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Evaluation of uniformity of physical and texture quality in manufacture of gluten-free noodles using single-screw extruders: a case study on local SMEs in Subang district-Indonesia

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Abstract

In the production of gluten-free noodles by using a single screw extruder, cooking is done at two consecutive stages. Initially, the dough of gluten-free formula is steamed manually at certain times and temperatures. During extrusion, the pre-cooked dough is re-cooked inside the extruder barrel. The purpose of this study was to evaluate the properties of gluten-free noodle (color, texture profile) produced from different production batches (batch 1 to 6) of two different single screw extruders (A: capacity 24 kg/hr, B: capacity 12 kg/hr) by using a single factor completely random design. The results showed that steaming process in batch cause intermitten time for extrusion and affected some non-uniform properties of the gluten-free noodles produced by the two extruders. The two extruders produced noodles with distinctive properties. The noodles from extruder A exhibited the hardness (average 26,925.14 ± 2,355.74gf) and adhesiveness (-7.66 ± 6.41 gs). The noodles of extruder B showed the elongation (157.91 ± 39.67%) and cohesiveness (0.91 ± 0.02).

Keywords: extruder; gluten-free noodles; single screw; steaming, uniformity.

Practical Application: Quality Control of gluten-free noodle products and evaluate the production process in small industries.

1 Introduction

Noodles are a popular food in Indonesia, which are generally made from wheat. Wheat cannot be grown in Indonesia, because it has a tropical climate. It is necessary to develop non-wheat (gluten fee) noodle, to reduce wheat imports. Generally, gluten-free noodles are made from a mixture of several flours, such as corn, cassava, soybeans, millet, taro, and so on (Kumalasari et al., 2018; Yulianti et al., 2019; Sholichah et al., 2020).

The production of gluten-free noodles has its own challenges. Gluten is a wheat protein that can form into a compact, rigid, and elastic dough. In general, gluten-free noodles are break more easily, less chewy and more sticky than wheat noodles. Some studies add other ingredients such as hydrocolloids to improve gluten-free noodles' texture and cooking properties (Ratnawati & Afifah, 2018; Sholichah et al., 2021).

The production of gluten-free noodles requires special equipment, which involves pressure, rotation, and heat to allow starch pre-gelatinization in the dough formation process. The pre-gelatinization and the pressure proses are determine the texture and cooking quality of the noodles. Extrusion is the manufacture of food products using a thermo-mechanical process. Heat and mass transfer, pressure changes, and shear are combined to produce effects such as kneading, cooking, drying, moistening, shaping, mashing, and compacting (Cheng & Friis, 2010).

Extruder is a tool used for extrusion, consists of a hopper, barrel, screw speed and temperature control, electric motor, and a mold that can replace to give different sizes and shapes to the final product (Sobowale et al., 2017). There are two types of extruders, single screw extruders and twin screw extruders. These two types differ in their mixing ability and process continuity but have almost the same operating principle. Despite the potential extrusion applications in the food industry, they are too expensive and unavailable for food processors, especially for SMEs. Siregar et al. (2013) have designed single screw extruder to produce gluten-free noodles and has been applied in SMEs.

There is one SME that produces gluten-free noodles in Subang district, Indonesia. This SME started operating in 2019 with a production capacity of 24 kg of raw materials/day. In general, the manufacture of gluten-free noodles in SMEs is weighing ingredients, mixing ingredients, steaming, and extrusion process. The production of gluten-free noodles in SMEs is still semi-manual in batches (not continuously using conveyors). Pre-gelatinization of flour through the steaming process using steamer pan at a temperature of 80-100 °C for 40-45 minutes (Sholichah et al., 2021).

Continuity of production and uniformity of product quality are still obstacles in the production of gluten-free noodles in SMEs. Moreover, the production process is still partially done manually per batch. In this paper, we will discuss the results of evaluating the uniformity of product quality produced from

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extruders with different capacities. The extruder used in this study is a modification of Siregar et al. (2013).

The purpose of this study was to evaluate the properties of gluten-free noodle (color, texture profile) produced from different production batches (batch 1 to 6) of two different single screw extruders (A: capacity 24 kg/hr, B: capacity 12 kg/hr).

