BUKTI KORESPONDENSI

Judul Artikel : Effect of Frozen Storage Condition on the Physicochemical and Sensory Properties of Cassava Sticks

Jurnal : Food Research
Volume 7, Supplementary 1, Februari 2023

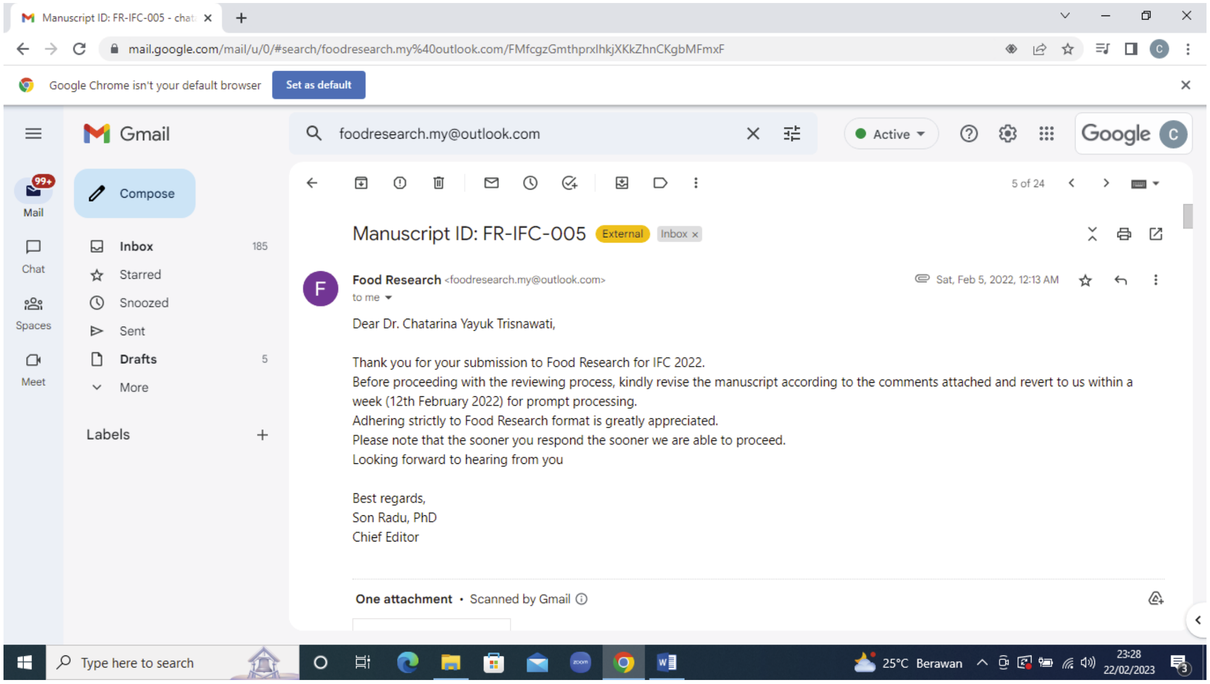
Penulis : *Trisnawati, C.Y., Sutedja, A.M., Kaharso, V.C.

No.	Perihal	Tanggal
1.	Bukti konfirmasi penerimaan submit artikel, artikel yang di-submit dan revisi artikel yang harus dilakukan	5 Februari 2022
2.	Bukti konfirmasi submit revisi artikel pertama	8 Februari 2022
3.	Bukti konfirmasi penerimaan submit revisi artikel	9 Februari 2022
4.	Bukti konfirmasi review dan hasil review dari 2 Reviewer	10 Maret 2022
5.	Bukti konfirmasi submit revisi artikel kedua, respon kepada reviewer dan artikel yang di-resubmit	20 Maret 2022
6.	Bukti konfirmasi revisi artikel yang harus dilakukan	23 Maret 2022
7.	Bukti konfirmasi submit revisi artikel ketiga	24 Maret 2022
8.	Bukti konfirmasi revisi artikel yang harus dilakukan	26 Maret 2022
9.	Bukti konfirmasi submit revisi artikel keempat dan balasannya	28 Maret 2022
10.	Bukti konfimasi artikel diterima dan acceptance letter	18 Oktober 2022
11.	Bukti konfirmasi galley proof artikel	4 Februari 2023
12.	Bukti konfirmasi submit revisi galley proof artikel dan galley proof artikel revisi yang di-resubmit	7 Februari 2023
13.	Bukti konfimasi galley proof hasil revisi, persetujuan galley proof dan balasannya	7 dan 8 Februari 2023

1.

Bukti konfirmasi penerimaan submit artikel, artikel yang di-submit dan revisi artikel yang harus dilakukan

(5 Februari 2022)



Manuscript ID: FR-IFC-005

Food Research <foodresearch.my@outlook.com>
Sat, Feb 5, 2022, 12:13 AM
to me

Dear Dr. Chatarina Yayuk Trisnawati,

Thank you for your submission to Food Research for IFC 2022.
Before proceeding with the reviewing process, kindly revise the manuscript according to the comments attached and revert to us within a week (12th February 2022) for prompt processing.
Adhering strictly to Food Research format is greatly appreciated.
Please note that the sooner you respond the sooner we are able to proceed.
Looking forward to hearing from you

Best regards,
Son Radu, PhD
Chief Editor

One attachment • Scanned by Gmail

2.

Bukti konfirmasi submit revisi artikel pertama

(8 Februari 2022)

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

Abstract

In this study, the cassava stick was stored at -20°C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that the frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance and had no significant difference ($P>0.05$) with other samples.

Keywords: Cassava, Cassava stick, Frozen Storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides

carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as tiwul, gatot, gaplek, gethuk, tapai, and cassava chips. Furthermore, it can also be processed to a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown color, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Despite those processes, other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one of the most used methods (Rahman & Velez-Ruiz, 2007). Generally, frozen storage temperature is 0^{o}F (-18^{o}C) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Several studies stated that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Celli *et al*., 2016; Medic *et al*., 2018; Sattar *et al*., 2015). However, based on our knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2) and purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassavas were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98^{o}C, 15 min) and cooled to room temperature before being pre-fried (170^{o}C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20^{o}C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All pre-fried and fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of the samples was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g samples were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink color occurred for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g sample was mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow color had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution

was added and the titration continued until the blue color disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Color

Cassava stick color was identified using a color reader (Color Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were color, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at $P<0.05$.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference (P>0.05) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also stated that freezing significantly (P<0.05) influenced the moisture content of the fried potato (Adedeji & Ngadi, 2017), lamb (Coombs *et al*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18^{o}C and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al*., 1988). Table 1 showed that frozen storage duration significantly increased (P<0,05) the oil absorption of cassava sticks. Cassava stick stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference on cassava stick stored frozen for 3 months (57.84%). In Adedeji & Ngadi (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also stated that there was no interaction between storage duration and freezing method, which contradicts our study.

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Dana & Saguy, 2006; Rimac-Brncic *et al*., 2004). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et*

al., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that Figure, frozen storage duration significantly affected ($P<0.05$) the hardness of the cassava sticks. Cassava stick that stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). Our results were in accordance with the results of Adedeji & Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. Our statement was supported by a similar study by Yu *et al*. (2010), where the hardness of cooked rice increased continually with the amylopectin retrogradation during frozen storage. So that, based on those findings, it indicates that amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/ kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased (P<0.05) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference (P>0.05) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased (P<0.05) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri & Mangaraj, 2012).

3.4. Color properties

Color is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Patras *et al*., 2011; Hutchings, 2002). In this study, the color of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* color attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All

samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Our results showed that the color of cassava sticks was greatly affected by the frozen storage duration. Research by Oner & Wall (2012) also found that frozen storage significantly influenced (P<0.05) the color of French fries. The color change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the color of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown color in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust color of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the color attribute was the 0-month storage cassava sticks (5.60) and significantly difference (P<0.05) with other samples (3.20 – 4.96). The decrease in panelists' color preference was due to the color changes in cassava sticks that tend to be darker and browny than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased (P<0.05) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with our objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference (P>0.05) with 2 months stored cassava stick (4.66) but showed significant difference ($P<0.05$) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced ($P<0.05$) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference ($P>0.05$) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect ($P>0.05$) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change. The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface color, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153. https://doi.org/10.1016/j.jfoodeng.2008.08.018

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32. https://doi.org/10.1016/j.jfoodeng.2017.08.024

Association of Analytical Communities. (2006). *Official Methods of Analysis of AOAC International 18th Edition*. Gaithersburg: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216. https://doi.org/10.4314/acsj.v12i3.27880

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304, https://doi.org/10.1080/87559129.2015.1075212

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb M. longissimus lumborum quality and safety parameters. *Meat Science*, 134, 86–97. https://doi.org/10.1016/j.meatsci.2017.07.017

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607. https://doi.org/10.1016/j.foodchem.2013.08.132

Dana, D. dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272. https://doi.org/10.1016/j.cis.2006.11.013

Fellows, P.J. (1990). *Food Processing Technology Principles and Practice*. London: Ellis Horwood

Fennema, G.R. (1985). *Principles of Food Science*. New York: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*. https://doi.org/10.1007/s12393-012-9053-0

Hutchings, J.B. 2002. *The Perception and Sensory Assessment of Colour*. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). *Cassava production guidelines for food security and adaptation to climate change in Asia and Africa*. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). *Pengawasan Mutu Makanan*. Malang: UB Press

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49. https://doi.org/10.1007/s13197-011-0257-8

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127. https://doi.org/10.1016/j.meatsci.2018.03.006

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373. https://doi.org/10.1016/S0924-2244(03)00050-5

Mohamed, S., Abdullah, N. and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252. https://doi.org/10.1007/s11947-009-0226-7

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9. https://doi.org/10.1016/j.foodres.2004.07.002

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In *Handbook of Food Preservation Second Edition*. CRC Press. https://doi.org/10.1201/9781420017373.ch26

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241. https://doi.org/10.1016/j.jfoodeng.2003.10.006

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168. https://doi.org/10.1007/s002170050017

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). *Prosedur Analisa untuk Bahan Makanan dan Pertanian*. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225. https://doi.org/10.1016/S0950-3293(01)00039-8

WFLO Commodity Storage Manual. (2008). *Frozen Foods Handling & Storage*. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143. https://doi.org/10.1016/j.lwt.2010.03.004

List of Figures

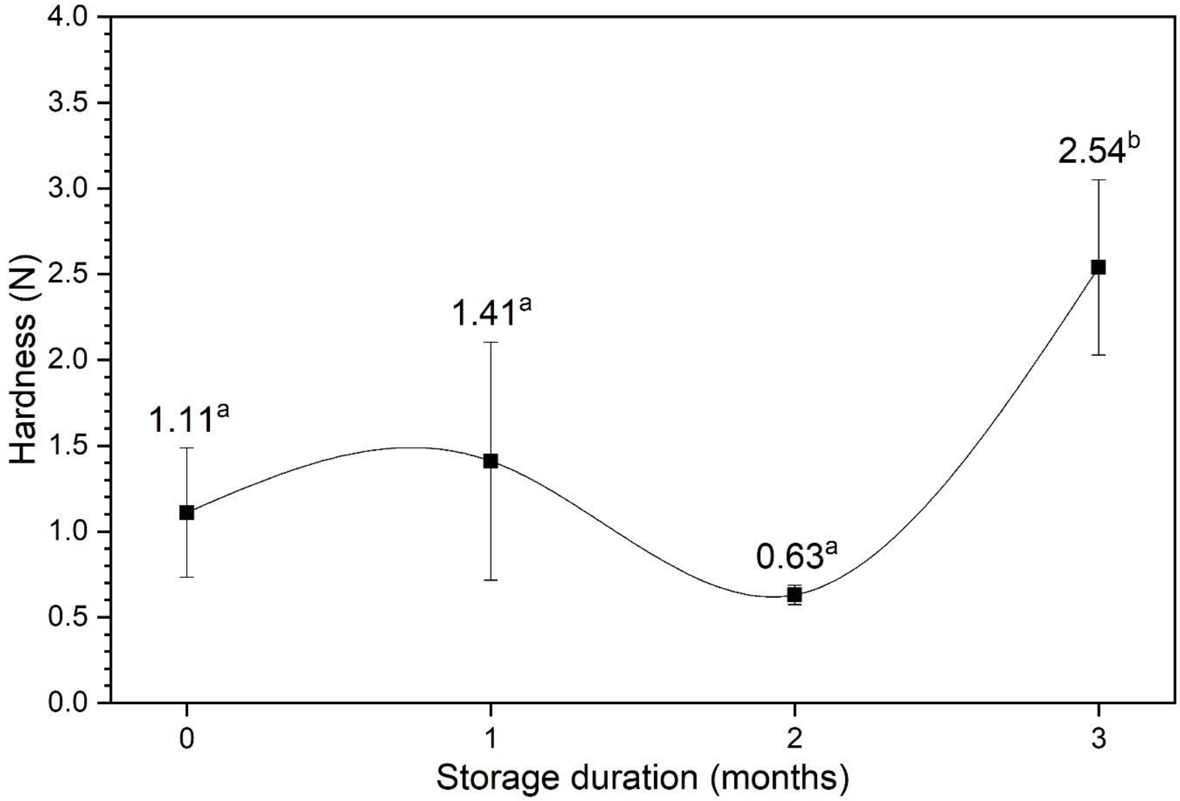


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

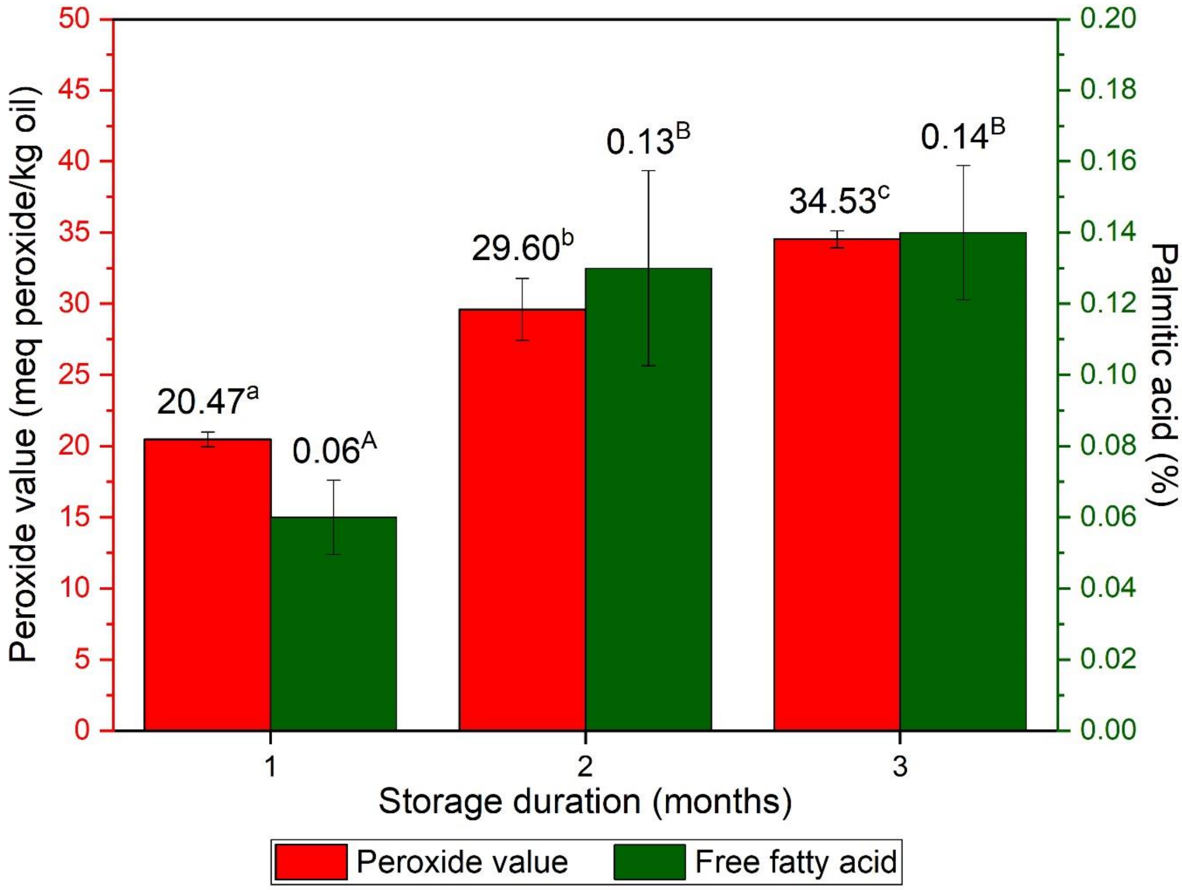


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

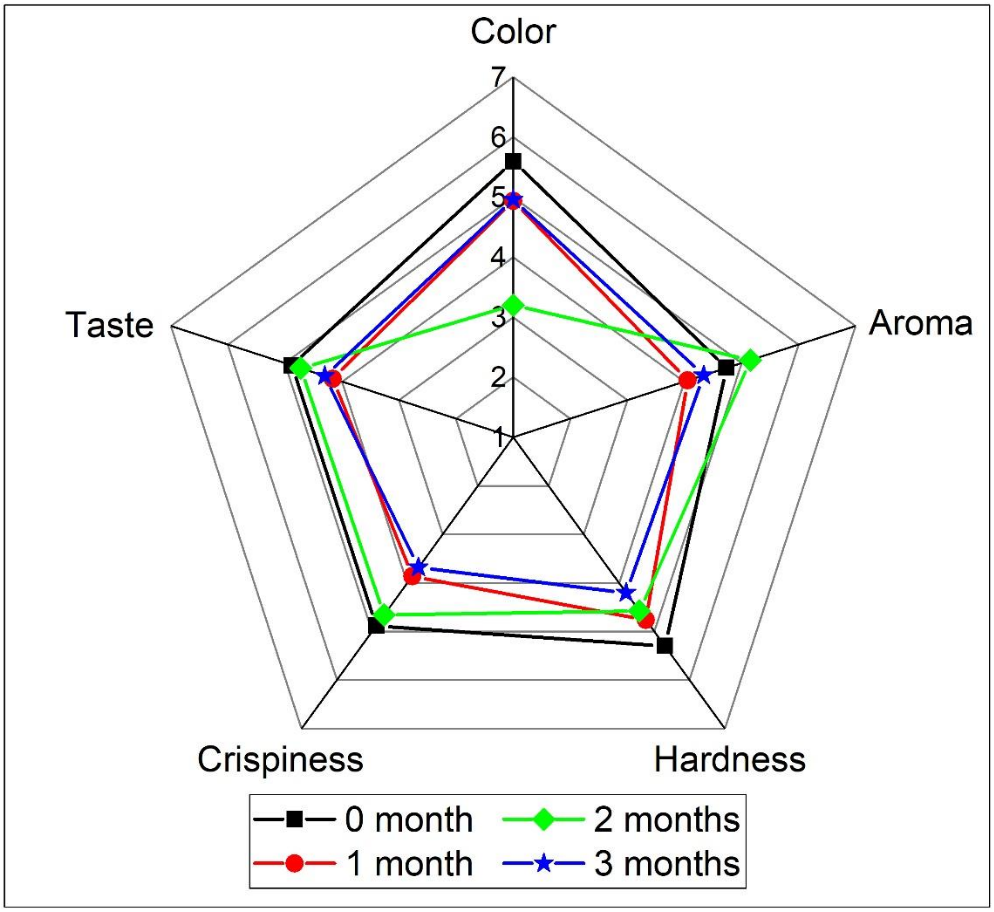


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13 ± 7.46 ^{a}	20.87 ± 15.91^{a}
1	48.83 ± 3.27 ^{a}	25.66 ± 9.51^{a}
2	28.68 ± 7.95 ^{a}	58.45 ± 2.47^{b}
3	27.75 ± 10.13 ^{a}	57.94 ± 24.71^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

Table 2. Color of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Color		
	L*	*a**	*b**
0	71.55 ± 4.08^{ab}	2.95 ± 0.78^{a}	32.08 ± 3.02^{b}
1	67.98 ± 2.78^{a}	4.62 ± 1.93^{a}	30.79 ± 1.87^{b}
2	66.52 ± 1.15^{a}	3.21 ± 0.37^{a}	25.77 ± 0.98^{a}
3	75.20 ± 1.80^{b}	4.01 ± 0.30^{a}	31.40 ± 1.66^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

[1*]Trisnawati, C. Y., [1]Sutedja, A.M. and [1]Kaharso, V. C.

[1]*Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia*

*Corresponding author: chatarina@ukwms.ac.id

Authors' ORCID ID:

Author 1 : 0000-0003-0595-9504

Author 2 : 0000-0002-7734-7163

Author 3 : 0000-0002-7373-7383

Abstract

In this study, the cassava stick was stored at -20ºC for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that the frozen storage duration affected the physical

and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference ($P>0.05$) with other samples.

Keywords: Cassava, Cassava stick, Frozen Storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as tiwul, gatot, gaplek, gethuk, tapai, and cassava chips. Furthermore, it can also be processed to a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown color, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Despite those processes, other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one of the most used methods (Rahman & Velez-Ruiz, 2007). Generally, frozen storage temperature is 0^oF (-18^oC) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Several studies stated that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Celli *et al*., 2016; Medic *et al*., 2018; Sattar *et al*., 2015). However, based on our knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2) and purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassavas were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98^{o}C, 15 min) and cooled to room temperature before being pre-fried (170^{o}C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20^{o}C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All pre-fried and fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of the samples was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g samples were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink color occurred for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g sample was mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow color had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue color disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Color

Cassava stick color was identified using a color reader (Color Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were color, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at P<0.05.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference (P>0.05) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also stated that freezing significantly (P<0.05) influenced the moisture content of the fried potato (Adedeji & Ngadi, 2017), lamb (Coombs *et al*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18^{o}C and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al*., 1988). Table 1 showed that frozen storage duration significantly increased (P<0,05) the oil absorption of cassava sticks. Cassava stick stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference on cassava stick stored frozen for 3 months (57.84%). In Adedeji & Ngadi (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also stated that there was no interaction between storage duration and freezing method, which contradicts our study.

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Dana & Saguy, 2006; Rimac-Brncic *et al*., 2004). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al*., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that Figure, frozen storage duration significantly affected ($P<0.05$) the hardness of the cassava sticks. Cassava stick that stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). Our results were in accordance with the results of Adedeji & Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. Our statement was supported by a similar study by Yu *et al*. (2010), where the hardness of cooked rice increased continually with the amylopectin retrogradation during frozen storage. So that, based on those findings, it indicates that amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/ kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased ($P<0.05$) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference ($P>0.05$) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased ($P<0.05$) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri & Mangaraj, 2012).

3.4. Color properties

Color is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products

(Patras *et al*., 2011; Hutchings, 2002). In this study, the color of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* color attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Our results showed that the color of cassava sticks was greatly affected by the frozen storage duration. Research by Oner & Wall (2012) also found that frozen storage significantly influenced (P<0.05) the color of French fries. The color change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the color of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown color in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust color of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the color attribute was the 0-month storage cassava sticks (5.60) and significantly difference (P<0.05) with other samples (3.20 – 4.96). The decrease in panelists' color preference was due to the color changes in cassava sticks that tend to be darker and browny than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased ($P<0.05$) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with our objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference ($P>0.05$) with 2 months stored cassava stick (4.66) but showed significant difference ($P<0.05$) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced ($P<0.05$) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference ($P>0.05$) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect ($P>0.05$) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change. The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface color, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O., & Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153. https://doi.org/10.1016/j.jfoodeng.2008.08.018

Adedeji, A. A., and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32. https://doi.org/10.1016/j.jfoodeng.2017.08.024

Association of Analytical Communities. (2006). *Official Methods of Analysis of AOAC International 18th Edition*. Gaithersburg: AOAC International.

Benesi, I. R. M., Labuschagne, M. T., Dixon, A. G. O., and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216. https://doi.org/10.4314/acsj.v12i3.27880

Commented [Editor1]: Please revise strictly according to food research format
Apply the comments below to all the references

Commented [Editor2]: Remove comma before 'and'

Commented [Editor3]: Replace all '&' with 'and'

Commented [Editor4]: Ensure to remove spacing between initials
A.A.

Celli, G. B., Ghanem, A., and Brooks, M. S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304, https://doi.org/10.1080/87559129.2015.1075212

Coombs, C. E. O., Holman, B. W. B., Collins, D., Friend, M. A., & Hopkins, D. L. (2017a). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb M. longissimus lumborum quality and safety parameters. *Meat Science*, 134, 86–97. https://doi.org/10.1016/j.meatsci.2017.07.017

Crosa, M. J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G., and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607. https://doi.org/10.1016/j.foodchem.2013.08.132

Dana, D., dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272. https://doi.org/10.1016/j.cis.2006.11.013

Fellows, P. J. (1990). *Food Processing Technology Principles and Practice*. London: Ellis Horwood

Fennema, G. R. (1985). *Principles of Food Science*. New York: Marcell Dekter Inc.

Giri, S. K., and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*. https://doi.org/10.1007/s12393-012-9053-0

Hutchings, J. B. 2002. *The Perception and Sensory Assessment of Colour*. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). *Cassava production guidelines for food security and adaptation to climate change in Asia and Africa*. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M. H., Ragab, M. H., and Youssef, M. M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S. T., Kurniawati, A. D., Rahmi, Y., Rusdan, I. H., Widyanto, R. M. (2017). *Pengawasan Mutu Makanan*. Malang: UB Press

Lamberg, I., Hallstrom, B., and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P. S., and Bawa, A. S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49. https://doi.org/10.1007/s13197-011-0257-8

Medić, H., Kušec, I. D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B., and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127. https://doi.org/10.1016/j.meatsci.2018.03.006

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373. https://doi.org/10.1016/S0924-2244(03)00050-5

Mohamed, S., Abdullah, N., and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M. E., and Wall, M. M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N. P., Tiwari, B. K., and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252. https://doi.org/10.1007/s11947-009-0226-7

Pedreschi, F., Moyano, P., Kaack, K., & Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9. https://doi.org/10.1016/j.foodres.2004.07.002

Rahman, M. S. and Velez-Ruiz, J. F. (2007). Food preservation by Freezing. In *Handbook of Food Preservation Second Edition*. CRC Press. https://doi.org/10.1201/9781420017373.ch26

Rimac-Brncic, S., Lelas, V., Rade, D., and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241. https://doi.org/10.1016/j.jfoodeng.2003.10.006

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168. https://doi.org/10.1007/s002170050017

Sattar, S., Sarower, K., Uddin, M. B., and Jubayer, M. F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B., and Suhardi. (1984). *Prosedur Analisa untuk Bahan Makanan dan Pertanian*. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225. https://doi.org/10.1016/S0950-3293(01)00039-8

WFLO Commodity Storage Manual. (2008). *Frozen Foods Handling & Storage*. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S. F., Ma, Y., and Sun, D. W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143. https://doi.org/10.1016/j.lwt.2010.03.004

List of Figures

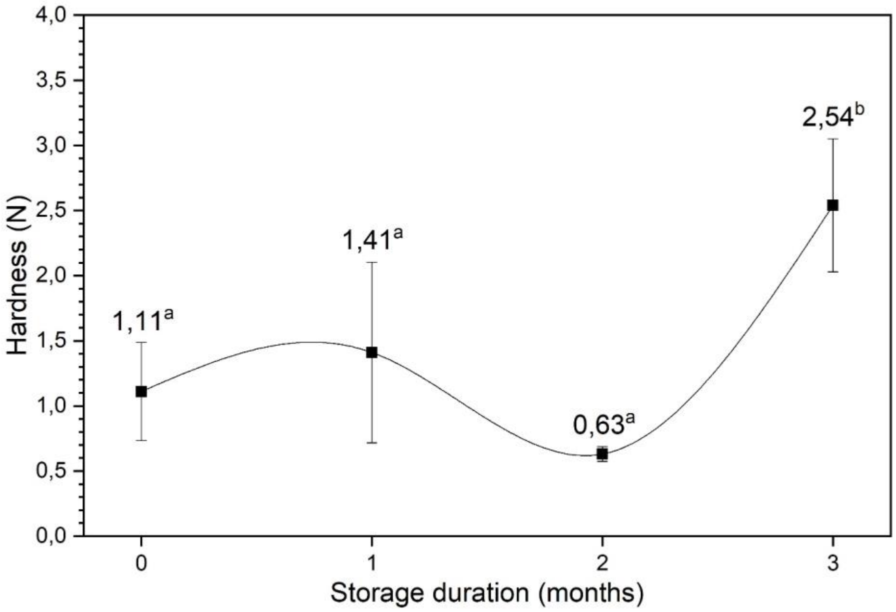


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

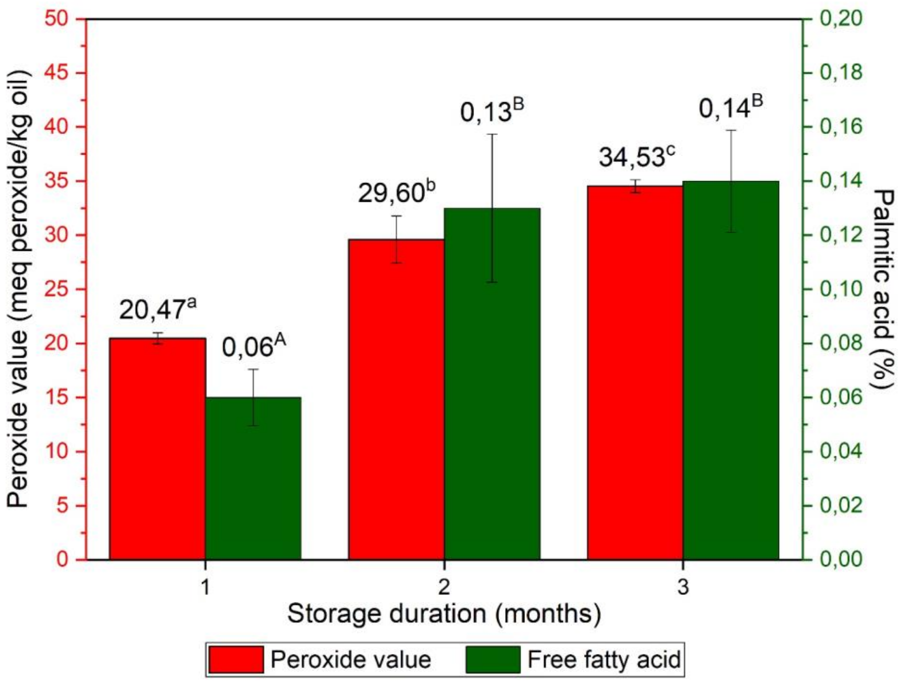


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

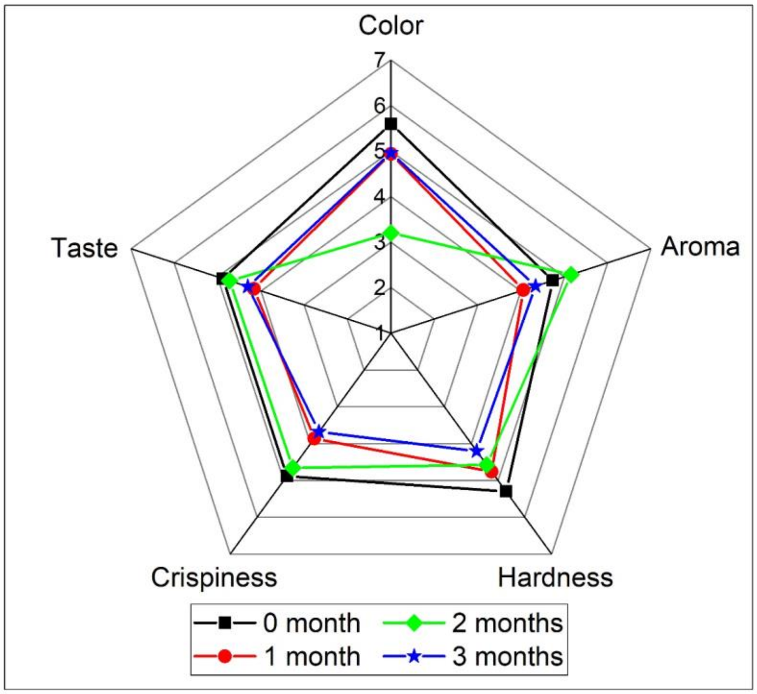


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45,13 ± 7,46 [a]	20,87 ± 15,91[a]
1	48,83 ± 3,27 [a]	25,66 ± 9,51[a]
2	28,68 ± 7,95 [a]	58,45 ± 2,47[b]
3	27,75 ± 10,13 [a]	57,94 ± 24,71[b]

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Table 2. Color of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Color		
	L*	*a**	*b**
0	71,55 ± 4,08[ab]	2,95 ± 0,78[a]	32,08 ± 3,02[b]
1	67,98 ± 2,78[a]	4,62 ± 1,93[a]	30,79 ± 1,87[b]
2	66,52 ± 1,15[a]	3,21 ± 0,37[a]	25,77 ± 0,98[a]
3	75,20 ± 1,80[b]	4,01 ± 0,30[a]	31,40 ± 1,66[b]

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Commented [Editor5]: Do not use comma as decimal point
Revise all values

Formatted: Highlight

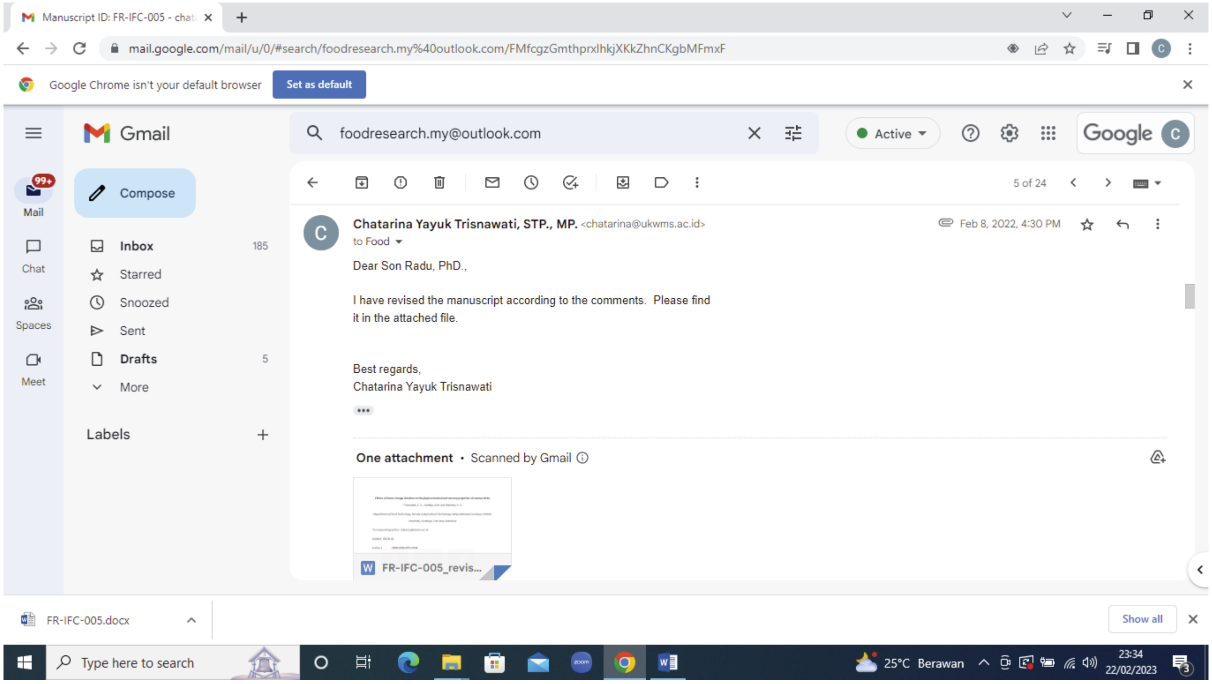
Formatted: Highlight

Formatted: Highlight

2.

