processes

Article

Gluten-Free Rice Instant Pasta: Effect of Extrusion-Cooking Parameters on Selected Quality Attributes and Microstructure

Abdallah Bouasla [1] and Agnieszka Wójtowicz [2,*]

[1] Laboratoire de Génie Agro-Alimentaire, Institut de la Nutrition, de l'Alimentation et des Technologies Agro-Alimentaires (INATAA), Université Frères Mentouri Constantine 1, 25000 Constantine, Algeria; abdallah.bouasla@umc.edu.dz

[2] Department of Thermal Technology and Food Process Engineering, University Life Sciences in Lublin, Głęboka 31, 20-612 Lublin, Poland

* Correspondence: agnieszka.wojtowicz@up.lublin.pl; Tel.: +48-81-4456127

Abstract: In the present study, we applied extrusion-cooking to polished rice flour so as to prepare gluten-free pasta. The aim of the work was to investigate the effect of feed moisture (28, 30 and 32%) and screw speed (60, 80 and 100 rpm) on selected rice pasta quality attributes (water absorption, cooking loss, firmness, stickiness and microstructure) and extrusion response (specific mechanical energy). Our results showed that feed moisture significantly affected all tested quality attributes of the rice pasta, while screw speed exhibited a significant effect on all quality attributes except cooking time and stickiness. Moreover, raising the feed moisture increased the cooking time, water absorption, cooking loss, hardness and stickiness, but decreased the firmness at high screw speed. In addition, increasing the screw speed enhanced the cooking loss and hardness, but diminished the water absorption and firmness of pasta with low feed moisture. Rice pasta prepared with 30% moisture content and at 80 rpm showed adequate quality, as confirmed by a firm texture and low cooking loss and stickiness. Microstructure analysis showed a compact and dense internal structure of the dry pasta, and the surface was smooth and even when at least 30% moisture was applied at 80 rpm screw speed during processing.

Keywords: extrusion-cooking; polished rice; pasta; gluten-free

check for updates

Citation: Bouasla, A.; Wójtowicz, A. Gluten-Free Rice Instant Pasta: Effect of Extrusion-Cooking Parameters on Selected Quality Attributes and Microstructure. *Processes* **2021**, *9*, 693. https://doi.org/10.3390/pr9040693

Academic Editor: Dariusz Dziki

Received: 31 March 2021
Accepted: 12 April 2021
Published: 15 April 2021

1. Introduction

Pasta is universally consumed and appreciated due to its many advantages including simplicity of manufacture, ease of handling, palatability, long shelf-life, diversity of the methods of its preparation and accessible cost [1]. It is generally produced from durum wheat semolina. This is considered to be the most suitable raw material for pasta-making [2] because of the presence of gluten which has special characteristics and impact on pasta cooking quality [3]. However, for some individuals, ingestion of gluten causes celiac disease. This affliction affects 0.7% to 1.4% of the world's population. It is a common chronic digestive disorder and studies show that the prevalence of the disease is increasing [4–7].

Currently, the only effective treatment for the disease is the adherence to a strict lifelong gluten-free diet based on the elimination of all products containing wheat, barley and rye [4,8,9]. Therefore, gluten-free products have been developed and commercialized not only for celiac patients and those with a gluten-related disorder, but also for other healthy people who wish to follow a gluten-free diet for its perceived health benefits, including weight loss and/or decreased future risk of gastrointestinal disease [9].

One of the approaches used for replacing gluten in cereal-based products focuses on the role of suitable processing conditions in promoting new and efficient starch organization [10]. In this regard, extrusion-cooking represents an interesting technique for the production of gluten-free pasta [10,11]. During extrusion-cooking, heat and shearing forces are applied to raw materials. These bring about chemical, structural and nutritional transformations. Herein, extrusion parameters (e.g., barrel temperature, screw speed and/or feed moisture) are accountable for product quality. Changing these processing conditions induces desirable modifications, allowing for the manufacturing of extruded products with specific characteristics and functionalities [12].

Polished rice is used to produce several commercial gluten-free products because of its attractive white color, high digestibility, bland taste, hypoallergenicity, good processing characteristics, inexpensiveness and abundance [13,14].

The objective of this work was to study the effect of extrusion-cooking parameters (feed moisture and screw speed) on the cooking quality, textural properties, energy consumption and microstructure of gluten-free rice instant pasta.

2. Materials and Methods

2.1. Raw Material

Polished rice flour was provided by Lubella Sp. z o.o. S.K., Lublin (Poland) and was sifted to obtain flour with a particle size below 0.5 mm. The chemical composition of rice flour (per 100 g dry raw materials) was as follows: protein 7.92 g, fat 2.30 g, ash 1.37 g, fiber 1.31 g [11].

2.2. Pasta Processing

The rice flour was first hydrated with tap water under conditions of continuous manual mixing to obtain the desired water content after feed moistening (28%, 30% or 32%), and left to stand for 30 min in sealed containers for good hydration. The hydrated flours were then introduced into a modified single-screw extruder-cooker type TS-45 (ZMCh, Gliwice, Poland) with the barrel length to diameter ratio L/D = 18 configuration set at a temperature of 90 °C in the first section, 100 °C in the second and 70 °C in the final section, and were extruded at different screw speeds (60, 80 and 100 rpm) through a spaghetti-type pasta die (0.8 mm). The obtained pasta strands were distributed on perforated stainless steel trays and subsequently dried at 40 °C for 4 h. The dry pasta products (moisture content less than 12%) were stored in hermetically sealed plastic bags.