2 Materials and methods

2.1 Material

The material used in this study were Mocaf flour, rice flour, corn flour, water, and salt.

2.2 Experimental design and data analysis

This study will observe the performance of two single screw extruders (1) extruder A (5 kW motor power, 780 mm screw length, capacity 24 kg/h), and (2) extruder B (3.77 kW motor power, 502 mm screw length, capacity 12 kg/h), using a single factor completely randomized design. The experimental factors consisted of 6 levels of steaming batches, there are Batch 1 (K1), Batch 2 (K2), Batch 3 (K3), Batch 4 (K4), Batch 5 (K5), and Batch 6 (K6) each level repeated three times (6x3). The properties of gluten-free noodles observed were color (colorimeter NH310, China) and texture (Texture analyzer XT plus, English). Analyzing the difference in treatment factors using analysis of variance (ANOVA) and Tukey HSD test ($P<0.05$), exploring the differences/comparing the performance test of the extruder on the uniformity of product quality using the Independent T-test and the Z test. The data will be presented in the form of graphs and tables.

2.3 Analysis method

Color test

The analyzed parameters include the values of L*, a*, and b*. The L* value represents the brightness level of the sample with a value range of 0-100, a* represents the reddish to greenish level and b* indicates the yellowish to bluish level.

Texture profile analysis

This test includes elongation and texture profile analysis. In the elongation test, the A/SPR probe was used with the pre-speed test conditions of 1 mm/s; test speed 3 mm/s; post-test speed 10 mm/s, distance 60 mm, and trigger force 25 g. The sample is wrapped around the probe and then pulled according to the test conditions until it breaks. In testing the texture profile analysis, the probe used was of the P/36 R type, the noodles were placed on the sample table and then pressed for two cycles referring to the pre speed test conditions of 2 mm/s; test speed 1 mm/s; post-test speed 10 mm/s; strain 85%, trigger force 2 g and time 5 seconds. The TPA parameters measured were hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness.

Gluten-free noodle production

The production of gluten-free noodles on local SMEs uses an extruder with 16 die holes with a diameter of 2 mm, a temperature setting of 60 °C, a rotation speed of 40 rpm. The ingredients are weighed according to the formula (25% corn flour, 35% rice flour, 40% Mocaf flour, 40% water, and 1% salt from the dough base), then mixed using a dough mixer and steamed in a steamer pan for 40-45 minutes (Sholichah et al., 2021). After that, the dough is molded using an extrusion technique using an extruder (Figure 1; Mayasti et al., 2018).

2.4 Extruder specifications

Extruder specification used is a single screw type because it has a simple design and is easier to maintain (Fayose et al., 2017). The experiment uses two different extruder specifications (Figure 2): extruder A (capacity: 24 kg/h) and extruder B (capacity: 12 kg/h). The specifications and differences between the two extruders presented in Table 1.

2.5 Gluten-free noodle steaming process

In the production of gluten-free noodles, the pre-gelatinization process for each dough is done manually using a steamer for 40-45 min (Sholichah et al., 2021). Next, the dough will be re-cooked inside the extruder barrels. Extrusion takes longer than steaming time, resulting in a queue of dough entering