Bukti konfirmasi submit revisi artikel pertama

(8 Februari 2022)



Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
to Food
Feb 8, 2022, 4:30 PM

Dear Son Radu, PhD.,

I have revised the manuscript according to the comments. Please find it in the attached file.

Best regards,
Chatarina Yayuk Trisnawati

One attachment • Scanned by Gmail

FR-IFC-005_revis...

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

[1*]Trisnawati, C. Y., [1]Sutedja, A.M., and [1]Kaharso, V. C.

[1]Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia

*Corresponding author: chatarina@ukwms.ac.id

Authors' ORCID ID:

Author 1 : 0000-0003-0595-9504

Author 2 : 0000-0002-7734-7163

Author 3 : 0000-0002-7373-7383

Abstract

Cassava sticks is a processed food made from cassava that has similar characteristics to French fries. However, cassava sticks are also classified as perishable food, so it is required to employ other process that might increases its preservation, such as frozen storage. In this study, the cassava stick was stored at -20°C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen condition significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat

oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference ($P>0.05$) with other samples.

Keywords: Cassava, Cassava stick, Frozen storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as *tiwul, gatot, gaplek, gethuk, tapai*, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown color, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one of the most used methods (Rahman and Velez-Ruiz, 2007). Generally, frozen storage temperature is 0°F (-18°C) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Several studies stated that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Celli *et al*., 2016; Medic *et al*., 2018; Sattar *et al*., 2015). However, based on our knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2), purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassava tubers were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98°C, 15 min) and cooled to room temperature before being pre-fried (170°C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20°C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket

was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of fried cassava stick was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g of fried cassava sticks were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink color occurred

for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g of fried cassava sticks were mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow color had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue color disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Color

The color of fried cassava stick was identified using a color reader (Color Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated

by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were color, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at $P<0.05$.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference ($P>0.05$) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al.* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also stated that freezing significantly ($P<0.05$) influenced the moisture content of the fried potato (Adedeji and Ngadi, 2017), lamb (Coombs *et al.*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at $-18^{o}C$ and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al*., 1988). Table 1 showed that frozen storage duration significantly increased ($P<0,05$) the oil absorption of cassava sticks. Cassava stick

stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference with cassava stick stored frozen for 3 months (57.84%). In Adedeji's and Ngadi's (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also stated that there was no interaction between storage duration and freezing method, which contradicts our study.

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Dana and Saguy, 2006; Rimac-Brncic *et al*., 2004). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al*., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that figure, frozen storage duration significantly affected ($P<0.05$) the hardness of the cassava sticks. Cassava stick that was stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). Our results were in accordance with the results of Adedeji and Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. Our statement was supported by a similar study by Yu *et al*. (2010), where the hardness

of cooked rice increased continually with the amylopectin retrogradation during frozen storage. Based on those findings, amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased ($P<0.05$) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference ($P>0.05$) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased ($P<0.05$) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with

oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri and Mangaraj, 2012).

3.4. Color properties

Color is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Patras *et al*., 2011; Hutchings, 2002). In this study, the color of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* color attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Research by Oner and Wall (2012) also found that frozen storage significantly influenced (P<0.05) the color of French fries. The color change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the color of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown color in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust color of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the color attribute was the 0-month storage cassava sticks (5.60) and significantly difference ($P<0.05$) with other samples (3.20 – 4.96). The decrease in panelists' color preference was due to the color changes in cassava sticks that tend to be darker and brownish than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased ($P<0.05$) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with our objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference ($P>0.05$) with 2 months stored cassava stick (4.66) but showed significant difference ($P<0.05$) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced ($P<0.05$) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference ($P>0.05$) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect ($P>0.05$) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change.

The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface color, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153.

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32.

Association of Analytical Communities. (2006). Official Methods of Analysis of AOAC International 18th Edition. Gaithersburg: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216.

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304,

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb *M. longissimus lumborum* quality and safety parameters. *Meat Science*, 134, 86–97.

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607.

Dana, D. dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272.

Fellows, P.J. (1990). Food Processing Technology Principles and Practice. London: Ellis Horwood

Fennema, G.R. (1985). Principles of Food Science. New York: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*.

Hutchings, J.B. 2002. The Perception and Sensory Assessment of Colour. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). Pengawasan Mutu Makanan. Malang: UB Press

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49.

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127.

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373.

Mohamed, S., Abdullah, N. and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252.

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9.

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In Handbook of Food Preservation Second Edition. CRC Press.

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241.

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168.

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). Prosedur Analisa untuk Bahan Makanan dan Pertanian. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225.

WFLO Commodity Storage Manual. (2008). Frozen Foods Handling & Storage. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143.

List of Figures

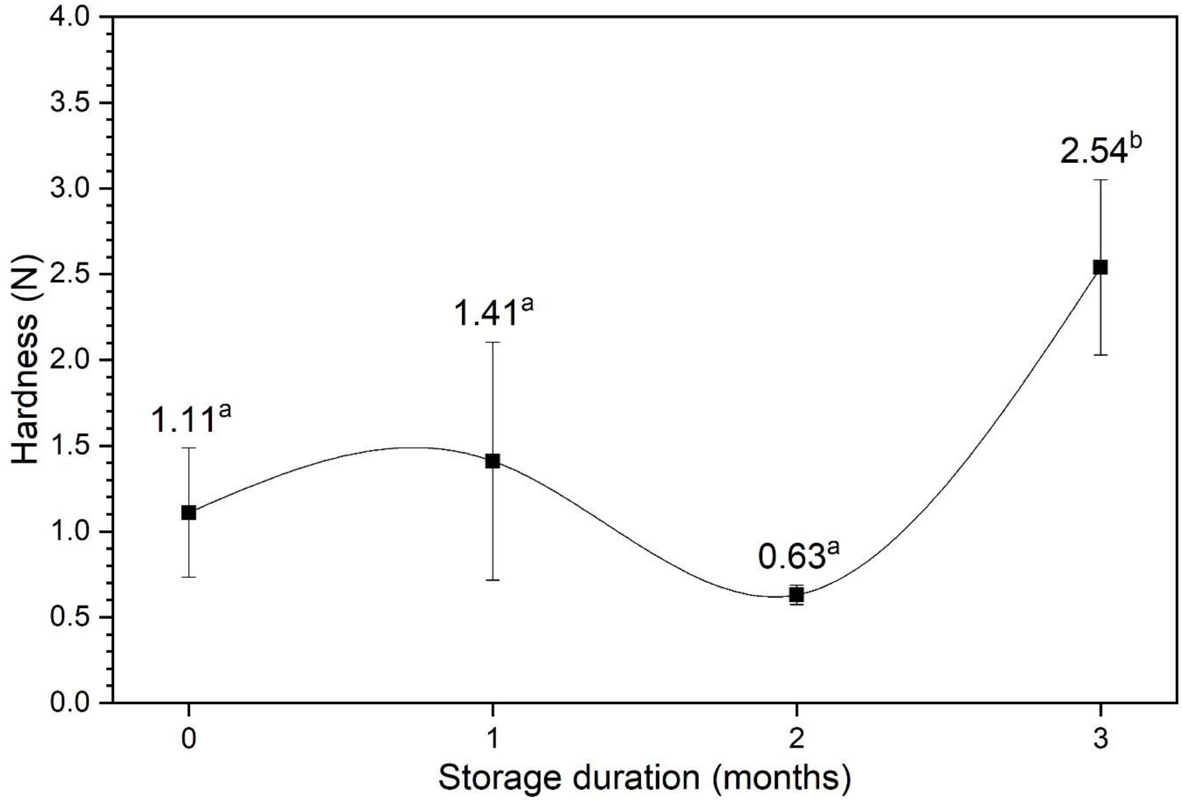


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

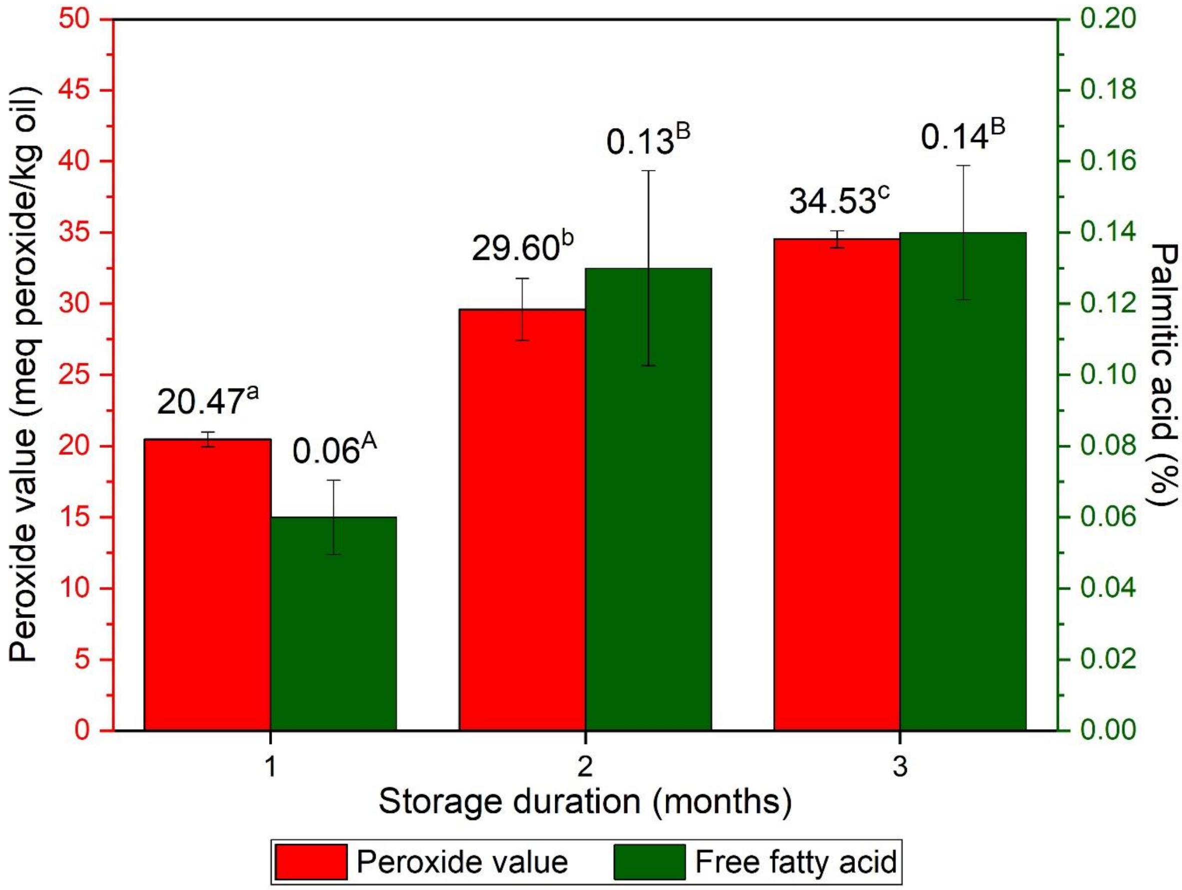


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

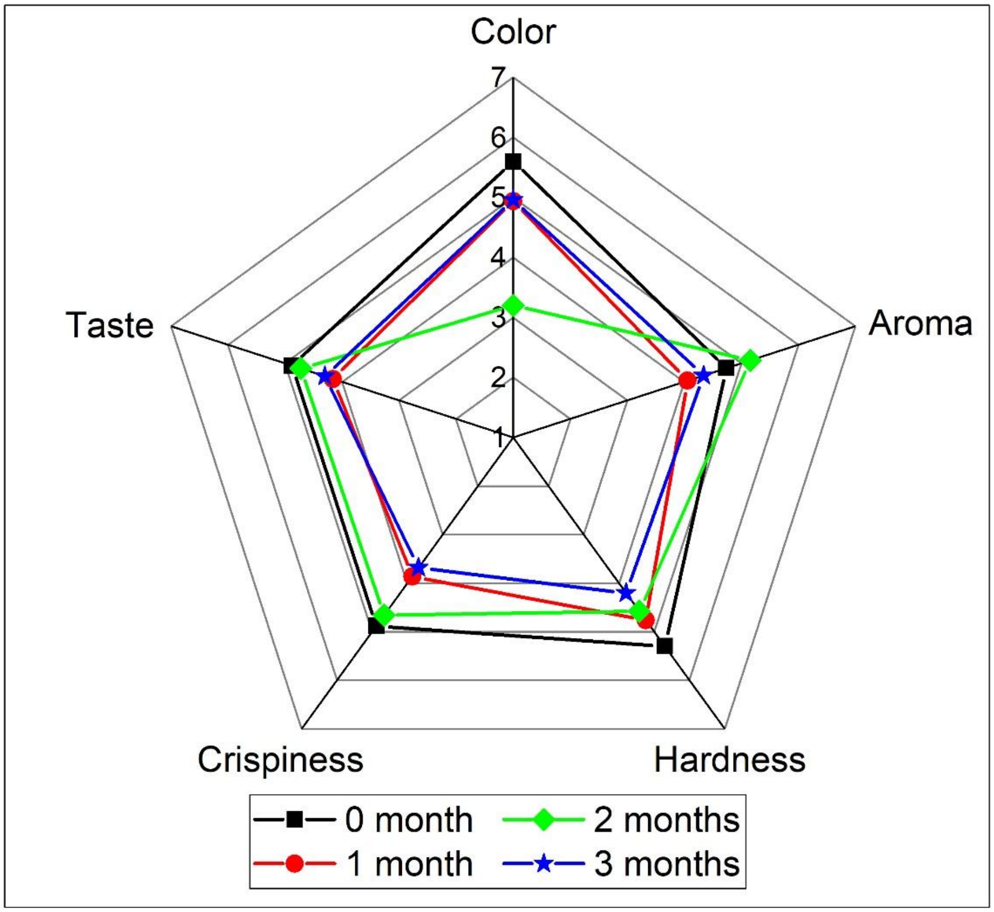


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13 ± 7.46 ^{a}	20.87 ± 15.91^{a}
1	48.83 ± 3.27 ^{a}	25.66 ± 9.51^{a}
2	28.68 ± 7.95 ^{a}	58.45 ± 2.47^{b}
3	27.75 ± 10.13 ^{a}	57.94 ± 24.71^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Table 2. Color of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Color		
	L*	*a**	*b**
0	71.55 ± 4.08^{ab}	2.95 ± 0.78^{a}	32.08 ± 3.02^{b}
1	67.98 ± 2.78^{a}	4.62 ± 1.93^{a}	30.79 ± 1.87^{b}
2	66.52 ± 1.15^{a}	3.21 ± 0.37^{a}	25.77 ± 0.98^{a}
3	75.20 ± 1.80^{b}	4.01 ± 0.30^{a}	31.40 ± 1.66^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

3.

Bukti konfirmasi penerimaan submit revisi artikel

(9 Februari 2022)

Manuscript ID: FR-IFC-005 - chat

mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF

Food Research <foodresearch.my@outlook.com> Feb 9, 2022, 12:34 AM
to me

Dear Dr. Chatarina Yayuk Trisnawati,

This message is to acknowledge receipt of the above manuscript that you submitted via email to Food Research. Your manuscript has been successfully checked-in. Please refer to the assigned manuscript ID number in any correspondence with the Food Research Editorial Office or with the editor.

Your paper will be reviewed by three or more reviewers assigned by the Food Research editorial board and final decision made by the editor will be informed by email in due course. Reviewers' suggestions and editor's comments will be then made available via email attached file. You can monitor the review process for your paper by emailing us on the "Status of my manuscript".

If your manuscript is accepted for publication, Food Research editorial office will contact you for the production of your manuscript.

Thank you very much for submitting your manuscript to Food Research.

Manuscript ID: FR-IFC-005 - chat

mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF

Sincerely,

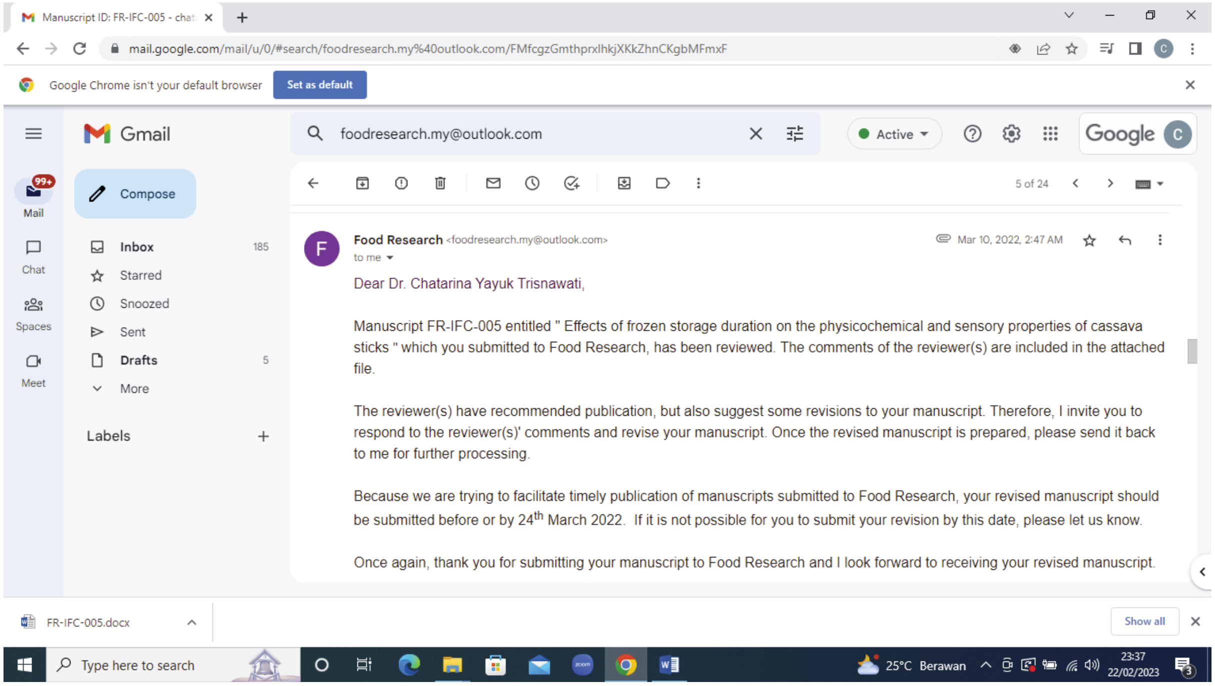
Son Radu, Ph.D.
Chief Editor
Email: foodresearch.my@outlook.com

From: Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>

4.

Bukti konfirmasi review dan hasil review dari 2 Reviewer

(10 Maret 2022)



Manuscript ID: FR-IFC-005 - chat

mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF

5 of 24

Food Research <foodresearch.my@outlook.com> Mar 10, 2022, 2:47 AM

to me

Dear Dr. Chatarina Yayuk Trisnawati,

Manuscript FR-IFC-005 entitled " Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks " which you submitted to Food Research, has been reviewed. The comments of the reviewer(s) are included in the attached file.

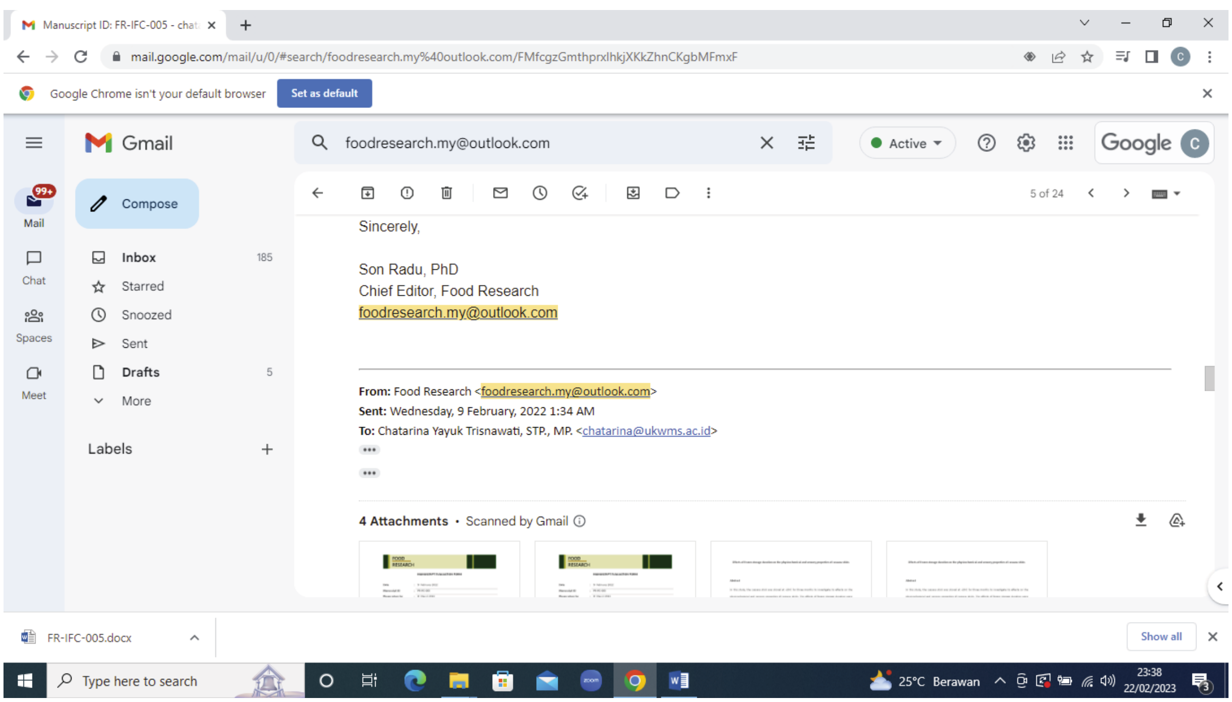
The reviewer(s) have recommended publication, but also suggest some revisions to your manuscript. Therefore, I invite you to respond to the reviewer(s)' comments and revise your manuscript. Once the revised manuscript is prepared, please send it back to me for further processing.

Because we are trying to facilitate timely publication of manuscripts submitted to Food Research, your revised manuscript should be submitted before or by 24th March 2022. If it is not possible for you to submit your revision by this date, please let us know.

Once again, thank you for submitting your manuscript to Food Research and I look forward to receiving your revised manuscript.

FR-IFC-005.docx

23:37 22/02/2023



Manuscript ID: FR-IFC-005 - chat

mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF

5 of 24

Sincerely,

Son Radu, PhD
Chief Editor, Food Research
foodresearch.my@outlook.com

From: Food Research <foodresearch.my@outlook.com>
Sent: Wednesday, 9 February, 2022 1:34 AM
To: Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>

4 Attachments • Scanned by Gmail

FR-IFC-005.docx

23:38 22/02/2023

FOOD
RESEARCH

MANUSCRIPT EVALUATION FORM

Date : 9th February 2022

Manuscript ID : FR-IFC-005

Please return by : 9th March 2022

Title of Manuscript : Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

1. IF YOU CANNOT REVIEW THIS MANUSCRIPT OR MEET THE DEADLINE, PLEASE INFORM US WITHOUT DELAY.

2. Your review should consider the article's scholarly merit including originality of the research issue and/or methodology, adequacy and rigor of the research methodology and techniques used, quality and rigor of data analysis, comprehensiveness of literature review, and the readability and presentation of the article. Please provide detailed and specific comments to all items. Also, where appropriate please provide suggestions for revision.

COMMENT SHEET

Using item 2 in page 1 as a guideline, please indicate the reasons for your recommendations. Most author(s) will appreciate frankness, combined with a modicum of tact. Even if you recommend that the manuscript be accepted for publication, please provide some general comments to the author(s).

Evaluation Criteria	Grade				
	A (Excellent)	B	C	D	E (Worst)
1. Appropriateness of Contents	√				
2. Originality of Topic	√				
3. Manuscript Format	√				
4. Research Methodology		√			
5. Data Analysis	√				
6. Relevance to the Journal	√				

(REVIEWER'S SECTION) REVIEWER'S COMMENTS/SUGGESTIONS		(AUTHOR'S SECTION) AUTHOR'S ACTION/RESPONSE *NOTE FOR AUTHOR: Please state your response to the reviewer's comments/suggestion below
1.	**Title** *It should reflect the article*	
2.	**Abstract** *Background, Aim, Methodology and Conclusion*	
3.	**Keywords** *Min. 3 and Max. 6*	
4.	**Introduction** *Concise with sufficient background*	
5.	**Research design/Methodology** *Clearly described and reproducible* The author has explained well the method of oil absorption analysis. The authors must describe the sample was analyzed for hardness, free fatty acid, peroxide value, and the color is pre-fried cassava stick or fried cassava stick?	
6.	**Data Analysis** *Results well presented and discussed* Line number 116, "the moisture content of fried cassava sticks is shown in Table 1", Is it only the water content of fried cassava sticks? Line number 61, all pre-fried and fried cassava stick samples were analyzed the moisture content	
7.	**Conclusion** *A clear summary of the study*	
8.	**References** *References should follow the journal's format*	

9.	**English Proficiency**	
10.	**Additional comments/suggestions by the reviewer about the article** The author has explained well the work investigated the characterization of the cassava sticks due to frozen storage duration. However, some things need to be fixed to be accepted.	

Overall Evaluation

Please choose one.

Accept		**Major Revision**	
Minor Revision	√	**Reject**	

Please return Manuscript and/or Review Comments to:

Food Research

Email: foodresearch.my@outlook.com

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

Abstract

In this study, the cassava stick was stored at -20°C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that the frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance and had no significant difference ($P>0.05$) with other samples.

Keywords: Cassava, Cassava stick, Frozen Storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides

carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as tiwul, gatot, gaplek, gethuk, tapai, and cassava chips. Furthermore, it can also be processed to a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown color, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Despite those processes, other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one of the most used methods (Rahman & Velez-Ruiz, 2007). Generally, frozen storage temperature is 0^{o}F (-18^{o}C) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Several studies stated that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Celli *et al*., 2016; Medic *et al*., 2018; Sattar *et al*., 2015). However, based on our knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2) and purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassavas were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98^{o}C, 15 min) and cooled to room temperature before being pre-fried (170^{o}C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20^{o}C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All pre-fried and fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of the samples was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g samples were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink color occurred for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g sample was mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow color had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution

was added and the titration continued until the blue color disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Color

Cassava stick color was identified using a color reader (Color Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were color, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at $P<0.05$.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference (P>0.05) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also stated that freezing significantly (P<0.05) influenced the moisture content of the fried potato (Adedeji & Ngadi, 2017), lamb (Coombs *et al*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18^{o}C and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al*., 1988). Table 1 showed that frozen storage duration significantly increased (P<0,05) the oil absorption of cassava sticks. Cassava stick stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference on cassava stick stored frozen for 3 months (57.84%). In Adedeji & Ngadi (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also stated that there was no interaction between storage duration and freezing method, which contradicts our study.

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Dana & Saguy, 2006; Rimac-Brncic *et al*., 2004). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et*

al., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that Figure, frozen storage duration significantly affected ($P<0.05$) the hardness of the cassava sticks. Cassava stick that stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). Our results were in accordance with the results of Adedeji & Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. Our statement was supported by a similar study by Yu *et al*. (2010), where the hardness of cooked rice increased continually with the amylopectin retrogradation during frozen storage. So that, based on those findings, it indicates that amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/ kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased (P<0.05) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference (P>0.05) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased (P<0.05) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri & Mangaraj, 2012).

