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Chickpeas (*Cicer arietinum* L.) and oats (*Avena sativa* L.) pre-gelatinised flour for instant food products

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Abstract: Chickpeas and oats are rich in essential nutrients and bioactive compounds, such as phenolics and flavonoids. Extrusion technology enhances food digestibility, nutrition, and shelf life, thus meeting consumer demands. Instant food products are experiencing market growth due to advancements in processing technologies that cater to healthier ingredients. This study aims to evaluate pre-gelatinised flours produced through extrusion using different proportions of chickpeas and oats (100 : 0, 90 : 10, and 80 : 20) and compare them with their respective raw versions. The physicochemical properties, technological characteristics [Rapid Viscosity Analysis (RVA) and Water Absorption Index (WAI)], applications within the instant food industry, and their potential for acceptance were evaluated. The extruded flours showed lower moisture content and water activity – finally, their application in instant soups, mainly at 10%, increased consumer acceptance. Incorporating oats in the flours resulted in higher water activity, WAI, final viscosity, peak viscosity and pasting temperature. Our results demonstrate that flours with suitable physicochemical and technological properties could be obtained using chickpeas, oats, and extrusion. Its incorporation into instant soups resulted in products with suitable acceptance by consumers.

Keywords: healthy food; rheology; modified starch; clean label

Chickpeas (*Cicer arietinum*) are one of the most-produced legume crops in the world; this legume has garnered significant interest in recent years due to its potential health benefits, mainly owing to its major compound classes, which include polyphenols, carotenoids, tannins, sterols, and peptides (Kaur and Prasad 2021). Just as chickpeas, the proteins in oats (*Avena sativa* L.) are highly accepted by consumers compared

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to other plant-based alternatives, such as soy, pea, and lupin proteins, due to the lack of off-flavours (Brückner-Gühmann et al. 2019).

Extrusion is a versatile process involving mixing, cooking, kneading, shearing, shaping, and forming. The process gelatinises starch, degrades protein, and forms complexes among lipids, starch, and proteins, leading to changes in the novel product's microstructure, chemical characteristics, and macroscopic shape (Arribas et al. 2017). Along the same lines, according to Martínez et al. (2015), severe treatment of flour through extrusion can generate a significant change in the viscosity of the products.

Lifestyle changes, increases in per capita income, the shift towards nuclear families, and the rise of the female workforce over the past few decades have transformed food consumption patterns worldwide. A sharp rise in the consumption of convenient meals has been observed in recent years (Thienhirun and Chung 2018).

This study, therefore, aims to evaluate pre-gelatinised flours produced through the extrusion process using different proportions of chickpeas (*Cicer arietinum*) and oats (*Avena sativa* L.) for application in the instant food industry and to compare them with their respective raw versions. The study evaluates the physicochemical properties of these flours, their technological characteristics through Rapid Visco Analysis (RVA), potential nutritional losses resulting from the process, and the potential acceptance of their texture through sensory analysis of an instant soup.

MATERIAL AND METHODS

Raw materials. Chickpeas (*Cicer arietinum*), Kabuli type, and oats (*Avena sativa* L.) were sourced from local suppliers.

Preparation of the flours. All the grains were ground using a knife mill (ACB Labor, Brazil), and the resulting grits were mixed according to the pre-established proportions for the study, established through preliminary research. In initial tests, blends with more than 25% oats failed to meet the sensory expectations for applications intended for pre-gelatinised flour. Therefore, proportions of 100%, 90%, and 80% chickpeas were prepared and supplemented with oats to produce R1, R2, and R3. Subsequently, they were moistened by adding 4% water (m/m), and the extrusion cooking process was conducted without a die plate using a single-screw extruder (50 mm diameter and a length of 200 mm/ Inbramaq, IB-50, Brazil) with a feed temperature of 25 °C and an operating temperature of 130 °C. Two batches were prepared for each grain mixture following the methodology of Monteiro et al. (2016). The extruded product obtained was then ground again using a knife mill (ACB Labor, Brazil) to produce the powdered flour, as seen in Figure 1.

Physicochemical and physical analysis. Moisture and ash content were determined using methods 8.20 and 2.80 AOAC (2006) methods. The means and standard deviations of the data were expressed on a dry basis from three replicates.

Water activity was determined with an Aqualab Series 4TE digital refractometer (Aqualab, UK) after equilibration of the samples at 25 °C.