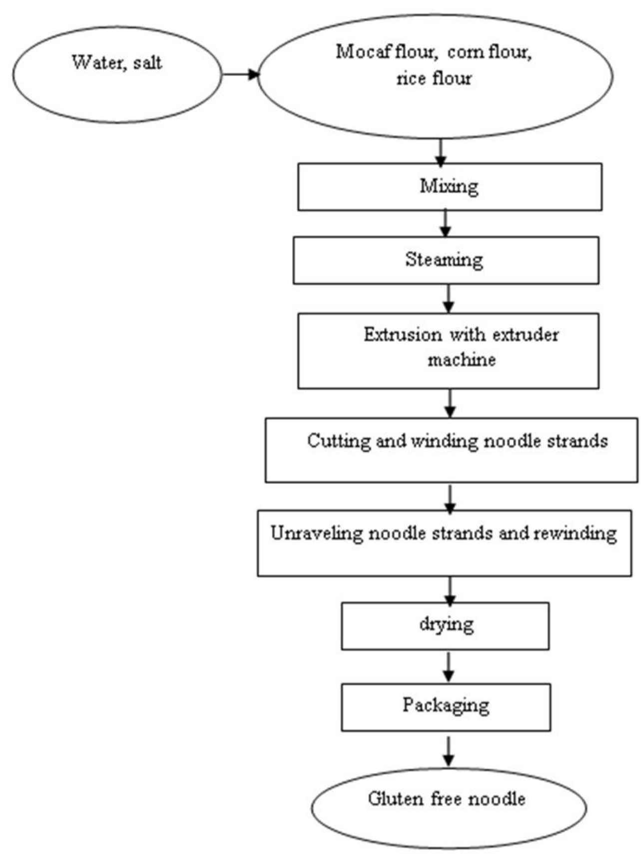

Figure 1. Flow diagram of gluten-free noodles production on local SMEs.

the extruder. The waiting time for the dough from the steamer to the extruder is thought to cause the product quality to be non-uniform.

Table 1. Specification of Extruders.

Specifications	Extruder A	Extruder B
Screw type	Single Screw	Single Screw
Capacity	24 kg/h	12 kg/h
Product	Gluten-free noodle	Gluten-free noodle
Length of the screw	780 mm	502 mm
Screw diameter	65 mm	62 mm
Screw pitch	61,5 mm	43 mm
Screw rotation	37 RPM	40-50 RPM
Transmission	Gearbox	Gearbox
Heater	Electric heater 1000 W	Electric heater 500 W
Motor	Electric motor 5 kW	Electric motor 3,77 kW
Materials (screw and barrel)	Stainless steel 304	Stainless steel 304

Every 2 kg of dough is wrapped using a filter cloth into a bundle, then put in a steamer. Each steaming pan contains 2 bundles of dough which are arranged in a stack (Figure 3). Steaming process using two stoves in parallel and each for 40-45 min. After 40 minutes, bundle A (dough in a filter cloths A) is removed. Next, the position of bundle B (dough in a filter cloths B) which was initially on top was moved to the bottom, then bundle C (dough in a filter cloths C) is stacked on top. This process is continued until dough bundles runs out.

3 Results and discussion

3.1 Evaluation of the physical quality of gluten-free noodles in SMEs

Elongation

The elongation of a product indicates the product's ability to maintain its structure when subjected to tensile forces. The elongation value of non-wheat noodles produced from extruder A and extruder B can be seen in Figure 4. Based on

a b

Figure 2. (a) Extruder A (b) Extruder B.