3.4. Color properties

Color is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Patras *et al*., 2011; Hutchings, 2002). In this study, the color of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* color attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All

samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Our results showed that the color of cassava sticks was greatly affected by the frozen storage duration. Research by Oner & Wall (2012) also found that frozen storage significantly influenced (P<0.05) the color of French fries. The color change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the color of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown color in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust color of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the color attribute was the 0-month storage cassava sticks (5.60) and significantly difference (P<0.05) with other samples (3.20 – 4.96). The decrease in panelists' color preference was due to the color changes in cassava sticks that tend to be darker and browny than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased (P<0.05) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with our objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference (P>0.05) with 2 months stored cassava stick (4.66) but showed significant difference (P<0.05) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced (P<0.05) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference (P>0.05) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect (P>0.05) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change. The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface color, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153. https://doi.org/10.1016/j.jfoodeng.2008.08.018

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32. https://doi.org/10.1016/j.jfoodeng.2017.08.024

Association of Analytical Communities. (2006). *Official Methods of Analysis of AOAC International 18th Edition*. Gaithersburg: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216. https://doi.org/10.4314/acsj.v12i3.27880

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304, https://doi.org/10.1080/87559129.2015.1075212

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb M. longissimus lumborum quality and safety parameters. *Meat Science*, 134, 86–97. https://doi.org/10.1016/j.meatsci.2017.07.017

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607. https://doi.org/10.1016/j.foodchem.2013.08.132

Dana, D. dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272. https://doi.org/10.1016/j.cis.2006.11.013

Fellows, P.J. (1990). *Food Processing Technology Principles and Practice*. London: Ellis Horwood

Fennema, G.R. (1985). *Principles of Food Science*. New York: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*. https://doi.org/10.1007/s12393-012-9053-0

Hutchings, J.B. 2002. *The Perception and Sensory Assessment of Colour*. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). *Cassava production guidelines for food security and adaptation to climate change in Asia and Africa*. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). *Pengawasan Mutu Makanan*. Malang: UB Press

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49. https://doi.org/10.1007/s13197-011-0257-8

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127. https://doi.org/10.1016/j.meatsci.2018.03.006

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373. https://doi.org/10.1016/S0924-2244(03)00050-5

Mohamed, S., Abdullah, N. and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252. https://doi.org/10.1007/s11947-009-0226-7

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9. https://doi.org/10.1016/j.foodres.2004.07.002

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In *Handbook of Food Preservation Second Edition*. CRC Press. https://doi.org/10.1201/9781420017373.ch26

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241. https://doi.org/10.1016/j.jfoodeng.2003.10.006

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168. https://doi.org/10.1007/s002170050017

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). *Prosedur Analisa untuk Bahan Makanan dan Pertanian*. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225. https://doi.org/10.1016/S0950-3293(01)00039-8

WFLO Commodity Storage Manual. (2008). *Frozen Foods Handling & Storage*. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143. https://doi.org/10.1016/j.lwt.2010.03.004

List of Figures

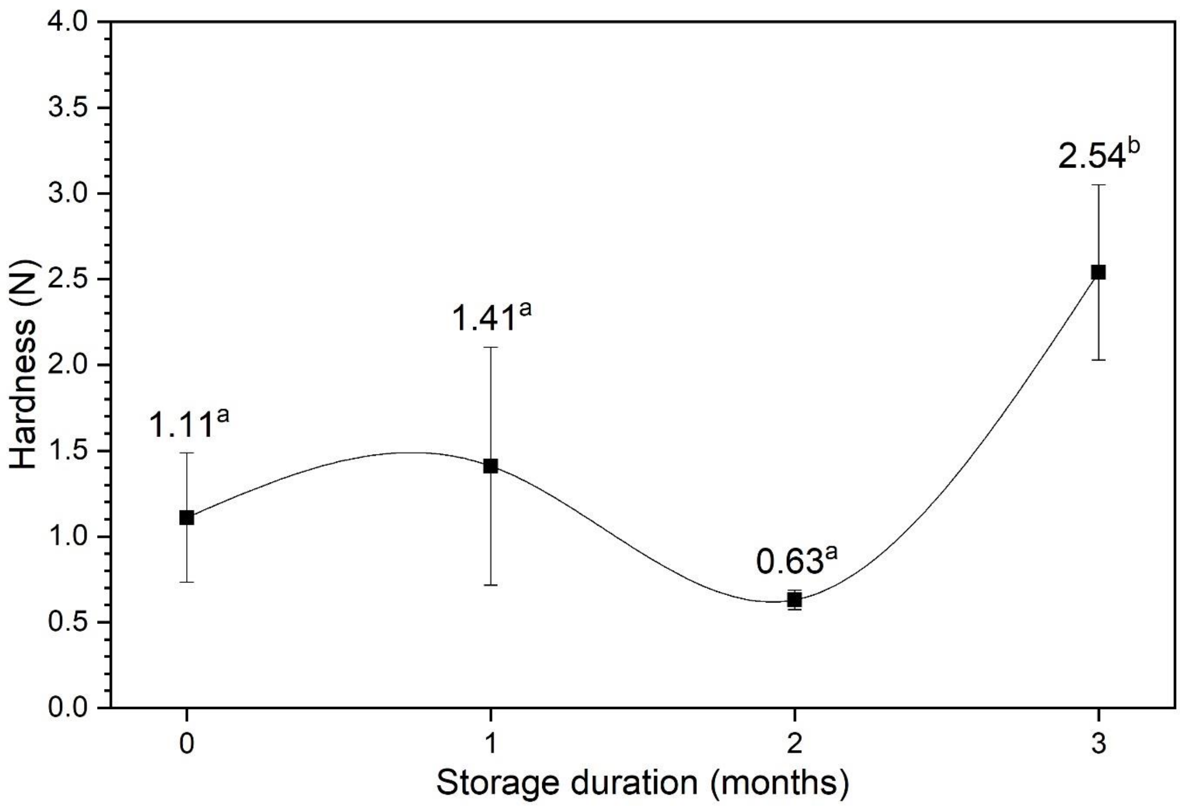


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

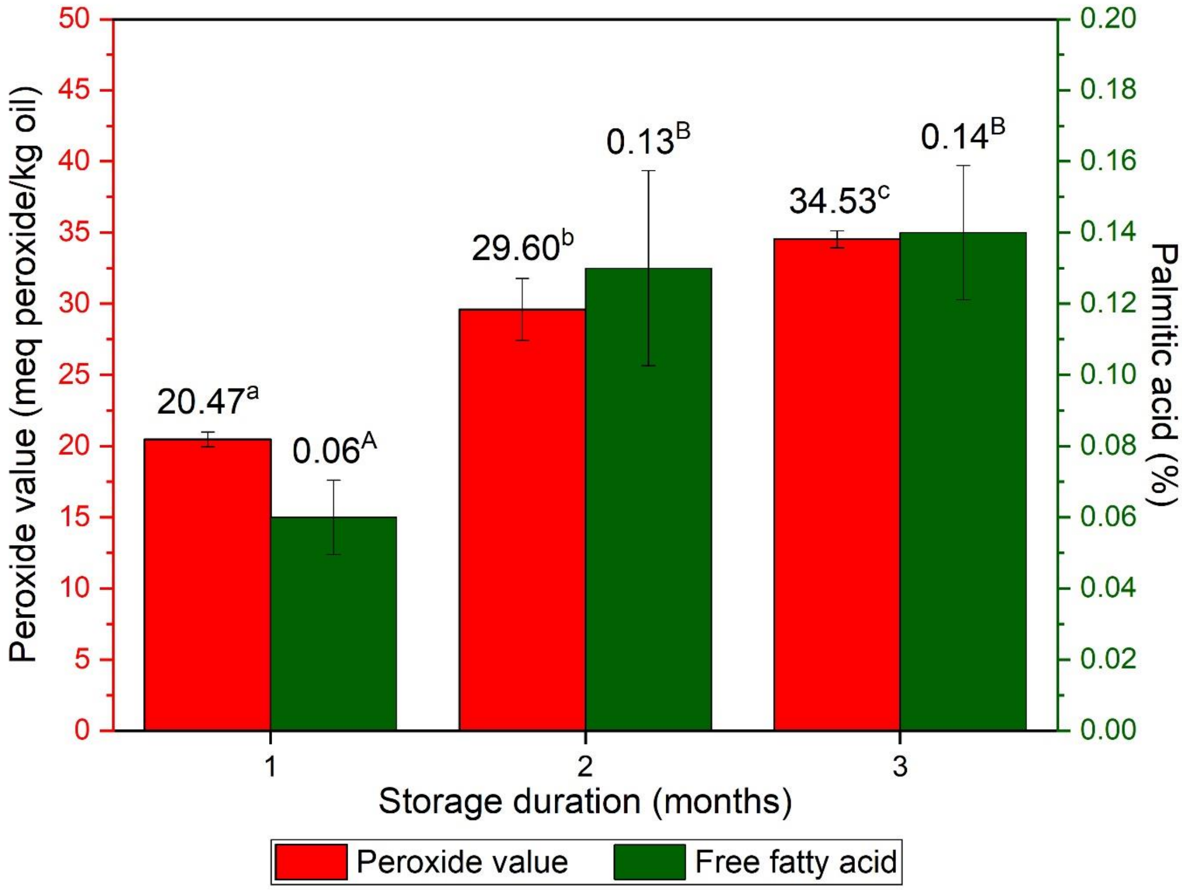


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

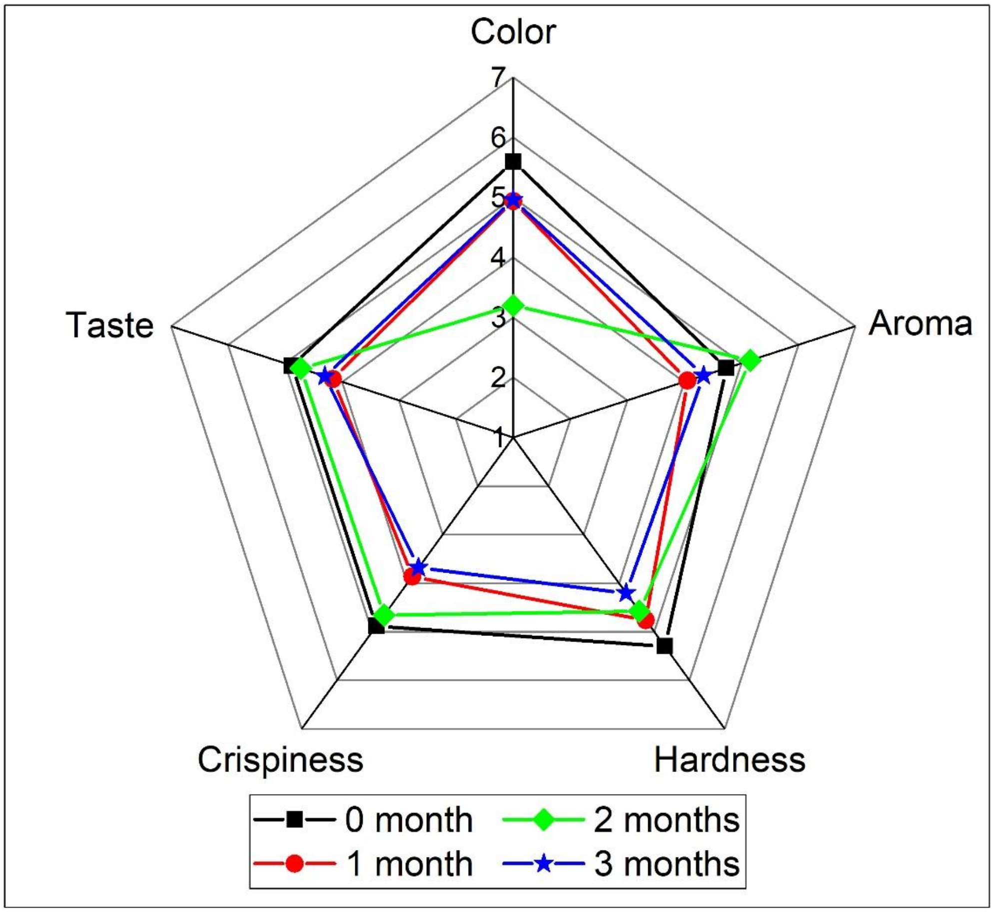


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13 ± 7.46 ^{a}	20.87 ± 15.91^{a}
1	48.83 ± 3.27 ^{a}	25.66 ± 9.51^{a}
2	28.68 ± 7.95 ^{a}	58.45 ± 2.47^{b}
3	27.75 ± 10.13 ^{a}	57.94 ± 24.71^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

Table 2. Color of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Color		
	L*	*a**	*b**
0	71.55 ± 4.08^{ab}	2.95 ± 0.78^{a}	32.08 ± 3.02^{b}
1	67.98 ± 2.78^{a}	4.62 ± 1.93^{a}	30.79 ± 1.87^{b}
2	66.52 ± 1.15^{a}	3.21 ± 0.37^{a}	25.77 ± 0.98^{a}
3	75.20 ± 1.80^{b}	4.01 ± 0.30^{a}	31.40 ± 1.66^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

FOOD RESEARCH

MANUSCRIPT EVALUATION FORM

Date : 9th February 2022

Manuscript ID : FR-IFC-005

Please return by : 9th March 2022

Title of Manuscript : Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

1. IF YOU CANNOT REVIEW THIS MANUSCRIPT OR MEET THE DEADLINE, PLEASE INFORM US WITHOUT DELAY.

2. Your review should consider the article's scholarly merit including originality of the research issue and/or methodology, adequacy and rigor of the research methodology and techniques used, quality and rigor of data analysis, comprehensiveness of literature review, and the readability and presentation of the article. Please provide detailed and specific comments to all items. Also, where appropriate please provide suggestions for revision.

COMMENT SHEET

Using item 2 in page 1 as a guideline, please indicate the reasons for your recommendations. Most author(s) will appreciate frankness, combined with a modicum of tact. Even if you recommend that the manuscript be accepted for publication, please provide some general comments to the author(s).

Evaluation Criteria	Grade				
	A (Excellent)	B	C	D	E (Worst)
1. Appropriateness of Contents	√				
2. Originality of Topic	√				
3. Manuscript Format	√				
4. Research Methodology	√				
5. Data Analysis	√				
6. Relevance to the Journal		√			

(REVIEWER'S SECTION) REVIEWER'S COMMENTS/SUGGESTIONS		(AUTHOR'S SECTION) AUTHOR'S ACTION/RESPONSE *NOTE FOR AUTHOR: Please state your response to the reviewer's comments/suggestion below
1.	**Title** *It should reflect the article* Acceptable.	
2.	**Abstract** *Background, Aim, Methodology and Conclusion* Lack of background.	
3.	**Keywords** *Min. 3 and Max. 6* Acceptable	
4.	**Introduction** *Concise with sufficient background* Acceptable.	
5.	**Research design/Methodology** *Clearly described and reproducible* Acceptable.	
6.	**Data Analysis** *Results well presented and discussed* Acceptable. A sentence or two might need double-checking.	
7.	**Conclusion** *A clear summary of the study* Acceptable.	
8.	**References** *References should follow the journal's format* Did not follow journal format.	
9.	**English Proficiency** Acceptable.	

10.	**Additional comments/suggestions by the reviewer about the article** Please remove page number.	

Overall Evaluation

Please choose one.

Accept		**Major Revision**	
Minor Revision	√	**Reject**	

Please return Manuscript and/or Review Comments to:

Food Research

Email: foodresearch.my@outlook.com

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

Abstract

In this study, the cassava stick was stored at -20^{o}C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen significantly increased (P<0.05) the oil absorption and had no effect (P>0.05) on the moisture content. A significant alteration (P<0.05) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced (P<0.05) the lightness and yellowness, but not the redness (P>0.05) of cassava sticks. Fat oxidation also occurred during storage, marked by a significant increase (P<0.05) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that ~~the~~ frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference (P>0.05) with other samples.

Commented [P1]: condition

Keywords: Cassava, Cassava stick, Frozen Storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides

carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100 g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as tiwul, gatot, gaplek, gethuk, tapai, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Commented [P2]: Italic

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown color, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). ~~Despite those processes,~~ other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one of the most used methods (Rahman & Velez-Ruiz, 2007). Generally, frozen storage temperature is 0^{o}F (-18^{o}C) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Commented [P3]: Please refrain from using '&'

Several studies stated that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Celli *et al*., 2016; Medic *et al*., 2018; Sattar *et al*., 2015). However, based on our knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2) ~~and~~ purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassavas were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98^{o}C, 15 min) and cooled to room temperature before being pre-fried (170^{o}C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20^{o}C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All pre-fried and fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of the samples was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g samples were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink color occurred for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g sample was mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow color had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution

was added and the titration continued until the blue color disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Color

Cassava stick color was identified using a color reader (Color Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were color, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at $P<0.05$.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference (P>0.05) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also stated that freezing significantly (P<0.05) influenced the moisture content of the fried potato (Adedeji & Ngadi, 2017), lamb (Coombs *et al*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18^{o}C and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Commented [P4]: Put period after *et al*

Formatted: Highlight

Formatted: Highlight

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al*., 1988). Table 1 showed that frozen storage duration significantly increased (P<0,05) the oil absorption of cassava sticks. Cassava stick stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference on cassava stick stored frozen for 3 months (57.84%). In Adedeji's & Ngadi's (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also stated that there was no interaction between storage duration and freezing method, which contradicts our study.

Commented [P5]: with

Formatted: Highlight

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Dana & Saguy, 2006; Rimac-Brncic *et al*., 2004). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et*

Formatted: Highlight

al., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that f~~F~~igure, frozen storage duration significantly affected (P<0.05) the hardness of the cassava sticks. Cassava stick that stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). Our results were in accordance with the results of Adedeji & Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. Our statement was supported by a similar study by Yu *et al*. (2010), where the hardness of cooked rice increased continually with the amylopectin retrogradation during frozen storage. ~~So that,~~ based on those findings, ~~it indicates that~~ amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

Commented [P6]: was

Formatted: Highlight

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased (P<0.05) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference (P>0.05) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased (P<0.05) as the frozen storage duration increased (0 – 34.53 meq peroxide/-kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri & Mangaraj, 2012).

Formatted: Highlight

3.4. Color properties

Color is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Patras *et al*., 2011; Hutchings, 2002). In this study, the color of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* color attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All

samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Our results showed that the color of cassava sticks was greatly affected by the frozen storage duration. Research by Oner & Wall (2012) also found that frozen storage significantly influenced (P<0.05) the color of French fries. The color change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the color of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown color in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust color of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the color attribute was the 0-month storage cassava sticks (5.60) and significantly difference (P<0.05) with other samples (3.20 – 4.96). The decrease in panelists' color preference was due to the color changes in cassava sticks that tend to be darker and browny than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased (P<0.05) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with our objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference (P>0.05) with 2 months stored cassava stick (4.66) but

Commented [P7]: Was it greatly affected?

Formatted: Highlight

Commented [P8]: Please use a different adjective showed significant difference (P<0.05) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced (P<0.05) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference (P>0.05) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect (P>0.05) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change. The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface color, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Commented [P9]: Please format according to FR guidelines

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153. https://doi.org/10.1016/j.jfoodeng.2008.08.018

Commented [P10]: Exclude

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32. https://doi.org/10.1016/j.jfoodeng.2017.08.024

Association of Analytical Communities. (2006). *Official Methods of Analysis of AOAC International 18th Edition*. Gaithersburg: AOAC International.

Commented [P11]: Not italicized

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216. https://doi.org/10.4314/acsj.v12i3.27880

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304, https://doi.org/10.1080/87559129.2015.1075212

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb M. longissimus lumborum quality and safety parameters. *Meat Science*, 134, 86–97. https://doi.org/10.1016/j.meatsci.2017.07.017

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607. https://doi.org/10.1016/j.foodchem.2013.08.132

Dana, D. dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272. https://doi.org/10.1016/j.cis.2006.11.013

Fellows, P.J. (1990). *Food Processing Technology Principles and Practice*. London: Ellis Horwood

Fennema, G.R. (1985). *Principles of Food Science*. New York: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*. https://doi.org/10.1007/s12393-012-9053-0

Hutchings, J.B. 2002. *The Perception and Sensory Assessment of Colour*. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). *Cassava production guidelines for food security and adaptation to climate change in Asia and Africa*. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). *Pengawasan Mutu Makanan*. Malang: UB Press

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49. https://doi.org/10.1007/s13197-011-0257-8

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127. https://doi.org/10.1016/j.meatsci.2018.03.006

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373. https://doi.org/10.1016/S0924-2244(03)00050-5

Mohamed, S., Abdullah, N. and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252. https://doi.org/10.1007/s11947-009-0226-7

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9. https://doi.org/10.1016/j.foodres.2004.07.002

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In *Handbook of Food Preservation Second Edition*. CRC Press. https://doi.org/10.1201/9781420017373.ch26

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241. https://doi.org/10.1016/j.jfoodeng.2003.10.006

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168. https://doi.org/10.1007/s002170050017

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). *Prosedur Analisa untuk Bahan Makanan dan Pertanian*. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225. https://doi.org/10.1016/S0950-3293(01)00039-8

WFLO Commodity Storage Manual. (2008). *Frozen Foods Handling & Storage*. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143. https://doi.org/10.1016/j.lwt.2010.03.004

List of Figures

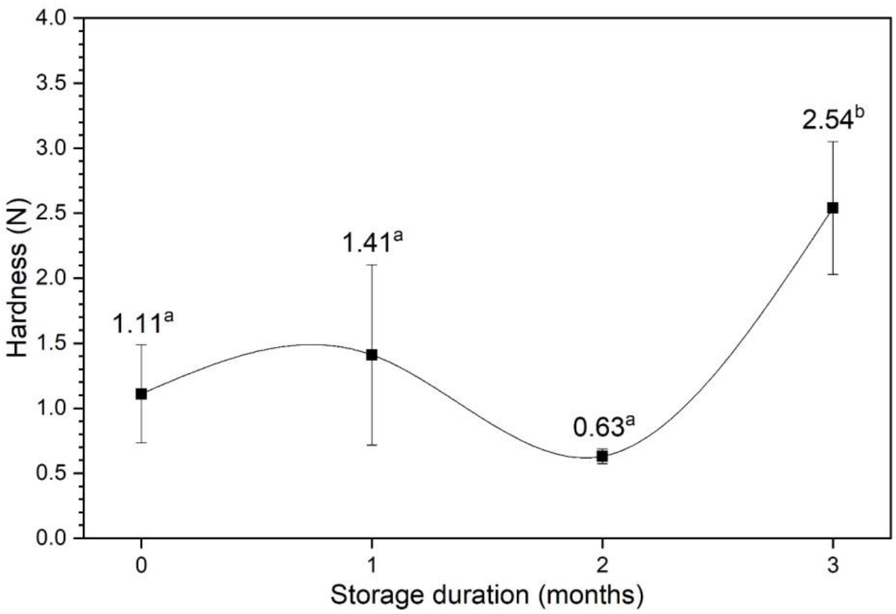


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

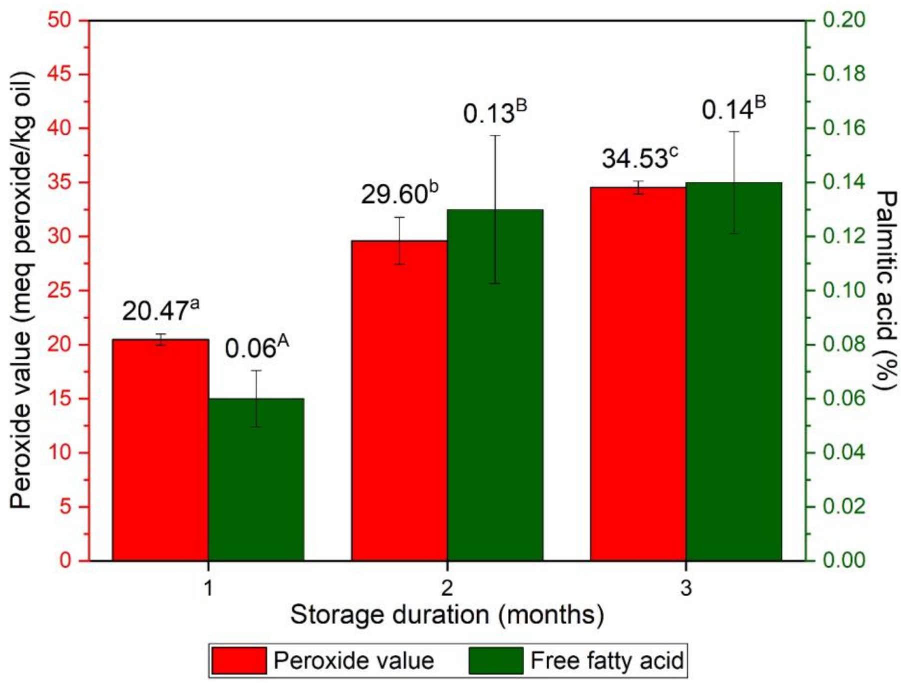


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

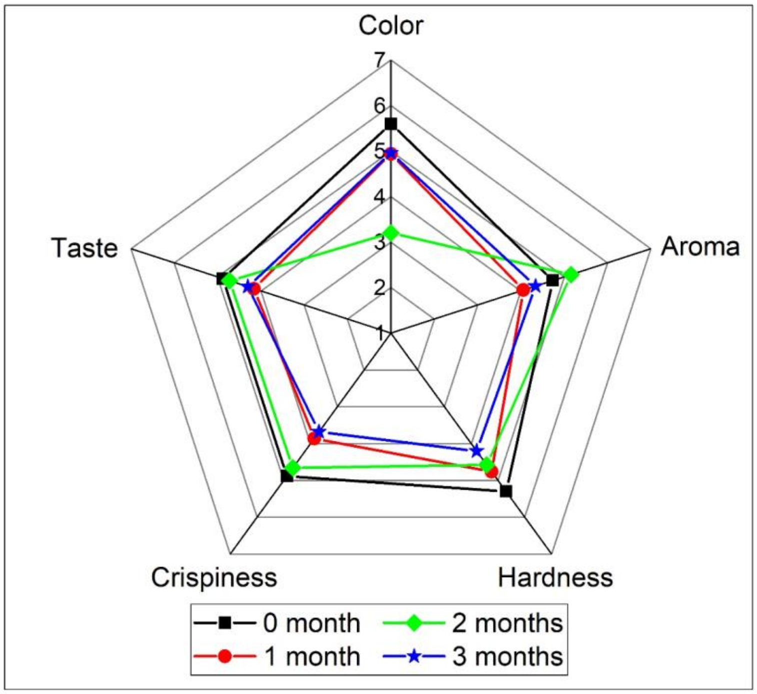


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13 ± 7.46 ^{a}	20.87 ± 15.91^{a}
1	48.83 ± 3.27 ^{a}	25.66 ± 9.51^{a}
2	28.68 ± 7.95 ^{a}	58.45 ± 2.47^{b}
3	27.75 ± 10.13 ^{a}	57.94 ± 24.71^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

Table 2. Color of cassava stick stored frozen in different storage duration

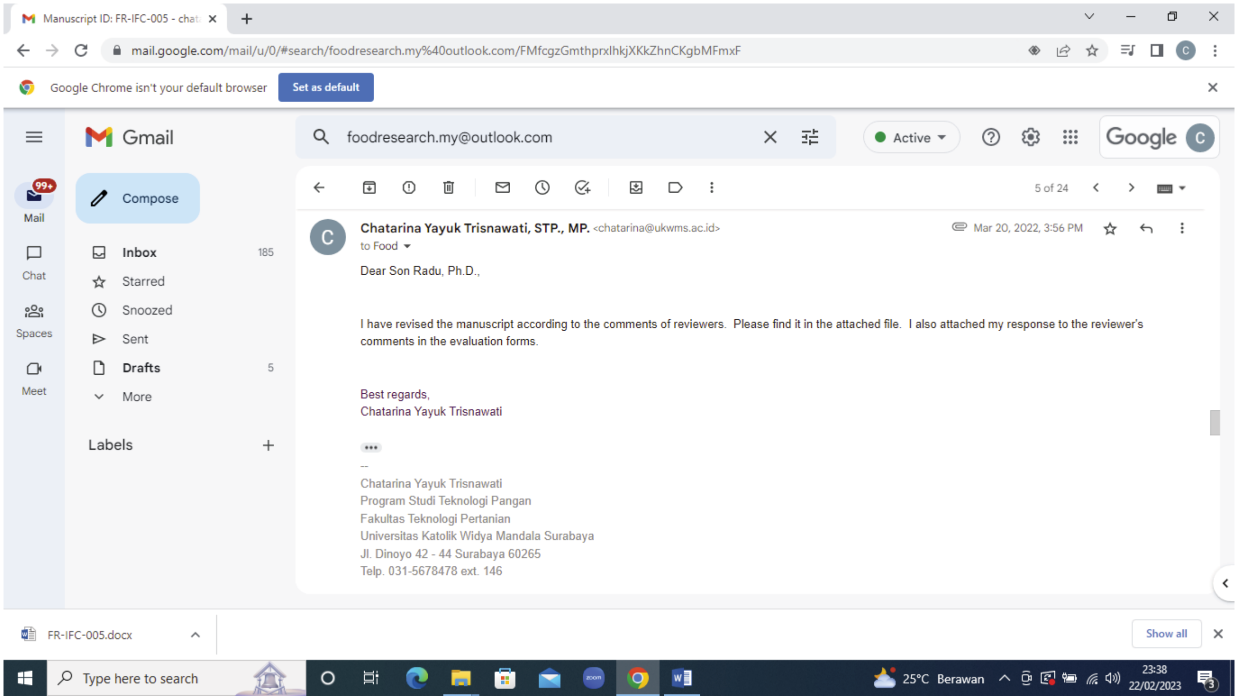
Frozen storage duration (months)	Color		
	L*	*a**	*b**
0	71.55 ± 4.08^{ab}	2.95 ± 0.78^{a}	32.08 ± 3.02^{b}
1	67.98 ± 2.78^{a}	4.62 ± 1.93^{a}	30.79 ± 1.87^{b}
2	66.52 ± 1.15^{a}	3.21 ± 0.37^{a}	25.77 ± 0.98^{a}
3	75.20 ± 1.80^{b}	4.01 ± 0.30^{a}	31.40 ± 1.66^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

5.

Bukti konfirmasi submit revisi artikel kedua, respon kepada reviewer dan artikel yang di-resubmit

(20 Maret 2022)



Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
to Food
Mar 20, 2022, 3:56 PM

Dear Son Radu, Ph.D.,

I have revised the manuscript according to the comments of reviewers. Please find it in the attached file. I also attached my response to the reviewer's comments in the evaluation forms.

Best regards,
Chatarina Yayuk Trisnawati

--
Chatarina Yayuk Trisnawati
Program Studi Teknologi Pangan
Fakultas Teknologi Pertanian
Universitas Katolik Widya Mandala Surabaya
Jl. Dinoyo 42 - 44 Surabaya 60265
Telp. 031-5678478 ext. 146

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

[1*]Trisnawati, C. Y., [1]Sutedja, A.M., and [1]Kaharso, V. C.

[1]*Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia*

*Corresponding author: chatarina@ukwms.ac.id

Authors' ORCID ID:

Author 1 : 0000-0003-0595-9504

Author 2 : 0000-0002-7734-7163

Author 3 : 0000-0002-7373-7383

Abstract

Cassava sticks is a processed food made from cassava that has similar characteristics to French fries. However, cassava sticks are also classified as perishable food, so it is required to employ other process that might increases its preservation, such as frozen storage. In this study, the cassava stick was stored at -20^{o}C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen condition significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat

oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference ($P>0.05$) with other samples.

Keywords: Cassava, Cassava stick, Frozen storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as *tiwul, gatot, gaplek, gethuk, tapai*, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown color, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one

of the most used methods (Rahman and Velez-Ruiz, 2007). Generally, frozen storage temperature is 0^{o}F (-18^{o}C) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Several studies stated that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Celli *et al*., 2016; Medic *et al*., 2018; Sattar *et al*., 2015). However, based on our knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2), purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassava tubers were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98^{o}C, 15 min) and cooled to room temperature before being pre-fried (170^{o}C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20^{o}C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket

was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of fried cassava stick was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g of fried cassava sticks were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink color occurred

for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \text{ x } N_{NaOH} \text{ x } Mr}{W \text{ x } 1000} \text{ x } 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g of fried cassava sticks were mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow color had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue color disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \text{ x } N_{thio} \text{ x } 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Color

The color of fried cassava stick was identified using a color reader (Color Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated

by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were color, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at $P<0.05$.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference ($P>0.05$) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al.* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also stated that freezing significantly ($P<0.05$) influenced the moisture content of the fried potato (Adedeji and Ngadi, 2017), lamb (Coombs *et al.*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18^{o}C and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al*., 1988). Table 1 showed that frozen storage duration significantly increased ($P<0,05$) the oil absorption of cassava sticks. Cassava stick

stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference with cassava stick stored frozen for 3 months (57.84%). In Adedeji's and Ngadi's (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also stated that there was no interaction between storage duration and freezing method, which contradicts our study.

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Dana and Saguy, 2006; Rimac-Brncic *et al*., 2004). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al*., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that figure, frozen storage duration significantly affected ($P<0.05$) the hardness of the cassava sticks. Cassava stick that was stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). Our results were in accordance with the results of Adedeji and Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. Our statement was supported by a similar study by Yu *et al*. (2010), where the hardness

of cooked rice increased continually with the amylopectin retrogradation during frozen storage. Based on those findings, amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased ($P<0.05$) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference ($P>0.05$) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased ($P<0.05$) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with

oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri and Mangaraj, 2012).

3.4. Color properties

Color is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Patras *et al*., 2011; Hutchings, 2002). In this study, the color of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* color attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different ($P>0.05$) with cassava stick that was not stored frozen (71.55) and significantly different ($P<0.05$) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference ($P>0.05$) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower ($P<0.05$) than other samples (30.79 – 32.08).

Research by Oner and Wall (2012) also found that frozen storage significantly influenced ($P<0.05$) the color of French fries. The color change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the color of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown color in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust color of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the color attribute was the 0-month storage cassava sticks (5.60) and significantly difference (P<0.05) with other samples (3.20 – 4.96). The decrease in panelists' color preference was due to the color changes in cassava sticks that tend to be darker and brownish than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased (P<0.05) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with our objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference (P>0.05) with 2 months stored cassava stick (4.66) but showed significant difference (P<0.05) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced (P<0.05) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference (P>0.05) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect (P>0.05) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change.

The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface color, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153.

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32.

Association of Analytical Communities. (2006). Official Methods of Analysis of AOAC International 18th Edition. Gaithersburg: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216.

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304,

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb *M. longissimus lumborum* quality and safety parameters. *Meat Science*, 134, 86–97.

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607.

Dana, D. dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272.

Fellows, P.J. (1990). Food Processing Technology Principles and Practice. London: Ellis Horwood

Fennema, G.R. (1985). Principles of Food Science. New York: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*.

Hutchings, J.B. 2002. The Perception and Sensory Assessment of Colour. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). Pengawasan Mutu Makanan. Malang: UB Press

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49.

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127.

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373.

Mohamed, S., Abdullah, N. and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252.

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9.

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In Handbook of Food Preservation Second Edition. CRC Press.

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241.

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168.

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). Prosedur Analisa untuk Bahan Makanan dan Pertanian. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225.

WFLO Commodity Storage Manual. (2008). Frozen Foods Handling & Storage. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143.

