

THE EFFECT OF TWIN-SCREW EXTRUSION ON TECHNO-FUNCTIONAL PROPERTIES OF KAÑIWA FLOUR FOR USE IN GLUTEN-FREE PRODUCTS

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ABSTRACT: The growing demand for gluten-free ingredients with improved technological performance has driven the search for alternative and sustainable raw materials. In this context, kañiwa (*Chenopodium pallidicaule*), an Andean pseudocereal with high nutritional value, shows potential for food applications. The aim of this study was to evaluate the effect of twin-screw extrusion on the techno-functional properties of kañiwa flour for use in gluten-free products. A central composite design (CCD, 2²), with the final barrel temperature (90–110 °C) and screw speed (405.6–609.2 RPM) as independent variables. Moisture content, water absorption capacity, water retention capacity, water solubility index, swelling power, oil absorption capacity and colour were analysed. The extruded flours showed increases in water absorption capacity, solubility and oil absorption compared to the control, indicating structural modifications associated with partial starch gelatinisation and protein denaturation. Water retention and moisture content remained stable. Furthermore, a decrease in brightness and an increase in yellow-brown hues were observed. The intermediate conditions (100 °C and 508.6 RPM) offered the best balance between functionality and visual quality. It is concluded that extrusion is a promising strategy for producing kañiwa flour with potential applications in gluten-free baking, puffed snacks and instant mixes.

Keywords: *Chenopodium pallidicaule*; index water absorption index; water retention capacity; water solubility index; colorimetry

INTRODUCTION

Kañiwa (*Chenopodium pallidicaule*) is an Andean pseudocereal of high nutritional value, recognised for its content of high-quality protein, dietary fibre, phenolic compounds, and essential minerals, making it a promising raw material for the development of functional and gluten-free foods. Sher et al. (2026) and Wang et al. (2026) highlighted its nutritional potential and applicability in food systems. Furthermore, it offers agronomic advantages such as frost tolerance and adaptation to the harsh conditions of the Andean highlands, promoting its sustainable production.

In recent years, interest in alternative ingredients and healthy products has driven the revaluation of Andean grains such as quinoa, kiwicha, and kañiwa within the food industry. However, the technological use of kañiwa flour remains limited due to certain functional constraints inherent to its native state, such as low solubility and variable behaviour in hydration systems. Rangira et al.

(2026) reported these limitations affecting its industrial application.

Extrusion is a thermo-mechanical processing technology widely used to modify the physicochemical and functional properties of cereals and pseudocereals. By combining temperature, pressure, and shear, this process can induce partial starch gelatinisation, protein denaturation, and the formation of structures with improved hydration, solubility, and textural characteristics. Zhang et al. (2026) and Singh et al. (2026) described these structural modifications and their impact on food functionality. Studies on quinoa and amaranth have demonstrated significant improvements following extrusion, increasing their suitability for use in snacks, instant mixes, and baked goods. Rangira et al. (2026) and Singh et al. (2026) supported these findings.

However, scientific information on the effect of extrusion on kañiwa flour remains scarce. Therefore, the aim of this study was to evaluate the influence of temperature and screw speed on the techno-functional and colorimetric properties of extruded kañiwa flour, in order to identify optimal conditions for its application in innovative gluten-free foods.

MATERIALS AND METHODS

Commercial kañiwa flour (Amantecados, Lima, Peru), with an initial moisture content of 5%, was processed in a twin-screw extruder equipped with a die containing 14 orifices of 0.5 cm diameter. A Central Composite Design (CCD, 2²) with 11 treatments and an axial distance of $\alpha = 2$ was applied using final barrel temperature (90–110 °C) and screw speed (405.6–609.2 RPM) as independent variables. The extrusion process was carried out under a progressive temperature profile (30–85 °C), with a constant water injection rate (10 cm³/min), feed rate (40 kg/h), and conditioning moisture content (20%). The extrudates were dried at 60 °C for 12 h, milled, and sieved to 250 μ m.

Moisture content, water absorption capacity (WAC), water retention capacity (WRC), water solubility index (WSI), swelling power (SP), oil absorption capacity (OAC), and colorimetric parameters (L^* , a^* , and b^*) were evaluated. Data were analyzed by analysis of variance (ANOVA) and response surface methodology (RSM) at a significance level of 5% ($p < 0.05$). Model adequacy was assessed using the coefficient of determination (R^2) and adjusted coefficient of determination (R^2_{adj}). The central point condition (100 °C and 508.6 RPM) was considered the most suitable processing condition based on the overall balance of techno-functional and color properties.

Table 1- Coded values and actual values for Central Composite Design (CCD, 2²)

T	Temperature (X1)	Screw speed (X2)	Temperature (°C)	Screw speed (RPM)
T1	-1	-1	95	454.5
T2	1	-1	105	454.5
T3	-1	1	95	556.6
T4	1	1	105	556.6
T5	$-\alpha$	0	90	508.6
T6	$+\alpha$	0	110	508.6
T7	0	$-\alpha$	100	405.6
T8	0	$+\alpha$	100	609.2
T9	0	0	100	508.6
T10	0	0	100	508.6
T11	0	0	100	508.6

RESULTS AND DISCUSSION

Extrusion significantly improved the functional properties of kañiwa flour (Table 2). The CAA increased from 4.13 g/g (control) to values close to 6.10 g/g, making it more suitable for use in doughs and bread-making. The ISA increased from 8.89% to 14.66%, indicating greater dispersibility and rapid hydration. The OAC also increased to 1.64 g/g, an important attribute for flavour retention and palatability.