2.3. Cooking Quality

2.3.1. Minimal Preparation Time

Water was heated to boiling and then a volume of 200 mL was immediately poured onto 10 g of pasta in a container that was kept closed. At regular time intervals (30 s), a pasta strand was taken then squeezed between two Plexiglas plates. The minimal preparation time (MPT) was determined in triplicate, and corresponded to the moment of disappearance of the white unhydrated core of the pasta [15].

2.3.2. Water Absorption Capacity

The water absorption capacity (WAC) was determined in triplicate according to the method described by Bouasla et al. [16]. Ten grams of pasta was hydrated to the MPT in 200 mL of boiling water, rinsed with cold water (20 °C) and drained for 5 min. The hydrated pasta was then weighed and the water absorption capacity was calculated as follows:

$$\text{WAC}\ (\%) = \frac{Weight\ of\ hydrated\ pasta - Weight\ of\ dry\ pasta}{Weight\ of\ dry\ pasta} \times 100 \quad (1)$$

2.3.3. Cooking Loss

Cooking loss was adjudged as described by Bouasla et al. [16]. Ten grams of pasta was immersed in 200 mL of boiling water. After the corresponding MPT, the hydrated sample was rinsed with 100 mL of cold water (20 °C) and drained for 5 min. Both hydration and rinsing water were collected in a container, and then completely evaporated in an oven at 110 °C to constant weight. The cooking loss (CL) was calculated in triplicate as follows:

$$CL\ (\%) = \frac{Weight\ of\ dry\ residue}{Weight\ of\ dry\ pasta} \times 100 \quad (2)$$

2.4. Texture Measurements

Rice pasta texture measurements were performed using the Zwick-Roell BDO-FB0.5 TH instrument (Zwick GmbH & Co., Ulm, Germany) with the working head of 0.5 kN at test speed of 3.3 mm/s [16]. TestXpert® 10.11 software was applied to record and analyze the values of the cutting and compression forces. The hardness of dry pasta, measured in 5 repetitions, corresponded to the maximum cutting force (N) required to break a single strand of pasta [17] using a Warner-Bratzler cutting knife. The firmness and stickiness of hydrated ready-to-eat pasta were assessed under double compression tests in duplicate by means of an OTMS cell (OttawaTexture Measuring System). Firmness (N) was recorded as the maximum force during compression, while stickiness (mJ) was assessed as the work required to overcome the adhesion between the sample and the cell material surface [18].

2.5. Specific Mechanical Energy

Specific mechanical energy (SME) was determined in triplicate for each variation in the extrusion-cooking parameters (feed content and screw speed) according to the method of Bouasla et al. [19], by using the following formula:

$$SME\ (kWh/kg) = \frac{n}{N} \times \frac{L}{100} \times \frac{P}{Q} \quad (3)$$

where n is the screw speed used (rpm), N is the maximum screw speed (rpm), L is the motor load (%), P is the motor electrical power (kW), and Q is the process efficiency (kg/h).

2.6. Microscopic Structure of Rice Pasta

The microstructure of rice pasta was characterized using scanning electron microscopy at different magnifications. Small specimens of dry pasta were placed on carbon discs using a silver tape and coated with gold. The surface (×100 and ×600) and the cross-section (×125, ×600, and ×2000) of dry pasta were observed with a VEGA LMU microscope (Tescan, Warrendale, PA, USA) at the accelerating voltage of 10 kV.

2.7. Statistical Analysis

Data from the experiments were analyzed using Statistica version 10 software (StatSoft Inc., Tulsa, OK, USA). Two-way analysis of variance (ANOVA) was used to evaluate the effect of process parameters on rice pasta quality at the significance level of $p < 0.05$. Pearson's linear correlation coefficients (r) were also calculated to determine the strength of the linear correlation between two quantitative variables: S (screw speed) and M (moisture content). Response surface methodology (RSM) was used to analyze multiple effects of processing variables on the tested features.

3. Results and Discussion

3.1. Effect of Extrusion-Cooking Parameters on Cooking Quality

The cooking quality of extruded products includes cooking time, water absorption capacity, and cooking loss. It generally depends upon the starch modification (gelatinization, degradation and retrogradation) and the water penetration rate inside the product [14]. The multiple regression equations for the cooking properties are as follows:

$$MPT = -212.56 + 16.25\ M - 0.49\ S - 0.29\ M^2 + 0.01\ MS + 0.0008\ S^2 \quad (4)$$

$$WAC = 4746.92 - 295.24\ M - 4.65\ S + 4.89\ M^2 + 0.09\ MS + 0.0084\ S^2 \quad (5)$$

$$CL = 13.91 - 2.60\ M + 0.55\ S + 0.08\ M^2 - 0.02\ MS + 0.0003\ S^2 \quad (6)$$

The minimal preparation time of polished rice pasta was in the range of 6–9 min of hot water hydration without the conventional cooking procedure, and it was significantly affected by the feed moisture (Table 1).

Table 1. Two-way ANOVA results for cooking quality, texture and energy consumption.