List of Figures

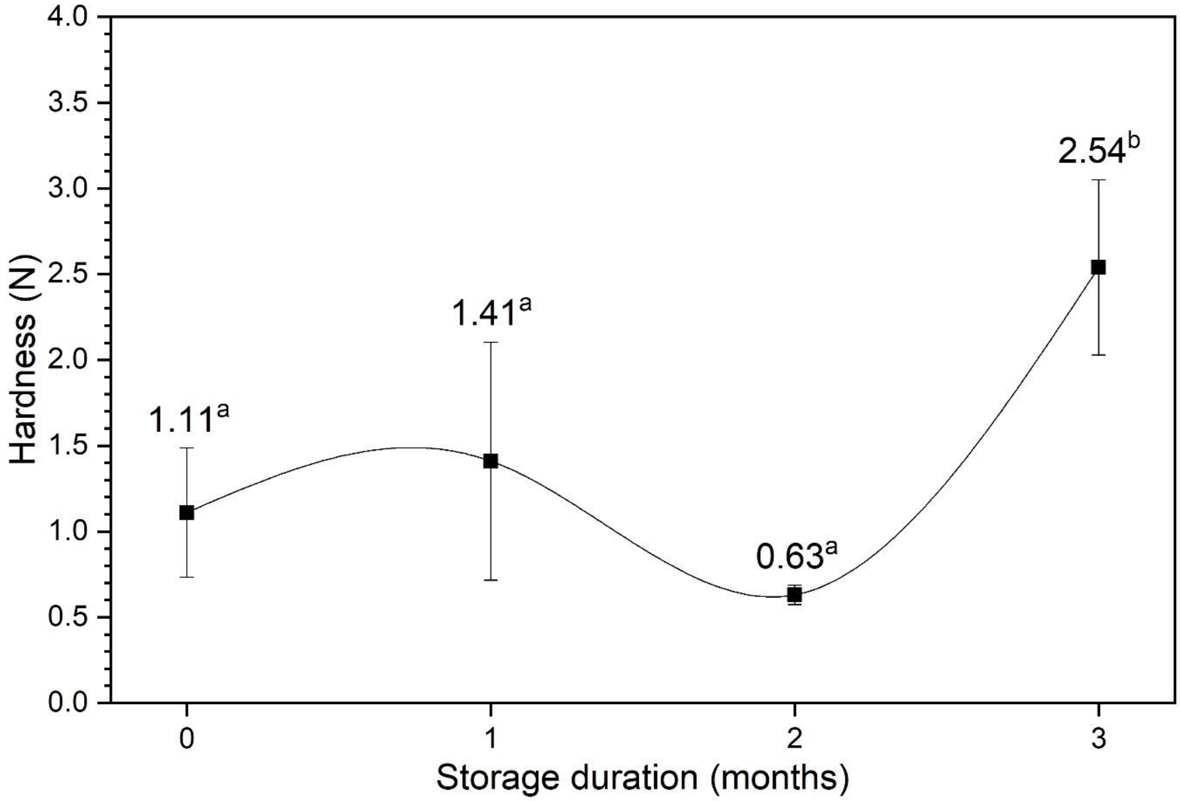


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

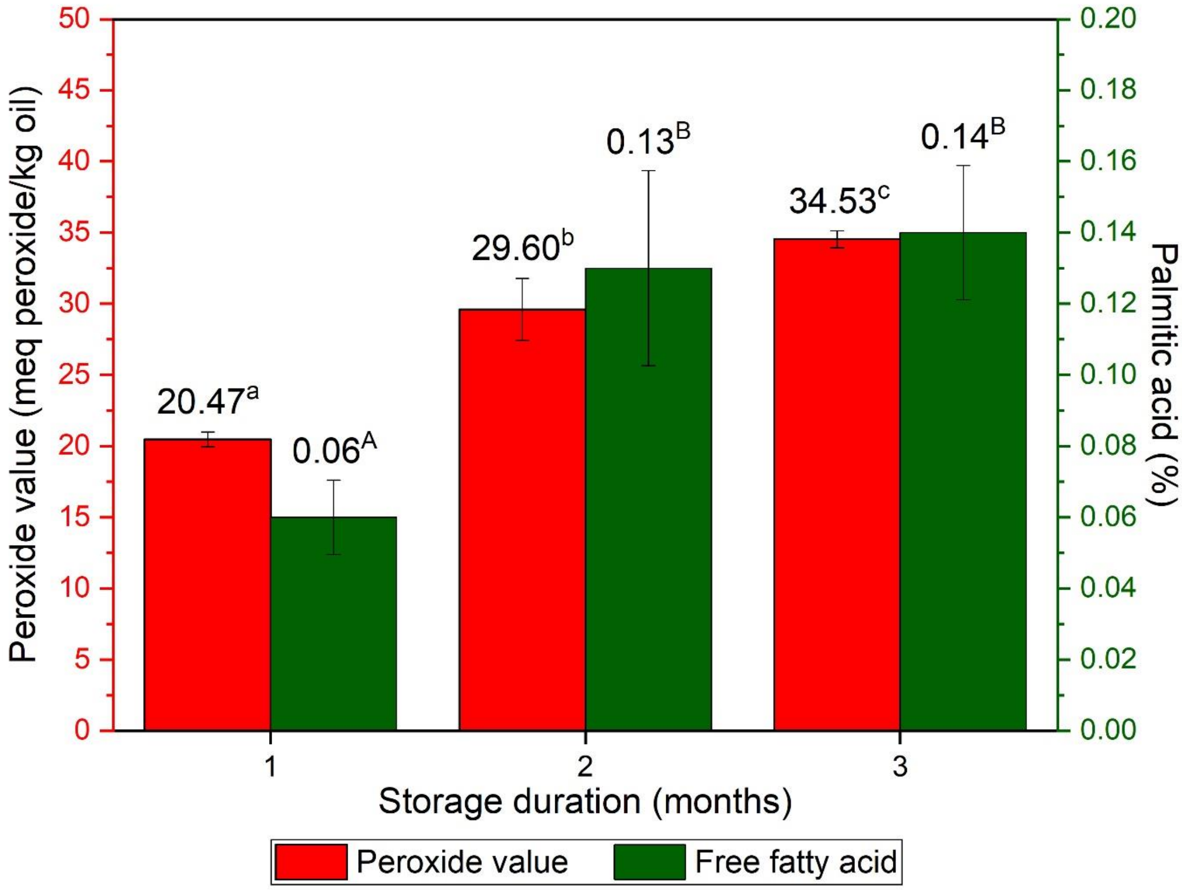


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

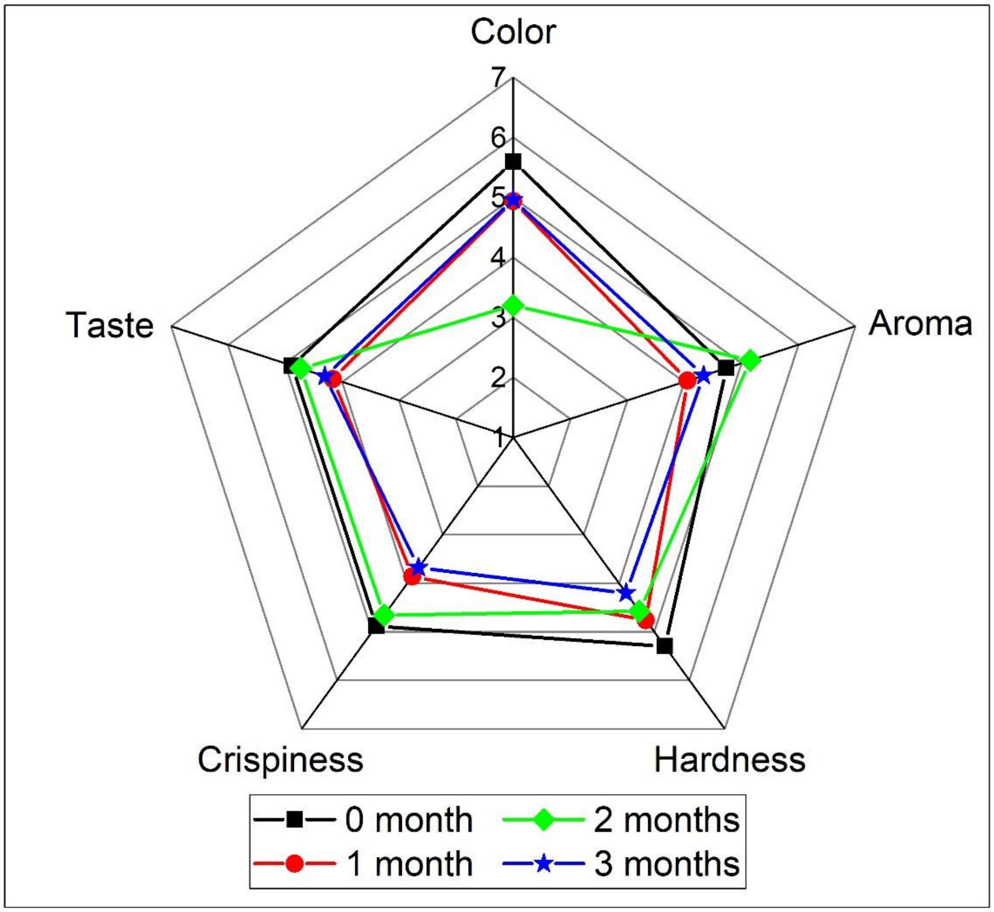


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13 ± 7.46 ^{a}	20.87 ± 15.91^{a}
1	48.83 ± 3.27 ^{a}	25.66 ± 9.51^{a}
2	28.68 ± 7.95 ^{a}	58.45 ± 2.47^{b}
3	27.75 ± 10.13 ^{a}	57.94 ± 24.71^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Table 2. Color of cassava stick stored frozen in different storage duration

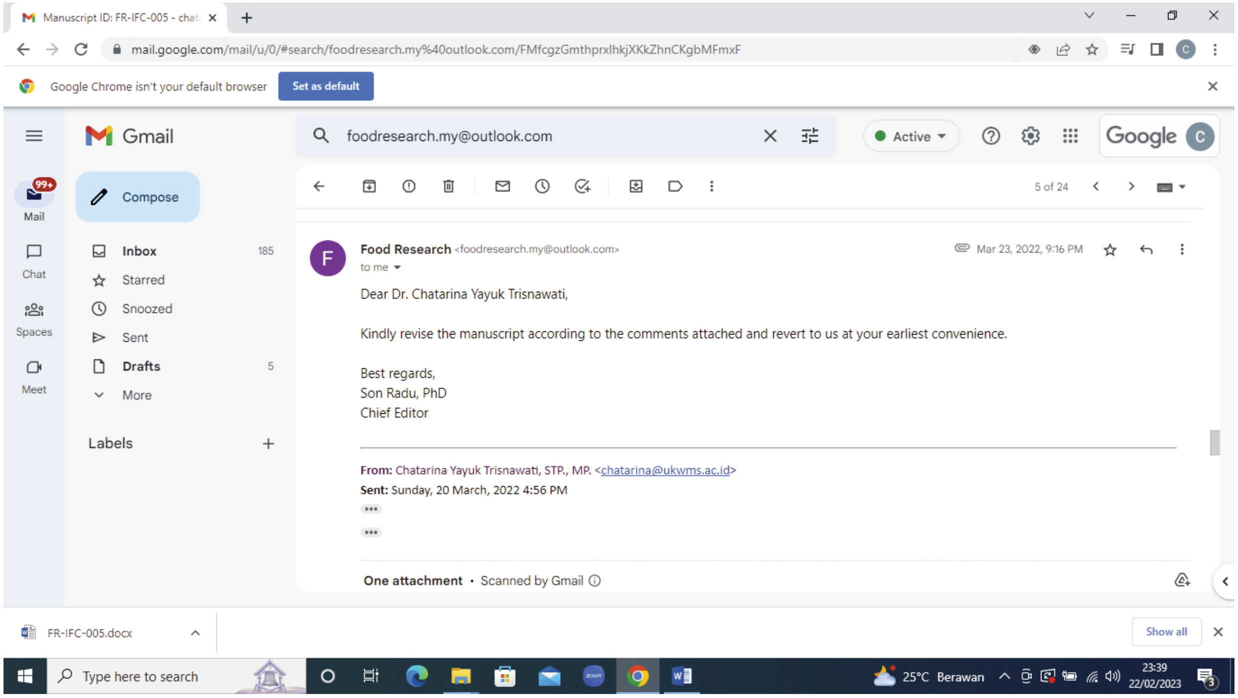
Frozen storage duration (months)	Color		
	L*	*a**	*b**
0	71.55 ± 4.08^{ab}	2.95 ± 0.78^{a}	32.08 ± 3.02^{b}
1	67.98 ± 2.78^{a}	4.62 ± 1.93^{a}	30.79 ± 1.87^{b}
2	66.52 ± 1.15^{a}	3.21 ± 0.37^{a}	25.77 ± 0.98^{a}
3	75.20 ± 1.80^{b}	4.01 ± 0.30^{a}	31.40 ± 1.66^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

6.

Bukti konfirmasi revisi artikel yang harus dilakukan

(23 Maret 2022)


Manuscript ID: FR-IFC-005 - chat
mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF
Google Chrome isn't your default browser
Set as default
Gmail
foodresearch.my@outlook.com
Active
Google
Compose
Mail
Chat
Spaces
Meet
Inbox 185
Starred
Snoozed
Sent
Drafts 5
More
Labels
5 of 24
Food Research <foodresearch.my@outlook.com>
to me
Mar 23, 2022, 9:16 PM
Dear Dr. Chatarina Yayuk Trisnawati,
Kindly revise the manuscript according to the comments attached and revert to us at your earliest convenience.
Best regards,
Son Radu, PhD
Chief Editor
From: Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
Sent: Sunday, 20 March, 2022 4:56 PM
One attachment • Scanned by Gmail
FR-IFC-005.docx
Show all
Type here to search
25°C Berawan
23:39
22/02/2023

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

[1*]Trisnawati, C. Y., [1]Sutedja, A.M., and [1]Kaharso, V. C.

[1]*Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia*

*Corresponding author: chatarina@ukwms.ac.id

Authors' ORCID ID:

Author 1 : 0000-0003-0595-9504

Author 2 : 0000-0002-7734-7163

Author 3 : 0000-0002-7373-7383

Abstract

Cassava sticks is a processed food made from cassava that has similar characteristics to French fries. However, cassava sticks are also classified as perishable food, so it is required to employ other process that might increases its preservation, such as frozen storage. In this study, the cassava stick was stored at -20^{o}C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen condition significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat

oxidation also occurred during storage, marked by a significant increase (P<0.05) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference (P>0.05) with other samples.

Keywords: Cassava, Cassava stick, Frozen storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as *tiwul, gatot, gaplek, gethuk, tapai*, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown color, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one

Commented [Editor1]: Revise all colors as colour in UK English
(Does not apply to references)

of the most used methods (Rahman and Velez-Ruiz, 2007). Generally, frozen storage temperature is 0^{o}F (-18^{o}C) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Several studies stated that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Celli *et al*., 2016; Medic *et al*., 2018; Sattar *et al*., 2015). However, based on our knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2), purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassava tubers were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98^{o}C, 15 min) and cooled to room temperature before being pre-fried (170^{o}C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20^{o}C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket

Commented [Editor2]: Avoid the use of stated , revise this and 2 other sentences with the word stated

Commented [Editor3]: Revise all multiple citations, ensure they are revised from oldest to latest
2015; 2016; 2018

Commented [Editor4]: Do not write in first person pronouns
Revise all sentences with 'our'

was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of fried cassava stick was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g of fried cassava sticks were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink color occurred

for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g of fried cassava sticks were mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow color had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue color disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Color

The color of fried cassava stick was identified using a color reader (Color Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated

by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were color, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at P<0.05.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference (P>0.05) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al.* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also stated that freezing significantly (P<0.05) influenced the moisture content of the fried potato (Adedeji and Ngadi, 2017), lamb (Coombs *et al.*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18^{o}C and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al*., 1988). Table 1 showed that frozen storage duration significantly increased (P<0,05) the oil absorption of cassava sticks. Cassava stick

stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference with cassava stick stored frozen for 3 months (57.84%). In Adedeji's and Ngadi's (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also stated that there was no interaction between storage duration and freezing method, which contradicts our study.

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Dana and Saguy, 2006; Rimac-Brncic *et al*., 2004). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al*., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

Commented [Editor5]: Please ensure all subheadings are italicized

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that figure, frozen storage duration significantly affected ($P<0.05$) the hardness of the cassava sticks. Cassava stick that was stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). Our results were in accordance with the results of Adedeji and Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. Our statement was supported by a similar study by Yu *et al*. (2010), where the hardness

of cooked rice increased continually with the amylopectin retrogradation during frozen storage. Based on those findings, amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased ($P<0.05$) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference ($P>0.05$) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased ($P<0.05$) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with

oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri and Mangaraj, 2012).

3.4. Color properties

Color is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Patras *et al*., 2011; Hutchings, 2002). In this study, the color of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* color attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different ($P>0.05$) with cassava stick that was not stored frozen (71.55) and significantly different ($P<0.05$) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference ($P>0.05$) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower ($P<0.05$) than other samples (30.79 – 32.08).

Research by Oner and Wall (2012) also found that frozen storage significantly influenced ($P<0.05$) the color of French fries. The color change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the color of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown color in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust color of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the color attribute was the 0-month storage cassava sticks (5.60) and significantly difference ($P<0.05$) with other samples (3.20 – 4.96). The decrease in panelists' color preference was due to the color changes in cassava sticks that tend to be darker and brownish than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased ($P<0.05$) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with our objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference ($P>0.05$) with 2 months stored cassava stick (4.66) but showed significant difference ($P<0.05$) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced ($P<0.05$) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference ($P>0.05$) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect ($P>0.05$) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change.

The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface color, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153.

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32.

Association of Analytical Communities. (2006). Official Methods of Analysis of AOAC International 18th Edition. Gaithersburg: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216.

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304,

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb *M. longissimus lumborum* quality and safety parameters. *Meat Science*, 134, 86–97.

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607.

Dana, D. dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272.

Fellows, P.J. (1990). Food Processing Technology Principles and Practice. London: Ellis Horwood

Fennema, G.R. (1985). Principles of Food Science. New York: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*.

Hutchings, J.B. 2002. The Perception and Sensory Assessment of Colour. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). Pengawasan Mutu Makanan. Malang: UB Press

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49.

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127.

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373.

Mohamed, S., Abdullah, N. and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252.

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9.

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In Handbook of Food Preservation Second Edition. CRC Press.

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241.

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168.

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). Prosedur Analisa untuk Bahan Makanan dan Pertanian. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225.

WFLO Commodity Storage Manual. (2008). Frozen Foods Handling & Storage. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143.

List of Figures

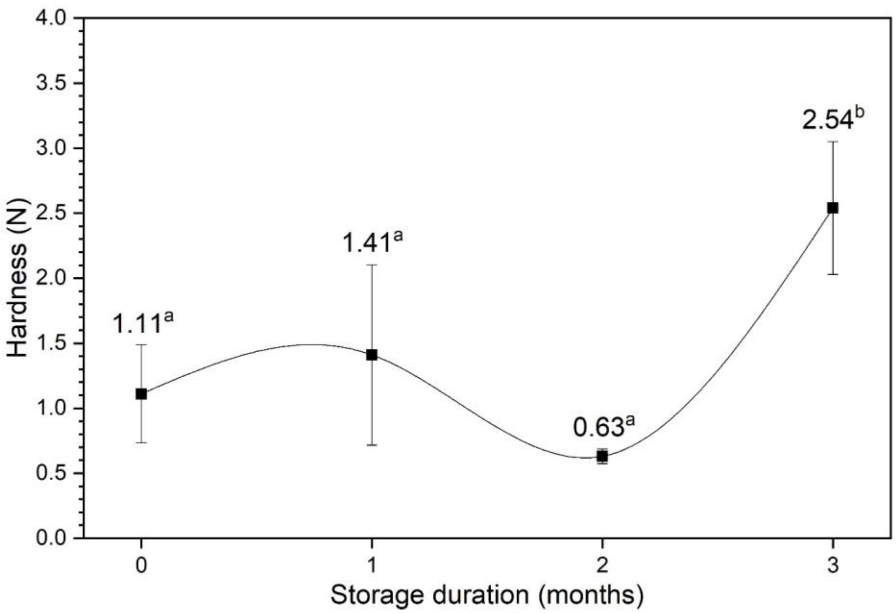


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

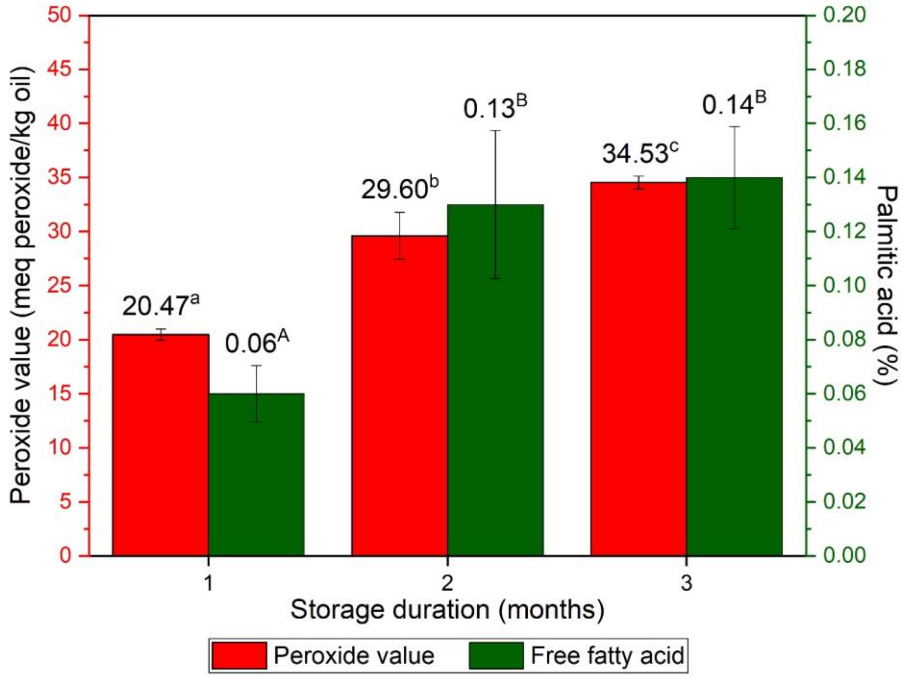


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

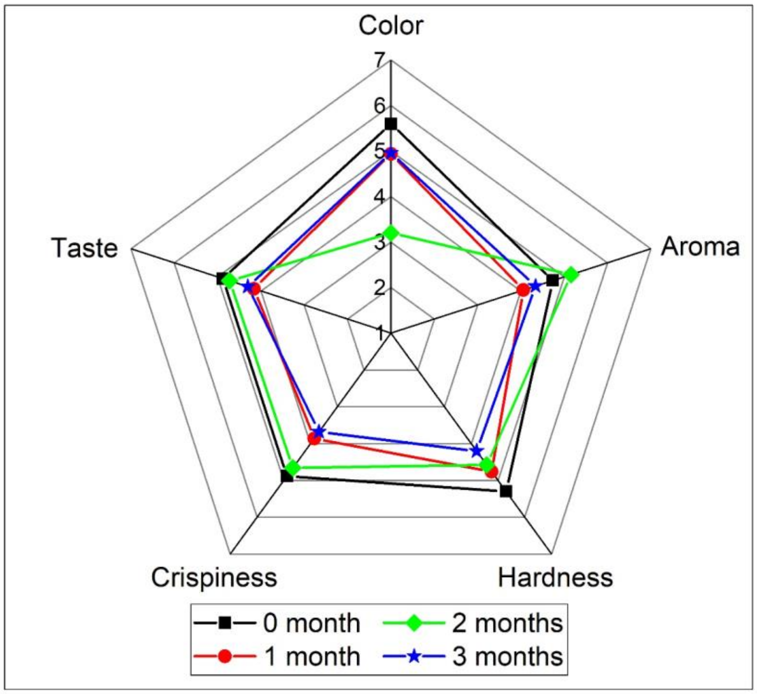


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13 ± 7.46 ^{a}	20.87 ± 15.91^{a}
1	48.83 ± 3.27 ^{a}	25.66 ± 9.51^{a}
2	28.68 ± 7.95 ^{a}	58.45 ± 2.47^{b}
3	27.75 ± 10.13 ^{a}	57.94 ± 24.71^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Table 2. Color of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Color		
	L*	*a**	*b**
0	71.55 ± 4.08^{ab}	2.95 ± 0.78^{a}	32.08 ± 3.02^{b}
1	67.98 ± 2.78^{a}	4.62 ± 1.93^{a}	30.79 ± 1.87^{b}
2	66.52 ± 1.15^{a}	3.21 ± 0.37^{a}	25.77 ± 0.98^{a}
3	75.20 ± 1.80^{b}	4.01 ± 0.30^{a}	31.40 ± 1.66^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Formatted: Highlight

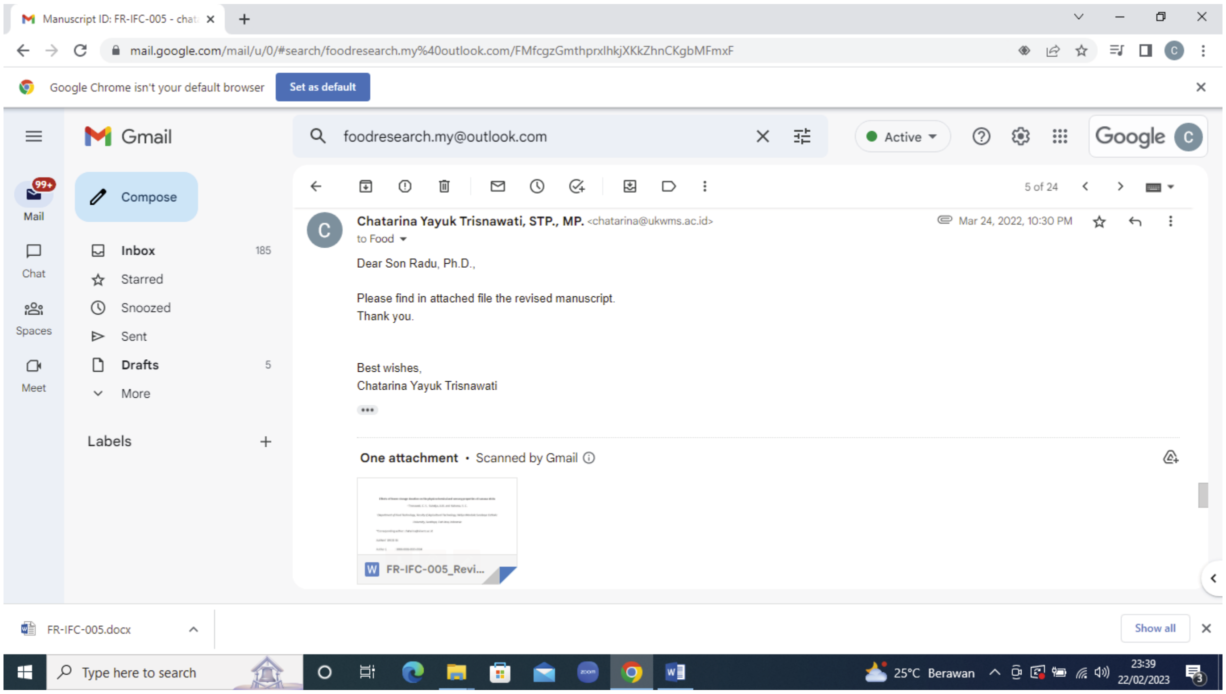
Formatted: Highlight

Formatted: Highlight

7.

Bukti konfirmasi submit revisi artikel ketiga

(24 Maret 2022)



Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
to Food

Mar 24, 2022, 10:30 PM

Dear Son Radu, Ph.D.,

Please find in attached file the revised manuscript.
Thank you.

Best wishes,
Chatarina Yayuk Trisnawati

One attachment • Scanned by Gmail

FR-IFC-005_Revi...

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

[1*]Trisnawati, C. Y., [1]Sutedja, A.M. and [1]Kaharso, V. C.

[1]Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia

*Corresponding author: chatarina@ukwms.ac.id

Authors' ORCID ID:

Author 1 : 0000-0003-0595-9504

Author 2 : 0000-0002-7734-7163

Author 3 : 0000-0002-7373-7383

Abstract

Cassava sticks is a processed food made from cassava that has similar characteristics to French fries. However, cassava sticks are also classified as perishable food, so it is required to employ other process that might increases its preservation, such as frozen storage. In this study, the cassava stick was stored at $-20^{o}C$ for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen condition significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat

oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference ($P>0.05$) with other samples.

Keywords: Cassava, Cassava stick, Frozen storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as *tiwul, gatot, gaplek, gethuk, tapai*, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown colour, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one

of the most used methods (Rahman and Velez-Ruiz, 2007). Generally, frozen storage temperature is 0°F (-18°C) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Several studies showed that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Sattar *et al*., 2015; Celli *et al*., 2016; Medic *et al*., 2018). However, so far there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2), purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassava tubers were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98°C, 15 min) and cooled to room temperature before being pre-fried (170°C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20°C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket

was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of fried cassava stick was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g of fried cassava sticks were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink colour occurred

for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g of fried cassava sticks were mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow colour had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue colour disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Colour

The colour of fried cassava stick was identified using a colour reader (Colour Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated

by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were colour, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at $P<0.05$.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference ($P>0.05$) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al.* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also found that freezing significantly ($P<0.05$) influenced the moisture content of the fried potato (Adedeji and Ngadi, 2017), lamb (Coombs *et al.*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18^{o}C and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al*., 1988). Table 1 showed that frozen storage duration significantly increased ($P<0,05$) the oil absorption of cassava sticks. Cassava stick

stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference with cassava stick stored frozen for 3 months (57.84%). In Adedeji's and Ngadi's (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also found that there was no interaction between storage duration and freezing method, which contradicts this study.

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Rimac-Brncic *et al*., 2004; Dana and Saguy, 2006). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al*., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that figure, frozen storage duration significantly affected ($P<0.05$) the hardness of the cassava sticks. Cassava stick that was stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). This results were in accordance with the results of Adedeji and Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. This statement was supported by a similar study by Yu *et al*. (2010), where the hardness

of cooked rice increased continually with the amylopectin retrogradation during frozen storage. Based on those findings, amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased ($P<0.05$) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference ($P>0.05$) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased ($P<0.05$) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with

oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri and Mangaraj, 2012).

3.4. Colour properties

Colour is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Hutchings, 2002; Patras *et al*., 2011). In this study, the colour of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* colour attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Research by Oner and Wall (2012) also found that frozen storage significantly influenced (P<0.05) the colour of French fries. The colour change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the colour of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown colour in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust colour of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the colour attribute was the 0-month storage cassava sticks (5.60) and significantly difference ($P<0.05$) with other samples (3.20 – 4.96). The decrease in panelists' colour preference was due to the colour changes in cassava sticks that tend to be darker and brownish than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased ($P<0.05$) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with the objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference ($P>0.05$) with 2 months stored cassava stick (4.66) but showed significant difference ($P<0.05$) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced ($P<0.05$) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference ($P>0.05$) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect ($P>0.05$) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change.

The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface colour, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153.

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32.

Association of Analytical Communities. (2006). Official Methods of Analysis of AOAC International 18th Edition. Gaithersburg: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216.

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304,

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb *M. longissimus lumborum* quality and safety parameters. *Meat Science*, 134, 86–97.

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607.

Dana, D. dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272.

Fellows, P.J. (1990). Food Processing Technology Principles and Practice. London: Ellis Horwood

Fennema, G.R. (1985). Principles of Food Science. New York: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*.

Hutchings, J.B. 2002. The Perception and Sensory Assessment of Colour. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). Pengawasan Mutu Makanan. Malang: UB Press

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49.

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127.

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373.

Mohamed, S., Abdullah, N. and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252.

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Colour changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9.

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In Handbook of Food Preservation Second Edition. CRC Press.

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241.

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168.

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). Prosedur Analisa untuk Bahan Makanan dan Pertanian. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225.

WFLO Commodity Storage Manual. (2008). Frozen Foods Handling & Storage. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143.