Table 2- Functional and colorimetric properties of extruded kañiwa flour and the control

T	Moisture%	CRA g/g	CAA g/g	ISA %	SP g/g	OAC g/g	<i>L</i> *	<i>a</i> *	<i>b</i> *	Colour	ΔE *
T1	8.2	4.3±0.2	5.97±0.04	12.1±0.3	2.67±0.04	1.6±0.1	34.55	-1.90	37.08		27.4
T2	9.1	4.4±0.1	5.9±0.2	11.5±1.2	3.74±0.04	1.44±0.02	34.12	-1.85	37.74		28.2
T3	7.3	4.17±0.03	5.5±0.4	12.8±0.7	2.63±0.03	1.6±0.1	34.95	-1.68	37.03		27.1
T4	8.0	4.16±0.09	5.1±0.8	12.5±0.5	3.70±0.07	1.4±0.1	34.64	-1.96	36.56		27.1
T5	9.2	4.3±0.2	5.8±0.2	13.06±0.09	3.59±0.08	1.5±0.1	33.20	-2.18	37.36		28.7
T6	8.5	4.06±0.04	5.7±0.4	14.7±1.4	4.1±0.1	1.4±0.1	33.91	-1.79	37.81		28.4
T7	7.7	4.2±0.1	6.0±0.1	12.7±0.7	2.90±0.02	1.3±0.1	35.49	-1.91	36.05		26.1
T8	8.5	4.06±0.07	6.1±0.3	12.9±0.6	3.8±0.2	1.4±0.2	33.83	-2.23	37.51		28.3
T9	8.7	4.4±0.5	5.8±0.1	13.9±0.4	3.7±0.2	1.5±0.1	35.91	-1.68	35.09		25.2
T10	9.0	4.3±0.1	6.1±0.2	13.1±0.9	3.5±0.1	1.51±0.02	35.44	-1.81	35.35		25.7
T11	9.0	4.2±0.2	6.0±0.2	12.5±0.5	3.6±0.1	1.5±0.1	34.00	-2.02	36.92		27.8
C	4.6	2.77±0.03	4.13±0.05	8.9±0.2	5.05±0.02	0.8±0.1	56.94	1.16	21.52		--

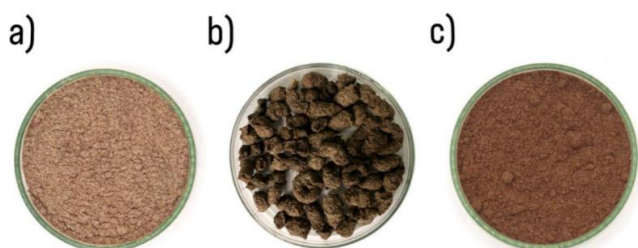
The screw speed mainly influenced oil absorption capacity, whilst temperature had a greater effect on the water solubility index, associated with starch gelatinisation and partial degradation of macromolecules. Rangira et al. (2026) and Singh et al. (2026) reported similar behaviour in extruded protein-based systems. Swelling capacity depended on both factors, whereas moisture content and water-holding capacity showed little variation between treatments.

Compared with native flour, the extruded flours exhibited improvements in water absorption capacity, oil absorption, and solubility. These changes are attributed to starch granule disruption, exposure of hydrophilic and hydrophobic groups, and protein denaturation induced by extrusion. Sher et al. (2026), Wang et al. (2026), and Rangira et al. (2026) described these structural modifications and their impact on techno-functional properties. Similar results have been reported for extruded flours of quinoa, amaranth, and green banana. Zhang et al. (2026) and Singh et al. (2026) supported these findings. These modifications increase the technological potential of kañiwa flour for applications in instant products, baked goods, and gluten-free foods.

With regard to colour, all extruded samples showed lower lightness (*L**) and higher *b** values, indicating darker products with yellow–brown hues compared to the control. This behaviour is related to Maillard reactions, caramelisation, and thermal degradation of natural pigments. Zhang et al. (2026) and Rangira et al. (2026) explained these changes as typical effects of high-temperature processing. The total colour difference (ΔE*) revealed noticeable visual changes in all treatments.

Among the treatments evaluated, T9 showed the greatest similarity to the native flour, exhibiting higher lightness values and a lower ΔE^* , and could therefore be considered the most favourable condition for preserving the product’s visual quality. Overall, extrusion stands out as an efficient technology for enhancing kañiwa flour (Figure 1), improving its functional properties and expanding its application in innovative gluten-free food formulations.

Figure 1- a) Kañiwa flour, b) extruded kañiwa, and c) extruded kañiwa flour (100 °C, 508.6 RPM)



CONCLUSIONS

Twin-screw extrusion proved effective in improving the functionality of kañiwa flour, increasing its hydration capacity, solubility and oil absorption without compromising the overall stability of the material. The intermediate processing conditions (100 °C and 508.6 RPM) yielded the best technological and visual performance. The extruded kañiwa flour showed high potential for applications in gluten-free bread, biscuits, snacks and instant mixes, contributing to the sustainable valorisation of Andean pseudocereals.

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