The samples were ground into fine powders to determine the Water Absorption Index (WAI) and Water Solubility Index (WSI), according to Singh and Muthukumarappan (2016).

The colour was measured using a Minolta CR-400 colourimeter (Minolta®, Japan).

Crude Fibre and Protein were measured according to the Association of Official Agricultural Chemists

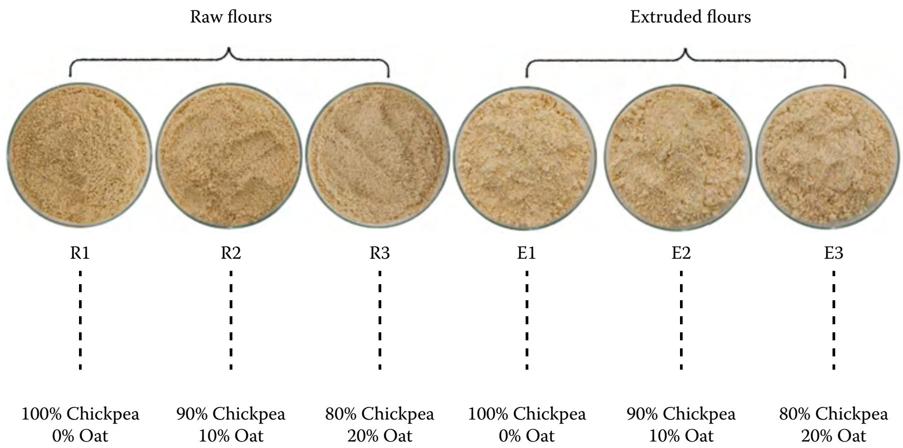

Figure 1. Pre-determined proportions and final characteristics of the flours used in the study

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(methods 3.15 and 9.70, respectively, respectively), even as Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) (AOAC 2006).

Rapid Viscosity Analysis. The pasting properties of the samples were determined according to Pumacahua-Ramos et al. (2015) using an RVA-4 rapid viscosity analyser (Newport Sci., Australia). Suspensions of 10% flour (m/m) in distilled water were prepared (total mass of the suspension: 28 g) and subjected to a controlled cycle of heating and cooling under constant shear (160 rpm). The samples were maintained at 50 °C for 2 min, heated from 50 °C to 95 °C at a rate of 6 $°C \cdot min^{-1}$, held at 95 °C for 5 min, cooled to 50 °C at 6 $°C \cdot min^{-1}$, and then maintained at 50 °C for a further 2 min.

Data on pasting temperature, peak viscosity, trough viscosity, breakdown, final viscosity, and setback viscosity were recorded throughout the analysis. The pasting temperature was determined by noting the initial temperature during the viscosity increase at the beginning of the curve. Peak viscosity was identified by the maximum value reached on the pasting curve. Trough viscosity was determined by measuring the minimum viscosity after the constant temperature of 95 °C was reached. Final viscosity was measured as the maximum viscosity at the final cooling temperature of 50 °C. The setback was calculated as the difference between the minimum viscosity at 95 °C and the final viscosity (Mendes et al. 2023).

Micrography. Chickpea flours were suspended in both cold (20 °C) and boiling (100 °C) demineralised water for microscopic observation, as per the method described by Noordraven et al. (2021). An inverted trinocular optical microscope (Biofocus®, Brazil) was employed to observe the microstructures at 20× magnification (scale bar: 50 μm), and photographs were taken.

Sensorial analysis. A discriminative paired comparison test was conducted to assess the acceptance characteristics of pre-gelatinised flours, focusing on the texture attributes of the samples. This was followed by a global preference choice between the samples selected by the tasters in the initial test by Dischsen et al. (2013).

In this procedure, an instant soup was prepared using the same amount of seasoning for each pre-gelatinised flour formulation (0.5% salt, 0.3% mustard powder, 0.1% parsley, and 0.05% chilli pepper powder). Boiling water was added at a ratio of 1 : 10, and the samples were coded and then presented at a temperature of 70 °C to 91 tasters (47 male and 44 female) aged 18 to 28 years.

The judges randomly evaluated the three formulations in the same session, drinking water at room temperature to cleanse the palate before and between evaluations of the formulations. This project was approved by the Ethics Committee Involving Human Beings of the State University of Maringá (Approval Number: 6.727.109 / CAAE: 76009123.6.0000.0104).