List of Figures

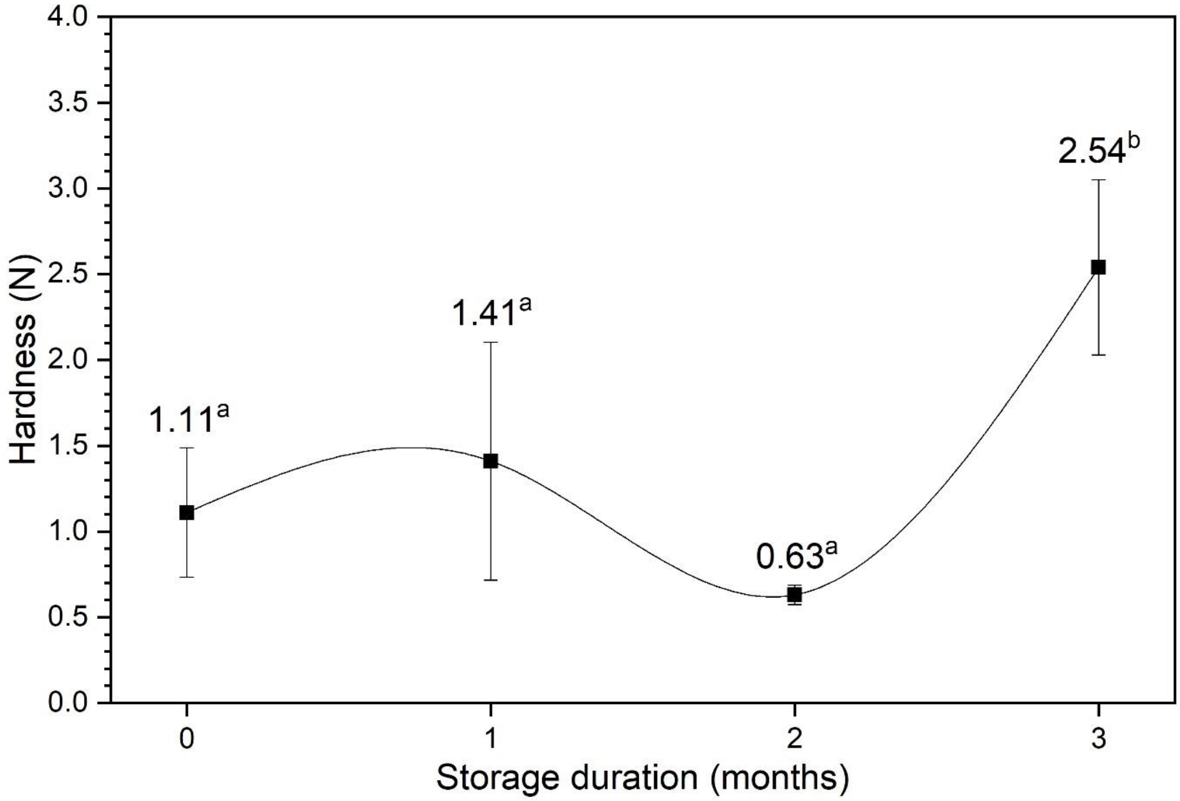


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

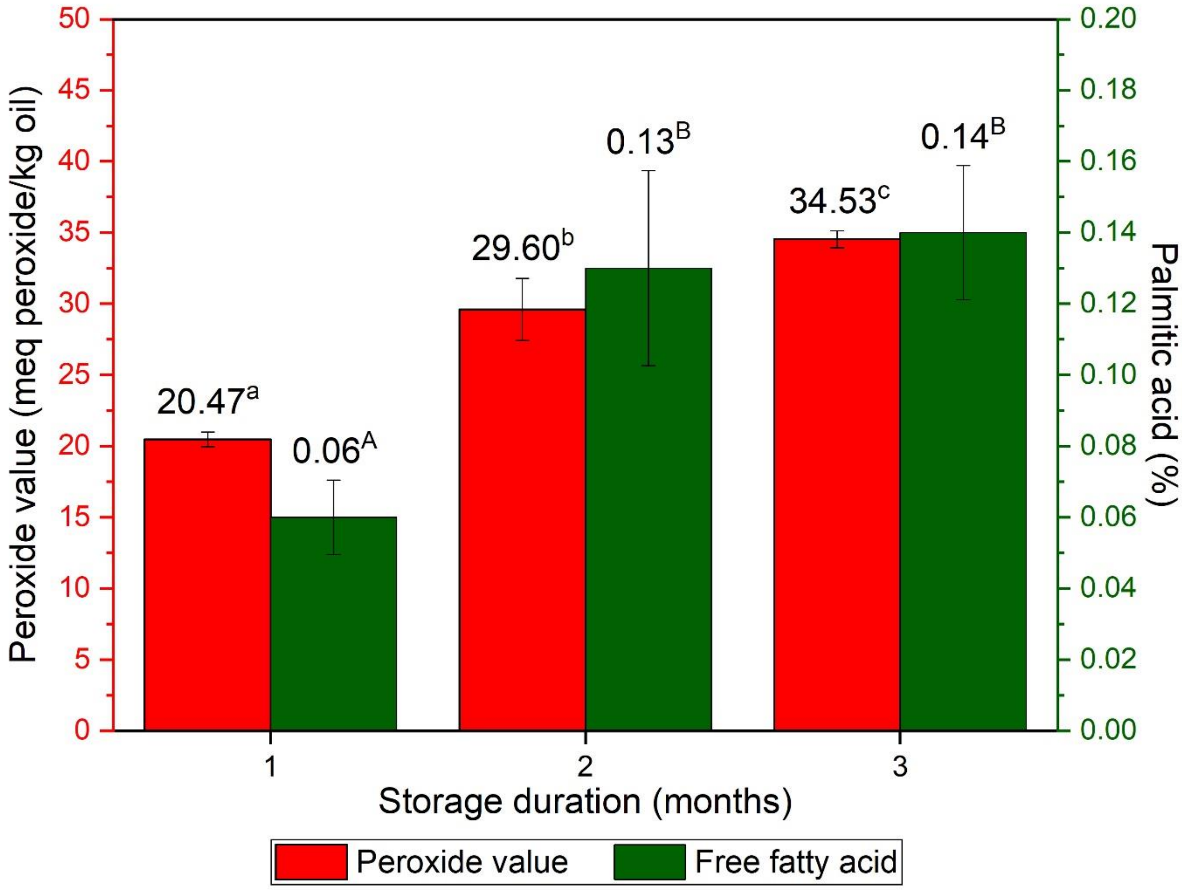


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

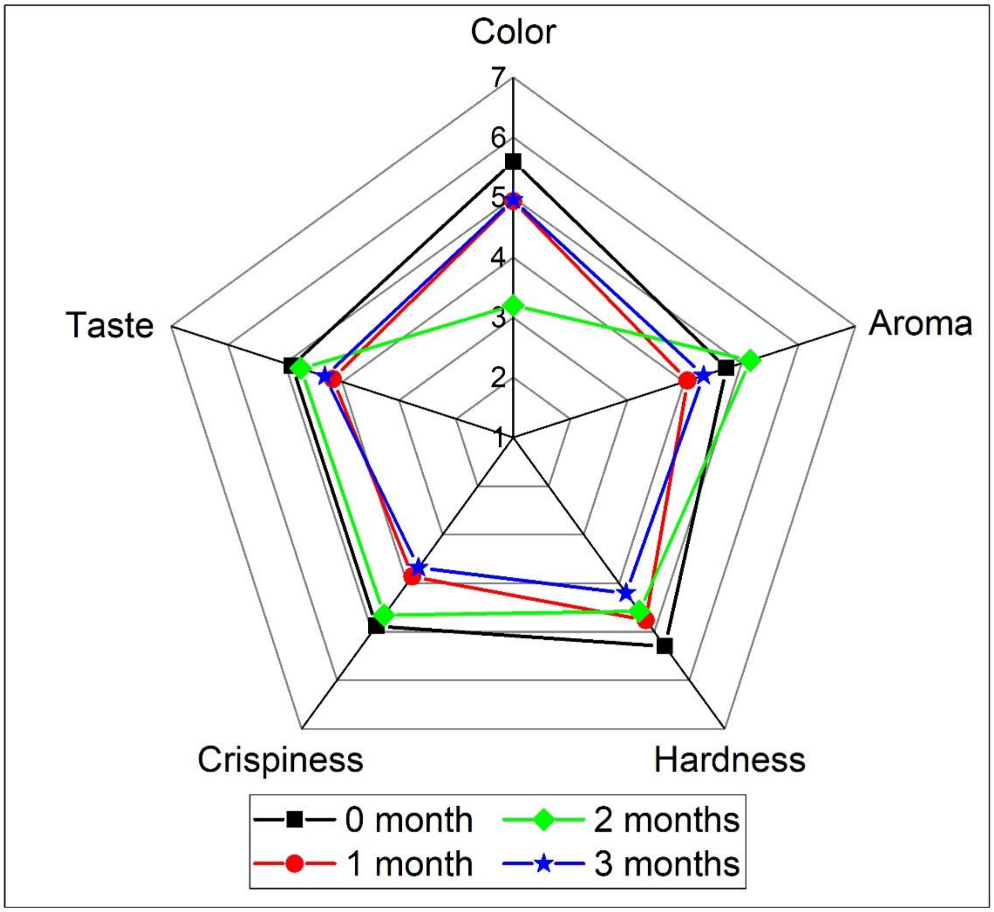


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13 ± 7.46 ^{a}	20.87 ± 15.91^{a}
1	48.83 ± 3.27 ^{a}	25.66 ± 9.51^{a}
2	28.68 ± 7.95 ^{a}	58.45 ± 2.47^{b}
3	27.75 ± 10.13 ^{a}	57.94 ± 24.71^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Table 2**.** Colour of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Colour		
	L*	*a**	*b**
0	71.55 ± 4.08^{ab}	2.95 ± 0.78^{a}	32.08 ± 3.02^{b}
1	67.98 ± 2.78^{a}	4.62 ± 1.93^{a}	30.79 ± 1.87^{b}
2	66.52 ± 1.15^{a}	3.21 ± 0.37^{a}	25.77 ± 0.98^{a}
3	75.20 ± 1.80^{b}	4.01 ± 0.30^{a}	31.40 ± 1.66^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

8.

Bukti konfirmasi revisi artikel yang harus dilakukan

(26 Maret 2022)

Manuscript ID: FR-IFC-005 - chat

mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF

foodresearch.my@outlook.com

Food Research <foodresearch.my@outlook.com>
to me

Mar 26, 2022, 6:31 PM

Dear Dr. Chatarina Yayuk Trisnawati,

Please revise Figure 3 spelling of the word 'color' to 'colour'.

Best regards,
Son Radu, PhD
Chief Editor

From: Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
Sent: Thursday, 24 March, 2022 11:30 PM

FR-IFC-005.docx

23:39
22/02/2023

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

[1*]Trisnawati, C. Y., [1]Sutedja, A.M. and [1]Kaharso, V. C.

[1]*Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia*

*Corresponding author: chatarina@ukwms.ac.id

Authors' ORCID ID:

Author 1 : 0000-0003-0595-9504

Author 2 : 0000-0002-7734-7163

Author 3 : 0000-0002-7373-7383

Abstract

Cassava sticks is a processed food made from cassava that has similar characteristics to French fries. However, cassava sticks are also classified as perishable food, so it is required to employ other process that might increases its preservation, such as frozen storage. In this study, the cassava stick was stored at -20^{o}C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen condition significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat

oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference ($P>0.05$) with other samples.

Keywords: Cassava, Cassava stick, Frozen storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as *tiwul, gatot, gaplek, gethuk, tapai*, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown colour, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one

of the most used methods (Rahman and Velez-Ruiz, 2007). Generally, frozen storage temperature is 0^{o}F (-18^{o}C) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Several studies showed that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Sattar *et al*., 2015; Celli *et al*., 2016; Medic *et al*., 2018). However, based on authors' knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2), purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassava tubers were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98^{o}C, 15 min) and cooled to room temperature before being pre-fried (170^{o}C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20^{o}C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket

was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of fried cassava stick was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g of fried cassava sticks were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink colour occurred

for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g of fried cassava sticks were mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow colour had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue colour disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Colour

The colour of fried cassava stick was identified using a colour reader (Colour Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated

by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were colour, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at $P<0.05$.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference ($P>0.05$) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al.* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also found that freezing significantly ($P<0.05$) influenced the moisture content of the fried potato (Adedeji and Ngadi, 2017), lamb (Coombs *et al.*, 2017), and pork ham (Medic *et al.*, 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at $-18^{o}C$ and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al.*, 1988). Table 1 showed that frozen storage duration significantly increased ($P<0,05$) the oil absorption of cassava sticks. Cassava stick

stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference with cassava stick stored frozen for 3 months (57.84%). In Adedeji's and Ngadi's (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also found that there was no interaction between storage duration and freezing method, which contradicts this study.

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Rimac-Brncic *et al*., 2004; Dana and Saguy, 2006). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al*., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that figure, frozen storage duration significantly affected ($P<0.05$) the hardness of the cassava sticks. Cassava stick that was stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). This results were in accordance with the results of Adedeji and Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. This statement was supported by a similar study by Yu *et al*. (2010), where the hardness

of cooked rice increased continually with the amylopectin retrogradation during frozen storage. Based on those findings, amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased ($P<0.05$) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference ($P>0.05$) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased ($P<0.05$) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with

oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri and Mangaraj, 2012).

3.4. Colour properties

Colour is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Hutchings, 2002; Patras *et al*., 2011). In this study, the colour of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* colour attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Research by Oner and Wall (2012) also found that frozen storage significantly influenced (P<0.05) the colour of French fries. The colour change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the colour of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown colour in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust colour of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the colour attribute was the 0-month storage cassava sticks (5.60) and significantly difference ($P<0.05$) with other samples (3.20 – 4.96). The decrease in panelists' colour preference was due to the colour changes in cassava sticks that tend to be darker and brownish than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased ($P<0.05$) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with the objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference ($P>0.05$) with 2 months stored cassava stick (4.66) but showed significant difference ($P<0.05$) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced ($P<0.05$) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference ($P>0.05$) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect ($P>0.05$) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change.

The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface colour, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153.

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32.

Association of Analytical Communities. (2006). Official Methods of Analysis of AOAC International 18th Edition. Gaithersburg: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216.

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304,

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb *M. longissimus lumborum* quality and safety parameters. *Meat Science*, 134, 86–97.

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607.

Dana, D. dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272.

Fellows, P.J. (1990). Food Processing Technology Principles and Practice. London: Ellis Horwood

Fennema, G.R. (1985). Principles of Food Science. New York: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*.

Hutchings, J.B. 2002. The Perception and Sensory Assessment of Colour. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). Pengawasan Mutu Makanan. Malang: UB Press

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49.

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127.

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373.

Mohamed, S., Abdullah, N. and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252.

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Colour changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9.

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In Handbook of Food Preservation Second Edition. CRC Press.

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241.

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168.

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). Prosedur Analisa untuk Bahan Makanan dan Pertanian. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225.

WFLO Commodity Storage Manual. (2008). Frozen Foods Handling & Storage. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143.

List of Figures

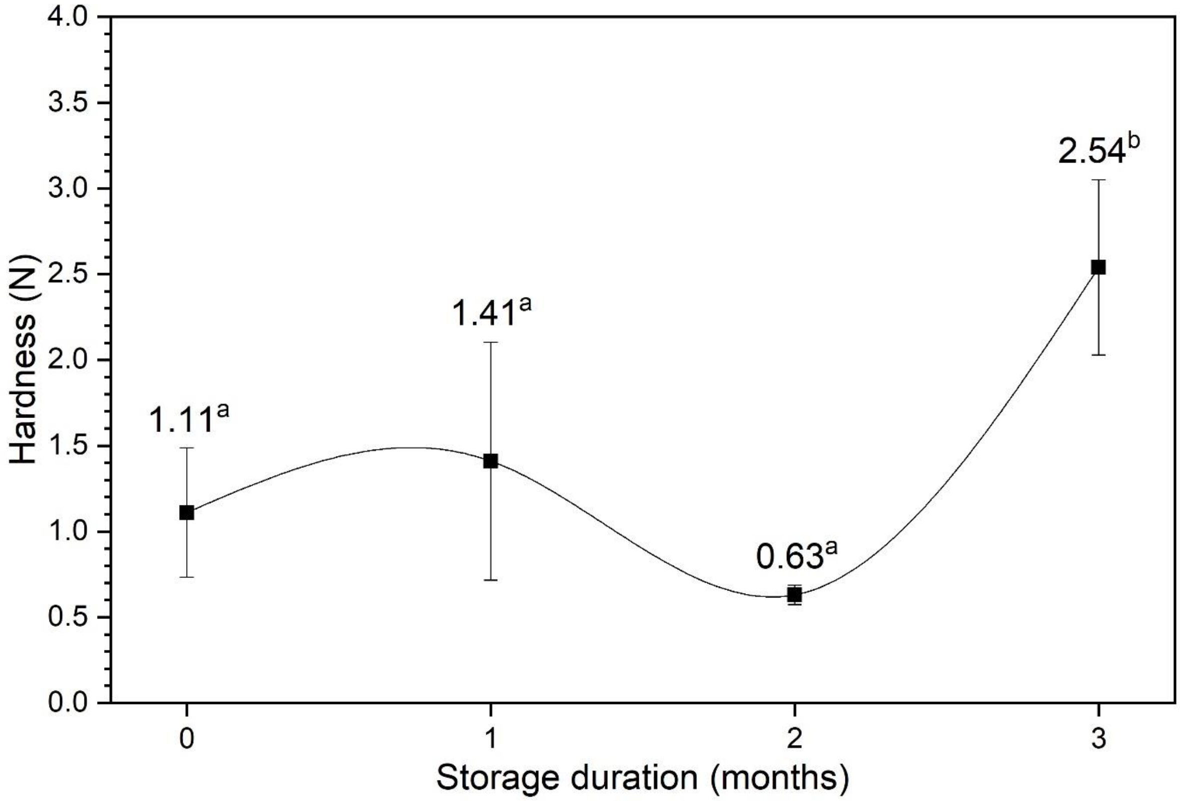


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

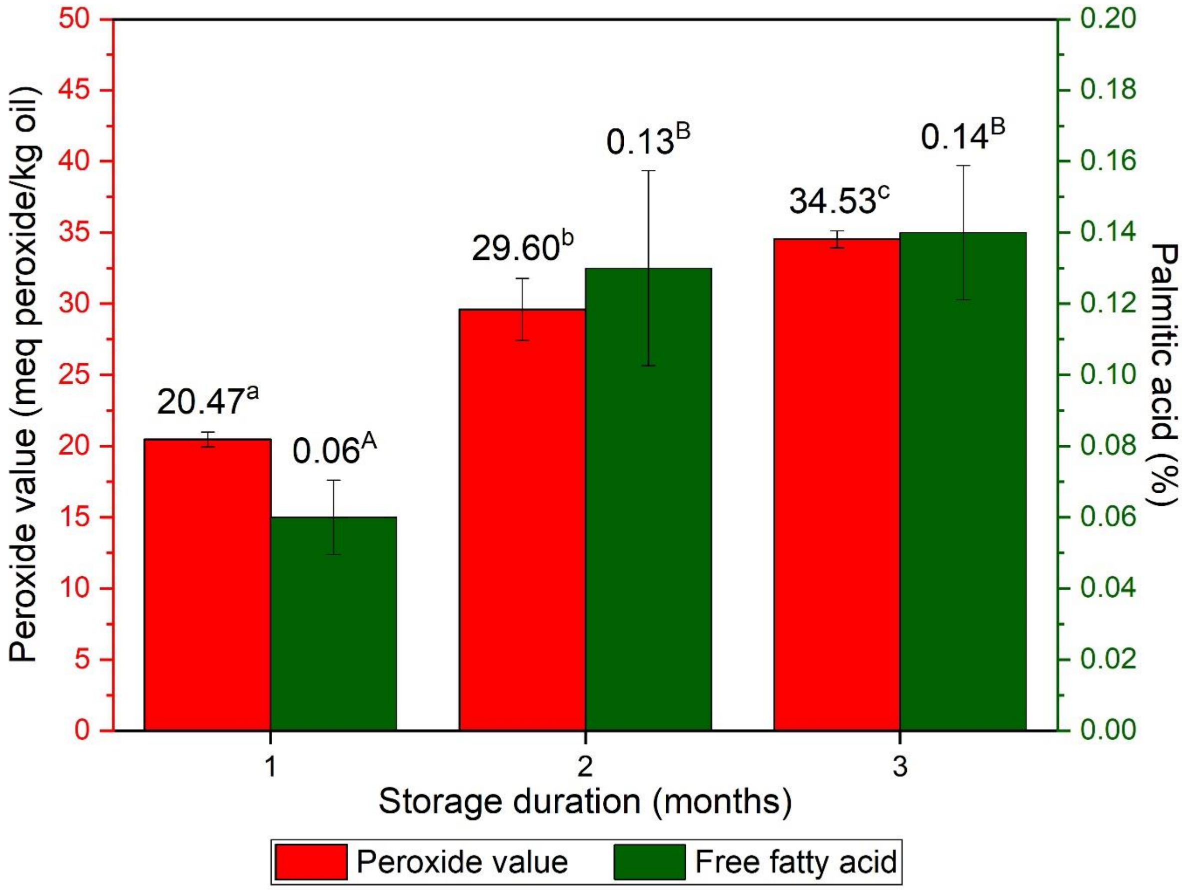


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different ($P<0.05$). The statistical significance was evaluated by one-way ANOVA followed by DMRT test ($\alpha = 0.05$).

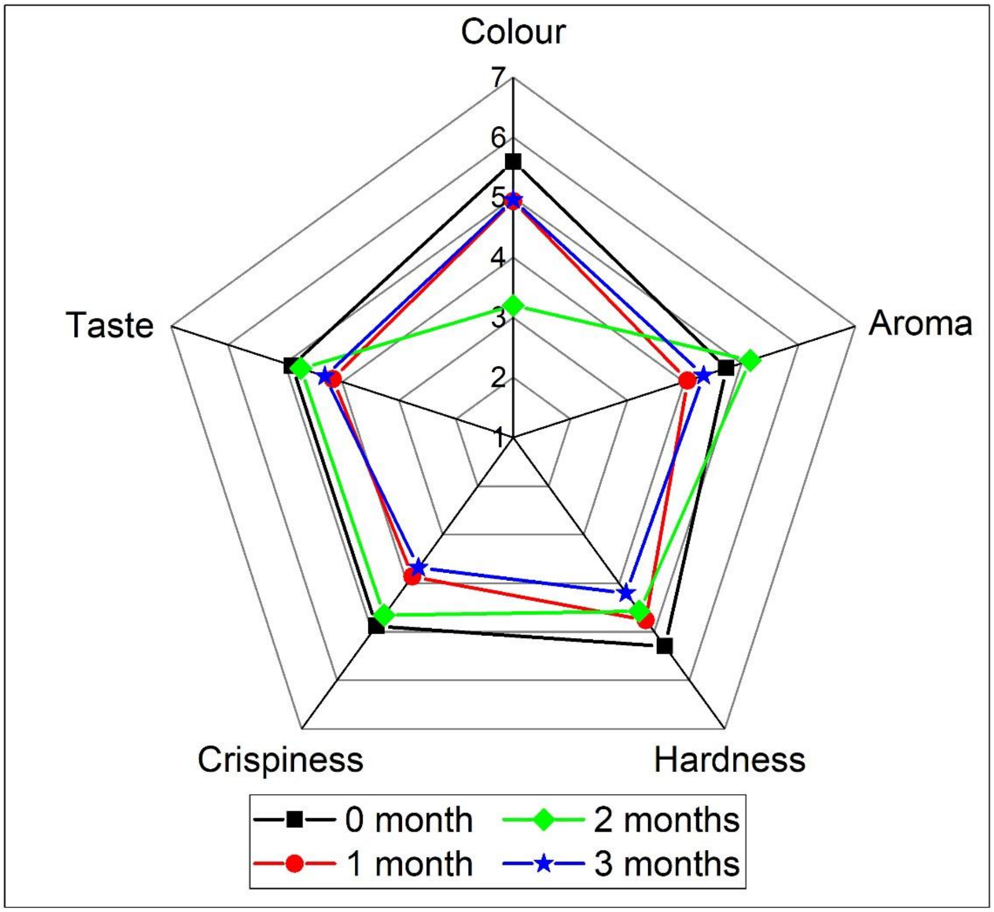


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13 ± 7.46 ^{a}	20.87 ± 15.91^{a}
1	48.83 ± 3.27 ^{a}	25.66 ± 9.51^{a}
2	28.68 ± 7.95 ^{a}	58.45 ± 2.47^{b}
3	27.75 ± 10.13 ^{a}	57.94 ± 24.71^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Table 2. Colour of cassava stick stored frozen in different storage duration

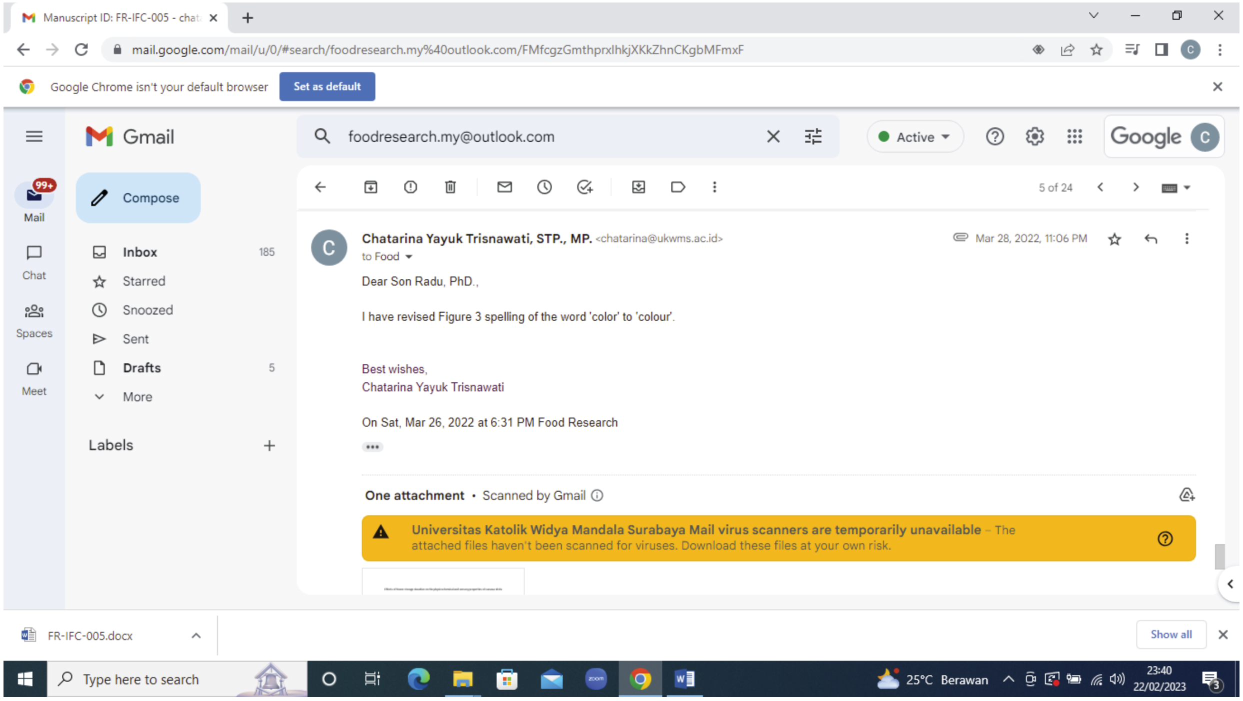
Frozen storage duration (months)	Colour		
	L*	*a**	*b**
0	71.55 ± 4.08^{ab}	2.95 ± 0.78^{a}	32.08 ± 3.02^{b}
1	67.98 ± 2.78^{a}	4.62 ± 1.93^{a}	30.79 ± 1.87^{b}
2	66.52 ± 1.15^{a}	3.21 ± 0.37^{a}	25.77 ± 0.98^{a}
3	75.20 ± 1.80^{b}	4.01 ± 0.30^{a}	31.40 ± 1.66^{b}

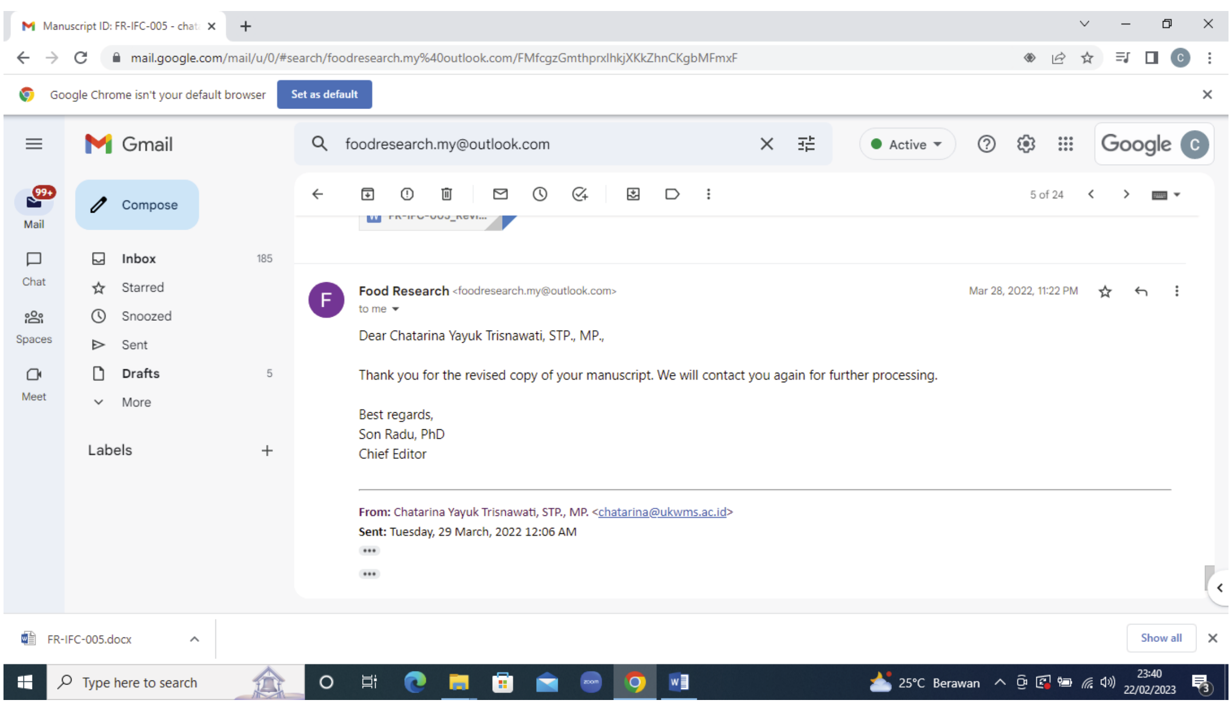
Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

9.

Bukti konfirmasi submit revisi artikel keempat dan balasannya

(28 Maret 2022)


Manuscript ID: FR-IFC-005 - chat
mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF
Google Chrome isn't your default browser
Set as default
Gmail
foodresearch.my@outlook.com
Active
Compose
Inbox 185
Starred
Snoozed
Sent
Drafts 5
More
Labels
5 of 24
Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
to Food
Mar 28, 2022, 11:06 PM
Dear Son Radu, PhD.,
I have revised Figure 3 spelling of the word 'color' to 'colour'.
Best wishes,
Chatarina Yayuk Trisnawati
On Sat, Mar 26, 2022 at 6:31 PM Food Research
One attachment • Scanned by Gmail
Universitas Katolik Widya Mandala Surabaya Mail virus scanners are temporarily unavailable – The attached files haven't been scanned for viruses. Download these files at your own risk.
FR-IFC-005.docx
Show all
Type here to search
25°C Berawan
23:40
22/02/2023


Manuscript ID: FR-IFC-005 - chat
mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF
Google Chrome isn't your default browser
Set as default
Gmail
foodresearch.my@outlook.com
Active
Compose
Inbox 185
Starred
Snoozed
Sent
Drafts 5
More
Labels
5 of 24
Food Research <foodresearch.my@outlook.com>
to me
Mar 28, 2022, 11:22 PM
Dear Chatarina Yayuk Trisnawati, STP., MP.,
Thank you for the revised copy of your manuscript. We will contact you again for further processing.
Best regards,
Son Radu, PhD
Chief Editor
From: Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
Sent: Tuesday, 29 March, 2022 12:06 AM
FR-IFC-005.docx
Show all
Type here to search
25°C Berawan
23:40
22/02/2023

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

[1*]Trisnawati, C. Y., [1]Sutedja, A.M. and [1]Kaharso, V. C.

[1]*Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia*

*Corresponding author: chatarina@ukwms.ac.id

Authors' ORCID ID:

Author 1 : 0000-0003-0595-9504

Author 2 : 0000-0002-7734-7163

Author 3 : 0000-0002-7373-7383

Abstract

Cassava sticks is a processed food made from cassava that has similar characteristics to French fries. However, cassava sticks are also classified as perishable food, so it is required to employ other process that might increases its preservation, such as frozen storage. In this study, the cassava stick was stored at -20°C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month with three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen condition significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat

oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference ($P>0.05$) with other samples.

Keywords: Cassava, Cassava stick, Frozen storage duration

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered as the substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as *tiwul, gatot, gaplek, gethuk, tapai*, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown colour, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one

of the most used methods (Rahman and Velez-Ruiz, 2007). Generally, frozen storage temperature is 0^{o}F (-18^{o}C) and even colder depending on the type of the food (WFLO Commodity Storage Manual, 2008).

Several studies showed that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Sattar *et al*., 2015; Celli *et al*., 2016; Medic *et al*., 2018). However, based on authors' knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1. Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2), purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2. Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassava tubers were then peeled, cut into strips of 4 x 1 x 1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 min to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98^{o}C, 15 min) and cooled to room temperature before being pre-fried (170^{o}C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20^{o}C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 min) and fried for 2 min at the same condition as the pre-frying process. At the end of frying, the fryer basket

was immediately shaken for 10 seconds and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3. Moisture content

All fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hours at 105 ± 2 °C.

2.4. Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohammed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hours and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5. Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of fried cassava stick was expressed as Newton and determined as the maximum force required to compress the sample.

2.6. Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g of fried cassava sticks were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink colour occurred

for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7. Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g of fried cassava sticks were mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 minute before 30 mL distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow colour had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue colour disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8. Colour

The colour of fried cassava stick was identified using a colour reader (Colour Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, - = blueness) of each sample were observed.

2.9. Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated

by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were colour, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10. Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at $P<0.05$.

3. Results and discussion

3.1. Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference ($P>0.05$) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al.* (2018), where frozen storage duration had no significant on the moisture content of pork loin and belly rib. However, several researchers also found that freezing significantly ($P<0.05$) influenced the moisture content of the fried potato (Adedeji and Ngadi, 2017), lamb (Coombs *et al.*, 2017), and pork ham (Medic *et al.*, 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18^{o}C and easily removed from food when the food is dried or fried; so that the moisture content decreases.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modifying thermogravimetric method (Mohamed *et al.*, 1988). Table 1 showed that frozen storage duration significantly increased ($P<0,05$) the oil absorption of cassava sticks. Cassava stick

stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference with cassava stick stored frozen for 3 months (57.84%). In Adedeji's and Ngadi's (2017) study, oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also found that there was no interaction between storage duration and freezing method, which contradicts this study.

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990) statement, where there is an oil transfer into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Rimac-Brncic *et al*., 2004; Dana and Saguy, 2006). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al*., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2. Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that figure, frozen storage duration significantly affected ($P<0.05$) the hardness of the cassava sticks. Cassava stick that was stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). This results were in accordance with the results of Adedeji and Ngadi (2017). In that study, they found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase of fried cassava sticks' hardness might be due to the retrogradation of cassava starch during frozen storage. This statement was supported by a similar study by Yu *et al*. (2010), where the hardness

of cooked rice increased continually with the amylopectin retrogradation during frozen storage. Based on those findings, amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

3.3. Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased ($P<0.05$) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference ($P>0.05$) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased ($P<0.05$) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with

oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri and Mangaraj, 2012).

3.4. Colour properties

Colour is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Hutchings, 2002; Patras *et al*., 2011). In this study, the colour of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* colour attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different ($P>0.05$) with cassava stick that was not stored frozen (71.55) and significantly different ($P<0.05$) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference ($P>0.05$) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower ($P<0.05$) than other samples (30.79 – 32.08).