	Source	SS	df	MS	F	*p*
MPT (min)	Feed moisture (M)	12.667	2	6.333	6.333	0.008 *
	Screw speed (S)	2.667	2	1.333	1.333	0.288
	M × S	5.333	4	1.333	1.333	0.296
WAC (%)	Feed moisture (M)	4334	2	2167	12.554	0.000 *
	Screw speed (S)	2577	2	1288	7.464	0.004 *
	M × S	865	4	216	1.253	0.324
CL (%)	Feed moisture (M)	18.802	2	9.401	50.463	0.000 *
	Screw speed (S)	5.180	2	2.590	13.903	0.000 *
	M × S	8.391	4	2.098	11.260	0.000 *
Hardness (N)	Feed moisture (M)	268.445	2	134.222	64.030	0.000 *
	Screw speed (S)	318.835	2	159.418	76.049	0.000 *
	M × S	141.310	4	35.328	16.853	0.000 *
Firmness (N)	Feed moisture (M)	21,794	2	10,897	71.928	0.000 *
	Screw speed (S)	3051	2	1525	10.069	0.005 *
	M × S	68,937	4	17,234	113.758	0.000 *
Stickiness (mJ)	Feed moisture (M)	705.640	2	352.820	115.329	0.000 *
	Screw speed (S)	8.126	2	4.063	1.328	0.312
	M × S	59.234	4	14.808	4.840	0.023 *
SME (kWh/kg)	Feed moisture (M)	0.002	2	0.001	8.13	0.003 *
	Screw speed (S)	0.203	2	0.101	980.71	0.000 *
	M × S	0.005	4	0.001	11.05	0.000 *

*: *p*-value significant at $\alpha = 0.05$; MPT: minimal preparation time; WAC: water absorption capacity; CL: cooking loss; SME: specific mechanical energy; SS: sum of the squares; df: degree of freedom; MS: mean of the squares.

MPT increased as feed moisture increased from 28% to 30%, and then decreased when feed moisture increased to 32% (Figure 1a). Wang et al. [20] and Wang et al. [21] also reported that the moisture content had a positive effect on cooking time with regard to pea pasta-like product and pea starch noodles, respectively. In contrast, screw speed had no significant effect on MPT.

The results of our work indicated that feed moisture had a significant effect on the WAC. This increased when feed moisture increased (Figure 1b). Similar results have been reported for pea pasta [20], corn-broad bean pasta [22], rice-yellow pea pasta [16] and brown rice pasta [3]. Indeed, Anderson et al. [23] reported that dough with high moisture content leads to extruded cereal products with higher water absorption. This behavior suggests that a more hydrophilic structure is formed during the extrusion-cooking at high feed moisture, leading to higher water absorption [24]. Moreover, a plasticizing effect is induced by higher feed moisture. This decreases starch gelatinization and degradation and thus increases the water absorption capacity of rice-based extrudates [14] because it negatively correlates with starch gelatinization [25–27]. In addition, we noted that screw speed had a significant effect on WAC (Table 1), as WAC decreased as screw speed increased ($r = -0.51$). A similar tendency was reported for gluten-free pasta made from pea flour [20] and pea starch [21]. The lower WAC observed for extruded pasta produced at higher screw speed might be related to structural modification of the starch (formation of retrograded amylose and amylose–lipid complexes) resulting from increased shear forces, as this provides greater restriction to water absorption during hydration in hot water [28–30]. Additionally, water absorption capacity was positively correlated with cooking loss ($r = 0.61$).

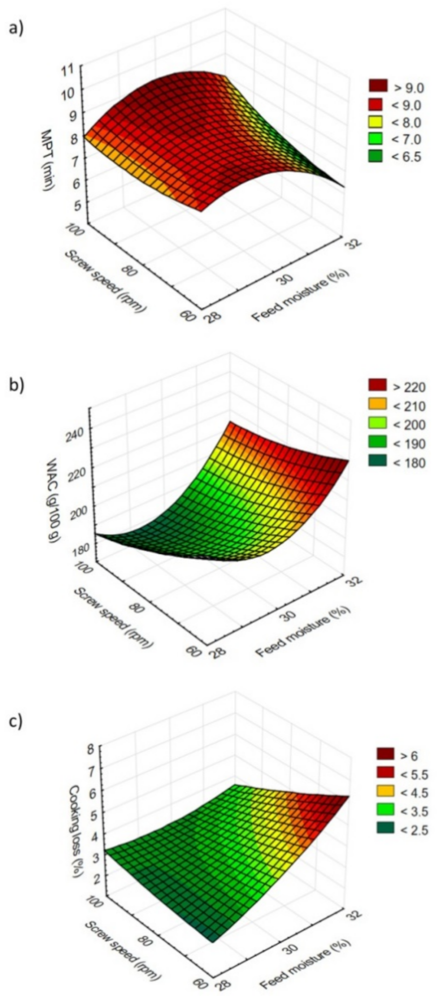

Figure 1. Minimum preparation time (MPT) (**a**), water absorption capacity (WAC) (**b**), and cooking loss (**c**) as affected by feed moisture and screw speed during the processing of rice pasta.

Raising the feed moisture increased the CL of rice pasta (r = 0.69) (Figure 1c). This outcome is in line with those of various authors who have indicated the significant positive effect of moisture content on the cooking loss of gluten-free pasta made from diverse raw materials [3,16,22,31]. However, the cooking loss values presented in the present study (2.20–7.40%) were lower than the 8% reported for semolina spaghetti [32] and below the 10% reported for precooked pasta [20]. This indicates the good quality of the product. Of note, the produced pasta with the best quality was processed at 28% or 30% moisture content, and had a CL below 5%. This outcome, as suggested by Giménez et al. [22], could be related to the formation of a less-soluble structure during the extrusioncooking at high temperature and low moisture content. In gluten-free pasta, starch is considered as the main structural network [33]. Extrusion-cooking conditions (heat, pressure, and shearing forces) applied to produce rice pasta lead to the formation of a compact structure of retrograded starch around the gelatinized starch which preserves the integrity of the pasta during hot water hydration, causing less leaching of gelatinized starch from the pasta surface [34]. Screw speed also significantly affected cooking loss (Table 1). Increasing the screw speed enhanced the CL. Wang et al. [20] demonstrated similar results for a pea pasta-like product manufactured by twin-screw extrusion. This effect could be due to the increase of the number of soluble solids triggered by higher screw speed [35,36] which reduces the polymeric chains due to mechanical shearing [12,14]. It is generally accepted that a higher screw speed applied during the extrusioncooking of raw materials induces extensive degradation of the starch. In some study, the obtained extrudates were characterized by lower molecular weight and higher water solubility, and thus higher amount of solids lost during cooking [37].