Statistical analysis. The entire experiment and physicochemical composition were assessed in triplicate. For acceptability and purchase intent, the experimental design consisted of randomised complete blocks (the formulations were the treatments, and the judges formed the blocks). Data were subjected to ANOVA and Tukey's comparison of means test (P = 0.05). Statistical analyses were performed using the SISVAR (Ferreira 2019).

RESULTS AND DISCUSSION

Physicochemical analysis. The results of the physicochemical properties of the raw and extruded flour samples (R1, R2, R3 and E1, E2, E3) are presented in Table 1.

The moisture content of the chickpea raw flour samples ranged from 11.66% to 12.27%, while the extruded samples ranged from 4.75% to 5.09%. No significant differences were observed within the groups; however, a substantial difference was detected when comparing the two groups. Moisture in the extruded samples decreased by more than half compared to the raw samples. This behaviour highlights how high temperature and pressure influence the final product during extrusion.

Regarding water activity, no significant differences were observed between samples R1 and R2 (0.48) in the raw flour group; however, both differed significantly from sample R3 (0.50). This may suggest that the higher the oat concentration in the formulation, the higher the water activity, which could impact conservation and shelf life for industrial applications. No differences were observed between the extruded samples (0.36 and 0.37) for this parameter, but the values for this group were noticeably lower than for the non-extruded samples. This again highlights the influence of the extrusion process on food product properties.

The WAI analysis showed no significant differences between the raw flour samples (ranging from 2.02 to 2.10), indicating a similar amount of water immobilised in each sample. However, the extruded flour samples differed significantly and exhibited significantly higher values than the raw samples, ranging from 2.77 to 3.44. Given

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Table 1. Physicochemical properties of raw and extruded flour samples (mean ± standard deviation)

Analysis	Raw flours			Extruded flours		
	R1	R2	R3	E1	E2	E3
Moisture (%)	11.66^{a} ± 00.10	12.27^{a} ± 00.02	11.93^{a} ± 00.96	5.09^{b} ± 00.21	4.75^{b} ± 00.21	4.82^{b} ± 00.04
Ash (%)	2.53^{a} ± 00.10	2.74^{ab} ± 00.01	2.97^{ab} ± 00.07	3.40^{b} ± 00.24	3.00^{ab} ± 00.06	2.74^{ab} ± 00.02
Crude protein (%)	20.75^{c} ± 00.02	20.14^{ab} ± 00.11	19.64^{a} ± 00.03	20.69^{bc} ± 00.08	20.82^{c} ± 00.03	20.38^{bc} ± 00.00
Crude fibre (%)	4.39^{a} ± 00.07	04.38^{a} ± 00.03	4.41^{a} ± 00.05	4.47^{a} ± 00.38	4.68^{a} ± 01.00	4.26^{a} ± 00.06
NDF (%)	23.34^{a} ± 06.49	23.74^{a} ± 00.06	22.53^{a} ± 01.49	8.88^{b} ± 01.74	10.24^{b} ± 00.37	7.62^{b} ± 00.02
ADF (%)	6.20^{a} ± 00.45	6.04^{a} ± 00.11	6.09^{a} ± 00.11	5.26^{a} ± 00.14	5.62^{a} ± 00.55	5.11^{a} ± 00.21
A_w	0.48^{a} ± 00.00	0.48^{a} ± 00.00	0.50^{b} ± 00.00	0.36^{c} ± 00.00	0.37^{c} ± 00.00	0.36^{c} ± 00.00
WAI (%)	2.08^{a} ± 00.00	2.02^{a} ± 00.00	2.10^{a} ± 00.00	02.77^{c} ± 00.00	03.44^{b} ± 00.00	03.00^{d} ± 00.01
WSI (%)	24.80^{a} ± 00.14	20.95^{b} ± 00.26	20.25^{b} ± 00.09	20.42^{b} ± 00.03	19.81^{b} ± 00.03	17.98^{c} ± 00.70
*L**	86.00^{a} ± 05.01	86.09^{a} ± 03.84	84.41^{a} ± 02.35	83.96^{a} ± 05.12	83.85^{a} ± 06.06	76.20^{b} ± 13.80
*a**	6.83^{a} ± 00.17	5.81^{ab} ± 00.05	6.29^{ab} ± 00.32	5.23^{b} ± 00.02	5.32^{b} ± 00.24	5.91^{ab} ± 00.20
*b**	23.20^{ab} ± 04.12	21.09^{a} ± 04.21	21.03^{a} ± 00.45	27.78^{c} ± 01.26	26.28^{bc} ± 00.51	26.74^{bc} ± 00.20
ΔE	–	–	–	5.26^{a} ± 02.62	5.67^{a} ± 02.49	10.01^{b} ± 02.89

