for the attributes of color and aroma. Among the set of treatments, the one with the highest evaluation within the scale, considering these two factors, is the one made up of the addition of 0.1% salt, generating an increase in the sensory aptitudes of the product. The treatment with 0.5% emulsifier is the worst evaluated, followed by the control treatment.

Table 6. Determination of sensory acceptability of the extruded French fries
Tabla 6. Determinación de la aceptabilidad sensorial de las papas fritas extrusionadas

Attribute	Control	1.0% Emulsifier	0.5% Emulsifier	0.1% Salt
Aroma	6.12[a]	6.90[a]	4.88[ab]	7.33[a]
Color	5.07[bc]	6.32[b]	2.95[c]	8.88[a]
Rod firmness	6.31[a]	8.29[a]	6.62[a]	6.40[a]
Flavor	5.61[a]	6.45[a]	4.52[a]	6.35[a]
Residual oiliness	7.17[a]	7.52[a]	6.95[a]	7.61[a]

*Different letters in the superscripts in a row indicate significant differences ($p < 0.05$). Source: own elaboration. Letras distintas en los superíndices seguidos indican diferencias significativas ($p < 0.05$). Fuente: elaboración propia.

The formulation with the best physicochemical and sensory properties is the one composed of 70% mashed potatoes, 30% rice flour, and 0.1% salt. This formulation was selected to continue with the study in process II.

3.2. Process II

3.2.1. Heat treatment on potato peels

In this process, there is a replacement for abrasive stripping by high-temperature, high-pressure heat treatment. The application of direct steam on the surface of the potato causes a detachment in the middle lamella of the peel, taking into account the direct relationship between the application time of the treatment and the ease of detachment of the peel, the applied treatments did not generate an excessive softening of the raw material. Table 7 shows the pressure and temperature conditions used to separate the skin from the middle lamella of the potato.

Table 7. Operating conditions for peeling potatoes (Pukará variety)
Tabla 7. Condiciones de operación para pelar papa (variedad Pukará)

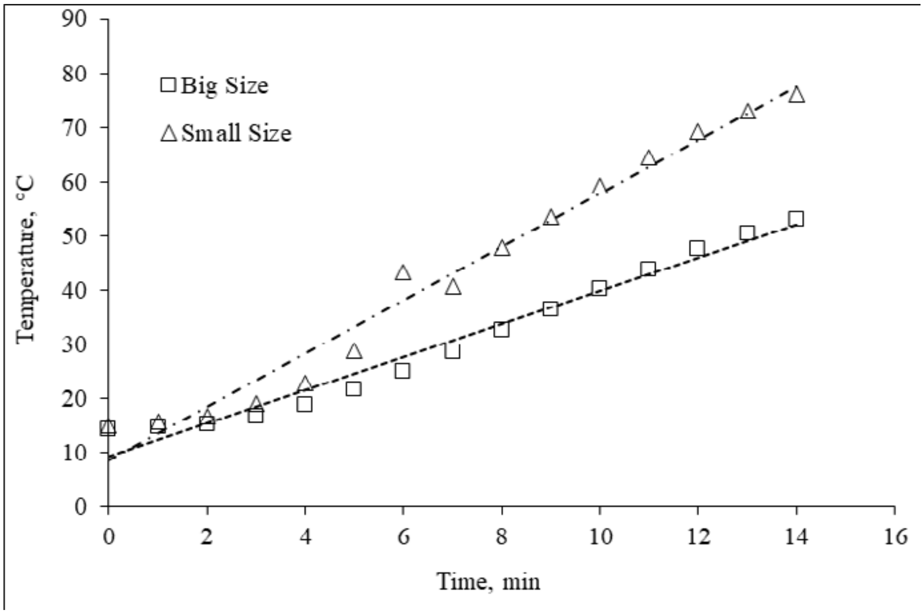
Technique	Pressure (psi)	Process time (min)	Yield (%)
Retort	15	3	92.15[a]
Retort	15	6	92.15[a]
Retort	15	9	92.45[a]
Retort + Shallow cut	15	3	92.20[a]
Direct steam	-	3	-

*The same letters in the superscripts in a column indicate no significant differences ($p < 0.05$). Source: own elaboration. *Las mismas letras en los superíndices de una columna indican que no hay diferencias significantes ($p < 0.05$). Fuente: elaboración propia.