Research by Oner and Wall (2012) also found that frozen storage significantly influenced ($P<0.05$) the colour of French fries. The colour change of fried cassava sticks during frozen storage duration might be due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the colour of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and as the result, increases the coloration of yellow, red, and brown colour in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust colour of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

3.5. Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the colour attribute was the 0-month storage cassava sticks (5.60) and significantly difference ($P<0.05$) with other samples (3.20 – 4.96). The decrease in panelists' colour preference was due to the colour changes in cassava sticks that tend to be darker and brownish than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased ($P<0.05$) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with the objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference ($P>0.05$) with 2 months stored cassava stick (4.66) but showed significant difference ($P<0.05$) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced ($P<0.05$) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference ($P>0.05$) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect ($P>0.05$) panelists' acceptance of the cassava stick.

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change.

The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface colour, was substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of food Engineering*, 91(1), 146-153.

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32.

Association of Analytical Communities. (2006). Official Methods of Analysis of AOAC International 18th Edition. Gaithersburg: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216.

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304,

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb *M. longissimus lumborum* quality and safety parameters. *Meat Science*, 134, 86–97.

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607.

Dana, D. dan Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128, 267-272.

Fellows, P.J. (1990). Food Processing Technology Principles and Practice. London: Ellis Horwood

Fennema, G.R. (1985). Principles of Food Science. New York: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*.

Hutchings, J.B. 2002. The Perception and Sensory Assessment of Colour. Cambridge: Woodhead Publishing Limited

International Atomic Energy Agency. (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. Retrieved on October 21, 2021. From https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1):18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). Pengawasan Mutu Makanan. Malang: UB Press

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23 (4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49.

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127.

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373.

Mohamed, S., Abdullah, N. and Muthu, M. K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252.

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Colour changes and acrylamide formation in fried potato slices. *Food Research International*, 38(1), 1-9.

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In Handbook of Food Preservation Second Edition. CRC Press.

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241.

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168.

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of french fried potatoes (Solanum tuberosum L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). Prosedur Analisa untuk Bahan Makanan dan Pertanian. Yogyakarta: Liberty.

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference* 13(4): 215–225.

WFLO Commodity Storage Manual. (2008). Frozen Foods Handling & Storage. Retrieved on October 25, 2021. From http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143.

List of Figures

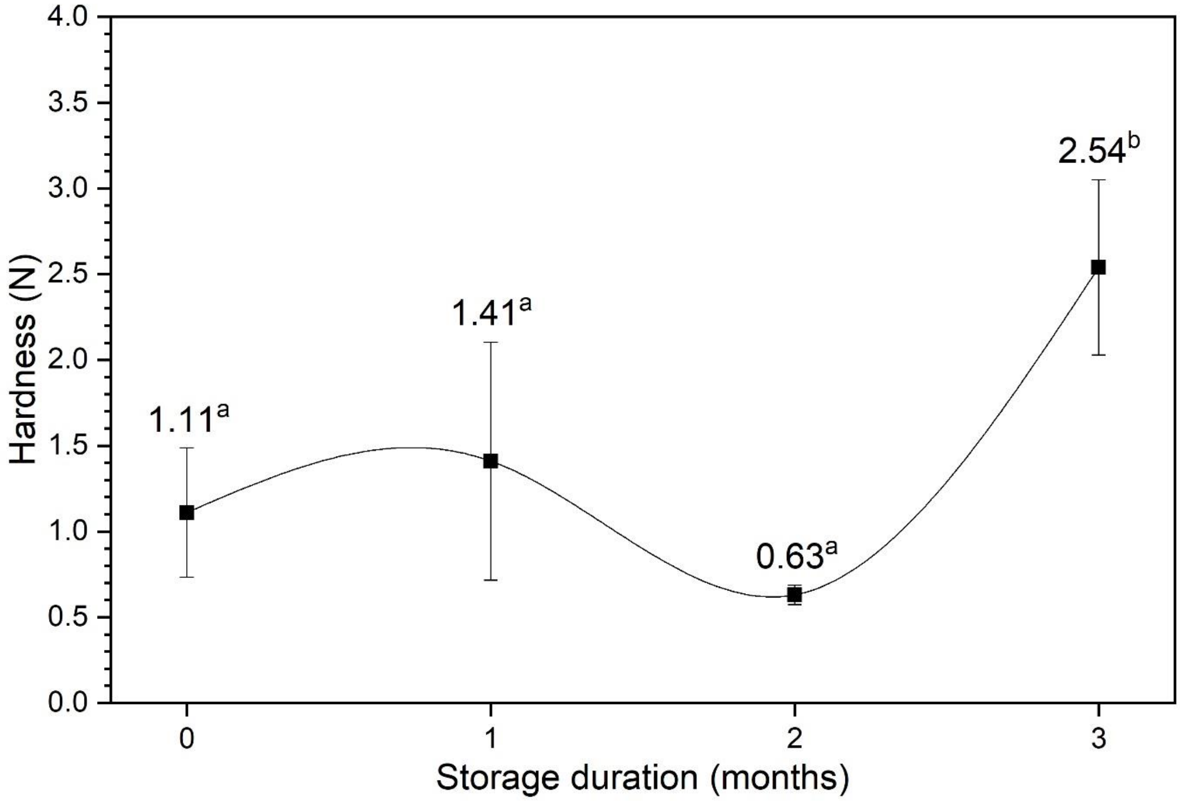


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

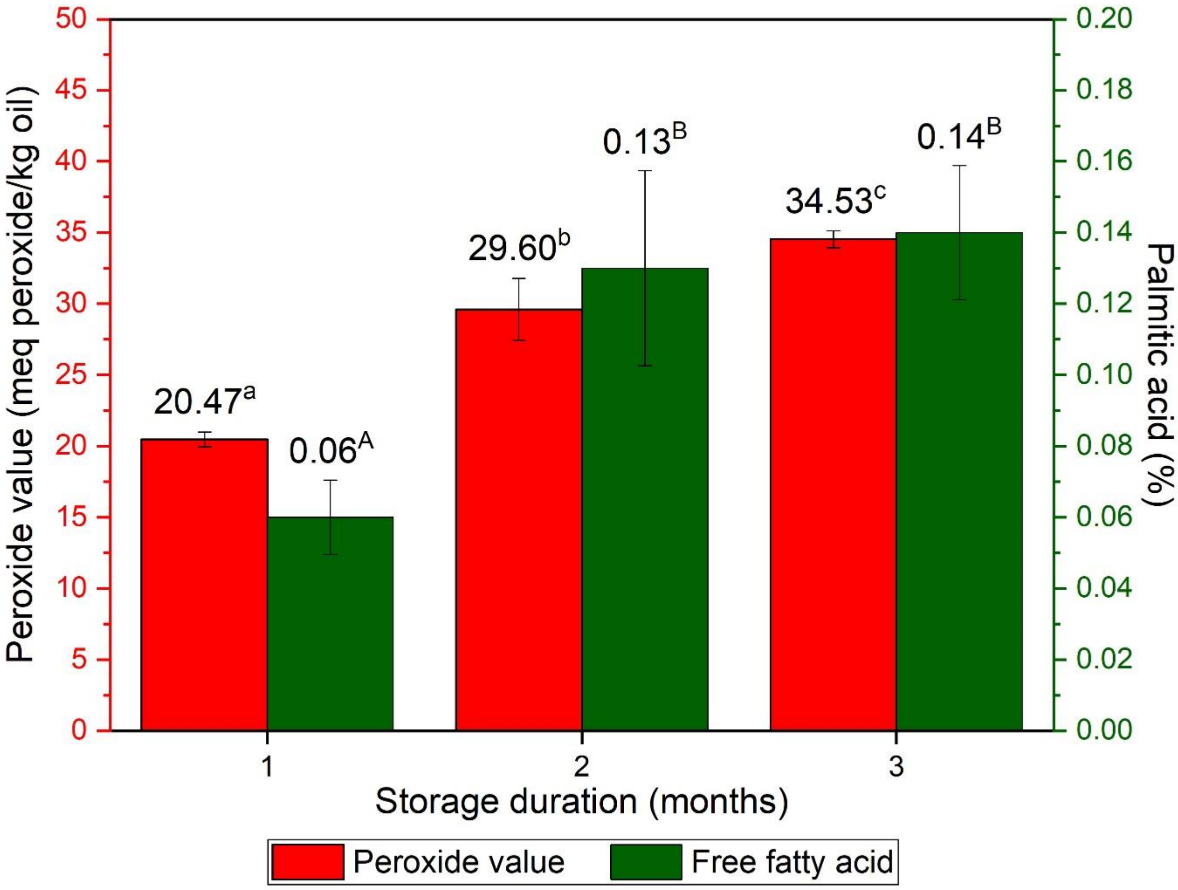


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

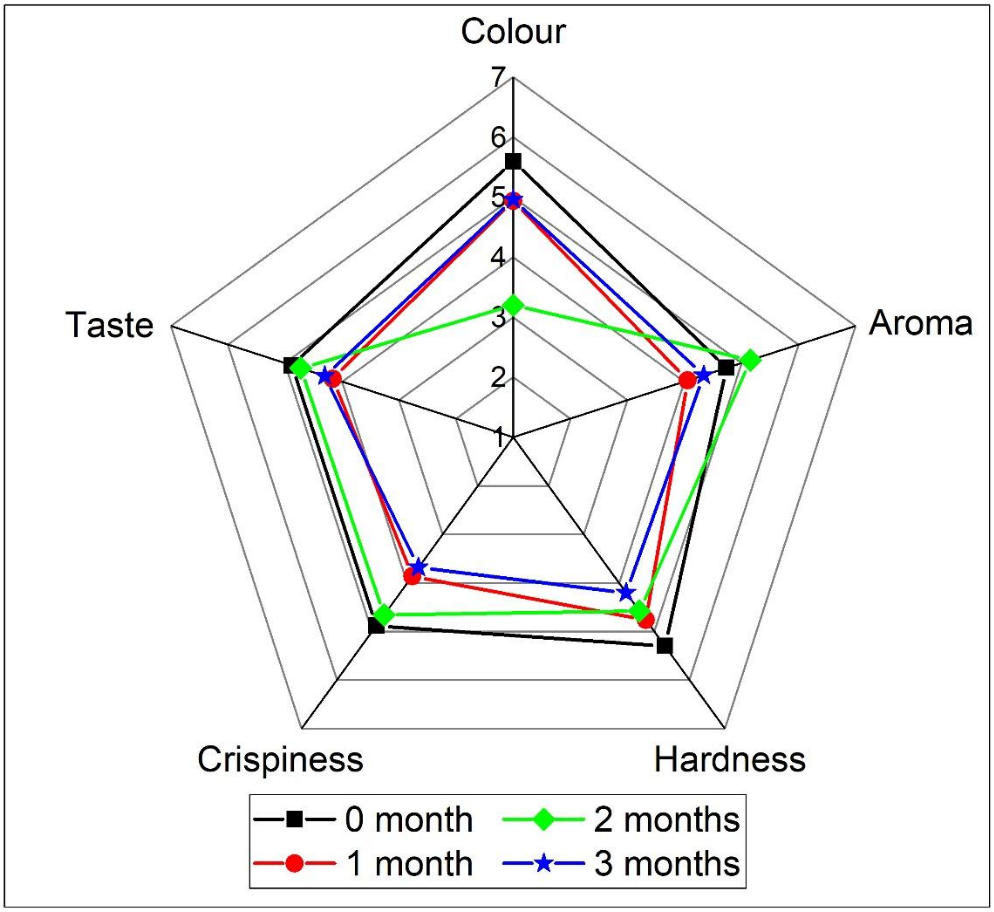


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Means ± standard deviation (n = 100 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

List of Tables

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13 ± 7.46 ^{a}	20.87 ± 15.91^{a}
1	48.83 ± 3.27 ^{a}	25.66 ± 9.51^{a}
2	28.68 ± 7.95 ^{a}	58.45 ± 2.47^{b}
3	27.75 ± 10.13 ^{a}	57.94 ± 24.71^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

Table 2. Colour of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Colour		
	L*	*a**	*b**
0	71.55 ± 4.08^{ab}	2.95 ± 0.78^{a}	32.08 ± 3.02^{b}
1	67.98 ± 2.78^{a}	4.62 ± 1.93^{a}	30.79 ± 1.87^{b}
2	66.52 ± 1.15^{a}	3.21 ± 0.37^{a}	25.77 ± 0.98^{a}
3	75.20 ± 1.80^{b}	4.01 ± 0.30^{a}	31.40 ± 1.66^{b}

Means ± standard deviation (n = 3 for each group) in the same column followed by the different letter are significantly different (P<0.05). The statistical significance was evaluated by one-way ANOVA followed by DMRT test (α = 0.05).

10.

Bukti konfimasi artikel diterima dan acceptance letter

(18 Oktober 2022)

FR-IFC-005 - Decision on your manuscript

Food Research <foodresearch.my@outlook.com>
to me

Tue, Oct 18, 2022, 8:45 AM

Dear Dr Trisnawati,

It is a pleasure to accept your manuscript for publication in Food Research journal. Please refer to the attachment for your acceptance letter. I will contact you again once the galley proof is ready for viewing and approval.
Due to high volumes of manuscripts in production, please expect some delay.

Thank you for your fine contribution. We look forward to your continued contributions to the Journal.

Sincerely,
Dr Vivian New
Editor
Food Research

FR-IFC-005.docx

FOOD
RESEARCH

18th October 2022

Dear Dr Trisnawati,

ACCEPTANCE LETTER

Food Research is pleased to inform you that the following manuscript has been accepted for publication in Food Research journal.

Manuscript Title	:	Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks
Authors	:	Trisnawati, C.Y., Sutedja, A.M. and Kaharso, V.C.

We thank you for your fine contribution to the Food Research journal and encourage you to submit other articles to the Journal.

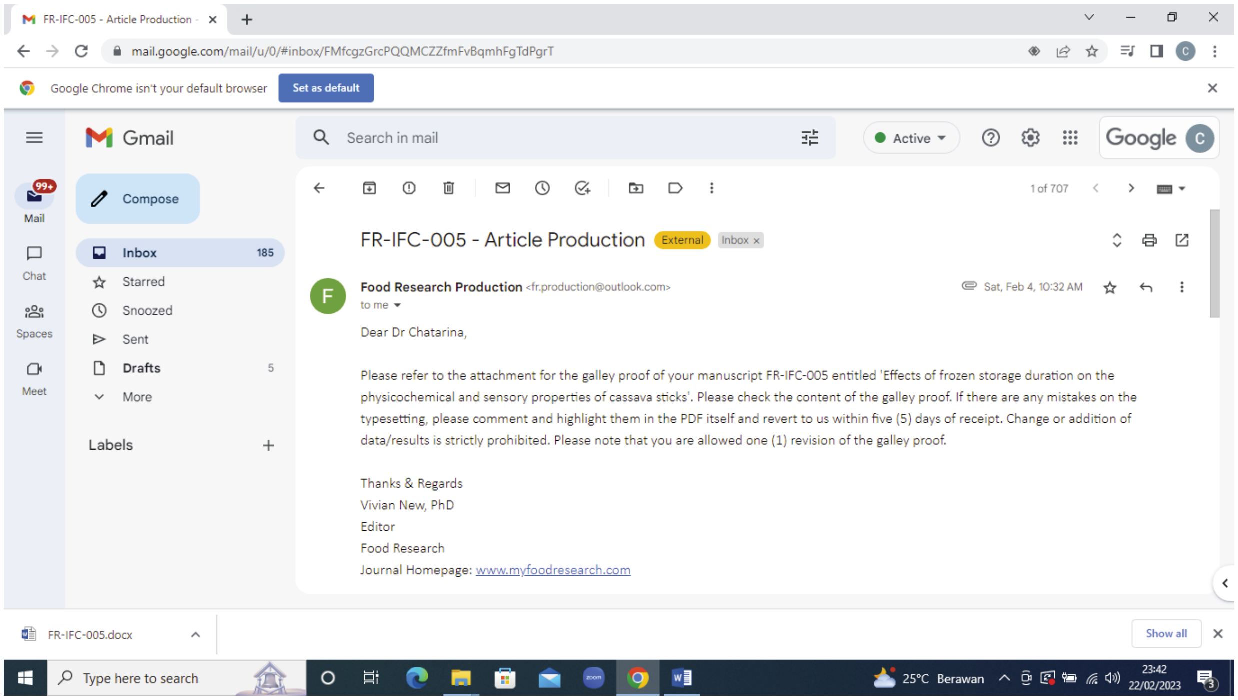
Yours sincerely,

Professor Dr. Son Radu
Chief Editor
Food Research

11.

Bukti konfirmasi galley proof artikel

(4 Februari 2023)



FR-IFC-005 - Article Production

Food Research Production <fr.production@outlook.com>
to me
Sat, Feb 4, 10:32 AM

Dear Dr Chatarina,

Please refer to the attachment for the galley proof of your manuscript FR-IFC-005 entitled 'Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks'. Please check the content of the galley proof. If there are any mistakes on the typesetting, please comment and highlight them in the PDF itself and revert to us within five (5) days of receipt. Change or addition of data/results is strictly prohibited. Please note that you are allowed one (1) revision of the galley proof.

Thanks & Regards
Vivian New, PhD
Editor
Food Research
Journal Homepage: www.myfoodresearch.com

Food Research (2023) : pp - pp
Journal homepage: https://www.myfoodresearch.com

FOOD RESEARCH

FULL PAPER

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

*Trisnawati, C.Y., Sutedja, A.M. and Kaharso, V.C.

Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia

Article history:
Received: 5 February 2022
Received in revised form: 28 March 2022
Accepted: 31 March 2022
Available Online:

Keywords:
Cassava,
Cassava stick,
Frozen storage duration

DOI:

Abstract

Cassava sticks is a processed food made from cassava that has similar characteristics to French fries. However, cassava sticks are also classified as perishable food, so it is required to employ other processes that might increase its preservation, such as frozen storage. In this study, the cassava stick was stored at -20°C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month carried out in three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen conditions significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference ($P>0.05$) with other samples.

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered a substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as *tiwul, gatot, gaplek, gethuk, tapai*, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown colour, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one of the most used methods (Rahman and Velez-Ruiz, 2007). Generally, frozen storage temperature is 0°F (-18°C) and even colder depending on the type of food (WFLO Commodity Storage Manual, 2008).

Several studies showed that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Sattar *et al*., 2015; Celli *et al*., 2016; Medic *et al*., 2018). However, based on authors' knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of

*Corresponding author.
Email: *chatarina@ukwms.ac.id*

eISSN: 2550-2166 / © 2023 The Authors.
Published by Rynnye Lyan Resources

cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1 Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2), purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2 Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassava tubers were then peeled, cut into strips of 4×1×1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 mins to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98°C, 15 mins) and cooled to room temperature before being pre-fried (170°C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20°C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 mins) and fried for 2 mins at the same condition as the pre-frying process. At the end of frying, the fryer basket was immediately shaken for 10 s and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3 Moisture content

All fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hrs at 105±2°C.

2.4 Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohamed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hrs and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5 Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of fried cassava stick was expressed as Newton and determined as the maximum force required to compress the sample.

2.6 Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g of fried cassava sticks were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink colour occurred for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7 Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g of fried cassava sticks were mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 min before 30 mL of distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow colour had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue colour disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8 Colour

The colour of fried cassava stick was identified using a colour reader (Colour Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, -

DOI

= blueness) of each sample were observed.

2.9 Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were colour, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10 Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at P<0.05.

3. Results and discussion

3.1 Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference (P>0.05) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al.* (2018), where frozen storage duration had no significant effect on the moisture content of pork loin and belly rib. However, several researchers also found that freezing significantly (P<0.05) influenced the moisture content of the fried potato (Adedeji and Ngadi, 2017), lamb (Coombs *et al.*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18°C and is easily removed from food when the food is dried or fried, causing the moisture content to decrease.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modified thermogravimetric method (Mohamed *et al*., 1988). Table 1 shows that the storage duration significantly increased (P<0.05) the oil absorption of cassava sticks. Cassava stick stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference with cassava stick stored frozen for 3 months (57.84%). In a study conducted by Adedeji and Ngadi (2017), oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also found that there was no interaction between storage duration and freezing method, which contradicts this study.

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13±7.46^a	20.87±15.91^a
1	48.83±3.27^a	25.66±9.51^a
2	28.68±7.95^a	58.45±2.47^b
3	27.75±10.13^a	57.94±24.71^b

Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990), where oil transfers into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Rimac-Brncic *et al*., 2004; Dana and Saguy, 2006). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al*., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2 Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that figure, frozen storage duration significantly affected (P<0.05) the hardness of the cassava sticks. Cassava stick that was stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). These results were in accordance to Adedeji and Ngadi (2017). They found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase in fried cassava stick hardness might be due to the retrogradation of cassava starch during frozen storage. This statement was supported by a similar study by Yu *et*

al. (2010), where the hardness of cooked rice increased continually with the amylopectin retrogradation during frozen storage. Based on those findings, amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

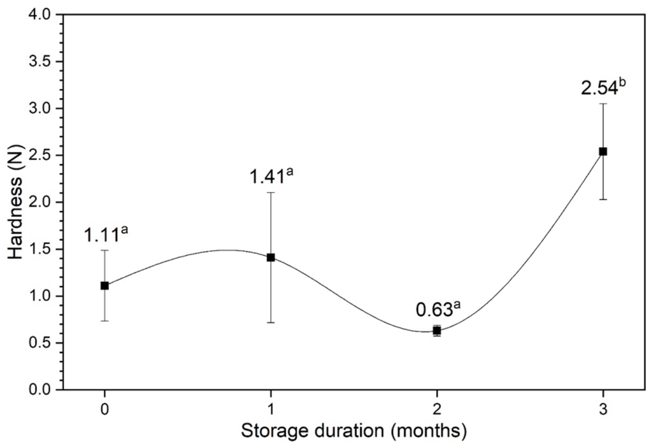


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

3.3 Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased (P<0.05) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference (P>0.05) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased (P<0.05) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri and Mangaraj, 2012).

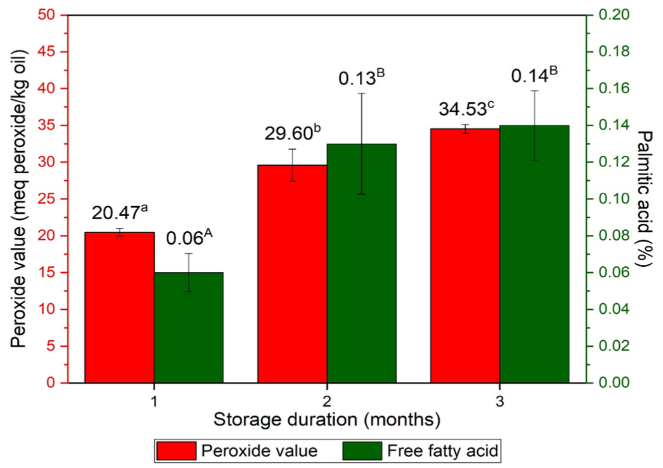


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

3.4 Colour properties

Colour is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Hutchings, 2002; Patras *et al*., 2011). In this study, the colour of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* colour attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Research by Oner and Wall (2012) also found that frozen storage significantly influenced (P<0.05) the colour of French fries. The colour change of fried cassava sticks during frozen storage duration might be

DOI

due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the colour of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and results in the increase in coloration of yellow, red, and brown in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust colour of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

Table 2. Colour of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Colour		
	L*	*a**	*b**
0	71.55±4.08[ab]	2.95±0.78[a]	32.08±3.02[b]
1	67.98±2.78[a]	4.62±1.93[a]	30.79±1.87[b]
2	66.52±1.15[a]	3.21±0.37[a]	25.77±0.98[a]
3	75.20±1.80[b]	4.01±0.30[a]	31.40±1.66[b]

Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

3.5 Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the colour attribute was the 0-month storage cassava sticks (5.60) and significantly different (P<0.05) with other samples (3.20 – 4.96). The decrease in panelists' colour preference was due to the colour changes in cassava sticks that tend to be darker and brownish than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased (P<0.05) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with the objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference (P>0.05) compared to 2 months stored cassava stick (4.66) but showed a significant difference (P<0.05) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced (P<0.05) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference (P>0.05) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect (P>0.05) panelists' acceptance of the cassava stick.

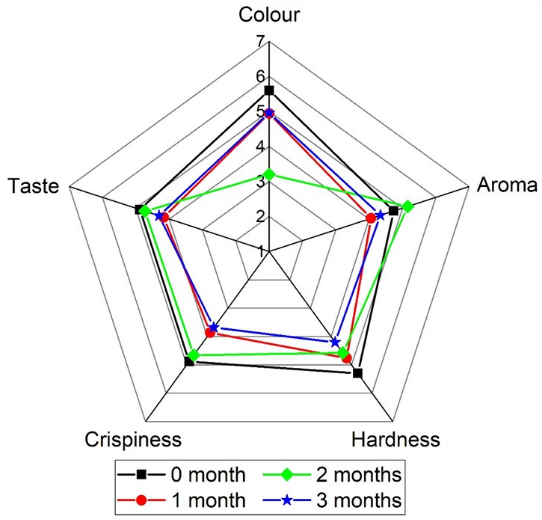


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change. The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface colour, substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with the elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

DOI

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of Food Engineering*, 91(1), 146-153. https://doi.org/10.1016/j.jfoodeng.2008.08.018

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32. https://doi.org/10.1016/j.jfoodeng.2017.08.024

AOAC (Association of Analytical Communities). (2006). Official Methods of Analysis of AOAC International. 18th ed. Gaithersburg, USA: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216. https://doi.org/10.4314/acsj.v12i3.27880

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304. https://doi.org/10.1080/87559129.2015.1075212

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb *M. longissimus lumborum* quality and safety parameters. *Meat Science*, 134, 86–97. https://doi.org/10.1016/j.meatsci.2017.07.017

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607. https://doi.org/10.1016/j.foodchem.2013.08.132

Dana, D. and Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128-130, 267-272. https://doi.org/10.1016/j.cis.2006.11.013

Fellows, P.J. (1990). Food Processing Technology Principles and Practice. London, United Kingdom: Ellis Horwood

Fennema, G.R. (1985). Principles of Food Science. New York, USA: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*, 4, 149-164. https://doi.org/10.1007/s12393-012-9053-0

Hutchings, J.B. (2002). The Perception and Sensory Assessment of Colour. Cambridge, United Kingdom: Woodhead Publishing Limited. https://doi.org/10.1201/9781439823194.pt1

International Atomic Energy Agency. (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. Retrieved on October 21, 2021 from website: https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1), 18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). Pengawasan Mutu Makanan. Malang, Indonesia: UB Press. [In Bahasa Indonesia].

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23(4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49. https://doi.org/10.1007/s13197-011-0257-8

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127. https://doi.org/10.1016/j.meatsci.2018.03.006

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science and Technology*, 14(9), 364-373. https://doi.org/10.1016/S0924-2244(03)00050-5

Mohamed, S., Abdullah, N. and Muthu, M.K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing

conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291. https://doi.org/10.13031/2013.42486

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252. https://doi.org/10.1007/s11947-009-0226-7

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Colour changes and acrylamide formation in fried potato slices. *Food Research International*, 38 (1), 1-9. https://doi.org/10.1016/j.foodres.2004.07.002

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In Handbook of Food Preservation. 2nd ed. USA: CRC Press. https://doi.org/10.1201/9781420017373-41

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241. https://doi.org/10.1016/j.jfoodeng.2003.10.006

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168. https://doi.org/10.1007/s002170050017

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of French fried potatoes (*Solanum tuberosum* L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). Prosedur Analisa untuk Bahan Makanan dan Pertanian. Yogyakarta, Indonesia: Liberty. [In Bahasa Indonesia]

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference*, 13(4), 215–225. https://doi.org/10.1016/S0950-3293(01)00039-8

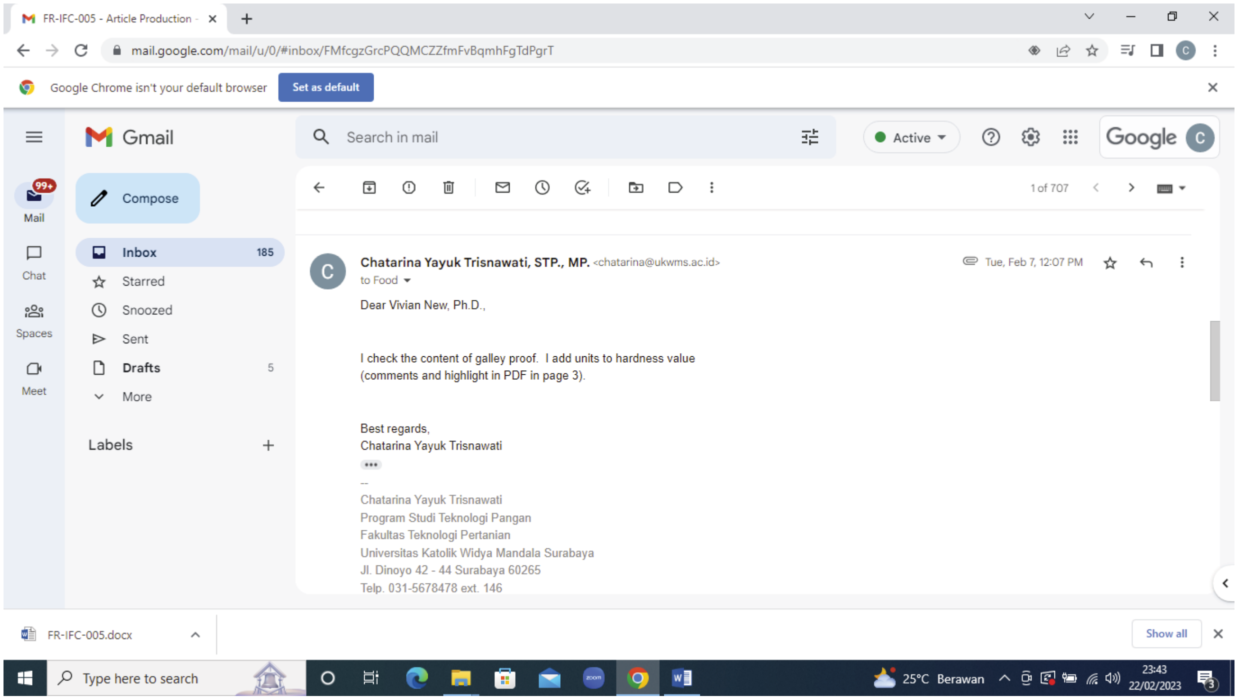
WFLO Commodity Storage Manual. (2008). Frozen Foods Handling and Storage. Retrieved on October 25, 2021, from website: http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143. https://doi.org/10.1016/j.lwt.2010.03.004

12.

Bukti konfirmasi submit revisi galley proof artikel dan galley proof artikel revisi yang di-resubmit

(7 Februari 2023)



FR-IFC-005 - Article Production

mail.google.com/mail/u/0/#inbox/FMfcgzGrcPQQMCZZfmFvBqmhFgTdPgrT

Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
to Food
Tue, Feb 7, 12:07 PM

Dear Vivian New, Ph.D.,

I check the content of galley proof. I add units to hardness value (comments and highlight in PDF in page 3).

Best regards,
Chatarina Yayuk Trisnawati

--
Chatarina Yayuk Trisnawati
Program Studi Teknologi Pangan
Fakultas Teknologi Pertanian
Universitas Katolik Widya Mandala Surabaya
Jl. Dinoyo 42 - 44 Surabaya 60265
Telp. 031-5678478 ext. 146

FR-IFC-005.docx

Food Research (2023) : pp - pp
Journal homepage: https://www.myfoodresearch.com

FOOD RESEARCH

FULL PAPER

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

*Trisnawati, C.Y., Sutedja, A.M. and Kaharso, V.C.

Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia

Article history:
Received: 5 February 2022
Received in revised form: 28 March 2022
Accepted: 31 March 2022
Available Online:

Keywords:
Cassava,
Cassava stick,
Frozen storage duration

DOI:

Abstract

Cassava sticks is a processed food made from cassava that has similar characteristics to French fries. However, cassava sticks are also classified as perishable food, so it is required to employ other processes that might increase its preservation, such as frozen storage. In this study, the cassava stick was stored at -20°C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month carried out in three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen conditions significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference ($P>0.05$) with other samples.

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered a substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as *tiwul, gatot, gaplek, gethuk, tapai*, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown colour, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one of the most used methods (Rahman and Velez-Ruiz, 2007). Generally, frozen storage temperature is 0°F (-18°C) and even colder depending on the type of food (WFLO Commodity Storage Manual, 2008).

Several studies showed that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Sattar *et al*., 2015; Celli *et al*., 2016; Medic *et al*., 2018). However, based on authors' knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of

*Corresponding author.
Email: *chatarina@ukwms.ac.id*

eISSN: 2550-2166

cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1 Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2), purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2 Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassava tubers were then peeled, cut into strips of 4×1×1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 mins to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98°C, 15 mins) and cooled to room temperature before being pre-fried (170°C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20°C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 mins) and fried for 2 mins at the same condition as the pre-frying process. At the end of frying, the fryer basket was immediately shaken for 10 s and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3 Moisture content

All fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hrs at 105±2°C.

2.4 Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohamed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hrs and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5 Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of fried cassava stick was expressed as Newton and determined as the maximum force required to compress the sample.