Results are expressed as mean ± standard deviation (SD). Values with different letters in the same line are significantly different ($P < 0.05$) by Tukey's test. Samples R1, R2, R3, E1, E2 and E3 are raw and extruded with 100% chickpea, 90% chickpea / 10% oat and 80% chickpea / 20% oats, respectively; NDF – neutral detergent fibre; ADF – acid detergent fibre; Aw – watter activity; WAI – water absorption index; WSI – water solubility index; *L** – lightness, *a** – red-green axis; *b** – yellow-blue axis

that starch dispersion increases with the degree of starch damage due to gelatinisation, higher WAI values suggest the presence of large starch fragments in the final product (Oikonomou and Krokida 2011).

In examining the WSI values, no significant differences were observed between the R2 and R3 samples of raw flours (20.95 and 20.25, respectively) or between the E1 and E2 samples of extruded flours (20.42 and 19.81, respectively). However, these values were lower than that of R1 (24.80) and higher than that of E3 (17.98). Therefore, oat addition resulted in a decrease in the WSI values both in raw and extruded flours. This behaviour suggests that pure chickpea flour contains more free polysaccharides or polysaccharides released from the granules upon adding excess water. This amount decreases with the inclusion of oats in the formulations and through the extrusion process (Oikonomou and Krokida 2011).

Considering the *L** colour parameter, the raw flour samples showed values ranging from 84.41 to 86.09, and samples E1 and E2 presented values between 83.96 and 83.85. The E3 flour showed a lower *L** value (76.20), suggesting that oat inclusion promoted a darkening of the extruded flour.

For the *a** colour parameter, no significant differences were detected within the groups, and only minor differences were observed when comparing the samples (a slight decrease only from R1 to E1), indicating homogeneous colour characteristics. A similar trend was observed for the *b** colour parameter.

The total colour difference (ΔE) value did not present significant differences when comparing the samples containing 100% chickpea and 10% oat in their composition. However, when the proportion of oats was increased to 20%, nearly double the ΔE was observed between extruded and non-extruded flour samples. Considering that the results show the human eye can visually detect the colour difference when the ΔE value exceeds 5 (Pourjavaher et al. 2017), in all cases, this perception was noted, being more pronounced when comparing formulations with 20% oat.

When analysing the crude protein levels, formulations R2 and R3 presented the lowest values (19.64% and 20.14%, respectively), both raw flour samples containing oats. No significant differences were found between samples R2, E1, and E3, nor between samples R1, E1, E2, and E3. This indicates that the extrusion process did not significantly impact the protein content across the developed formulations.

They reported values between 0.20% and 4.40% for crude fibre, which are also consistent with the range observed in our research. Notably, no significant differences were detected in crude fibre content across all formulations, whether raw or extruded.

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Bayomy and Alamri (2022) found a crude fibre content of 4.38% in chickpea flour and a range of 2.19% to 4.07% in noodles produced with 15–25% chickpea. Conversely, Mousa et al. (2021) detected values ranging from 0.89% to 1.25% in instant soup powder prepared with 5–15% dehydrated green curd pea peel. The lower crude fibre values in formulations using green pea peel rather than chickpeas in industrial products suggest that extruded chickpea flour has considerable potential for enhancing protein content in food industry applications.

A similar trend was observed in the ADF (Acid Detergent Fibre) analysis, where no significant differences were found between formulations, which ranged from 5.11% to 6.20%. This suggests that the extrusion process does not affect the grain's cell wall or the composition of cellulose and lignin.

However, for NDF (Neutral Detergent Fibre), values ranged from 22.53% to 23.74% across the non-extruded samples, with no significant differences. In contrast, all extruded samples exhibited significant differences compared to the non-extruded ones (lower values). However, no significant differences were observed among the extruded samples, ranging from 7.62% to 10.24%.

Rapid Viscosity Analysis. The RVA analysis profiles are presented in Figure 2, with the corresponding results shown in Table 2.

The first noteworthy point is that adding oatmeal increases the final viscosity in both the raw and extruded flours. In other words, a higher proportion of oat flour in the mixtures increased final viscosity. A similar trend was observed for peak viscosity, pasting temperature, and setback in the raw flours, with no breakdown detected in any of the flours, as seen in Table 2: all samples, both raw and extruded, demonstrated stability under shear-cooking conditions.