3.2. Effect of Extrusion-Cooking Parameters on the Textural Properties of Rice Pasta

Because it determines the acceptance of pasta by consumers, texture is considered as an important aspect of pasta quality [3]. RSM analysis yielded multiple regression equations for textural properties as follows:

$$\text{Hardness} = -886.99 + 56.69\ \text{M} + 1.39\ \text{S} - 0.91\ \text{M}^2 - 0.04\ \text{MS} - 0.0004\ \text{S}^2 \quad (7)$$

$$\text{Firmness} = 21414.89 - 1260.29\ \text{M} - 56.87\ \text{S} + 18.35\ \text{M}^2 + 2.02\ \text{MS} - 0.03\ \text{S}^2 \quad (8)$$

$$\text{Stickiness} = 1815.89 - 120.98\ \text{M} - 1.01\ \text{S} + 1.99\ \text{M}^2 + 0.06\ \text{MS} - 0.000\ \text{S}^2 \quad (9)$$

Figure 2 displays the effects of extrusion-cooking parameters on the textural properties of the rice pasta. We found that the hardness of the dry rice pasta during the cutting test increased when the screw speed increased (r = 0.65) (Figure 2a). Bouasla and Wójtowicz [38] and Wójtowicz [39] reported similar findings for gluten-free pasta made from rice-buckwheat flour and buckwheat flour, respectively.

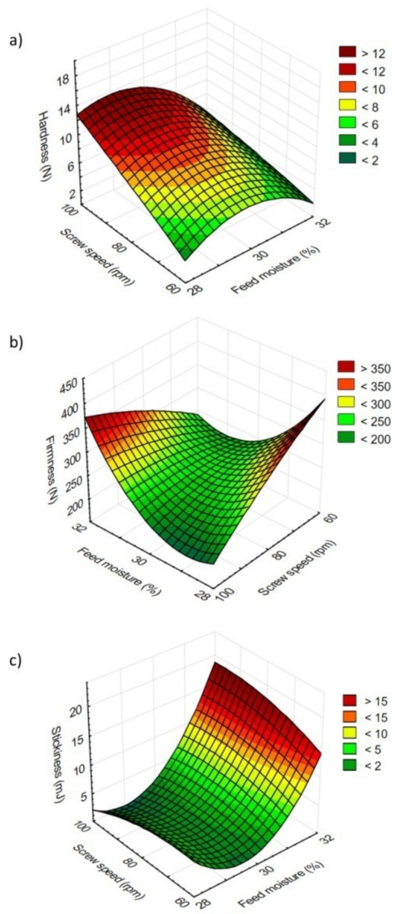

Figure 2. Hardness of dry pasta (**a**) as well as firmness (**b**) and stickiness (**c**) of hydrated pasta as affected by feed moisture and screw speed during the processing of rice pasta.

The hardness of rice pasta also increased as feed moisture increased from 28% to 30% and then decreased when feed moisture increased to 32%. A similar tendency was reported for rice-yellow pea pasta [16]. In fact, hardness depends on product structure, and in our study, hardness was negatively correlated with cooking loss (r = −0.57). This result could be explained by the strong structure of the pasta processed at low feed moisture (28%), as confirmed by its lower cooking loss values and higher hardness.

Both feed moisture and screw speed had a significant effect on the firmness of hydrated ready-to-eat pasta tested under the double compression test. At lower screw speed, rice pasta firmness decreased when moisture content increased. In contrast, at higher screw speed, the hydrated pasta firmness increased as the moisture content increased (Figure 2b). Similar observations have been reported for other gluten-free pastas [3,20,21,38,39]. At higher moisture content and lower screw speed, shearing stresses are low, and therefore the degree of starch gelatinization decreases, resulting in poor strength and lower firmness (the opposite is true for lower moisture content and higher screw speed) [40].

We also noted that the stickiness of hydrated pasta increased as the feed moisture increased (r = 0.75) (Figure 2c), while the screw speed had no significant effect (Table 1). Bouasla et al. [16], Wang et al. [21] and Bouasla and Wójtowicz [38] reported similar observations for gluten-free pasta produced by means of the extrusion-cooking technique. This behavior could be attributed to the relatively low viscosity of starch at higher moisture content, which minimizes the shearing forces and thus decreases the degradation of amylose and amylopectin in extruded pasta. Pasta stickiness is influenced by pasta surface structure and amylose released onto the pasta surface during cooking [41,42]. High stickiness, which indicates high cooking loss, leads to sticky mouth feel and turbid water [43]. Stickiness and cooking loss are positively correlated (r = 0.48).

3.3. Effect of Extrusion-Cooking Parameters on Specific Mechanical Energy

Figure 3 depicts the effect of feed moisture and screw speed on SME during the processing of the polished rice instant pasta.

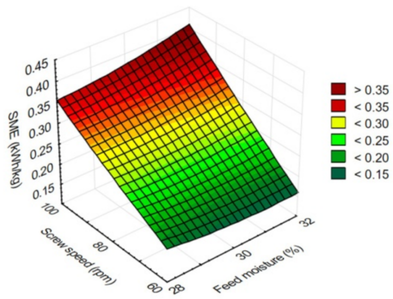

Figure 3. Specific mechanical energy (SME) as affected by feed moisture and screw speed during the processing of rice pasta.