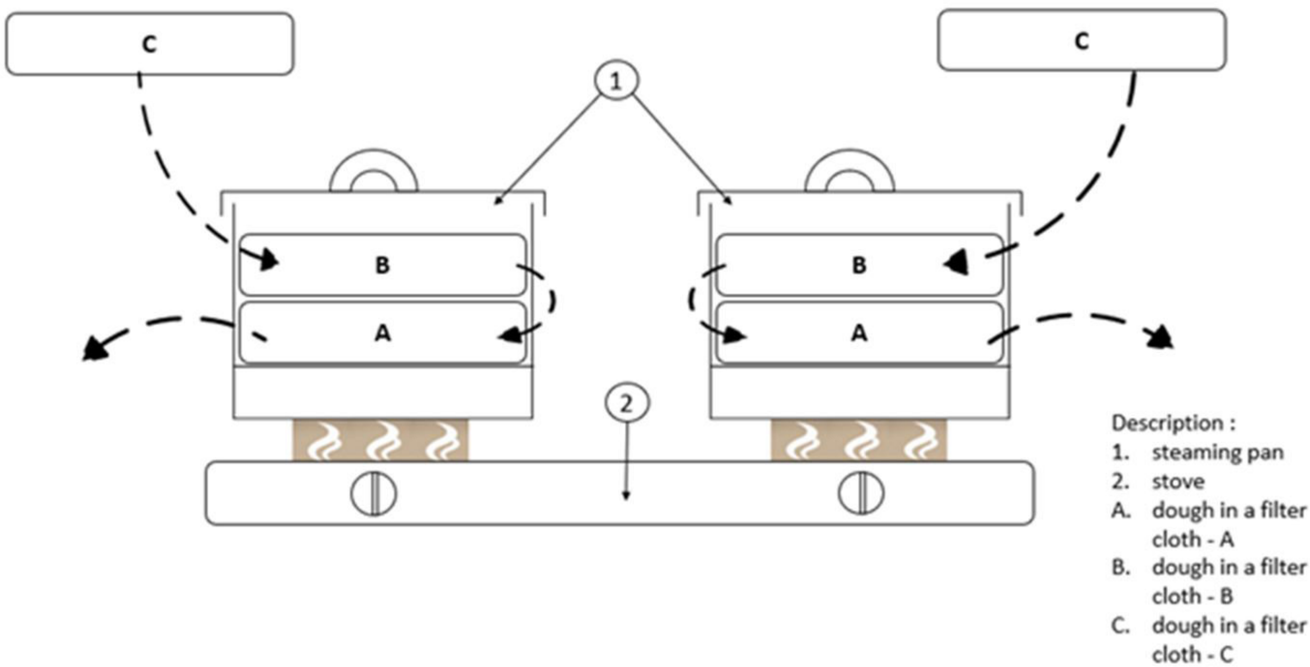

Figure 3. Dough steaming process.

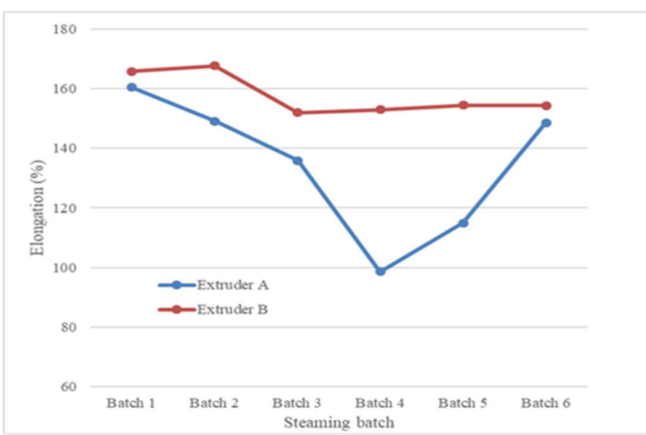

Figure 4. Elongation value of gluten-free noodles produced by extruder A and extruder B in each steaming batch.

Figure 4, it is known that the elongation of gluten-free noodles from extruder B (152.97 ± 36.67% - 167.74 ± 57.67%) is higher than that of extruder A (66 ± 22.35% -160.45 ± 40.66%). The elongation value shows that the noodles molded using extruder B can maintain a better noodle structure when a tensile force is applied. In general, the steaming batch treatment was not significantly different from the elongation of gluten-free noodles produced by the two extruders. The elongation of the noodle strands produced by extruder A in the batch 1 had the highest value. It was significantly different from the batch 4. Extruder A produces non-uniformity elongation value. Meanwhile, extruder B produces uniform elongation quality.

Generally, consumers prefer elastic noodles with higher elongation values. The elongation value of gluten-free noodles produced by SMEs was 168.48% ± 4.76%. This value is lower than gluten-free pasta products enriched with seaweed (Sholichah et al., 2021) and the commercial gluten-free pasta (Mayasti et al., 2018).

Color

The noodle color gives a first impression for consumers which is influenced by the ingredients. Corn flour contains chemical compounds such as anthocyanin and carotenoid as the color generator of noodle. Table 2 shows no significant difference in L* and b* for all batches of the two types of extruders. However, a* value of batch 1 is lower than batch 2 and others. Batch 1 is the first material input to the extruder, where the extruder temperature is low (55°C), and than the temperature increases gradually because of friction beetwen material and screw. The value of a* is positive, which indicate a reddish color of noodles. Lucisano et al. (2012) reported that gluten-free spaghetti made of cornflour had the highest a* (redness) value. The reddish color of the noodles is formed by anthocyanin compounds and changes due to the heating on extrusion processes (Žilić et al., 2016; Oliveira et al., 2017). Corn flour also contains carotenoid compound which produced a yellowish color (b*) (Suarni & Widowati, 2007).