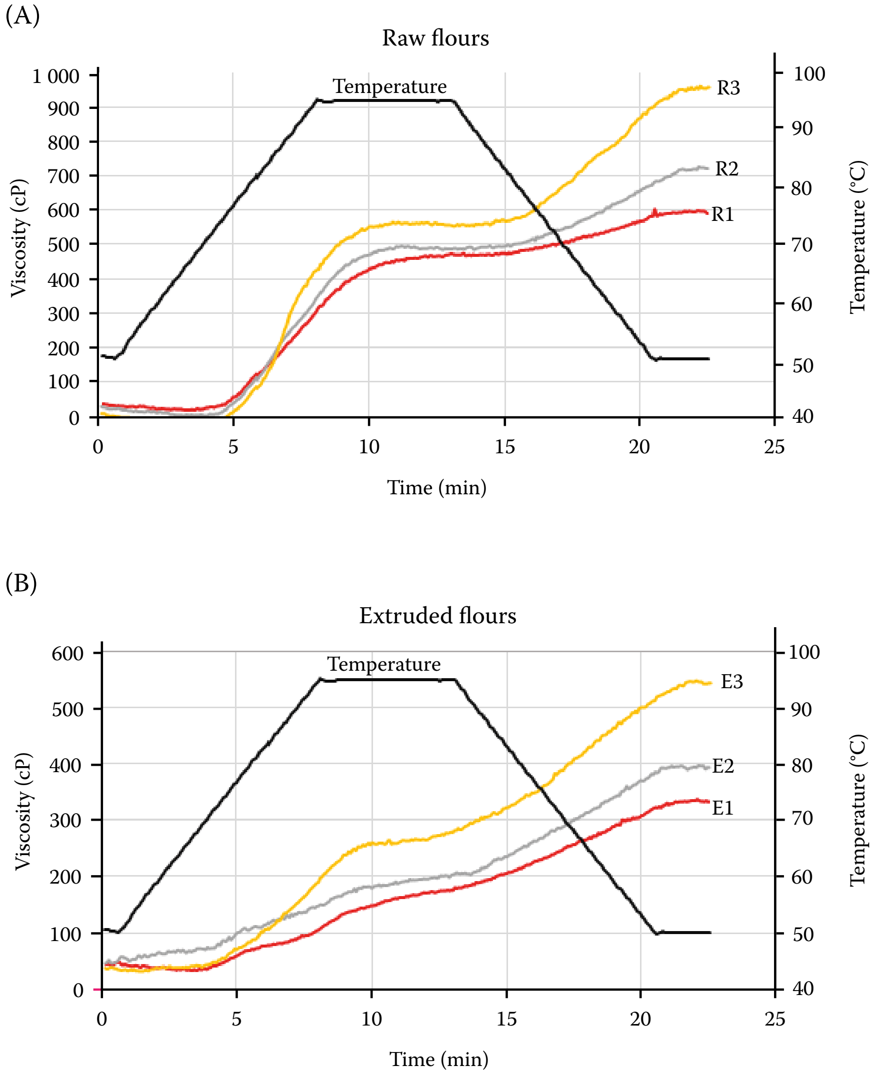

Figure 2. Rapid Viscosity Analysis (RVA) profiles for raw and extruded flour

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Table 2. Results of Rapid Viscosity Analysis (RVA)

Sample	*PT* (° C)	*PV* (cP)	*TV* (cP)	*FV* (cP)	*BD* (cP)	*SB* (cP)
R1	73.2	303	313	590	–	287
R2	74.0	340	346	719	–	379
R3	76.8	429	555	958	–	530
E1	71.5	104	107	332	–	228
E2	71.5	149	151	395	–	247
E3	71.0	198	200	546	–	348

Samples R1, R2, R3, E1, E2 and E3 are raw and extruded with 100% chickpea, 90% chickpea / 10% oat and 80% chickpea / 20% oats, respectively; *PT* – pasting temperature; *PV* – peak viscosity; *TV* – through/minimum viscosity; *FV* – final viscosity; *BD* – breakdown; *SB* – setback

The RVA curves of all samples showed low viscosity, which is understandable since flours were used instead of pure starches. The formulations contain proteins, lipids and fibres that can influence the results. From a nutritional perspective, chickpeas are an excellent source of protein (18–29%), carbohydrates (59–65%), fibre (3–17%), lipids (4.5–6.6%) and ash (2.48–3.50%), in addition to presenting very high protein digestibility, increasing from 53% to 89% (Boye et al. 2010). On the other hand, according to Syed et al. (2020), oats have a moisture content of 4.21%, ash of 1.97%, total carbohydrates of 55.75%, crude protein of 12.62%, crude fat of 6.91%, and total fibre of 13.65%.