Here, the SME values varied from 0.15 to 0.40 kWh/kg. The multiple regression equation for SME was as follows:

$$SME = 2.79 - 0.16\,M - 0.01\,S + 0.002\,M^2 + 0.0005\,MS - 0.000009\,S^2 \quad (10)$$

Kantrong et al. [44] indicated that the SME for the extrusion process must be below 0.28 kWh/kg. In our study, the SMEs of all rice pasta products were below the mentioned limit (except the pasta processed at 100 rpm), regardless of the moisture content of the raw materials. However, we saw that the SME was significantly affected by both feed moisture and screw speed. Increased feed moisture appeared to cause a slight increase in SME, and increased screw speed from 60 rpm to 100 rpm induced the SME to increase sharply (r = 0.98). This could be due to the higher viscosity of dough inside the extruder caused by more intensive gelatinization of the dough during processing when a higher moisture content and screw speed were applied. Similar findings have been reported for precooked wheat pasta [45], as well as rice-yellow pea pasta [19]. This can be also related to the fact that shear force increases as screw speed increases. This in turn causes higher friction inside the extruder barrel, leading to the increase in SME [44].

3.4. Effect of Extrusion-Cooking Parameters on the Microstructure of Rice Pasta

The surface structure of rice instant pasta was affected by both the moisture content and the screw speed applied during processing. During the observation of samples by scanning electron microscopy, rice pasta processed at low moisture content (28%) showed a corrugated surface due to insufficient water content in the processed material. This observation was more evident for pasta processed at a lower screw speed (Figure 4a,e). Moreover, samples of instant pasta processed at a higher screw speed showed a smoother surface (Figure 4f,h) than samples processed at a lower screw speed (Figure 4b,d). Additionally, at high magnification, the surface of all samples demonstrated melted materials (Figure 4b,d,f,h), indicating the impact of the extrusion-cooking conditions on the starch structure.

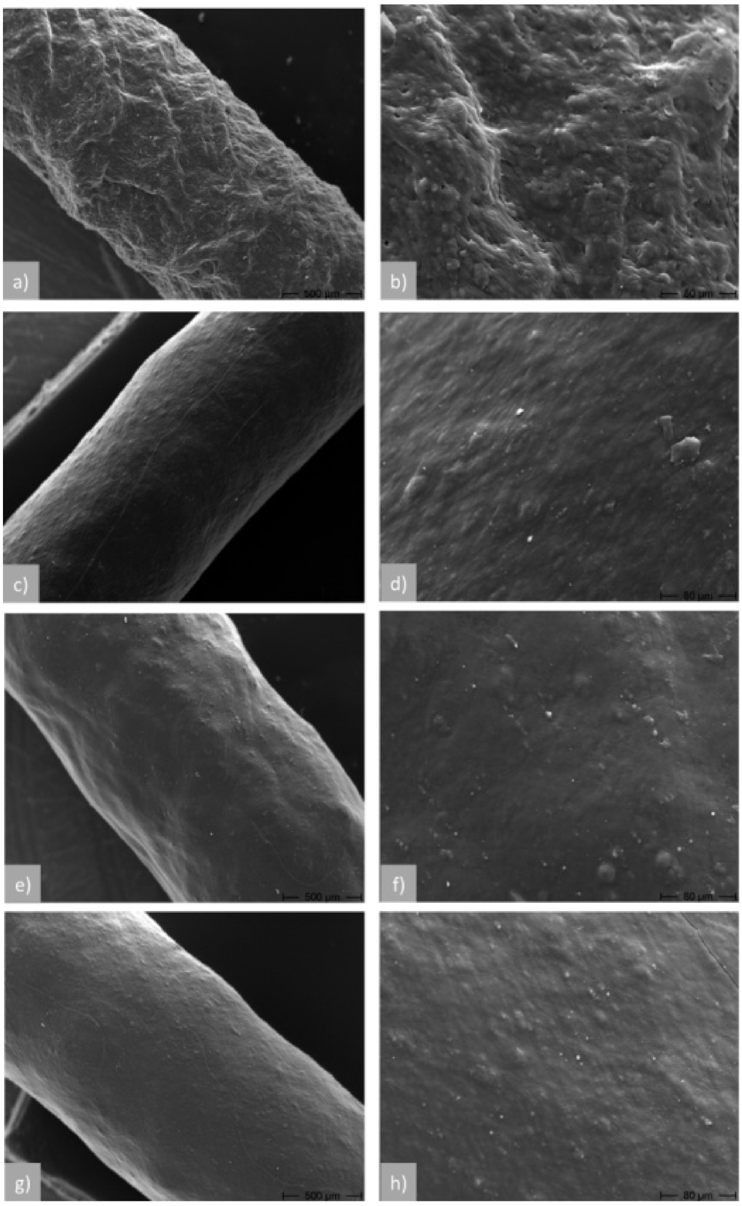

Figure 4. Surface of rice instant pasta processed at variable moisture content and screw speed: (**a**,**b**) 28%, 60 rpm; (**c**,**d**) 30%, 60 rpm; (**e**,**f**) 30%, 80 rpm; (**g**,**h**) 32%, 100 rpm; magnifications ×100 (left column) and ×600 (right column).

The extrusion-cooking parameters did not seem to significantly affect the cross-sectional microstructure of pasta. We observed for all instant pasta samples an almost homogenous and compact internal structure with a melted starch-protein matrix (Figure 5). Inside the pasta processed at low moisture content (28% and 30%) and low screw speed (60 rpm), several ungelatinized or partly gelatinized starch granules were present in a small space of the pasta treads, suggesting incompletely gelatinized material due to insufficient moisture and low friction during extrusion [46]. The few aggregates of swollen starch granules embedded in the gelatinized and compact matrix were visible at high magnifications when increased moisture content and higher screw speeds were applied for pasta processing (Figure 5i,l). This structure is caused by the impact of extrusion-cooking conditions (moisture, heat, and shear forces) which trigger starch gelatinization and coherent structure [16,27,45]. This observation supports the low CL values found in the present study.