The yields produced by using the retort are similar. However, it is important to highlight that the 3-minute process can result in areas on the potato surface where steam fails to generate changes in the middle lamella. On the other hand, using the retort for 6 minutes allows for manual peeling without difficulties. After 9 minutes, the potato surface shows cracks, and the skin peels off easily. However, the 9-minute time leads to overcooking of the food, which is a disadvantage.

For the heat treatment, two calibers of potatoes were used, one for large potatoes (mean length 11.44 cm and mean width 6.94 cm) and the other for small ones (mean length 8.69 cm and mean width 4.27 cm). The heat treatment was determined to be 15 psi with a cut-out time of 3 min. The results showed that the ideal peeling time of 6 minutes does not generate enzymatic inactivation in the tuber, but it is necessary to add sodium metabisulfite to prevent browning (Moon et al., 2020). Figure 3 shows that the size of the potato is essential in defining the best processing time. A smaller potato requires less processing time than a larger one due to its greater thermal transmittance.

Figure 3. Heating curve of Pukará potato variety with different sizes
Figura 3. Curva de calentamiento de papa variedad Pukará con diferentes tamaños



Source: own elaboration. Fuente: elaboración propia.

3.2.2. Moisture content

The comments made by the panelists of the sensory analysis of process I revealed that the extruded product had a slight aftertaste of rice. Taking this background into account, the addition of two flavorings was considered: merkén and onion, which mask the perceived taste of rice. The new formulations developed are shown in Table 8.

Table 8. New extruded product formulations with the addition of different flavorings
Tabla 8. Nuevas formulaciones de productos extruidos con adición de diferentes aromas

Treatment	Vacuum application	Mashed potatoes (%)	Rice flour (%)	Salt (%)	Merkén (%)	Onion (%)
Control	Not	70	30	0.1	-	-
1	Yes	70	30	0.1	-	-
2	Yes	70	30	0.1	0.7	-
3	Yes	70	30	0.1	-	3

Source: own elaboration. Fuente: elaboración propia.

Monitoring the moisture content of the food at each phase is crucial as this factor directly impacts the organoleptic characteristics of the product, certain physical-chemical parameters, the growth of microorganisms, and the shelf life.

The data in Table 9 differ in some samples but, mainly, for the onion sample, this is attributed to the high percentage of flavoring incorporated, since being a powder, it reduces the moisture content, trapping the available water in the mixture. Figure 4 shows the formulations by the extrusion process.

Table 9. Moisture values corresponding to the extruded samples (with stove at 105 °C)
Tabla 9. Valores de humedad correspondientes a las muestras extruidas (con estufa a 105 °C)

Sample	Moisture (%)*
Mashed potatoes	79.00 ± 0.14[a]
Mix (potatoe + rice)	59.05 ± 0.12[b]
Merkén	58.88 ± 0.12[b]
Onion	55.68 ± 0.22[c]

*Moisture values correspond to the Mean ± Standard Deviation of three repetitions. Different letters in the superscripts indicate significant differences ($p < 0.05$). Source: own elaboration. *Los valores de humedad corresponden a la Media ± Desviación estándar de tres repeticiones. Letras distintas en los superíndices indican diferencias significaticas ($p < 0.05$). Fuente: elaboración propia.

Figure 4. Prototypes made by extrusion: (a) base formulation (mashed potatoes, rice flour, and salt), (b) base formulation with onion addition, and (c) base formulation with merkén addition.
Figura 4. Prototipos elaborados por medio de extrusión: (a) formulación base (puré de papa, harina de arroz y sal), (b) formulación base con adición de cebolla y (c) formulación base con adición de merkén.

