Evaluation of the production process of biodegradable drinking straws from corn kernel

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ABSTRACT

New product development is one of the most effective methods to expand the economic value of corn, which is currently a low-cost agricultural material. The present study was conducted to determine the production process of straws from corn kernel under the laboratory scale. The influences of mixing formula, steaming time, screw speed, and drying temperature on hardness and expansion time of the drinking straws from corn kernels were investigated. In addition, the biodegradability of the resultant straws was also tested in the natural environment. The study determined the most suitable recipe for producing the drinking straw product, including corn flour (75%), tapioca starch (20%), rice flour (5%), with the addition of 0.5% xanthan gum and 0.2% potassium sorbate (w/w). The operating conditions of steaming time (10 min), screw speed (40 rpm), and air drying temperature (40°C) were found to be the most appropriate. For the decomposition study, the results indicated that the drinking straw product was capable to be decomposed after 40 days at a temperature of 30 ± 2°C. As such, it can be concluded that it is highly potential to build up the practical production process for making environmentally friendly drinking straws from corn kernels.

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1. Introduction

One of the most important factors causing environmental pollution is the increase in plastic waste. Plastic straws have gained global attention due to growing concerns about their impact on human health and the environment. The amount of plastic waste in the oceans is estimated to double between 2010 and 2025, increasing from about 8 million tons in 2010 to 9 million tons in 2015, and to 16 million in 2025 (Jambeck et al., 2015; Mortillaro, 2017). More than 50% of manufactured plastics, including plastic straws, are disposed of after single-use, leading to 150 million tons of annual plastic waste worldwide (James et al., 2019). The average decomposition time of plastic straws was 100 - 200 years, which causes many negative impacts on the environment (Garcia & Robertson, 2017; Ramirez & George, 2019). So far, many researchers have focused on the development of biodegradable materials that could substitute synthetic polymers. Natural materials, such as paper, leaves, bamboo, grass, among others, showed the potential to apply plant-based materials, possibly replacing plastic due to the safety in usage and the friendliness to the environment. Global agriculture aims to minimize its impacts on the environment and human health. Thus, a broader beneficial effect on the environment will only be attained through consumer acceptance and behavioral changes.

Corn (*Zea mays* L.) has been a popular food crop in the world. It is grown on soils of widely different properties from the raw sands to the clays of delta regions and from shallow soils on residual material to those very deep on loess, till, or alluvium. Moreover, corn was grown in areas with rainfall from 250 mm to more than 5000 mm per year and a growth cycle of 3 to 13 months (Murdia et al., 2016). In Vietnam, corn is grown a lot in the northern mountainous areas, the Central Highlands, and the Southeast region. The total corn production in Vietnam in the 2015 - 2016 crop year reached up to 5.28 million tons (Dang & Nguyen, 2020). It is well-known that corn has a high content of starch. However, the focus of research on products that can replace single-use plastic from starch, to reduce environmental pollution, is still limited.

The extrusion technique is one of the most appropriate technologies for the production of extruded products such as straw, pasta, and noodle, among others (Marti & Pagani, 2013). According to Zieliński et al. (2006) and Oniszczuk et al. (2019), extrusion technology does not degrade the valuable compounds present in raw materials and improves the physicochemical properties of the extruded products. As such, the physical properties of the straw such as hardness and expansion time could be positively obtained by optimizing the processing parameters, including steaming time, screw speed, and drying temperature. There is a need to determine the most suitable operating variables.

Therefore, this study aimed to determine the production process for making straws from corn kernels on a laboratory scale. Specific objectives were to determine the mixing recipe, extrusion conditions, and biodegradable time of drinking straw from the corn kernel.

2. Materials and Methods

2.1. Materials

The dried corn kernels (Zea may L.) used in the present study, that was the feed grain type, were purchased in District 12, Ho Chi Minh City, Vietnam. The dried kernels without pest and deterioration were selected. Then, the dried kernels were ground and sieved through a 0.5 mm open diameter to collect the powdery homogeneous sample. The powdery sample referred to as corn flour (moisture content $\leq$ 10%) was stored in an aluminum foil bag at ambient temperature (30 $\pm$ 2°C).

Tapioca starch and rice flour were purchased in Co.opXtra supermarket Thu Duc city, Ho Chi Minh City, Vietnam. Xanthan gum and potassium sorbate were purchased from PATH Co., Ltd (Vietnam).