Generally, starch gelatinisation and protein denaturation are accompanied by increased viscosity. Initially, gelatinisation is the primary factor contributing to viscosity development, primarily due to the pasting temperature. This is followed by protein denaturation, which occurs at higher temperatures (up to 95 °C) and contributes to viscosity to a lesser degree (Meares et al. 2004). This helps to explain the starch-like behaviour observed in the RVA profiles, where the setback is very low, and there is no breakdown, particularly in the raw flours. The protein content stabilises the viscosity during the heating process.

Setback is a valuable parameter for understanding the short-term retrogradation of a starchy material, which occurs due to the crystallisation of amylose. Although the setback values are low, it is noteworthy that the flours with the highest oat addition exhibited the highest setback results. This may be attributed to the high amylose content in oat starch, representing up to 33.6% of this cereal component (Autio and Eliasson 2009).

Regarding the pasting temperature for raw flour, Meares et al. (2004) explain that this property positively correlates with starch concentration. Therefore, a higher starch content typically results in a higher pasting temperature. Chickpeas contain between 59% and 65% carbohydrates (Boye et al. 2010), of which 30.8% to 37.9% is starch (Kaur and Prasad 2021), while oats contain 55.75% (Syed et al. 2020).

For the extruded flours, the pasting temperature was almost identical across all samples, suggesting that the level of cooking achieved through extrusion was consistent, regardless of the starch content in the formulations. The extruded flours exhibited an ever-increasing viscosity without breakdown during testing. Notably, the E3 sample showed a more subtle starch behaviour curve, as depicted in Figure 2.

The initial viscosity of the extruded flours was higher than that of the raw flours, likely because the extruded flours are pre-gelatinised, allowing the starch to hydrate and swell quickly, forming a gel instantly. However, the final viscosity of all raw flours was higher than that of their extruded counterparts. This behaviour has been documented in several studies, where the thermal treatment of extrusion consistently reduces pasting properties such as peak viscosity, final viscosity, and setback. Examples include studies with extruded corn flour (Zhang et al. 2020) and cassava and cowpea flours with varying moisture content (Kesselly et al. 2023).

In summary, extrusion cooking reduces viscosity due to starch depolymerisation, which diminishes breakdown and setback. As demonstrated in this study, the extruded flours lack distinct breakdowns and have shallow setbacks, reflecting a non-conventional starch RVA curve. Consequently, these flours are more stable and better suited for products with high starch content that require enhanced stability, such as instant soup (Zhang et al. 2020).

Micrography. Given that pre-gelatinisation induces swelling of the granules, leading to the formation

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of a cohesive mass (agglomerates) and residual granule fragments, this behaviour can be visibly observed in the micrographs presented in Figure 3. In these images, the non-gelatinised samples (A1, A2, and A3) exhibit different swelling behaviour than the pre-gelatinised samples (A4, A5, and A6).

Except for sample A1, where no apparent differences in starch molecule size were observed between 20 °C and 100 °C, there is a noticeable increase in granule size for the starch in boiling water compared to the native granules in cold water. This behaviour is consistent with findings reported by Noordraven et al. (2021).

Regarding the starch granules, only minor differences were noted between the samples when comparing compositions without oats (R1 and E1) and those with 10% and 20% oats. This indicates that adding oats has a minimal physical impact on the flours, enhancing their nutritional properties without significantly altering their physical or visual characteristics.

Sensorial Analysis. Table 3 presents the results of the first part of the test, where tasters indicated their preference for the texture of either the non-extruded or extruded (pre-gelatinised) sample.

We can also observe the overall preference for the texture attribute among the samples selected in the initial stage of the test: E2 (30.77%); E3 (26.37%); E1 (20.88%); R2 (16.48%); R3 (3.30%) and R1 (2.20%).