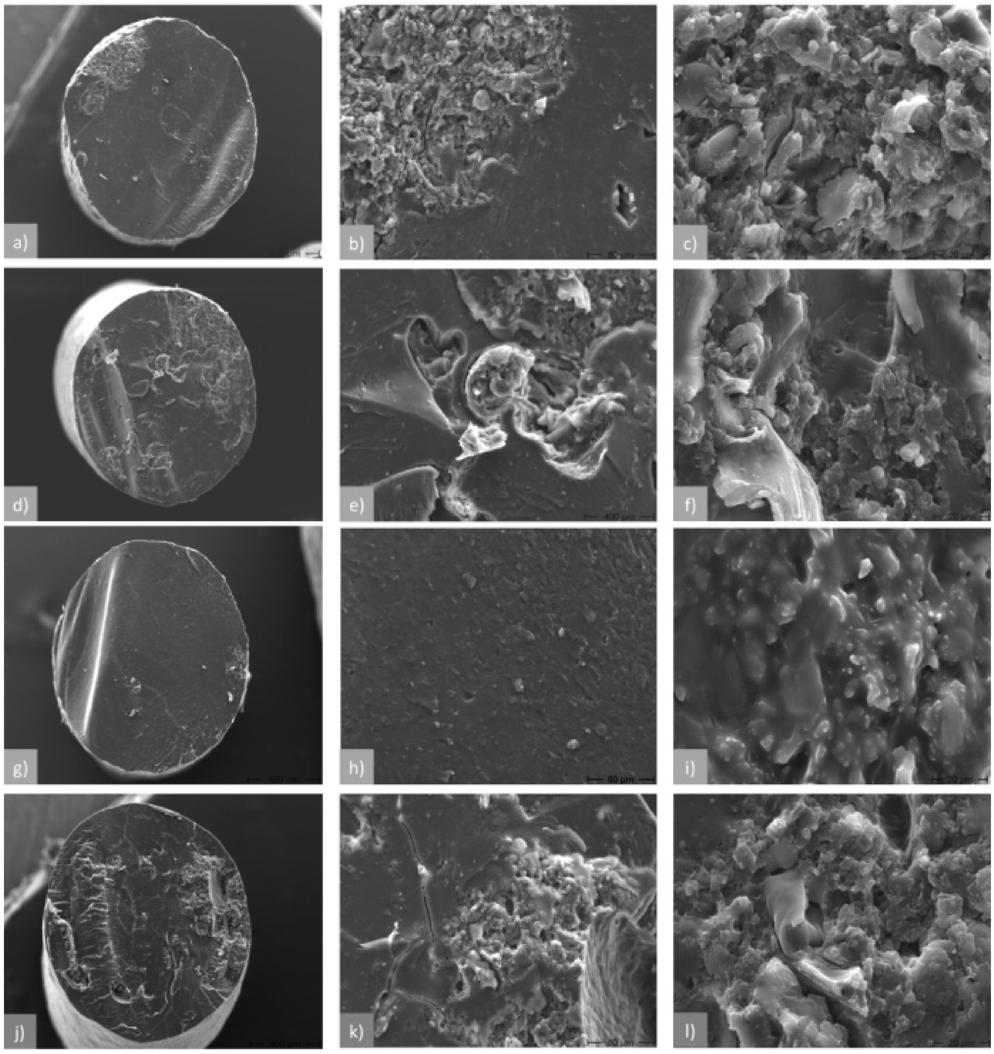

Figure 5. Cross-section of instant rice pasta processed at variable moisture content and screw speed: (**a**–**c**) 28%, 60 rpm; (**d**–**f**) 30%, 60 rpm; (**g**–**i**) 30%, 80 rpm; (**j**–**l**) 32%, 100 rpm; magnifications ×125 (left column), ×600 (middle column), and ×2000 (right column).

4. Conclusions

Both feed moisture and screw speed had significant effects on the cooking and textural properties of polished rice instant pasta quality attributes, as well as on the energy consumption of its production. Moreover, feed moisture had a positive significant effect on cooking time, water absorption, cooking loss and stickiness, but it had a negative significant effect on the firmness of instant pasta processed at high screw speed. Screw speed had a positive significant effect on the cooking loss and hardness of gluten-free pasta, but it had a negative significant effect on the water absorption and firmness of products processed at low feed moisture. Furthermore, the variable screw speed had no significant effect on the cooking time or stickiness of the pasta. Appropriate extrusion-cooking parameters for the production of polished rice instant pasta with good quality would be a feed moisture of 30% and a screw speed of 80 rpm. These conditions allow for obtaining gluten-free polished rice instant pasta with suitable cooking and textural characteristics, acceptable energy consumption during processing and compact internal structure.