Equipment used in this study included a single screw laboratory extruder (made in Vietnam), a texture analyzer (Zwick Roell, Germany), and a moisture balance MX-50 (Sartorius, Japan).

2.2. Experimental design

2.2.1. The effect of mixing recipe on hardness and expansion time of drinking straw

The corn kernel flour as described in Section 2.1 was mixed with four different ingredients, including tapioca starch, rice flour, xanthan gum, and potassium sorbate. The ratio of the corn flour: tapioca starch: rice flour was 70%: 25%: 5% (Formula 1); 75%: 20%: 5% (Formula 2); 70%: 20%: 10% (Formula 3) (w/w). Then, an amount of 0.5% xanthan gum and 0.2% potassium sorbate (w/w) was added to each formula. Next, a fixed amount of water was added into the mixture at the ratio of 3:2 (w/w). The slurry (or dough-like) obtained was fed into the extruder. The obtained straws were evaluated the hardness and the expansion time.

The one factor (mixing recipe) was randomly designed to investigate the effect of different materials on the hardness and expansion time. The mixing recipe runs and subsequent measurements were carried out in triplicate. A total of 9 runs were conducted.

2.2.2. Effect of steaming time, screw speed, and drying temperature on hardness and expansion time of drinking straw

In the next step of the production process of straws, the one-factor experiments were designed at a time. The best formula (the results obtained from Section 2.2.1) was applied. After mixing all materials, steaming time was investigated at three levels (5, 10, and 15 min). After that, the screw speed was surveyed at three levels (40, 80, and 120 rpm). Finally, straws were air-dried at three temperatures (40, 50, and 60°C) in a hot air oven. The air drying was terminated when the final moisture content of each straw sample was constant (approximately 10%). The obtained straws were sealed into a high barrier bag, using a hot sealing machine, and analyzed hardness and expansion time. All experiments and subsequent analyses were performed in triplicate.

2.2.3. Investigation of the biodegradability of drinking straws in the natural environmental conditions

After the determination of the best parameters for the production process of straws from corn kernels, the biodegradability of the straws in the natural environment was evaluated. The straw samples were cut into short pieces in 5 - 7 cm and buried in the soil at a depth of 8 - 10 cm. The decomposition time of the straws in the environment from the beginning to the complete decomposition was periodically recorded. The plastic straws were also used as a negative control. In addition, the experimented straws were evaluated at ambient temperature (30 ± 2°C). The decomposition time of straws was recorded on the first day and after every 5 days for up to 45 days. The experiment was carried out in duplicate.

2.2.4. Moisture content

The moisture was determined by infrared moisture drying balance MX-50 (0.01%/max 51 g), (Sartorius, Japan). One gram of sample was weighed and dried until a constant weight was obtained.

2.2.5. Hardness

The hardness of the tested straws was measured by using a texture analyzer (Zwick Roell, Germany). The probe moved to the point of contact with the sample, applied force to the sample, and penetrated. During penetration, the force value increased gradually and started to decrease at the point where the suction straw's texture was broken. The recorded force values continued when the penetration reached the specified distance. The maximum force value reflected the hardness of the suction straws.

2.2.6. Expansion time

The tested straws with an equal length of approximately 20 cm were placed in 300 - 350 mL of water, and the expansion time at 30 ± 2°C was measured. The time of use was counted from the initial time when the straw was submerged in the water until the signs of cracking, breaking, or any non-integrity were observed.

2.3. Statistical analysis

The experiments were carried out in triplicate and the results were presented as mean values with standard deviations. Different mean values were analyzed by analysis of variance method (ANOVA) and least significant difference (LSD) using Statgraphics software.

3. Results and Discussion

3.1. The effect of mixing recipe on hardness and expansion time of drinking straw

This study aimed to investigate the effect of different mixing recipes on the hardness and expansion time of the straws from corn kernels under the laboratory scale. The most suitable recipes would be chosen according to the highest value of hardness and longer expansion time. The results of this experiment are shown in Table 1.