Texture profile

Hardness is the resistance to break/fracture due to the applied compressive force. Tables 3 and 4 show the magnitude of the force (gf) exerted by a tool with a cylindrical probe on fresh noodles until the noodle product breaks. In extruded gluten-free noodle products, higher hardness values also indicate higher noodle density and higher elongation. In the extrusion process, the product's density is a function of the pressure received by

Table 2. Color of gluten-free noodles produced from two extruders in each steaming batch.

Batch Steamning	Extruder A			Extruder B		
	L	a	b	L	a	b
Batch 1	70.85 ± 0.98[a]	0.10 ± 0.15[a]	3.41 ± 1.02[a]	65.17 ± 0.73[a]	0.10 ± 0.26[a]	2. 11 ± 0.86[a]
Batch 2	70.95 ± 1.22[a]	0.24 ± 0.08[ab]	3.20 ± 0.43[a]	65.58 ± 0.72[a]	0.53 ± 0.18[b]	2.76 ± 0.65[a]
Batch 3	70.72 ± 0.86[a]	0.21 ± 0.11[ab]	3.55 ± 1.17[a]	65.66 ± 1.03[a]	0.43 ± 0.19[b]	2.74 ± 0.63[a]
Batch 4	71.06 ± 0.78[a]	0.29 ± 0.10[b]	3.29 ± 0.81[a]	65.58 ± 1.22[a]	0.41 ± 0.15[b]	2.77 ± 0.62[a]
Batch 5	70.28 ± 0.53[a]	0.34 ± 0.08[b]	3.29 ± 0.82[a]	65.62 ± 1.12[a]	0.41 ± 0.18[b]	2.97 ± 0.83[a]
Batch 6	69.90 ± 1.31[a]	0.24 ± 0.12[ab]	3.02 ± 0.52[a]	65.73 ± 0.93[a]	0.47 ± 0.24[b]	3.07 ± 0.80[a]

Note: Different lowercase letters in each column indicate a significant difference (Tukey HSD < 0.05).

Table 3. The texture Evaluation of gluten-free noodles produced by Extruder A.

Batch Steaming	Hardness (gf)	Adhesiveness (gs)	Springiness	Cohesiveness	Gumminess (gf)	Chewiness (gf)
Batch 1	26,771.60 ± 1,117.61[a]	-3.04 ± 2.08[a]	0.85 ± 0.01[a]	0.83 ± 0.04[a]	22,824.72 ± 972.85[a]	14,193.01 ± 406.43[a]
Batch 2	27,903.29 ± 2,347.60[a]	-3.59 ± 2.19[a]	0.82 ± 0.01[a]	0.83 ± 0.02[a]	25,281.81 ± 476.94[c]	18,304.92 ± 938.74[ab]
Batch 3	25,208.55 ± 3,.401.26[a]	-7.02 ± 5.03[a]	0.81 ± 0.04[a]	0.82 ± 0.03[a]	19,739.95 ± 1,980.99[b]	15,694.15 ± 2,103.03[a]
Batch 4	26,658.55 ± 549.46[a]	-7.90 ± 3.49[ab]	0.76 ± 0.03[b]	0.82 ± 0.03[a]	19,817.41 ± 2,642.47[b]	14,613.40 ± 2,368[a]
Batch 5	26,916.38 ± 675.41[a]	-9.62 ± 7.34[ab]	0.82 ± 0.04[a]	0.83 ± 0.03[a]	19,311.08 ± 915.14[b]	18,629.44 ± 2,259.65[a]
Batch 6	28,092.45 ± 2,355.74[a]	-14.77 ± 8.21[b]	0.85 ± 0.04[a]	0.85 ± 0.04[a]	22,536.40 ± 731.54[a]	20,527.02 ± 2,156.6[b]

Note: Different lowercase letters in each column indicate a significant difference (Tukey HSD < 0.05).

Table 4. The texture Evaluation of gluten-free noodles produced by Extruder B.