Author Contributions: Conceptualization, A.W.; methodology, A.B. and A.W.; validation, A.B. and A.W.; formal analysis, A.B.; investigation, A.B. and A.W.; writing—original draft preparation, A.B.; writing—review and editing, A.B. and A.W.; supervision, A.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mercier, S.; Moresoli, C.; Mondor, M.; Villeneuve, S.; Marcos, B. A meta-analysis of enriched pasta: What are the effects of enrichment and process specifications on the quality attributes of pasta? *Compr. Rev. Food Sci. Food Saf.* **2016**, *15*, 685–704. [CrossRef] [PubMed]
2. Petitot, M.; Boyer, L.; Minier, C.; Micard, V. Fortification of pasta with split pea and faba bean flours: Pasta processing and quality evaluation. *Food Res. Int.* **2010**, *43*, 634–641. [CrossRef]
3. Rafiq, A.; Sharma, S.; Singh, B. Regression analysis of gluten-free pasta from brown rice for characterization and in vitro digestibility. *J. Food Proc. Preserv.* **2017**, *41*, e12830. [CrossRef]
4. Elli, L.; Branchi, F.; Tomba, C.; Villalta, D.; Norsa, L.; Ferretti, F.; Roncoroni, L.; Bardella, M.T. Diagnosis of gluten related disorders: Celiac disease, wheat allergy and non-celiac gluten sensitivity. *World J. Gastroenterol.* **2015**, *21*, 7110–7119. [CrossRef] [PubMed]
5. Plugis, N.M.; Khosla, C. Therapeutic approaches for celiac disease. *Best Prac. Res. Clin. Gastroenterol.* **2015**, *29*, 503–521. [CrossRef] [PubMed]
6. Tovoli, F.; Masi, C.; Guidetti, E.; Negrini, G.; Paterini, P.; Bolondi, L. Clinical and diagnostic aspects of gluten related disorders. *World J. Clin. Cases* **2015**, *3*, 275–284. [CrossRef] [PubMed]
7. Shannahan, S.; Leffler, D.A. Diagnosis and updates in celiac disease. *Gastrointest. Endosc. Clin. N. Am.* **2017**, *27*, 79–92. [CrossRef]
8. Bascuñán, K.A.; Vespa, M.C.; Araya, M. Celiac disease: Understanding the gluten free diet. *Eur. J. Nutr.* **2017**, *56*, 449–459. [CrossRef]
9. Gobbetti, M.; Pontonio, E.; Filannino, P.; Rizzello, C.G.; De Angelis, M.; Di Cagno, R. How to improve the gluten-free diet: The state of the art from a food science perspective. *Food Res. Int.* **2018**, *110*, 22–32. [CrossRef]
10. Marti, A.; Pagani, M.A. What can play the role of gluten in gluten free-pasta? *Trends Food Sci. Technol.* **2013**, *31*, 63–71. [CrossRef]
11. Bouasla, A.; Wójtowicz, A.; Zidoune, M.N. Gluten-free precooked rice pasta enriched with legumes flours: Physical properties, texture, sensory attributes and microstructure. *LWTFood Sci. Technol.* **2017**, *75*, 569–577. [CrossRef]
12. Alam, M.S.; Kaur, J.; Khaira, H.; Gupta, K. Extrusion and extruded products: Changes in quality attributes as affected by extrusion process parameters: A review. *Crit. Rev. Food Sci. Nutr.* **2016**, *56*, 445–473. [CrossRef]
13. Rosell, C.M.; Marco, C. Rice. In *Gluten-Free Cereal Products and Beverages*; Arendt, E.K., Dal Bello, F., Eds.; Academic Press: Cambridge, MA, USA, 2008; pp. 81–100.
14. Dalbhagat, C.G.; Mahato, D.K.; Mishra, H.N. Effect of extrusion processing on physicochemical, functional and nutritional characteristics of rice and rice-based products: A review. *Trends Food Sci. Technol.* **2019**, *85*, 226–240. [CrossRef]
15. Wójtowicz, A.; Mościcki, L. Influence of legume type and addition level on quality characteristics, texture and microstructure of enriched precooked pasta. *LWTFood Sci. Technol.* **2014**, *59*, 1175–1185. [CrossRef]
16. Bouasla, A.; Wójtowicz, A.; Zidoune, M.N.; Olech, M.; Nowak, R.; Mitrus, M.; Oniszczuk, A. Gluten-free precooked rice-yellow pea pasta: Effect of extrusion-cooking conditions on phenolic acids composition, selected properties and microstructure. *J. Food Sci.* **2016**, *81*, 1070–1079. [CrossRef]
17. Charutigon, C.; Jitpupakdree, J.; Namsree, P.; Rungsardthong, V. Effects of processing conditions and the use of modified starch and monoglyceride on some properties of extruded rice vermicelli. *LWT Food Sci. Technol.* **2008**, *41*, 642–651. [CrossRef]
18. Ross, A. Instrumental measurement of physical properties of cooked Asian wheat flour noodles. *Cereal Chem.* **2006**, *83*, 42–51. [CrossRef]