Source: own elaboration. Fuente: elaboración propia.

3.2.3. Oil absorption

The results corresponding to the oil absorption for process II did not present statistically significant variations ($p < 0.05$) concerning process I.

3.2.4. Proximal analysis

The data presented in Table 10 empirically confirms that the lipid values recorded in Table 5 correspond to the addition of monoglycerides from vegetable fat. Secondly, the absence of pressing leads to a 15% increase in moisture content in extrusion treatments.

In terms of moisture, the samples with vacuum application in Table 10 show a higher moisture content compared to the samples without vacuum application. This is because the application of a vacuum in food processing affects moisture retention. When a vacuum is applied, a reduced pressure is created around the food, which facilitates the evaporation of the water present in the product (Parikh, 2015). Regarding the ash content, the formulations without vacuum application present higher values. One possible explanation is that during non-vacuum processing, the mineral compounds present in the ingredients become more concentrated due to the evaporation of water (Shao and Wan, 2019). In addition, the content of non-nitrogenous extract showed a decrease in the samples in the group with vacuum application, a possible explanation is that during vacuum processing, greater evaporation of the water present in the samples may occur, resulting in a higher concentration of soluble components in the feed, this would include soluble carbohydrates, which could lead to a decrease in the ENN content (Paudel et al., 2013). Finally, the energy content also varies for different vacuum conditions. By removing part of the water present in the samples, the water content is reduced and, consequently, the total energy content decreases.

Table 10. Proximal analysis of extruded potato product with and without vacuum application
Tabla 10. Análisis proximal del producto de papa extruido con y sin aplicación de vacío

Analysis	Without vacuum application	Vacuum application
Moisture (g/100g)	58.1[a]	60[a]
Proteins (%N x 6.25)	3.4[a]	3.3[a]
Lipids (g/100g)*	ND	ND
Ashes (g/100g)	1.7[a]	1.6[a]
Crude fiber (g/100g)**	ND	ND
NNE (g/100g)	36.8[a]	35.1[b]
Energy (Kcal/100g)	161[a]	154[b]

*NNE: non-nitrogenous extracts. ND: non-detected. **Detection limit < 0.59g/100g. Different letters in the superscripts in a row indicate significant differences (p < 0.05). Source: own elaboration. *NNE: extractos no nitrogenados. ND: no detectado. **Límite de detección < 0.59g/100g. Letras distintas en los superíndices seguidos indican diferencias significativas (p < 0.05). Fuente: elaboración propia.

3.2.5. Sensory analysis

To carry out the sensory analysis of the formulations evaluated in process II, the methodology described in point 2.8 of this article was replicated. Table 11 shows the results of the sensory acceptability evaluation of extruded potato chips with the addition of different flavorings. The evaluated attributes include aroma, color, firmness, flavor, and residual oiliness. The results are presented as average scores.

Table 11. Determination of sensory acceptability of extruded potato chips with the addition of different flavorings
Tabla 11. Determinación de la aceptabilidad sensorial de papas fritas extrusionadas con la adición de diferentes saborizantes

Attribute	Control	Merkén	Onion
Aroma	6.15[a]	6.79[a]	8.53[b]
Color	5.04[a]	3.21[b]	6.67[c]
Rod firmness	6.33[a]	6.35[a]	6.36[a]
Flavor	5.62[a]	3.20[b]	1.27[c]
Residual oiliness	7.19[a]	6.99[a]	7.12[a]

*Different letters in the superscripts in a row indicate significant differences (p < 0.05). Source: own elaboration. Letras distintas en los superíndices seguidos indican diferencias significativas (p < 0.05). Fuente: elaboración propia.