Batch Steaming	Hardness (gf)	Adhesiveness (gs)	Springiness	Cohesiveness	Gumminess (gf)	Chewiness (gf)
Batch 1	26,182.89 ± 1.673.88[a]	-6.88 ± 2.65[a]	0.75 ± 0.06[a]	0.88 ± 0.01[a]	22,365.12 ± 1.830.29[a]	16,561.95 ± 1.832.57[a]
Batch 2	28,879.74 ± 758.06[ab]	-14.04 ± 3.64[b]	0.78 ± 0.06[ab]	0.91 ± 0.08[bc]	26,124.62 ± 1.170.85[a]	21,045.13 ± 1.999.49[bc]
Batch 3	33,374.045 ± 688.15[c]	-15.26 ± 5.65[b]	0.91 ± 0.03[d]	0.91 ± 0.01[bc]	25,038.4667 ± 2.494.57[a]	23,800.77 ± 1.731.44[c]
Batch 4	30,637.17 ± 2.700.014[bc]	-13.56 ± 5.21[b]	0.84 ± 0.02[bc]	0.92 ± 0.01[c]	24,101.12 ± 2.981.19[a]	23,426.95 ± 2.395.97[bc]
Batch 5	28,348.36 ± 3.766.17[ab]	-13.48 ± 6.04[b]	0.87 ± 0.02[cd]	0.90 ± 0.01[b]	26,025.79 ± 4.172.96[a]	20,316.76 ± 3.313.34[b]
Batch 6	30,083.17 ± 3.387.59[bc]	-15.02 ± 2.53[b]	0.88 ± 0.02[cd]	0.92 ± 0.02[bc]	25,972.35 ± 2.528.95[a]	22,534.14 ± 1.844.15[bc]

Note: Different lowercase letters in each column indicate a significant difference (Tukey HSD < 0.05).

the dough during the molding process. In noodle products, it is usually preferred if it has a good level of elongation (not easily broken when pulled) but not hard. In general, the effect produced from extruder A has uniform hardness for all steaming batches. It shows that the pressure of the noodle extrusion process in extruder A is relatively stable (Table 3). Meanwhile, the results from extruder B had relatively non-uniform hardness values and, on average higher than those of extruder A (Table 4).

Adhesiveness can be expressed as the work (gs) required to overcome the attractive forces between the probe surface and the food. So the value is negative (-). The adhesiveness value of extruder A noodle product is not uniform tends to increase with the length of time the noodle molding process takes. Adhesiveness increased steadily from the first batch to the last (from -3.04 to -14.77 gs). Noodles produced by extruder B had relatively uniform adhesiveness values (-13.46 gs to -15.26 gs), except for the first batch (-6.88 gs). This adhesiveness value is smaller than the results of a previous study conducted by Sholichah et al. (2021) with the same formula and extruder but with a longer steaming time (45 minutes). In this study, the steaming time carried out by SMEs varied between 30-42 minutes for extruder B and 43-59 minutes for extruder A. This variation in steaming time was because the process was still carried out and semi-manual (not using conveyors, some of the work was done by labor), causing a continuous waiting time and input queue for the extrusion process. The extrusion time in extruder B is faster, presumably because the length of the screw is shorter than extruder B, so the noodle formation process is more rapid than extruder A.

Cohesiveness is defined as the ratio of the pressure area during the second compression to the first compression. Cohesiveness can be expressed as the degree of integrity/compactness of the material when crushed mechanically. Secondary parameters of cohesiveness include gumminess and chewiness. Gluten-free noodles produced by extruder A had uniform compactness (0.82-0.85). Meanwhile, gluten-free noodles made by the extruder B had a non-uniform cohesiveness value (0.88-0.92). The cohesiveness value of gluten-free noodles is higher than that of non-wheat noodles from previous research (Sholichah et al., 2021).

The springiness (elasticity) can be interpreted as the ratio of the material recovery time between the first compression

Table 5. Comparison of extruder performance on physical properties and texture of gluten-free noodles.