19. Bouasla, A.; Wójtowicz, A.; Juśko, S.; Zidoune, M.N. Energy consumption and process efficiency as affected by extrusion-cooking conditions and recipe formulation during the production of gluten-free rice-legumes products. *Agric. Eng.* **2017**, *21*, 39–46. [CrossRef]
20. Wang, N.; Bhirud, P.R.; Sosulski, F.W.; Tyler, R.T. Pasta-like product from pea flour by twin-screw extrusion. *J. Food Sci.* **1999**, *64*, 671–678. [CrossRef]
21. Wang, N.; Maximiuk, L.; Toews, R. Pea starch noodles: Effect of processing variables on characteristics and optimisation of twin-screw extrusion process. *Food Chem.* **2012**, *133*, 742–753. [CrossRef]
22. Giménez, M.A.; González, R.J.; Wagner, J.; Torres, R.; Lobo, M.O.; Samman, N.C. Effect of extrusion conditions on physicochemical and sensorial properties of corn-broad beans (Viciafaba) spaghetti type pasta. *Food Chem.* **2013**, *136*, 538–545. [CrossRef] [PubMed]
23. Anderson, R.A.; Conway, H.F.; Pfeifer, V.F.; Griffin, E.L.J. Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. *Starch* **1969**, *22*, 130–135. [CrossRef]
24. Marti, A.; Seetharaman, K.; Pagani, M.A. Rice-based pasta: A comparison between conventional pasta-making and extrusion-cooking. *J. Cereal Sci.* **2010**, *52*, 404–409. [CrossRef]
25. Camire, M.E.; Camire, A.; Krumhar, K. Chemical and nutritional changes in foods during extrusion. *Crit. Rev. Food Sci. Nutr.* **1990**, *29*, 35–57. [CrossRef] [PubMed]
26. Cunningham, S.; McMinn, W.; Magee, T.; Richardson, P. Modeling water absorption of pasta during soaking. *J. Food Eng.* **2007**, *82*, 600–607. [CrossRef]
27. Wójtowicz, A.; Mościcki, L. Influence of extrusion-cooking parameters on some quality aspects of precooked pasta-like products. *J. Food Sci.* **2009**, *74*, 226–233. [CrossRef]
28. Diosady, L.L.; Paton, D.; Rosen, N.; Rubin, L.J.; Athanssoulias, C. Degradation of wheat starch in a single-screw extruder: Mechano-kinetic breakdown of cooked starch. *J. Food Sci.* **1985**, *50*, 1697–1706. [CrossRef]
29. Amerayo, Y.; Gonzalez, R.; Drago, S.; Torres, R.; De Greef, D. Extrusion condition and zea mays endosperm affecting gluten-free spaghetti quality. *J. Food Sci. Technol.* **2011**, *46*, 2321–2328. [CrossRef]
30. Marti, A.; Pagani, M.; Seetharaman, K. Understanding starch organisation in gluten-free pasta from rice flour. *Carbohydr. Polym.* **2011**, *84*, 1069–1074. [CrossRef]
31. Galvez, F.C.F.; Resurreccion, A.V.A.; Ware, G.O. Process variables, gelatinized starch and moisture effects on physical properties of mungbean noodles. *J. Food Sci.* **1994**, *59*, 378–381. [CrossRef]
32. Sissons, M.; Abecassis, J.; Marchylo, B.; Cubadda, R. Methods used to assess and predict quality of durum wheat, semolina, and pasta. In *Durum Wheat: Chemistry and Technology*, 2nd ed.; Sissons, M., Abecassis, J., Marchylo, B., Carcea, R., Eds.; American Association of Cereal Chemists International: St. Paul, MN, USA, 2012; pp. 213–234.
33. Lucisano, M.; Cappa, C.; Fongaro, L.; Mariotti, M. Characterisation of gluten-free pasta through conventional and innovative methods: Evaluation of the cooking behavior. *J. Cereal Sci.* **2012**, *56*, 667–675. [CrossRef]
34. Resmini, P.; Pagani, M.A. Ultrastructure studies of pasta: A review. *Food Microstruct.* **1983**, *2*, 1–12.
35. Guha, M.; Ali, S.Z.; Bhattacharya, S. Twin-screw extrusion of rice flour without a die: Effect of barrel temperature and screw speed on extrusion and extrudate characteristics. *J. Food Eng.* **1997**, *32*, 251–267. [CrossRef]
36. Singha, P.; Singh, S.K.; Muthukumarappan, K.; Krishnan, P. Physicochemical and nutritional properties of extrudates from food grade distiller's dried grains, garbanzo flour, and corn grits. *Food Sci. Nutr.* **2018**, *6*, 1914–1926. [CrossRef]
37. Colonna, P.; Mercier, C. Macromolecular modifications of manioc starch components by extrusion-cooking with and without lipids. *Carbohydr. Polym.* **1983**, *3*, 87–108. [CrossRef]
38. Bouasla, A.; Wójtowicz, A. Rice-buckwheat gluten-free pasta: Effect of processing parameters on quality characteristics and optimization of extrusion-cooking process. *Foods* **2019**, *8*, 496. [CrossRef]
39. Wójtowicz, A. Influence of process conditions on selected texture properties of precooked buckwheat pasta. *Teka Com. Motor. Energ. Agric.* **2012**, *12*, 315–322.
40. Jalgaonkar, K.; Jha, S.K.; Mahawar, M.K.; Yadav, D.N. Pearl millet based pasta: Optimization of extrusion process through response surface methodology. *J. Food Sci. Technol.* **2019**, *56*, 1134–1144. [CrossRef]
41. Dexter, J.E.; Matsuo, R.R.; Macgregor, A.W. Relationships of instrumental assessment of spaghetti cooking quality to the type and the amount of material rinsed from cooked spaghetti. *J. Cereal Sci.* **1985**, *3*, 39–53. [CrossRef]
42. Wood, J.A. Texture, processing and organoleptic properties of chickpea-fortified spaghettiwith insights to the underlying mechanisms of traditional durum pasta quality. *J. Cereal Sci.* **2009**, *49*, 128–133. [CrossRef]
43. Bhattacharya, M.; Zee, S.Y.; Corke, H. Physicochemical properties related to quality of rice noodles. *Cereal Chem.* **1999**, *76*, 861–867. [CrossRef]
44. Kantrong, H.; Charunuch, C.; Limsangouan, N.; Pengpinit, W. Influence of process parameters on physical properties and specific mechanical energy of healthy mushroom-rice snacks and optimization of extrusion process parameters using response surface methodology. *J. Food Sci. Technol.* **2018**, *55*, 3462–3472. [CrossRef]
45. Wójtowicz, A.; Mościcki, L. Energy consumption during extrusion-cooking of precooked pasta. *Teka. Com. Motor. Energ. Agric.* **2008**, *8*, 311–318.
46. Wójtowicz, A. Precooked pasta. In *Extrusion-Cooking Techniques. Applications, Theory and Sustainability*; Mościcki, L., Ed.; Wiley: Weinheim, Germany, 2011; pp. 99–117.