2.6 Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g of fried cassava sticks were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink colour occurred for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7 Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g of fried cassava sticks were mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 min before 30 mL of distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow colour had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue colour disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8 Colour

The colour of fried cassava stick was identified using a colour reader (Colour Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, -

DOI

= blueness) of each sample were observed.

2.9 Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al.*, 2017). The sensory evaluation was evaluated by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were colour, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10 Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at P<0.05.

3. Results and discussion

3.1 Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference (P>0.05) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al.* (2018), where frozen storage duration had no significant effect on the moisture content of pork loin and belly rib. However, several researchers also found that freezing significantly (P<0.05) influenced the moisture content of the fried potato (Adedeji and Ngadi, 2017), lamb (Coombs *et al.*, 2017), and pork ham (Medic *et al.*, 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18°C and is easily removed from food when the food is dried or fried, causing the moisture content to decrease.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modified thermogravimetric method (Mohamed *et al.*, 1988). Table 1 shows that the storage duration significantly increased (P<0.05) the oil absorption of cassava sticks. Cassava stick stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference with cassava stick stored frozen for 3 months (57.84%). In a study conducted by Adedeji and Ngadi (2017), oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also found that there was no interaction between storage duration and freezing method, which contradicts this study.

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13±7.46^{a}	20.87±15.91^{a}
1	48.83±3.27^{a}	25.66±9.51^{a}
2	28.68±7.95^{a}	58.45±2.47^{b}
3	27.75±10.13^{a}	57.94±24.71^{b}

Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

According to Adedeji *et al.* (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990), where oil transfers into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Rimac-Brncic *et al.*, 2004; Dana and Saguy, 2006). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al.*, 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2 Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that figure, frozen storage duration significantly affected (P<0.05) the hardness of the cassava sticks. Cassava stick that was stored frozen for 3 months has the highest force (2.54) among other samples (0.63 – 1.41). These results were in accordance to Adedeji and Ngadi (2017). They found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase in fried cassava stick hardness might be due to the retrogradation of cassava starch during frozen storage. This statement was supported by a similar study by Yu *et*

DOI

al. (2010), where the hardness of cooked rice increased continually with the amylopectin retrogradation during frozen storage. Based on those findings, amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

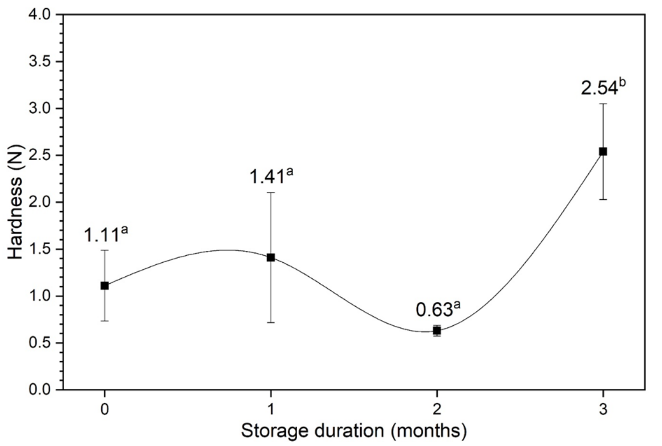


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

3.3 Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased (P<0.05) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference (P>0.05) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased (P<0.05) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri and Mangaraj, 2012).

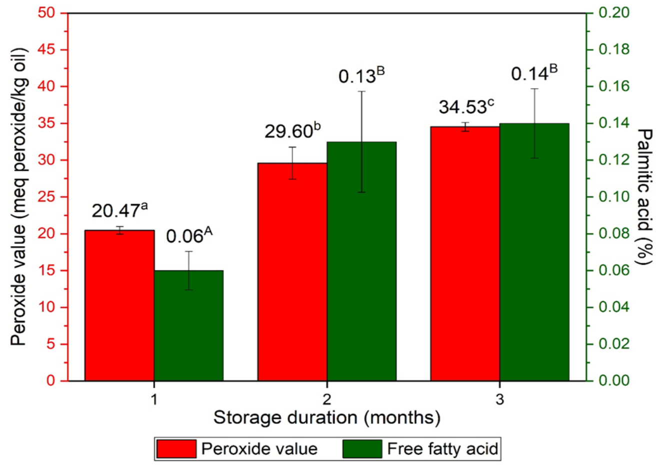


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

3.4 Colour properties

Colour is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Hutchings, 2002; Patras *et al*., 2011). In this study, the colour of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* colour attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Research by Oner and Wall (2012) also found that frozen storage significantly influenced (P<0.05) the colour of French fries. The colour change of fried cassava sticks during frozen storage duration might be

DOI

due to the surface moisture desiccation (Maity *et al.*, 2012). The amount of moisture loss during the frying process also influence the colour of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and results in the increase in coloration of yellow, red, and brown in fried food (Pedreschi *et al.*, 2005). Another factor that might influence the crust colour of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al.*, 2012).

Table 2. Colour of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Colour		
	L*	*a**	*b**
0	71.55±4.08[ab]	2.95±0.78[a]	32.08±3.02[b]
1	67.98±2.78[a]	4.62±1.93[a]	30.79±1.87[b]
2	66.52±1.15[a]	3.21±0.37[a]	25.77±0.98[a]
3	75.20±1.80[b]	4.01±0.30[a]	31.40±1.66[b]

Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

3.5 Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the colour attribute was the 0-month storage cassava sticks (5.60) and significantly different (P<0.05) with other samples (3.20 – 4.96). The decrease in panelists' colour preference was due to the colour changes in cassava sticks that tend to be darker and brownish than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased (P<0.05) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with the objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference (P>0.05) compared to 2 months stored cassava stick (4.66) but showed a significant difference (P<0.05) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced (P<0.05) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference (P>0.05) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect (P>0.05) panelists' acceptance of the cassava stick.

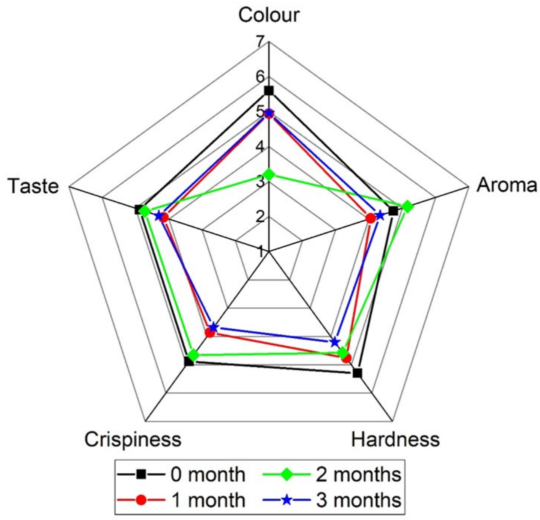


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change. The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface colour, substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with the elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of Food Engineering*, 91(1), 146-153. https://doi.org/10.1016/j.jfoodeng.2008.08.018

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32. https://doi.org/10.1016/j.jfoodeng.2017.08.024

AOAC (Association of Analytical Communities). (2006). Official Methods of Analysis of AOAC International. 18th ed. Gaithersburg, USA: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216. https://doi.org/10.4314/acsj.v12i3.27880

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304. https://doi.org/10.1080/87559129.2015.1075212

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb *M. longissimus lumborum* quality and safety parameters. *Meat Science*, 134, 86–97. https://doi.org/10.1016/j.meatsci.2017.07.017

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607. https://doi.org/10.1016/j.foodchem.2013.08.132

Dana, D. and Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128-130, 267-272. https://doi.org/10.1016/j.cis.2006.11.013

Fellows, P.J. (1990). Food Processing Technology Principles and Practice. London, United Kingdom: Ellis Horwood

Fennema, G.R. (1985). Principles of Food Science. New York, USA: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*, 4, 149-164. https://doi.org/10.1007/s12393-012-9053-0

Hutchings, J.B. (2002). The Perception and Sensory Assessment of Colour. Cambridge, United Kingdom: Woodhead Publishing Limited. https://doi.org/10.1201/9781439823194.pt1

International Atomic Energy Agency. (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. Retrieved on October 21, 2021 from website: https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1), 18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). Pengawasan Mutu Makanan. Malang, Indonesia: UB Press. [In Bahasa Indonesia].

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23(4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49. https://doi.org/10.1007/s13197-011-0257-8

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127. https://doi.org/10.1016/j.meatsci.2018.03.006

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science and Technology*, 14(9), 364-373. https://doi.org/10.1016/S0924-2244(03)00050-5

Mohamed, S., Abdullah, N. and Muthu, M.K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing

conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291. https://doi.org/10.13031/2013.42486

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252. https://doi.org/10.1007/s11947-009-0226-7

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Colour changes and acrylamide formation in fried potato slices. *Food Research International*, 38 (1), 1-9. https://doi.org/10.1016/j.foodres.2004.07.002

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In Handbook of Food Preservation. 2nd ed. USA: CRC Press. https://doi.org/10.1201/9781420017373-41

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241. https://doi.org/10.1016/j.jfoodeng.2003.10.006

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168. https://doi.org/10.1007/s002170050017

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of French fried potatoes (*Solanum tuberosum* L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). Prosedur Analisa untuk Bahan Makanan dan Pertanian. Yogyakarta, Indonesia: Liberty. [In Bahasa Indonesia]

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference*, 13(4), 215–225. https://doi.org/10.1016/S0950-3293(01)00039-8

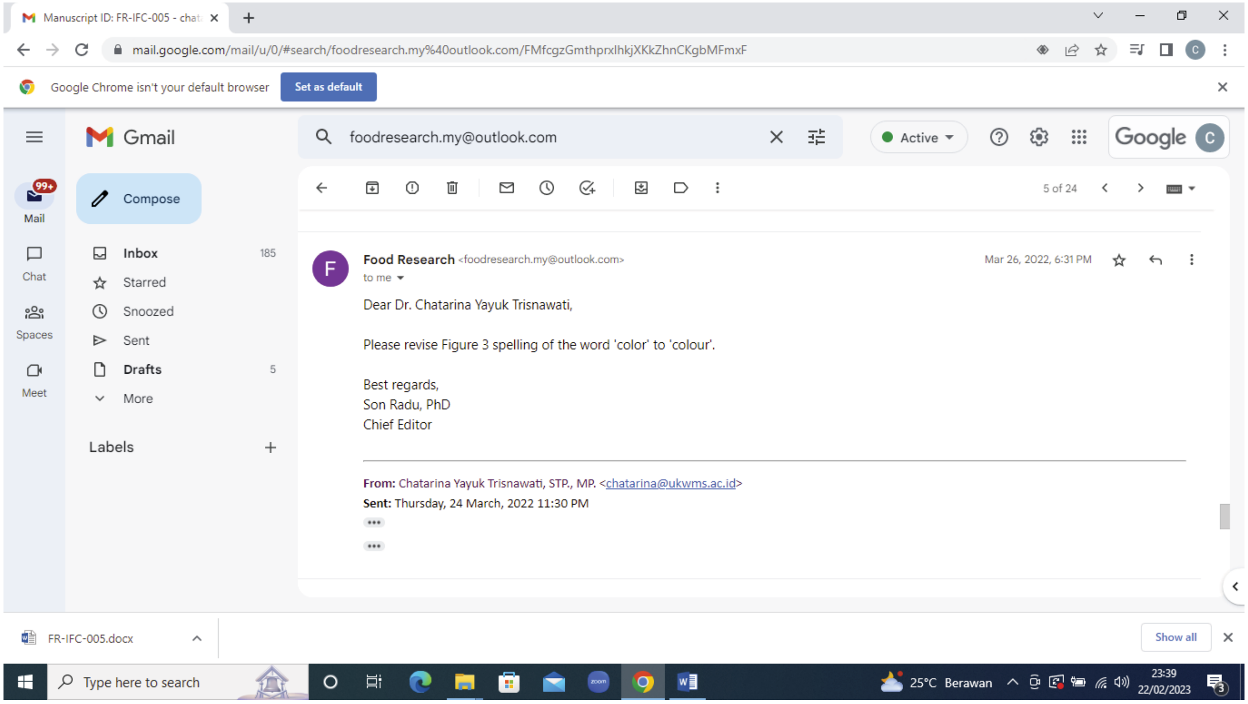
WFLO Commodity Storage Manual. (2008). Frozen Foods Handling and Storage. Retrieved on October 25, 2021, from website: http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143. https://doi.org/10.1016/j.lwt.2010.03.004

8.

Bukti konfirmasi revisi artikel yang harus dilakukan

(26 Maret 2022)



Manuscript ID: FR-IFC-005 - chat

mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF

foodresearch.my@outlook.com

5 of 24

Food Research <foodresearch.my@outlook.com> — Mar 26, 2022, 6:31 PM

to me

Dear Dr. Chatarina Yayuk Trisnawati,

Please revise Figure 3 spelling of the word 'color' to 'colour'.

Best regards,
Son Radu, PhD
Chief Editor

From: Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
Sent: Thursday, 24 March, 2022 11:30 PM

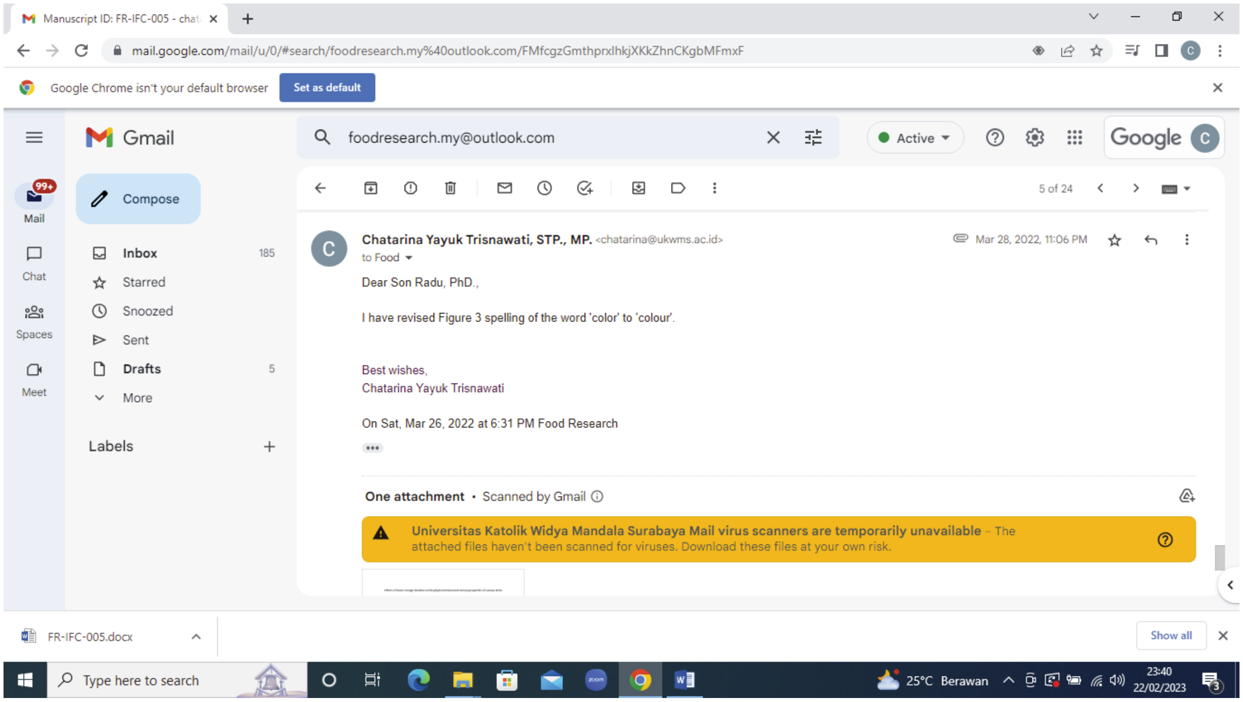
FR-IFC-005.docx

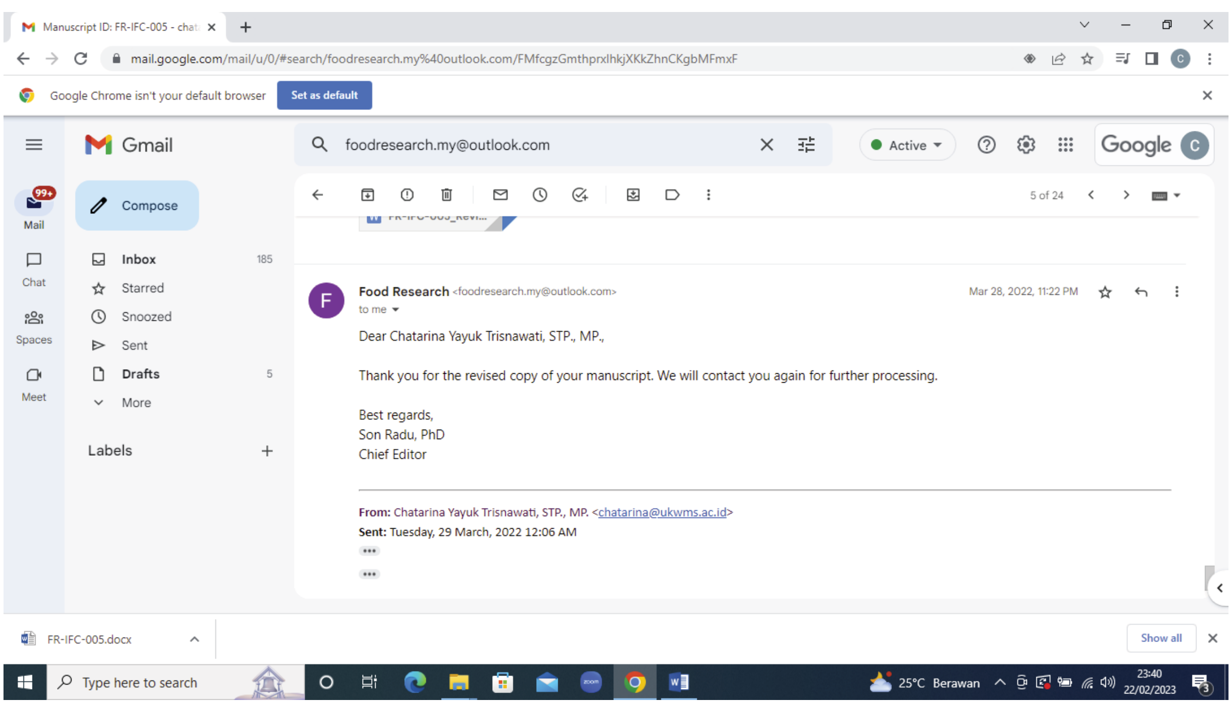
23:39 22/02/2023

9.

Bukti konfirmasi submit revisi artikel keempat dan balasannya

(28 Maret 2022)


Manuscript ID: FR-IFC-005 - chat
mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF
Google Chrome isn't your default browser
Set as default
Gmail
foodresearch.my@outlook.com
Active
Compose
Inbox 185
Starred
Snoozed
Sent
Drafts 5
More
Labels
Mail
Chat
Spaces
Meet
5 of 24
Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
to Food
Mar 28, 2022, 11:06 PM
Dear Son Radu, PhD.,
I have revised Figure 3 spelling of the word 'color' to 'colour'.
Best wishes,
Chatarina Yayuk Trisnawati
On Sat, Mar 26, 2022 at 6:31 PM Food Research
One attachment • Scanned by Gmail
Universitas Katolik Widya Mandala Surabaya Mail virus scanners are temporarily unavailable – The attached files haven't been scanned for viruses. Download these files at your own risk.
FR-IFC-005.docx
Show all
Type here to search
25°C Berawan
23:40
22/02/2023


Manuscript ID: FR-IFC-005 - chat
mail.google.com/mail/u/0/#search/foodresearch.my%40outlook.com/FMfcgzGmthprxlhkjXKkZhnCKgbMFmxF
Google Chrome isn't your default browser
Set as default
Gmail
foodresearch.my@outlook.com
Active
Compose
Inbox 185
Starred
Snoozed
Sent
Drafts 5
More
Labels
Mail
Chat
Spaces
Meet
5 of 24
Food Research <foodresearch.my@outlook.com>
to me
Mar 28, 2022, 11:22 PM
Dear Chatarina Yayuk Trisnawati, STP., MP.,
Thank you for the revised copy of your manuscript. We will contact you again for further processing.
Best regards,
Son Radu, PhD
Chief Editor
From: Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
Sent: Tuesday, 29 March, 2022 12:06 AM
FR-IFC-005.docx
Show all
Type here to search
25°C Berawan
23:40
22/02/2023

10.

Bukti konfimasi artikel diterima dan acceptance letter

(18 Oktober 2022)

FR-IFC-005 - Decision on your manuscript

Food Research <foodresearch.my@outlook.com>
to me

Tue, Oct 18, 2022, 8:45 AM

Dear Dr Trisnawati,

It is a pleasure to accept your manuscript for publication in Food Research journal. Please refer to the attachment for your acceptance letter. I will contact you again once the galley proof is ready for viewing and approval.
Due to high volumes of manuscripts in production, please expect some delay.

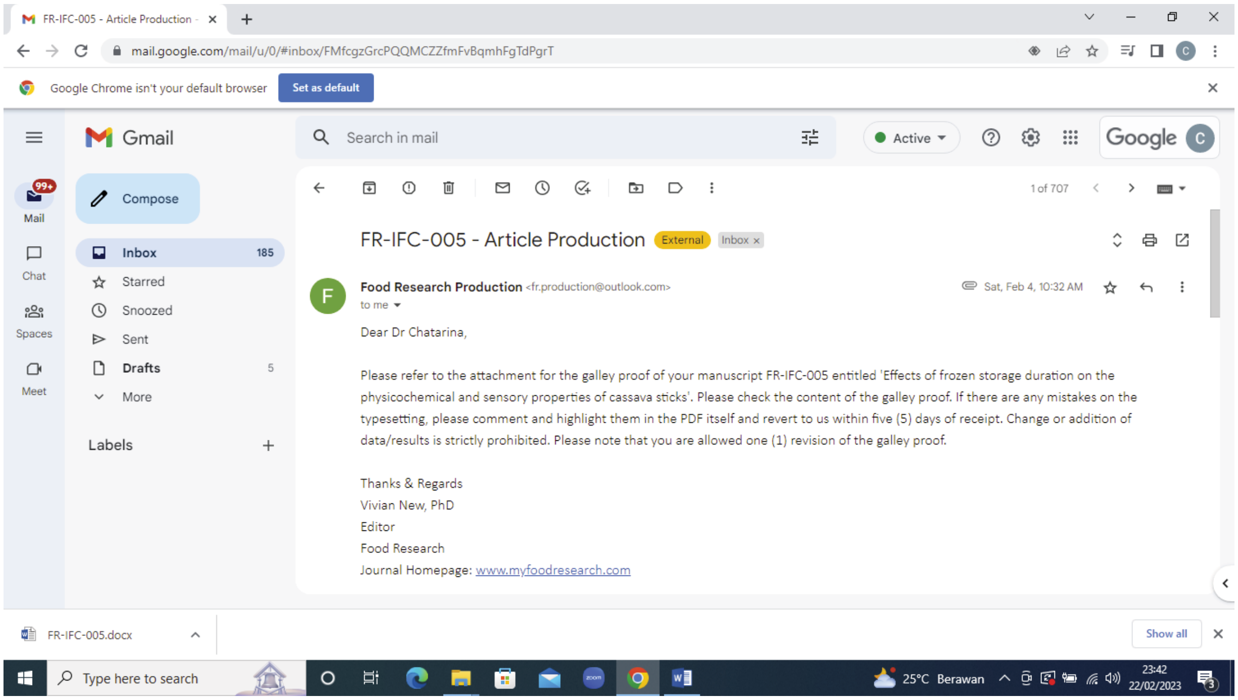
Thank you for your fine contribution. We look forward to your continued contributions to the Journal.

Sincerely,
Dr Vivian New
Editor
Food Research

11.

Bukti konfirmasi galley proof artikel

(4 Februari 2023)



FR-IFC-005 - Article Production

Food Research Production <fr.production@outlook.com>

to me

Sat, Feb 4, 10:32 AM

Dear Dr Chatarina,

Please refer to the attachment for the galley proof of your manuscript FR-IFC-005 entitled 'Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks'. Please check the content of the galley proof. If there are any mistakes on the typesetting, please comment and highlight them in the PDF itself and revert to us within five (5) days of receipt. Change or addition of data/results is strictly prohibited. Please note that you are allowed one (1) revision of the galley proof.

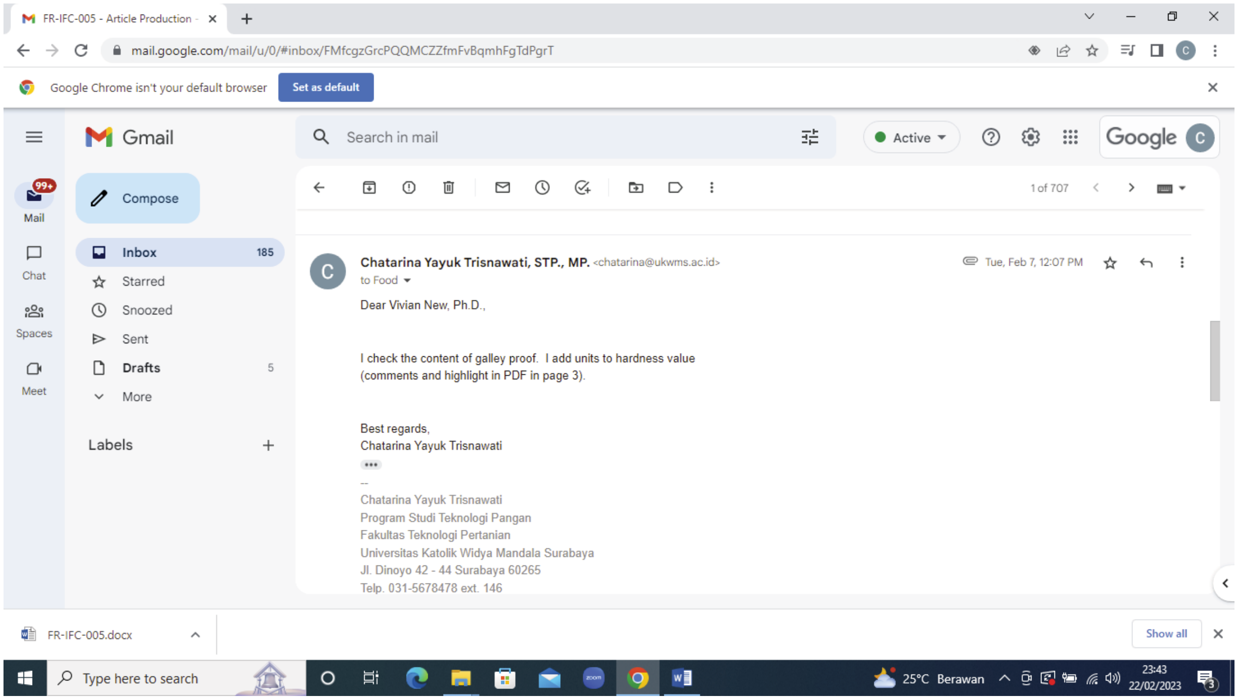
Thanks & Regards
Vivian New, PhD
Editor
Food Research
Journal Homepage: www.myfoodresearch.com

FR-IFC-005.docx

12.

Bukti konfirmasi submit revisi galley proof artikel dan galley proof artikel revisi yang di-resubmit

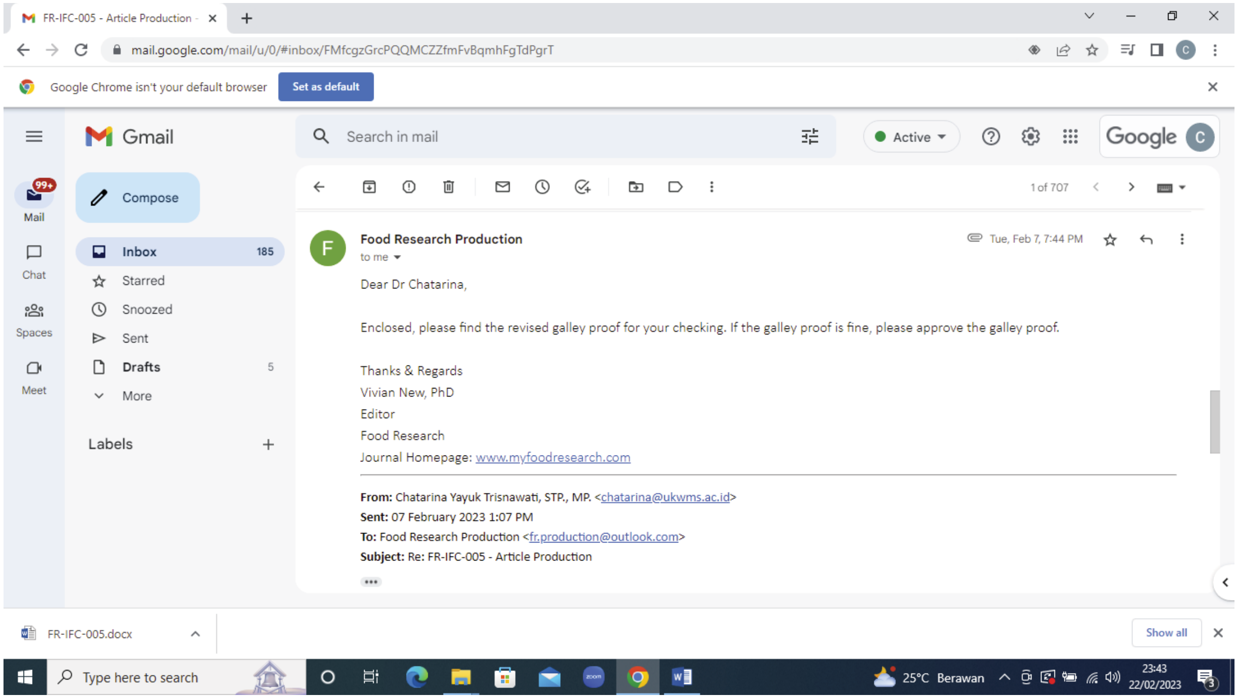
(7 Februari 2023)


FR-IFC-005 - Article Production
mail.google.com/mail/u/0/#inbox/FMfcgzGrcPQQMCZZfmFvBqmhFgTdPgrT
Google Chrome isn't your default browser
Set as default
Gmail
Search in mail
Active
Compose
Mail
Chat
Spaces
Meet
Inbox 185
Starred
Snoozed
Sent
Drafts 5
More
Labels
1 of 707
Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
to Food
Tue, Feb 7, 12:07 PM
Dear Vivian New, Ph.D.,
I check the content of galley proof. I add units to hardness value (comments and highlight in PDF in page 3).
Best regards,
Chatarina Yayuk Trisnawati
--
Chatarina Yayuk Trisnawati
Program Studi Teknologi Pangan
Fakultas Teknologi Pertanian
Universitas Katolik Widya Mandala Surabaya
Jl. Dinoyo 42 - 44 Surabaya 60265
Telp. 031-5678478 ext. 146
FR-IFC-005.docx
Show all
Type here to search
25°C Berawan
23:43
22/02/2023

13.

Bukti konfimasi galley proof hasil revisi, persetujuan galley proof dan balasannya

(7 dan 8 Februari 2023)



FR-IFC-005 - Article Production

mail.google.com/mail/u/0/#inbox/FMfcgzGrcPQQMCZZfmFvBqmhFgTdPgrT

Food Research Production
to me

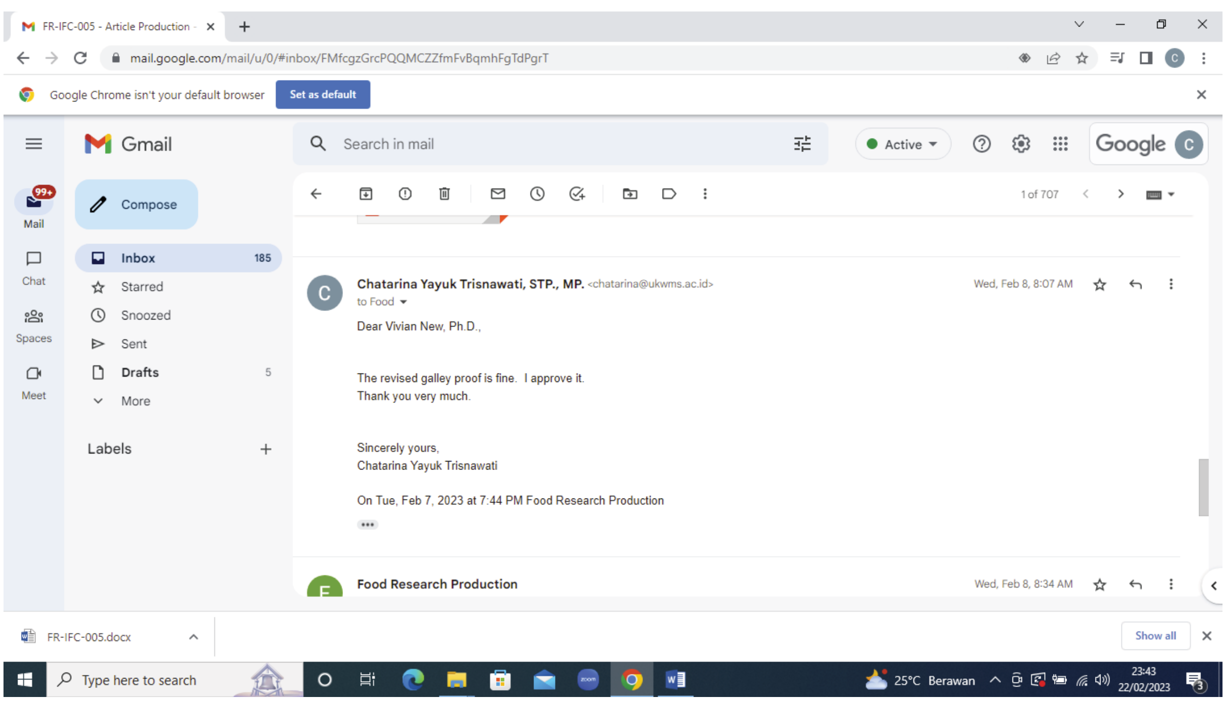
Tue, Feb 7, 7:44 PM

Dear Dr Chatarina,

Enclosed, please find the revised galley proof for your checking. If the galley proof is fine, please approve the galley proof.