This analysis reveals a consistent preference for extruded samples over non-extruded ones across all formulations. In every analysis (Formulations 1, 2, and 3), over 40% of tasters preferred the extruded flour option. This indicates a marked consumer preference for the texture of pre-gelatinised flours compared to non-extruded alternatives.

Table 3. Results of the discriminative paired comparison test regarding the texture attribute of each flour sample (not-extruded and extruded)

Sample 1 (%)		Sample 2 (%)		Sample 3 (%)	
R1	E1	R2	E2	R3	E3
14.29	86.81	28.57	71.43	18.68	81.32

Further examination of Table 3 shows that Formulations 1 and 3 exhibited an even greater preference for pre-gelatinised flours than Formulation 2. The second part of the test reveals that Formulation 2 of the extruded flour achieved the highest overall preference for texture attribute (30.77%) among the samples selected in the first part of the test, followed by extruded Formulations 3 (26.37%) and 1 (20.88%). Once again, extruded flour samples were preferred over non-extruded samples. Ding et al. (2023) observed that incorporating highland barley flour with proteins and pre-gelatinised flour/starch in noodle development increased intermolecular forces, contributing to enhanced protein cross-linking, structural order, and textural properties of the product. Similarly, Zhang et al. (2023) showed that the oat extrusion process, due to the increase in umami amino acids and decrease in bitter amino acids, significantly impacts the sensory characteristics of acceptance.

CONCLUSION

In conclusion, the findings indicate significant changes in the flour formulations' moisture content and water activity following extrusion, highlighting the ef-

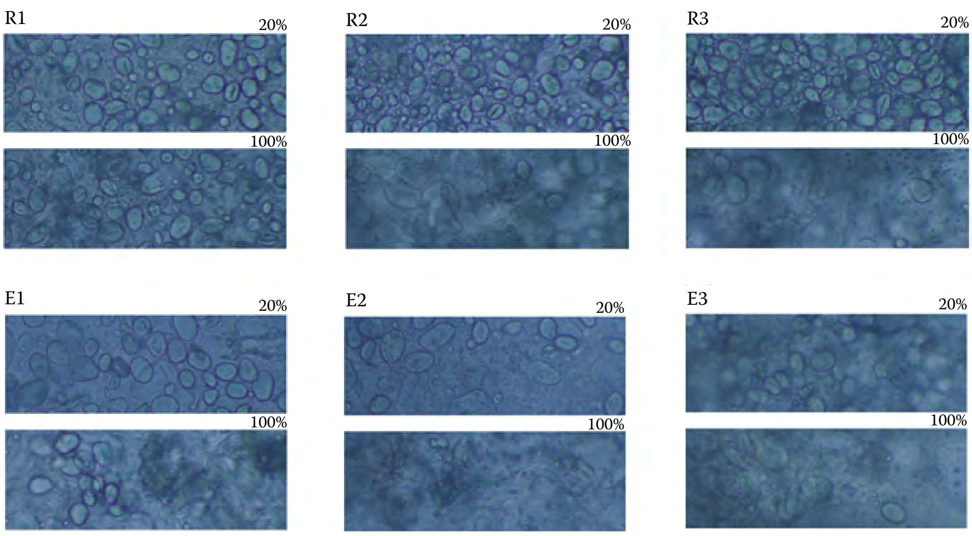

Figure 3. Micrographs displaying the microstructure of starch sample suspensions (R1, R2, and R3 non-gelatinised open-cell chickpea, E1, E2, and E3 pre-gelatinised open-cell chickpea flour) dispersed in cold (20 °C) and boiling (100 °C) water (magnification 20×, scale bar: 50 μm)

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fects of temperature and pressure on product characteristics and adding oats notably affected parameters such as crude protein and fibre content, underscoring the potential for enhancing chickpea flour with essential nutrients. The extrusion process significantly influenced water absorption and solubility indices, starch dispersion, colour parameters, and viscosity profiles, ultimately improving the suitability of extruded flours for stable starch-based products like the developed instant soup.

Additionally, sensory analysis revealed a clear consumer preference for extruded flour samples over non-extruded ones, especially concerning texture attributes. This suggests a promising opportunity for developing new products. Samples incorporating oats were particularly favoured, indicating the potential for using these formulations to create innovative food products aligned with evolving consumer preferences. Overall, this study offers valuable insights into applying extrusion technology without nutritional losses, enhancing the sensory attributes of chickpea and oat-based flours, thereby supporting the development of novel and consumer-friendly food products in the instant food sector.

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