Table 1 shows that each hardness and expansion time was displayed differently under the different mixing recipes. The hardness of the test straws was in decreasing order of formula 2 (18.83 N), formula 1 (16.27 N), and formula 3 (14.77 N). For the expansion time, the effect of formulas used to mix was found to be decreased as follows: Formula 2 (18.94 h), Formula 1 (4.26 h), and Formula 3 (2.64 h). These values were statistically significant at the confidence level $\alpha < 0.05$.

The investigated drinking straws became harder and the expansion time was longer due to an increase in the percentage of corn flour and a decrease in the ratio of tapioca and rice flour. The molecular structures of amylose and amylopectin may have an impact on the functional properties of the starch-based product. When the flours were heated, starch gelatinization occurred, the amylose inside the grain was likely to be released and created a three-dimensional network structure. As such, changing the flour ratio affected the ratio of amylose: to amylopectin, which affected starch gelatinization, causing the network structure to be altered (Cai et al., 2014; Li et al., 2018). Therefore, it can be concluded that formula 2, which was corn flour: tapioca starch: rice flour of 75: 20: 5 (%, w/w) should be the most

Table 1. The effect of mixing recipes on structured and expansion time of drinking straw

Formula	Hardness (N)	Expansion time (h)
Corn flour: tapioca starch: rice flour: 70: 25: 5 (%, w/w); (Formula 1)	16.27^{ab} ± 1.95	4.26^{b} ± 1.58
Corn flour: tapioca starch: rice flour: 75: 20: 5 (%, w/w); (Formula 2)	18.83^{a} ± 0.97	18.94^{a} ± 6.06
Corn flour: tapioca starch: rice flour: 70: 20: 10 (%, w/w); (Formula 3)	14.77^{b} ± 0.80	2.64^{b} ± 2.78

Values are mean ± SD (triplicates) after statistical analyses.
The values in the same column followed by different superscripts (a, b) were significantly different ($P < 0.05$).

suitable choice for the following experiments.

3.2. The effect of steaming time, screw speed, and drying temperature on hardness and expansion time of drinking straw

To build up the production process for making straws from corn kernels, it is important to investigate key operating conditions of steaming time, screw speed, and drying temperature. The impacts of steaming time, screw speed, and drying temperature on the hardness and expansion of the resultant straws are presented in Tables 2, 3, and 4, respectively.

Table 2. The effect of steaming time on hardness and expansion time of drinking straw

Steaming time (min)	Hardness (N)	Expansion time (h)
5	16.8^{a} ± 1.57	3.11^{b} ± 1.0
10	17.33^{a} ± 1.42	11.14^{a} ± 4.46
15	17.43^{a} ± 0.60	11.25^{a} ± 5.23

Values are mean ± SD (triplicates) after statistical analyses. The values in the same column followed by different superscripts (a, b) were significantly different ($P < 0.05$).

Table 3. The effect of screw speed on hardness and expansion time of drinking straw

Screw speed (rpm)	Hardness (N)	Expansion time (h)
40	19.93^{a} ± 0.35	17.31^{a} ± 5.94
80	16.17^{b} ± 0.32	7.42^{ab} ± 5.96
120	15.53^{b} ± 1.59	2.86^{b} ± 2.37

Values are mean ± SD (triplicates) after statistical analyses. The values in the same column followed by different superscripts (a, b) were significantly different ($P < 0.05$).

For a steaming time, the hardness of straws was found to be statistically non-significant ($P > 0.05$). The corn flour had high amylose content, about 24% (Pereira et al., 2021), so the gelatinization time took longer, the investigated time duration did not differ much. As such, it did not have a great influence on the amount of gelatinized starch. In contrast, the steaming time significantly influenced the expansion time of straws ($P < 0.05$). The time used when steaming at 10 min and 15 min resulted in expansion time ranging from 11.14 h to 11.25 h, which was found to be a non-significant difference ($P > 0.05$). However, an expansion time of 3.11 h was obtained when the steaming time was 5 min and was statistically different compared to the other two. Therefore, it can be seen that the steaming time of 10 min gave the best results in the production process of straws because of its economic relevance.

Table 4. The effect of drying temperature on hardness and expansion time of drinking straw

Drying Temperature (°C)	Hardness (N)	Expansion time (h)
40	21.2^{a} ± 1.76	14.87^{a} ± 8.93
50	21.9^{a} ± 3.08	1.52^{b} ± 0.87
60	17.73^{a} ± 5.23	0.3^{b} ± 0.06

Values are mean ± SD (triplicates) after statistical analyses. The values in the same column followed by different superscripts (a, b) were significantly different ($P < 0.05$).