Paramaters	Extruders	Mean	Std. Devition	Sign (0.05%)
Elongation	Extruder A	134.63	40.65	*
	Extruder B	157.91	39.67	
Hardness (gf)	Extruder A	26.925.14	2.355.74	*
	Extruder B	29.584.23	3.245.37	
Adhesiveness (gs)	Extruder A	-7.66	6.41	ns
	Extruder B	-13.04	5.16	
Springiness	Extruder A	0.82	0.04	ns
	Extruder B	0.84	0.07	
Cohesiveness	Extruder A	0.83	0.03	*
	Extruder B	0.91	0.02	
Gumminess (gf)	Extruder A	21.585.23	2.598.61	*
	Extruder B	24.937.91	2.907.52	
Chewiness (gf)	Extruder A	16.993.66	2.931.19	*
	Extruder B	21.280.95	3.267.35	
L	Extruder A	70.63	1.02	ns
	Extruder B	65.56	0.95	
a	Extruder A	0.24	0.13	*
	Extruder B	0.37	0.29	
b	Extruder A	3.29	0.81	*
	Extruder B	2.74	0.77	

*Significantly different; ns = not significantly different (Z-test < 0.05).

and the second compression. The elasticity gives a chewy effect when the food is bitten. The higher the elasticity value, the more elastic the material is when chewed. The noodles produced by extruder A have a uniform springiness. Springiness values range from 0.76-0.85. Noodles made by extruder B have non-uniform springiness values (0.75-0.91). This springiness value is higher than the results of previous studies (Sholichah et al., 2021).

Gumminess is defined as the result of calculating the hardness value multiplied by the cohesiveness value. Gumminess is expressed as the force (gf) used to shrink food ingredients so it can swallow (Szczesniak, 2002). The gumminess value of noodles from extruder A in each steaming batch was not uniform, and the initial and final batches tended to have higher gumminess than the mid-process batch. The gumminess value of noodles from extruder A was 19.311.0 gf - 25.281.81 gf, noodles from extruder B each steaming batch had a uniform gumminess value (22.365.12 gf - 26.124.62 gf).

The chewiness is expressed as the amount of force (gf) required to chew solid food in pressing, piercing, cutting, tearing, and grinding activities. In testing the characteristics of the texture profile of a material, chewiness is a mathematical calculation determined by the values of hardness, adhesiveness, and elasticity. The chewiness value of noodles in each steaming batch from extruder A was not uniform (14,193.01 gf - 20,527.02 gf). Noodles from extruder B had a non-uniform chewiness value in each steaming batch (16,561.95 gf - 23,800.77 gf).

Comparison of the performance of the extruder used on the physical quality and texture of the product

Extruder B design is the scaling down extruder A (capacity 24 kg/h) to make it more applicable to SMEs. The driving motor power consumption of the extruder B is less and does not change the technical characteristics of the extruder. Table 5 shows the comparison of the performance of the two extruders on the physical properties and the texture of gluten-free noodles. Extruder A produces noodles with better hardness and adhesiveness values, extruder B produces noodles with better elongation and cohesiveness values. Low hardness and adhesiveness values and high elongation, cohesiveness, and springiness values will produce good quality spaghetti (Mayasti et al., 2018).

The extruder process is pressing, milling, and sliding the dough to produce a compact product (Fadeyibi et al., 2016) due to the compression ratio (Altan & Maskan, 2012). extruder B has a better compression ratio and is more compact due to the larger pitch to screw shaft length ratio. The pitch and length of the screw of the extruder B is 43 mm and 502 mm, extruder A is 61.5 mm and 780 mm, it affects the elongation parameter. Bxtruder B produces noodle with higher hardness and cohesiveness value. Residence time is also a factor that affects the product's compactness, stickiness, and maturity level. Extruder A has a longer thread, a 1000 watt heating element, and a faster process. Extruder B has a very narrow residence time distribution providing a homogeneous balance. Longer processing time causes the dough to be exposed to heat longer, resulting in decreased product stickiness.

4 Conclusion

Extruders with different production capacities produce different product quality uniformities for several parameters. The length of the screw affects the cooking time of the dough in the barrel, this causes differences in product quality (especially for texture parameters). Extruder A produces uniformity in

Hardness, cohesiveness, and springiness values. Extruder B produces uniformity in adhesiveness, gumminess, elongation. The two extruders produced non-uniform chewiness values. Extruder A produces noodles with better hardness (average 26.925.14 ± 2.355.74 gf) and adhesiveness values (-7.66 ± 6.41 gs), extruder B produces noodles with better elongation (157.91 ± 39.67) and cohesiveness values (0.91 ± 0.02).

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