Thanks & Regards
Vivian New, PhD
Editor
Food Research
Journal Homepage: www.myfoodresearch.com

From: Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
Sent: 07 February 2023 1:07 PM
To: Food Research Production <fr.production@outlook.com>
Subject: Re: FR-IFC-005 - Article Production



FR-IFC-005 - Article Production

mail.google.com/mail/u/0/#inbox/FMfcgzGrcPQQMCZZfmFvBqmhFgTdPgrT

Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
to Food

Wed, Feb 8, 8:07 AM

Dear Vivian New, Ph.D.,

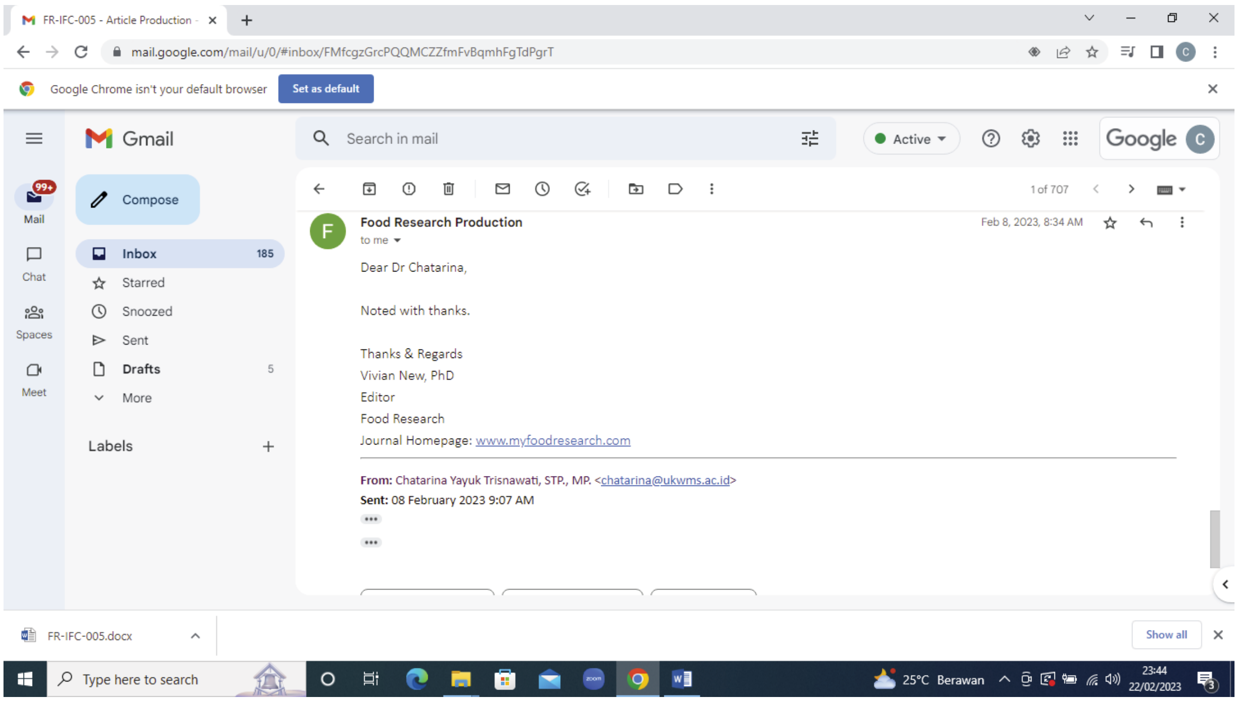
The revised galley proof is fine. I approve it.
Thank you very much.

Sincerely yours,
Chatarina Yayuk Trisnawati

On Tue, Feb 7, 2023 at 7:44 PM Food Research Production

Food Research Production

Wed, Feb 8, 8:34 AM



Food Research Production
to me
Feb 8, 2023, 8:34 AM

Dear Dr Chatarina,

Noted with thanks.

Thanks & Regards
Vivian New, PhD
Editor
Food Research
Journal Homepage: www.myfoodresearch.com

From: Chatarina Yayuk Trisnawati, STP., MP. <chatarina@ukwms.ac.id>
Sent: 08 February 2023 9:07 AM

Food Research (2023) : pp - pp
Journal homepage: https://www.myfoodresearch.com

FOOD RESEARCH

FULL PAPER

Effects of frozen storage duration on the physicochemical and sensory properties of cassava sticks

*Trisnawati, C.Y., Sutedja, A.M. and Kaharso, V.C.

Department of Food Technology, Faculty of Agricultural Technology, Widya Mandala Surabaya Catholic University, Surabaya, East Java, Indonesia

Article history:
Received: 5 February 2022
Received in revised form: 28 March 2022
Accepted: 31 March 2022
Available Online:

Keywords:
Cassava,
Cassava stick,
Frozen storage duration

DOI:

Abstract

Cassava sticks is a processed food made from cassava that has similar characteristics to French fries. However, cassava sticks are also classified as perishable food, so it is required to employ other processes that might increase its preservation, such as frozen storage. In this study, the cassava stick was stored at -20°C for three months to investigate its effects on the physicochemical and sensory properties of cassava sticks. The effects of frozen storage duration were monitored every month carried out in three replications. A randomized block design with a single factor was used as the experimental design. According to the results, storing cassava sticks under frozen conditions significantly increased ($P<0.05$) the oil absorption and had no effect ($P>0.05$) on the moisture content. A significant alteration ($P<0.05$) in texture was observed through the increase of cassava stick hardness from 1.11 to 2.54 N. Frozen storage duration also influenced ($P<0.05$) the lightness and yellowness, but not the redness ($P>0.05$) of cassava sticks. Fat oxidation also occurred during storage, marked by a significant increase ($P<0.05$) of free fatty acid (0.06 to 0.14%) and peroxide value (0 to 34.53 mg peroxide/kg lipid) on three months of frozen storage. Thus, this study concludes that frozen storage duration affected the physical and chemical properties of cassava sticks. Moreover, cassava sticks stored frozen for three months were acceptable for panelists with neither like nor dislike (4.30) average acceptance, and had no significant difference ($P>0.05$) with other samples.

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed crops in the world, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Vietnam, and Laos (Benesi *et al*., 2004; International Atomic Energy Agency, 2018). Cassava is considered a substitute for rice as the primary carbohydrate source and can be consumed in various ways (fried, boiled, or steamed). Besides carbohydrates, cassava is also rich in calcium (50 mg/100 g), phosphorus (40 mg/100 g), vitamin C (25 mg/100g) and contains a significant amount of thiamine, riboflavin, and nicotinic acid (International Atomic Energy Agency, 2018). In Indonesia, cassava is generally processed into traditional food such as *tiwul, gatot, gaplek, gethuk, tapai*, and cassava chips. Furthermore, it can also be processed into a modern food such as cassava stick.

Cassava stick has similar characteristics to French fries due to its shoestring-like shape, golden brown colour, crunchy exterior, and fluffy interior. Those characteristics are obtained through several processes such as blanching, drying, frying, and each step affects the quality of the final product (Lamberg *et al*., 1990). Other processes are also required to extend shelf life since cassava sticks are classified as perishable food. Among other processes that might be employed for long-term preservation (high pressure, infrared irradiation, pulsed electric field, and ultrasound), freezing or frozen storage is still one of the most used methods (Rahman and Velez-Ruiz, 2007). Generally, frozen storage temperature is 0°F (-18°C) and even colder depending on the type of food (WFLO Commodity Storage Manual, 2008).

Several studies showed that storing food (fruit, meat, and French fries) under freezing temperatures affects the physical and chemical properties (Sattar *et al*., 2015; Celli *et al*., 2016; Medic *et al*., 2018). However, based on authors' knowledge, there is no study reported about the effect of frozen storage on the cassava sticks properties. Therefore, this study aimed to investigate the physical and chemical changes on cassava sticks during frozen storage. In addition, the sensory evaluation of

*Corresponding author.
Email: *chatarina@ukwms.ac.id*

eISSN: 2550-2166 / © 2023 The Authors.
Published by Rynnye Lyan Resources

cassava sticks during frozen storage was also studied.

2. Materials and methods

2.1 Materials

Cassava tubers (*Manihot esculenta* Crantz) used in this study were yellow cassava (Malang 2), purchased from a local market in Malang, Indonesia. The cooking oil was purchased from a market in Surabaya, Indonesia. All chemicals and other reagents used in this study were analytical grades.

2.2 Preparation of cassava stick

Cassava tubers were washed two times using tap water to remove physical contaminations. The cleaned cassava tubers were then peeled, cut into strips of 4×1×1 cm, and soaked in 0.1% (w/v) $CaCl_2$ for 15 mins to increase the crispiness of the cassava stick. Next, the soaked cassava sticks were steamed in a steamer (98^{o}C, 15 mins) and cooled to room temperature before being pre-fried (170^{o}C, 30 s) in cassava sticks : cooking oil ratio of 1:12 (w/v) using a deep fryer (Fritel Professional 35 SICO, Belgium). Later, the pre-fried cassava sticks were vacuum packed in a polypropylene plastic bag using a vacuum sealer (Maksindo DZ300, Indonesia) and frozen at -20^{o}C for different storage duration (0, 1, 2, 3 months) in a chest freezer (Modena MD 45, Italy). The frozen cassava sticks were then thawed in a water bath (15 mins) and fried for 2 mins at the same condition as the pre-frying process. At the end of frying, the fryer basket was immediately shaken for 10 s and sticks were cooled to room temperature before analyzing the physicochemical properties.

2.3 Moisture content

All fried cassava stick samples were minced before immediately analyzing the moisture content. The moisture content was determined using a drying oven (Binder ED 53, Germany) with the thermogravimetric method (AOAC, 2006) for 3-5 hrs at 105±2°C.

2.4 Oil absorption analysis

The oil absorption analysis was determined according to the method by Mohamed *et al*. (1988). Approximately 5 g of minced pre-fried and fried cassava sticks were oven-dried at 105°C for 3-5 hrs and weighed until a stable weight of the sample was obtained. The oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\%$$

where W_1 is the weight of pre-fried cassava stick (g) and W_2 is the weight of fried cassava stick (g).

2.5 Hardness

Hardness as the selected texture characteristics were determined using a TA-XT plus (Stable Micro System, UK) equipped with a three-point bend rig using compression test mode with the following conditions: pre-test speed= 2 mm/s, test speed= 0.5 mm/s, post-test speed= 10 mm/s, and distance= 10 mm. The hardness of fried cassava stick was expressed as Newton and determined as the maximum force required to compress the sample.

2.6 Free fatty acid analysis

The free fatty acid of cassava sticks was analyzed using a method by Sudarmadji *et al*. (1984). Approximately 28.2 g of fried cassava sticks were minced before adding 50 mL of neutralized alcohol and 2 mL phenolphthalein. The mixture was then titrated with 0.1 N NaOH until a stable pink colour occurred for 30 s. The percentage of free fatty acid was expressed as the percentage of palmitic acid and calculated using the following equation:

$$\text{Palmitic acid (\%)} = \frac{V_{NaOH} \times N_{NaOH} \times Mr}{W \times 1000} \times 100\%$$

where V_{NaOH} is the titre of NaOH (mL), N_{NaOH} is the concentration of NaOH (N), Mr is the molecular weight of palmitic acid (256.42 g/mol), and W is the sample weight (g).

2.7 Peroxide value

An iodometric titration method was used to analyze the peroxide value as the primary oxidation product (Sudarmadji *et al*., 1984). Briefly, 5 g of fried cassava sticks were mixed with 30 mL acetic acid – chloroform (3:2) and 0.5 mL saturated aqueous potassium iodide solution was added. Later, the mixture was shaken vigorously for 1 min before 30 mL of distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until the yellow colour had almost disappeared. Next, 0.5 mL of 1% (w/v) starch indicator solution was added and the titration continued until the blue colour disappeared. The peroxide value was calculated using the following formula:

$$\text{Peroxide value (meq peroxide/kg oil)} = \frac{V_{thio} \times N_{thio} \times 1000}{W}$$

where V_{thio} is the titre of $Na_2S_2O_3$ (mL), N_{thio} is the concentration of $Na_2S_2O_3$, and W is the sample weight (g).

2.8 Colour

The colour of fried cassava stick was identified using a colour reader (Colour Reader Minolta, CR-10). The L* value (0 = blackness, 100 = whiteness), a* value (+ = redness, - = greenness), and b* value (+ = yellowness, -

= blueness) of each sample were observed.

2.9 Sensory evaluation

In this study, the Hedonic Scale Scoring (preferred test) was used to measure the level of preference and acceptance of the product by consumers (Kusuma *et al*., 2017). The sensory evaluation was evaluated by 100 untrained panelists. The panelists were students of the Faculty of Agricultural Technology, Widya Mandala Catholic University Surabaya. The sensory attributes tested were colour, hardness, crispiness, aroma, and taste. A scoring system of 1-7 points was used to represent the sensory characteristics of each sample. On this scale, 1 was defined as dislike extremely, 2 was defined as dislike moderately, 3 was defined as dislike slightly, 4 was defined as neither like nor dislike, 5 was defined as like slightly, 6 was defined as like moderately, and 7 was defined as like extremely.

2.10 Statistical analysis

All experiments were analyzed at least three times in triplicate and represented as mean values ± SD. Statistical analyses were performed using SPSS for Windows (version 19.0, SPSS Inc., USA) and compared with Duncan Multiple Range Test (DMRT) at P<0.05.

3. Results and discussion

3.1 Moisture content and oil absorption

The moisture content of fried cassava sticks is shown in Table 1. Based on the result, different frozen storage durations have no significant difference (P>0.05) on the moisture content of cassava sticks, even though there was a downward trend in the moisture content of frozen cassava sticks for 2 and 3 months. Similar results were reported by Medic *et al.* (2018), where frozen storage duration had no significant effect on the moisture content of pork loin and belly rib. However, several researchers also found that freezing significantly (P<0.05) influenced the moisture content of the fried potato (Adedeji and Ngadi, 2017), lamb (Coombs *et al.*, 2017), and pork ham (Medic *et al*., 2018). According to Fennema (1985), water in food converts to ice crystals during freezing at -18^{o}C and is easily removed from food when the food is dried or fried, causing the moisture content to decrease.

Oil absorption analysis was conducted to measure the ability of cassava sticks to absorb oil during frying by using a modified thermogravimetric method (Mohamed *et al*., 1988). Table 1 shows that the storage duration significantly increased (P<0.05) the oil absorption of cassava sticks. Cassava stick stored frozen for 2 months has the highest oil absorption (58.45%) but has no significant difference with cassava stick stored frozen for 3 months (57.84%). In a study conducted by Adedeji and Ngadi (2017), oil absorption also showed a significant increase in fried potato that was stored frozen. However, they also found that there was no interaction between storage duration and freezing method, which contradicts this study.

Table 1. Moisture content and oil absorption of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Moisture content (%)	Oil absorption (%)
0	45.13±7.46^{a}	20.87±15.91^{a}
1	48.83±3.27^{a}	25.66±9.51^{a}
2	28.68±7.95^{a}	58.45±2.47^{b}
3	27.75±10.13^{a}	57.94±24.71^{b}

Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

According to Adedeji *et al*. (2009), moisture loss during frying affects the amount of oil absorbed in fried food. This statement is in accordance with Fellows (1990), where oil transfers into the product to replace evaporated water during frying. In addition, moisture evaporation from fried food during frying damages the cellular structure of plant tissues, resulting in an increase in porosity which contributes to oil absorption (Mellema, 2003; Rimac-Brncic *et al*., 2004; Dana and Saguy, 2006). On the other hand, during frozen storage, all water in food converts to ice crystal and causes volume expansion which is characterized by the damage to cell membranes during ice crystal formation (Fennema, 1985; Celli *et al*., 2016). This volume expansion causes the water in cassava sticks to be easier to evaporate during frying and increases oil absorption.

3.2 Hardness

In this study, hardness was chosen as the analyzed texture attribute to evaluate the impact of frozen storage duration on the texture of cassava sticks. According to Szczesniak (2002), hardness is the force required to change the shape of material due to its resistance to resist deformation. The effect of frozen storage duration on the hardness of cassava sticks is presented in Figure 1. As shown in that figure, frozen storage duration significantly affected (P<0.05) the hardness of the cassava sticks. Cassava stick that was stored frozen for 3 months has the highest force (2.54 N) among other samples (0.63 – 1.41 N). These results were in accordance to Adedeji and Ngadi (2017). They found a marginal increase in the hardness of fried potatoes as the frozen storage duration increased. Therefore, the increase in fried cassava stick hardness might be due to the retrogradation of cassava starch during frozen storage. This statement was supported by a similar study by Yu *et*

al. (2010), where the hardness of cooked rice increased continually with the amylopectin retrogradation during frozen storage. Based on those findings, amylopectin retrogradation contributed to the hardness increase during storage on the high starch food products.

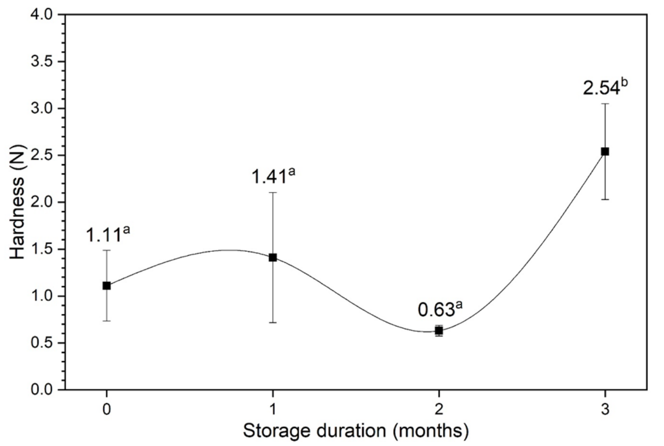


Figure 1. Hardness of cassava stick stored frozen in different storage duration. Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

3.3 Free fatty acid and peroxide value

This study assessed the percentage of free fatty acid and peroxide values to monitor the fat oxidation in cassava sticks during frozen storage. The increase of free fatty acid and peroxide value indicates the rancidity of food products that produce off-flavors (Maity *et al*., 2012) and might reduce consumers' preferences. The free fatty acid of cassava stick was expressed as the percentage of palmitic acid since the cooking oil used to fry was palm oil. Meanwhile, the peroxide value as the primary oxidation product of fat oxidation was expressed as meq peroxide/kg fat. The percentage of free fatty acid and peroxide value of fried cassava sticks is shown in Figure 2. A significant increased (P<0.05) of free fatty acid was recorded during 2 months of frozen storage (0.13 %) and had no significant difference (P>0.05) with cassava sticks stored frozen for 3 months (0.14%). On the other hand, the peroxide value of cassava stick was also significantly increased (P<0.05) as the frozen storage duration increased (0 – 34.53 meq peroxide/ kg fat). Similar results were also reported by some studies where frozen storage duration increased the free fatty acid and peroxide value of potato strips (Kizito *et al*., 2017), pork meat (Medic *et al*., 2018), and ready-to-fry vegetable snacks (Maity *et al*., 2012).

According to Crosa *et al*. (2014), free fatty acids are formed through the nucleophilic attack at triacylglycerol's ester bond and have been associated with the undesirable odors and taste of food products. Furthermore, the formation of hydroperoxides during storage generally occurred during the early stage of oxidation (Fennema, 1985) and later decomposed to other secondary oxidation products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (Kizito *et al*., 2017; Medic *et al*., 2018). Another factor that might increase the formation of hydroperoxides was the contact of cassava stick with oxygen before and after storage; since oxygen is one of the reactants that caused fat oxidation (Giri and Mangaraj, 2012).

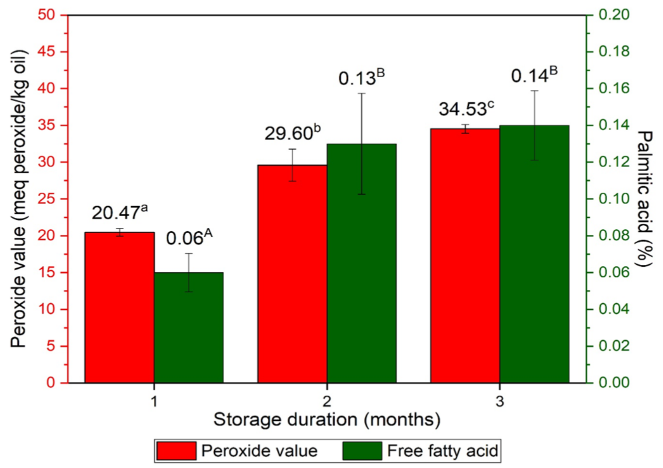


Figure 2. Free fatty acid and peroxide value of cassava stick stored frozen in different storage duration. Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

3.4 Colour properties

Colour is generally considered an important attribute that significantly affects the physical properties of food, the perception of consumers, and determines the nutritional quality of food products (Hutchings, 2002; Patras *et al*., 2011). In this study, the colour of cassava sticks is shown in Table 2 and was measured using Hunter's L*, a*, and b* colour attributes. The L* value expressed the degree of lightness, where the highest value was measured in the cassava stick stored frozen for 3 months (75.20). However, the results were not significantly different (P>0.05) with cassava stick that was not stored frozen (71.55) and significantly different (P<0.05) with other samples (66.52 – 67.98). The different results were shown on the a* value, which expressed the degree of redness (+a*) and greenness (-a*) of cassava sticks. All samples had no significant difference (P>0.05) on the degree of redness (2.94 – 4.62). Meanwhile, the b* value expressed the degree of yellowness (+b*) and blueness (-b*). The results show that the b* values of cassava stick (25.77) that stored frozen for 2 months was significantly lower (P<0.05) than other samples (30.79 – 32.08).

Research by Oner and Wall (2012) also found that frozen storage significantly influenced (P<0.05) the colour of French fries. The colour change of fried cassava sticks during frozen storage duration might be

DOI

due to the surface moisture desiccation (Maity *et al*., 2012). The amount of moisture loss during the frying process also influence the colour of fried cassava stick since moisture loss is associated with crust formation and accelerates the Maillard browning (Sahin, 2000). The Maillard browning occurs due to the reaction between amino acid and reducing sugar during frying and results in the increase in coloration of yellow, red, and brown in fried food (Pedreschi *et al*., 2005). Another factor that might influence the crust colour of cassava sticks was the heat transfer rate in the cassava sticks during frying (Maity *et al*., 2012).

Table 2. Colour of cassava stick stored frozen in different storage duration

Frozen storage duration (months)	Colour		
	L*	*a**	*b**
0	71.55±4.08[ab]	2.95±0.78[a]	32.08±3.02[b]
1	67.98±2.78[a]	4.62±1.93[a]	30.79±1.87[b]
2	66.52±1.15[a]	3.21±0.37[a]	25.77±0.98[a]
3	75.20±1.80[b]	4.01±0.30[a]	31.40±1.66[b]

Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

3.5 Sensory evaluation

The sensory evaluation results of cassava sticks stored frozen in different storage durations are shown as a spider plot in Figure 3. According to the results, the highest score for the colour attribute was the 0-month storage cassava sticks (5.60) and significantly different (P<0.05) with other samples (3.20 – 4.96). The decrease in panelists' colour preference was due to the colour changes in cassava sticks that tend to be darker and brownish than the regular cassava sticks. Meanwhile, on the hardness attribute, the panelists' preference significantly decreased (P<0.05) as the frozen storage duration increased (5.30 – 4.20). This result was in accordance with the objective analysis on hardness, where frozen storage duration significantly increased the hardness of cassava sticks due to the starch retrogradation. The next sensory attribute tested was the crispiness and the results were quite varied. Cassava sticks stored frozen for 0 months (4.88) had no significant difference (P>0.05) compared to 2 months stored cassava stick (4.66) but showed a significant difference (P<0.05) with cassava sticks stored frozen for 1 month (3.86) and 3 months (3.68). This result indicated that panelists perceived that frozen storage duration influenced the crispiness of fried cassava sticks. Furthermore, the frozen storage duration significantly influenced (P<0.05) the panelists' preferences on the aroma of cassava sticks. The aroma of cassava sticks tended to be different for each treatment and might be influenced by the formation of hydroperoxides and free fatty acids. The last sensory attribute evaluated was the taste of cassava sticks. According to the result, the frozen storage duration had no significant difference (P>0.05) on the panelists' perception of the taste of cassava sticks (4.16 – 4.88). Overall, the average score of panelists' preference showed that frozen storage duration did not significantly affect (P>0.05) panelists' acceptance of the cassava stick.

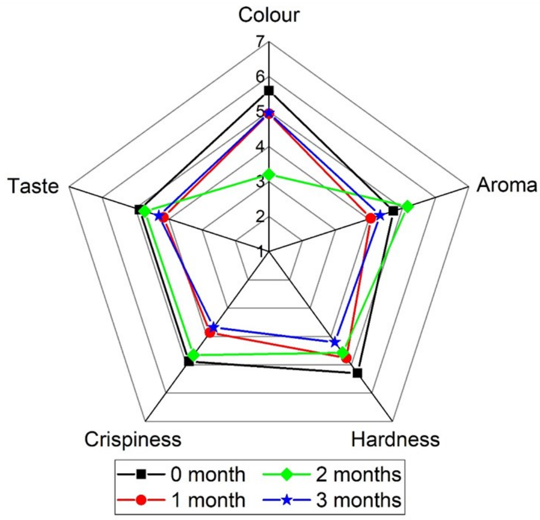


Figure 3. Sensory evaluation of cassava stick stored frozen in different storage duration. Values are presented as mean±SD (n = 3 for each group). Values with different superscript are significantly different (P<0.05) by one-way ANOVA followed by DMRT test (α = 0.05).

4. Conclusion

Frozen storage can be used to extend the shelf life of food products. However, the use of frozen storage on cassava sticks affects its physical and chemical properties. Different frozen storage duration influenced the oil absorption of cassava sticks, though the moisture content showed no significant change. The effect of frozen storage duration was also significant on the texture of cassava sticks, especially on hardness. Another studied quality characteristic, such as cassava stick surface colour, substantially declined during the frozen storage. The free fatty acid and peroxide value of cassava sticks was gradually increased with the elongation of frozen storage duration. According to the sensory evaluation results, frozen storage duration influenced all of the sensory attributes besides the taste of cassava sticks. Cassava sticks stored frozen for 3 months were still acceptable by the panelists and the acceptance was defined as neither like nor dislike.

Conflict of interest

The authors declare no conflict of interest.

DOI

Acknowledgments

This study was financially supported by the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Widya Mandala Surabaya Catholic University through PPPG Research Grants 2015/2016.

References

Adedeji, A.A., Ngadi, M.O. and Raghavan, G.S.V. (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *Journal of Food Engineering*, 91(1), 146-153. https://doi.org/10.1016/j.jfoodeng.2008.08.018

Adedeji, A.A. and Ngadi, M. (2017) Impact of freezing method, frying and storage on fat absorption kinetics and structural changes of parfried potato. *Journal of Food Engineering*, 218, 24-32. https://doi.org/10.1016/j.jfoodeng.2017.08.024

AOAC (Association of Analytical Communities). (2006). Official Methods of Analysis of AOAC International. 18th ed. Gaithersburg, USA: AOAC International.

Benesi, I.R.M., Labuschagne, M.T., Dixon, A.G.O. and Mahungu, N.M. (2004). Genotype X environment interaction effects on native cassava starch quality and potential for starch use in the commercial sector. *African Journal of Crop Science*, 12(3), 205-216. https://doi.org/10.4314/acsj.v12i3.27880

Celli, G.B., Ghanem, A. and Brooks, M.S. (2016) Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International*, 32(3), 280-304. https://doi.org/10.1080/87559129.2015.1075212

Coombs, C.E.O. Holman, B.W.B., Collins, D., Friend, M.A. and Hopkins, D.L. (2017). Effects of chilled-then-frozen storage (up to 52 weeks) on lamb *M. longissimus lumborum* quality and safety parameters. *Meat Science*, 134, 86–97. https://doi.org/10.1016/j.meatsci.2017.07.017

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazabal, L., Silva, R., Suburu, G. and Torres, M. (2014). Changes produced in oil during vacuum and traditional frying of potato strips. *Food Chemistry*, 146, 603-607. https://doi.org/10.1016/j.foodchem.2013.08.132

Dana, D. and Saguy, I.S. (2006). Review: Mechanism of oil uptake during deep fat frying and surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128-130, 267-272. https://doi.org/10.1016/j.cis.2006.11.013

Fellows, P.J. (1990). Food Processing Technology Principles and Practice. London, United Kingdom: Ellis Horwood

Fennema, G.R. (1985). Principles of Food Science. New York, USA: Marcell Dekter Inc.

Giri, S.K. and Mangaraj, S. (2012). Processing Influences on Composition and Quality Attributes of Soymilk and its Powder. *Food Engineering Reviews*, 4, 149-164. https://doi.org/10.1007/s12393-012-9053-0

Hutchings, J.B. (2002). The Perception and Sensory Assessment of Colour. Cambridge, United Kingdom: Woodhead Publishing Limited. https://doi.org/10.1201/9781439823194.pt1

International Atomic Energy Agency. (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. Retrieved on October 21, 2021 from website: https://www.iaea.org/publications/12311/cassava-production-guidelines-for-food-security-and-adaptation-to-climate-change-in-asia-and-africa

Kizito, K.F., Abdel-Aal, M.H., Ragab, M.H. and Youssef, M.M. (2017). Quality attributes of French fries as affected by different coatings, frozen storage and frying conditions. *Journal of Agricultural Science and Botany*, 1(1), 18-24.

Kusuma, S.T., Kurniawati, A.D., Rahmi, Y., Rusdan, I.H. and Widyanto, R.M. (2017). Pengawasan Mutu Makanan. Malang, Indonesia: UB Press. [In Bahasa Indonesia].

Lamberg, I., Hallstrom, B. and Olsson, H. (1990). Fat uptake in a potato drying/frying process. *Lebensmittel-Wissenschaft und –Technologie*, 23(4), 295–300

Maity, T., Shah, A., Raju, P.S. and Bawa, A.S. (2012). Development of ready-to-fry frozen vegetable snack and its quality evaluation. *Journal of Food Science and Technology*, 49(1), 42–49. https://doi.org/10.1007/s13197-011-0257-8

Medić, H., Kušec, I.D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B. and Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119-127. https://doi.org/10.1016/j.meatsci.2018.03.006

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science and Technology*, 14(9), 364-373. https://doi.org/10.1016/S0924-2244(03)00050-5

Mohamed, S., Abdullah, N. and Muthu, M.K. (1988). Expansion, oil absorption, elasticity, and crunchiness of keropok (fried chips) in relation to the physicochemical nature starch flours. *Proceeding of the Food Conference,* 88, 108-113.

Oner, M.E. and Wall, M.M. (2012). Processing

conditions for producing french fries from purple-fleshed sweet potatoes. *American Society of Agricultural and Biological Engineers*, 55(6), 2285-2291. https://doi.org/10.13031/2013.42486

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food Bioprocess Technology*, 4, 1245–1252. https://doi.org/10.1007/s11947-009-0226-7

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Colour changes and acrylamide formation in fried potato slices. *Food Research International*, 38 (1), 1-9. https://doi.org/10.1016/j.foodres.2004.07.002

Rahman, M.S. and Velez-Ruiz, J.F. (2007). Food preservation by Freezing. In Handbook of Food Preservation. 2nd ed. USA: CRC Press. https://doi.org/10.1201/9781420017373-41

Rimac-Brncic, S., Lelas, V., Rade, D. and Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, 64(2), 237-241. https://doi.org/10.1016/j.jfoodeng.2003.10.006

Sahin, S. (2000). Effect of frying parameters on the colour development of fried potatoes. *European Food and Research Technology*, 211, 165-168. https://doi.org/10.1007/s002170050017

Sattar, S., Sarower, K., Uddin, M.B. and Jubayer, M.F. (2015). Impacts of varieties and freezing storage condition on the quality of French fried potatoes (*Solanum tuberosum* L.). *Food Science and Technology: An International Journal*, 1(1), 9-19

Sudarmadji, S., Haryono, B. and Suhardi. (1984). Prosedur Analisa untuk Bahan Makanan dan Pertanian. Yogyakarta, Indonesia: Liberty. [In Bahasa Indonesia]

Szczesniak, A.S. (2002). Texture is a Sensory Property. *Food Quality and Preference*, 13(4), 215–225. https://doi.org/10.1016/S0950-3293(01)00039-8

WFLO Commodity Storage Manual. (2008). Frozen Foods Handling and Storage. Retrieved on October 25, 2021, from website: http://www.cold.org.gr/library/downloads/docs/frozenfoodshandling.pdf

Yu, S.F., Ma, Y. and Sun, D.W. (2010). Effects of freezing rates on starch retrogradation and textural properties of cooked rice during storage. *LWT - Food Science and Technology*, 43(7), 1138-1143. https://doi.org/10.1016/j.lwt.2010.03.004