As can be seen in Table 3, the hardness and expansion time of the resultant straws were significantly affected by the machine's screw speed ($P < 0.05$). The value of hardness of the straws was found to be decreased as increasing the screw speed from 40, 80, and 120 rpm. Similar trends in expansion time were also found to be significant ($P < 0.05$) as the speed was increased.

It can be explained that changes during the extrusion process led to some changes such as loss of crystal structure, disruption of grain structure, glycosidic bond breakage, and new molecular interactions (Zhong & Sun, 2005). Furthermore, according to Wang et al. (2016) the physical and chemical properties of the extruded product may be also positively and negatively affected by extrusion conditions including temperature, pivot speed, and screw structure affected. During the extrusion process, starch partially gelatinizes due to the effect of temperature (Mishra et al., 2012). When the screw speed is too fast, the dough is overworked, which affects the quality of the finished product (Cubadda & Carcea, 2003), resulting in reduced hardness, short expansion time, and easy cracking and breakage. This finding is also in agreement with other studies (Bouasla & Wójtowicz, 2019). Therefore, screw speed at 40 rpm was the best result in the production process of straws from corn kernels.

Table 4 shows the effect of air drying temperature on the hardness of straws was found to be statistically non-significant at $P > 0.05$. However, the value of expansion time of the resultant straws was significantly impacted by the air drying temperature ($P < 0.05$). The expansion time was reduced by increasing the drying temperature from 40, 50, and 60°C.

It is well-known that during the drying process, the air temperature and relative humidity must be controlled appropriately, if the drying process is too slow, which is less than 40°C, the product may become moldy or damaged. However, if the drying process is too fast, the moisture content product will evaporate rapidly, which can cause cracking or breakage of the product (Cubadda & Carcea, 2003). Therefore, the drying temperature at 40°C was found to be the most suitable for drying the corn straw product in terms of hardness and expansion time.

3.3. Investigation of the biodegradability of drinking straws in the natural environmental conditions

The results of the degradability of the resultant corn straws (Figure 1) were periodically recorded at 30 ± 2°C for up to 40 days as presented in Table 5.

At 30 ± 2°C, after 5 days of the track, both samples had not started decomposition. Keeping recording results until the 10th day, the decomposition of the corn straw sample appeared and continued in the following days, for up to 45 days. After 40 days, the corn straws were completely decomposed in the natural environment,

Figure 1. Biodegradable drinking straws made from corn kernel.

Table 5. Decomposition time of the corn straw buried in the soil

Treatments	Time (day)									
	0	5	10	15	20	25	30	35	40	45
Corn straws	-	-	+	+	+	+	+	+	+	+
Control	-	-	-	-	-	-	-	-	-	-

(-) absence (+) presence.

however, the control samples were neither. The study proved that corn straws were biodegradable in the natural environment. As such, it can be concluded that agricultural materials such as corn kernels could be used for making biodegradable straws. The degradation characteristics of the straw obtained from this study with the biodegradable straws reported in other studies should be done.

4. Conclusions

The study determined the production process of the drinking straws from corn kernels with the important parameters. The results showed that the most appropriate recipe for making the drinking corn straws was 75% corn flour, 20% tapioca starch, 5% rice flour, 0.5% xanthan gum, and 0.2% potassium sorbate (w/w). The most suitable operating conditions of steaming time, screw speed, and air drying temperature were found to be 10 min, 40 rpm, and 40°C, respectively. The resultant drinking straws product were capable of decomposing after 40 days at a temperature of 30 ± 2°C. Therefore, it can be concluded that it is highly potential to build up the practical production process for making environmentally friendly drinking straws from corn kernels.

Conflict of interest

The authors declare no conflict of interest.

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References

Bouasla, A., & Wójtowicz, A. (2019). Rice-buckwheat gluten-free pasta: effect of processing parameters on quality characteristics and optimization of extrusion-cooking process. *Foods* 8(10), 496. https://doi.org/10.3390/foods8100496.

Cai, C., Cai, J., Zhao, L., & Wei, C., (2014). *In situ* gelatinization of starch using not stage microscopy. *Food Science and Biotechnology* 23(1), 15-22. https://doi.org/10.1007/s10068-014-0003-x.