Regarding the aroma attribute, it can be observed that the samples with onion flavoring obtained the highest score, followed closely by the samples with Merkén flavoring, and then the samples without flavoring (control). This indicates that the onion-flavored potato chips have a more pronounced and appreciated aroma compared to the other samples. In terms of color, a clear difference is observed among the samples. The onion-flavored potato chips obtained the highest score, indicating a more attractive color. On the other hand, the samples with Merkén flavoring obtained the lowest score in terms of color, while the control samples fell in an intermediate range. Regarding firmness, all the samples obtained similar scores, indicating no significant difference in the texture of the potato chips with different flavorings. In terms of flavor, a clear difference is observed among the samples. The control samples (without flavoring) obtained the highest score in flavor, followed by the samples with Merkén flavoring, and then the samples with onion flavoring. This indicates that the plain potato chips have a more appreciated flavor compared to the other samples. Regarding residual oiliness, all the samples obtained similar scores, indicating no significant difference in the perception of residual oiliness after consuming the potato chips with different flavorings. In summary, the sensory evaluation results show that the samples with onion flavoring had a more pronounced aroma and a more attractive color, while the control samples had a more appreciated flavor.

3.3. Process III

In this process, the best formulations and mechanisms that stood out in the improvement of the extruded product will be considered. That is, from process I, it was established that the mixture composed of 70% mashed potatoes, 30% rice flour, and 0.1% salt was the one that obtained the best physicochemical and sensory properties. In process II, the use of a vacuum in the extrusion process stands out, in addition to the incorporation of onion flavoring in the final product. To complement these results, process III includes a comparison of the formation process of the sticks (manual molding and semi-industrial process) in the physicochemical, sensory and, texture properties measured instrumentally in the final product.

3.3.1. Moisture content

When comparing the moisture values of processes, I, II, and III, it is evident that the extruded product in process III presents the lowest moisture values (43%). This value is influenced by the extrusion conditions, where the screw speed decreased, causing the mixture to remain a little longer inside the transport line. In addition, the application of vacuum caused an increase in humidity. The product formed by a semi-industrial process has a defined, slightly round shape, similar to a stick. The manually formed product uses the same formulation as the semi-industrial one, however, the fresh product obtained is fragile to handle, which is considered a deficiency compared to the extruded product, which is easily handled.

3.3.2. Oil absorption

The results corresponding to the oil absorption for process III did not present statistically significant variations ($p < 0.05$) with respect to processes II and I.

3.3.3. Proximal analysis

The proximal characterization analyses are presented in Table 12, which differentiates between fresh and fried products and is subdivided into manual molded products (X) and extruded products (Y). Both products, in a fresh state, do not present significant differences since in both cases the same formulation was used. On the other hand, by subjecting the products to frying, they are modified, registering lipid values from the sunflower oil and consequently an increase in the calories of the product (Rustad, 2009). The calculation of the energy intake is influenced by the Atwater factors (4 kcal per g of protein, 9 kcal per g of lipids, and 4 Kcal per g of carbohydrates), which would increase the calories of the product when subjected to frying.

Table 12. Proximal analysis of the extruded potato product with manual (X) and semi-industrial (Y) molding treatment

Tabla 12. Análisis proximal del producto de patata extrusionada con tratamiento de moldeo manual (X) y semi-industrial (Y)

Analysis	Fresh Product (100g)		Fried Product (100g)	
	(X)	(Y)	(X)	(Y)
Moisture (g/100g)	52.2[a]	51.7[a]	53.6[c]	30.6[c]
Proteins (%N x 6.25)	3.3[a]	3.4[a]	4.6[b]	4.4[b]
Lipids (g/100g)*	ND	ND	5.6[a]	5.6[a]
Ashes (g/100g)	0.6[a]	0.7[a]	0.9[b]	0.9[b]
Crude fiber (g/100g)**	ND	ND	0.7[a]	0.7[a]
NNE (g/100g)	43.9[a]	48.2[b]	52.8[b]	57.8[c]
Energy (Kcal/100g)	189[a]	206[b]	278[c]	299[d]