Cubadda, R., & Carcea, M. (2003) Pasta and macaroni: methods of manufacture. In Caballero, B. (Ed). *Encyclopedia of food sciences and nutrition* (4374-4378). San Diego, USA: Academic Press.

Dang, T. T. T., & Nguyen, H. V. (2020). Structure changing in maize-based agriculture production in Vietnam: Case study in Son La province. *Sustainable Environment Agricultural Science* 4(1), 65-76. https://doi.org/10.22225/seas.4.1.1690.65-76.

Garcia, J. M., & Robertson, M. L., (2017). The future of plastics recycling. *Science* 358(6365) 870-872. https://doi.org/10.1126/science.aaq0324.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science* 347(6223), 768-771. https://doi.org/10.1126/science.1260352.

James, J. J., Silva, D. D., Varghese, S., Xavier, J., & Paari, K. A., (2019). Drinking straw from coconut leaf: a study of its epicuticular wax content and phenol extrusion properties. *Asian Journal of Plant Sciences* 18, 139-147. https://doi.org/10.3923/ajps.2019.139.147.

Li, W, Xu, Z., Wang, Z., & Xing, J. (2018). One-step quaternization/hydroxypropylsulfonation to improve paste stability, adhesion, and film properties of oxidized starch. *Polymers* 10(10), 1110. https://doi.org/10.3390/polym10101110.

Marti, A., & Pagani, M. A. (2013). What can play the role of gluten in gluten free pasta? *Trends in Food Science & Technology* 31(1), 63-71. https://doi.org/10.1016/j.tifs.2013.03.001.

Mishra, A., Mishara, H. N., & Rao, P. S. (2012). Preparation of rice analogues using extrusion technology. *International Journal of Food Science & Technology* 47(9), 1789-1797. https://doi.org/10.1111/j.1365-2621.2012.03035.x.

Mortillaro, N. (2017). Humans have produced 8.3 billion tonnes of plastic, researchers say. *CBC News*. Retrieved November 30, 2021, from https://cbc.ca/news/science/humans-produce-billions-tonnes-plastic-1.4210279.

Murdia, L. K., Wadhwani, R., Wadhawan, N., Bajpai, P., & Shekhawat, S. (2016). Maize utilization in India: An overview. *American Journal of Food and Nutrition* 4(6), 169-176. https://doi.org/10.12691/ajfn-4-6-5.

Oniszczuk, A., Kasprzak, K., Wójtowicz, A., Oniszczuk, T., & Olech, M. (2019). The impact of processing parameters on the content of phenolic compounds in new gluten-free precooked buckwheat pasta. *Molecules* 24(7), 1262. https://doi.org/10.3390/molecules24071262.

Pereira, A. M., Schriele, M., Souza, E. J. D. d., Ávila, B. P., Romos, A. H., Zavareze, E. D. d. R., & Gularte, M. A. (2021). Extrudate gluten-free breakfast cereals from rice and corn flours with different amylose content: technological and sensory properties. *International Journal of Food Science & Technology* 56(8), 4182-4190. https://doi.org/10.1111/ijfs.15048.

Ramirez, A., & George, B. (2019). Plastic recycling and waste reduction in the hospitality industry: Current challenges and some potential solutions. *Economics, Management and Sustainability* 4(1), 6-20. https://doi.org/10.14254/jems.2019.4-1.1.

Wang, L., Duan, W., Zhou, S., Qian, H., Zhang, H., & Qi, X. (2016). Effects of extrusion responses and the quality of brown rice pasta. *Food Chemistry* 204, 320-325. https://doi.org/10.1016/j.foodchem.2016.02.053.

Zhong, Z., & Sun, X. S. (2005). Thermal characterization and phase behavior of cornstarch studied by differential scanning calorimetry. *Journal of Food Engineering* 69(4), 453-459. https://doi.org/10.1016/j.jfoodeng.2004.07.023.

Zieliński, H., Michalska, A., Piskuła, M. K., & Kozłowska, H. (2006). Antioxidants in thermally treated buckwheat groats. *Molecular Nutrition & Food Research* 50(9), 824-832. https://doi.org/10.1002/mnfr.200500258.