Where (X): molded; (Y): extruded; NNE: non-nitrogenous extracts; ND: non-detected. *Detection limit ≤ 0.52g/100g **Detection limit < 0.59g/100g. Different letters in the superscripts in a row indicate significant differences ($p < 0.05$). Source: own elaboration. Donde (X): moldeado; (Y): extruido; NNE: extractos no nitrogenados; ND: no detectado. *Límite de detección ≤ 0.52g/100g **Límite de detección < 0.59g/100g. Letras distintas en los superíndices seguidos indican diferencias significativas ($p < 0.05$). Fuente: elaboración propia.

According to the new nutritional labeling law, if the fried extruded product (Y) is sold to the general public, it would comply with the regulations implemented in 2016. The values imposed by the regulations, which include a maximum limit of 350 kcal energy, 800 mg sodium, 22.5 g total sugars, and 6 g saturated fat, are exceeded by this food product. These limits are established in the Food Sanitary Regulations of Chile.

3.3.4. Sensory analysis

To carry out the sensory analysis of the formulations evaluated in process III, the methodology described in point 2.8 of this article was replicated. Table 13 shows the results of the sensory acceptability evaluation of manually extruded French fries (X) and with a semi-industrial process (Y). The evaluated attributes include aroma, color, firmness, flavor, and residual oiliness. Results are presented as mean acceptability zone scores.

RIVAR I Volumen 11, n° 32, 2024: 276-296 • ISSN online 0719-4994
Instituto de Estudios Avanzados, Universidad de Santiago de Chile

Table 13. Acceptability test for the extruded potato with different treatments (X and Y)
Tabla 13. Prueba de aceptabilidad para la papa extrusionada con diferentes tratamientos (X e Y)

	Attribute				
Treatment	Aroma	Color	Rod Firmness	Flavor	Residual Oiliness
(X)	9.50a	10.28a	8.11a	8.14a	10.58a
(Y)	10.13a	9.45a	11.72b	8.88a	9.66a

Where (X): molded; (Y): extruded. Different letters in the superscripts in a row indicate significant differences ($p < 0.05$). Source: own elaboration. Donde (X): moldeado; (Y): extruido. Letras distintas en los superíndices seguidos indican diferencias significativas ($p < 0.05$). Fuente: elaboración propia.

Based on the data presented in Table 13, stick firmness was identified as the distinctive parameter between the two evaluated products, with significant differences observed in terms of the measurements (cm). The extruded product was rated higher with a measurement of 11.72 cm, while the comments suggested that the manually molded product had a hard texture.

3.3.5. Instrumental texture analysis

To evaluate fracturability, texture analysis was conducted on the extruded and manually molded products, using simile fries with twelve samples per variety. A penetration speed of 1 mm s-1, a penetration distance of 15 mm, and a cylindrical attachment of 5 mm diameter were used. The fracturability values for the extruded fries were 636.85 ± 10.86 kgf, while those for the manual molded fries were 472.04 ± 23.84 kgf. Although there is no comparable data available in the literature for this new food product, a clear differentiation between the two products was observed. The extruded product had a higher fracturability value, indicating that it required more force to break the crust formed during frying due to the heat treatment it underwent inside the extruder. As per the directly proportional relationship between fracturability and crispness, the higher the force required to break the product, the greater the crispness. This perception was also reflected in the comments of the evaluators, who noted that the extruded product had a better texture sensation.

4. Conclusions

Through the analysis of the results of processes I, II, and III, it was possible to address in detail the process to develop an extruded product similar to traditional French fries, with the combination of rice flour and food additives as well as with the inclusion vacuum in the extrusion process, a product with better physicochemical and sensory properties is obtained.

It was determined that the most crucial parameter in the development of the process is humidity, with a working range of 40-60%. The working conditions of the extruder, including the screw speed, the product outlet temperature of 50-60 °C, and the use of a vacuum registered the best processing conditions. The incorporation of food additives, such as table salt, and onion flavoring had a positive sensory impact, generating significant improvements in the formulation not only in the organoleptic field but also in technology. The sensory acceptability evaluations of the treatments exposed in each process were essential to improve the product since they provided the opinions and qualifications of the panelists.

Finally, it was established that the energy value of the extruded products developed in this study was within the regulatory norm of nutritional labeling, complying with the limits imposed in the Chilean Food Sanitary Regulation. It is stated that it is possible to produce a product similar to conventional French fries; however, further studies on the acceptability of the product itself are needed to refine its sensory acceptability and physicochemical properties. This will facilitate direct comparative studies with commercial and traditional French fries.

References

Almendares Calderón, L., García Mena, V.A., and Román Miranda, J.M. (2020). Development of an Extruded Food Product Similar to Fried Potatoes, Based on By-products of Potatoes and Rice. Physicochemical and Microbiological evaluation. *Food Science and Technology*, *41*, 359-364. https://doi.org/10.1590/fst.03820

AOAC (2016). *The Official Methods of Analysis of AOAC International.* 20th edition. Association of Official Chemist.

Arslan, M. et al. (2018). Oil Uptake by Potato Chips or French Fries: A Review. *European Journal of Lipid Science and Technology*, *120*(10), 1800058. https://doi.org/10.1002/ejlt.201800058

Choton, S., Gupta, N., Bandral, J.D., Anjum, N., and Choudary, A. (2020). Extrusion Technology and its Application in Food Processing: A Review. *The Pharma Innovation Journal*, *9*(2), 162-168. https://doi.org/10.22271/tpi.2020.v9.i2d.4367

Csákvári, T., Elmer, D., Németh, N., Komáromy, M., Kajos, L.F., Kovács, B., and Boncz, I. (2023). Assessing the Per Capita Food Supply Trends of 38 OECD Countries Between 2000 and 2019–A Joinpoint Regression Analysis. *Life*, *13*(5), 1091. https://doi.org/10.3390/life13051091

Devaux, A., Goffart, J.P., Kromann, P., Andrade-Piedra, J., Polar, V., and Hareau, G. (2021). The Potato of the Future: Opportunities and Challenges in Sustainable Agri-food Systems. *Potato Research*, *64*(4), 681-720. https://doi.org/10.1007/s11540-021-09501-4

Eliasson, A.C. (Ed.). (2004). *Starch in Food: Structure, Function and Applications*. CRC Press.

Gheorghe, L., Nemteanu, R., Clim, A., Botnariu, G.E., Costache, I.I., and Plesa, A. (2023). Risk Scores for Prediction of Major Cardiovascular Events in Non-Alcoholic Fatty Liver Disease: A No Man's Land? *Life*, *13*(4), 857. https://doi.org/10.3390/life13040857

Haros, C.M., Reguera, M., Sammán, N., and Paredes-López, O. (Eds.). (2023). *Latin-American Seeds: Agronomic, Processing and Health Aspects*. CRC Press. https://doi.org/10.1201/9781003088424

Heydari, F., Mohebbi, M., Varidi, M.J., and Varidi, M. (2021). Development of Low-fat Chicken Nuggets Using Fish Protein Concentrate in Batter Formulation. *Iranian Food Science & Technology Research Journal*, *17*(3). https://doi.org/10.22067/ifstrj.v17i3.82606

Kutlu, N., Pandiselvam, R., Saka, I., Kamiloglu, A., Sahni, P., and Kothakota, A. (2022). Impact of Different Microwave Treatments on Food Texture. *Journal of Texture Studies*, *53*(6), 709-736. https://doi.org/10.1111/jtxs.12635

Liu, Y., Tian, J., Zhang, T., and Fan, L. (2021). Effects of Frying Temperature and Pore Profile on the Oil Absorption Behavior of Fried Potato Chips. *Food Chemistry*, *345*, 128832. https://doi.org/10.1016/j.foodchem.2020.128832

Mambrini, S.P. et al. (2023). Ultra-Processed Food Consumption and Incidence of Obesity and Cardiometabolic Risk Factors in Adults: A Systematic Review of Prospective Studies. *Nutrients*, *15*(11), 2583. https://doi.org/10.3390/nu15112583

Mathlouthi, M. (2001). Water Content, Water Activity, Water Structure and the Stability of Foodstuffs. *Food Control*, *12*(7), 409-417.
https://doi.org/10.1016/S0956-7135(01)00032-9

Moon, K.M., Kwon, E.B., Lee, B., and Kim, C.Y. (2020). Recent Trends in Controlling the Enzymatic Browning of Fruit and Vegetable Products. *Molecules*, *25*(12), 2754.
https://doi.org/10.3390/molecules25122754

Mullay, M. (2010). Dictionary of Food Science and Technology. *Reference Reviews*, *24*(6), 31-32. https://doi.org/10.1108/09504121011067148

Oppong, D., Panpipat, W., Cheong, L.Z., and Chaijan, M. (2022). Rice Flour-emulgel as a Bifunctional Ingredient, Stabiliser-cryoprotactant, for Formulation of Healthier Frozen Fish Nugget. *LWT*, *159*, 113241. https://doi.org/10.1016/j.lwt.2022.113241

Parikh, D.M. (2015). Vacuum Drying: Basics and Application. *Chemical Engineering*, *122*(4), 48-54.

Paudel, A., Worku, Z.A., Meeus, J., Guns, S., and Van den Mooter, G. (2013). Manufacturing of Solid dispersions of Poorly Water Soluble Drugs by Spray Drying: Formulation and process Considerations. *International Journal of Pharmaceutics*, *453*(1), 253-284. https://doi.org/10.1016/j.ijpharm.2012.07.015

Rustad, T. (2009). Lipid oxidation. In L.M.L. Nollet and F. Toldrá (Eds.), *Handbook of Seafood and Seafood Products Analysis* (pp. 87-93). CRC Press.

Saini, R., Kaur, S., Aggarwal, P., and Dhiman, A. (2023). The Influence of Conventional and Novel Blanching Methods on Potato Granules, Phytochemicals, and Thermal Properties of Colored Varieties. *Frontiers in Nutrition*, *10*, 1178797.
https://doi.org/10.3389/fnut.2023.1178797

Shao, F. and Wan, Q. (2019). Recent Progress on Jet Printing of Oxide-based thin Film Transistors. *Journal of Physics D: Applied Physics*, *52*(14), 143002.
https://doi.org/10.1088/1361-6463/aafd79

Weber, A.C., Weber, D.A., Costa, B., Dahmer, B.R., Cordeiro, S.G., Hoehne, L., and Ethur, E.M. (2023). Nutritional, Textural and Sensory Properties of Lasagna Dough Containing Air Yam, a Non-conventional Edible Plant. *Journal of Food Science and Technology*, *60*(4), 1332-1341. https://doi.org/10.1007/s13197-023-05679-2

Yadav, G.P., Dalbhagat, C.G., and Mishra, H.N. (2022). Effects of Extrusion Process Parameters on Cooking Characteristics and Physicochemical, Textural, Thermal, Pasting, Microstructure, and Nutritional Properties of Millet-based Extruded Products: A Review. *Journal of Food Process Engineering*, *45*(9), e14106.
https://doi.org/10.1111/jfpe.14106

Zhang, X., Zhang, M., and Adhikari, B. (2020). Recent Developments in Frying Technologies Applied to Fresh Foods. *Trends in Food Science & Technology*, *98*, 68-81.
https://doi.org/10.1016/j.tifs.2020.02.007