The Effect of Steaming Time on the Textural Characteristics of Two Sweet Potatoes with Different Flesh Colors

Pengaruh Waktu Pengukusan terhadap Karakteristik Tekstur Dua Ubi jalar Berbeda Warna Daging Ubi

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ABSTRACT

Sweet potatoes have various physical characteristics based on their flesh colors. Two selected sweet potato (SP) with white (WF) and yellow-fleshed (YF) colors were collected from local market and analyzed their textural characteristics using an Uniaxial compression and Texture Profile Analysis (TPA) test. The study was conducted at the Food Processing Technology Laboratory, Faculty of Food Science Technology, University of Putra Malaysia. All textural attributes were collected from the samples treated with steaming for 5, 10, 15 and 20 min. The moisture content of the samples were determined before and after steaming. The results showed that the moisture content of WF was lower than YF both before and after steaming, which could be declared as a typical moisture content for each flesh color. This resulted in a greater peak deformation or firmness of the fresh tuber found in WF relative to YF. Steaming SP for 5 min exhibited the "raw" properties tissue, whereas steaming for more than 10 min would generate the "cooked" tissue that significantly affected the textural characteristics. The hardness level decreased considerably along with the time of steaming and was similar for both flesh colors after 15-min steaming. The WF was less adhesive and less elastic; however, it had less chewiness than that of YF. This suggests that the use of WF as a raw material for mashed products would have advantages, such as easiness to mash, less tendency to stick with the cooking tools, and less elastic.

Keywords: flesh color, steaming, sweet potato, TPA

ABSTRAK

Ubijalar memiliki sifat fisik yang berbeda berdasarkan warna daging umbinya. Dua jenis ubijalar masing-masing mempunyai daging umbi berwarna putih dan kuning yang diperoleh dari pasar lokal, dianalisis karakteristik teksturnya menggunakan uji kompresi Uniaksial (*Uniaxial compression test*) dan Analisis Profil Tekstur (*Texture Profile Analysis* TPA). Penelitian dilakukan di Laboratorium Prosesing dan Teknologi Pangan, Fakultas Ilmu dan Teknologi Pangan, Universitas Putra Malaysia. Sampel dikukus selama 5, 10, 15 dan 20 menit dan selanjutnya diuji karakteristik teksturnya. Kadar air umbi segar dan umbi kukus juga diamati. Hasil penelitian menunjukkan bahwa kadar air umbi putih lebih rendah dibandingkan umbi kuning baik pada umbi segar maupun umbi setelah dikukus. Hal ini menunjukkan tipikal kadar air alami atau genetis dari masing-masing kultivar yang diuji. Perbedaan kadar air tersebut menyebabkan nilai deformasi puncak ataupun kekompakan (*firmness*) umbi segar dari ubijalar yang berwarna putih lebih besar dibandingkan dengan umbi kuning. Pengukusan umbi selama 5 menit menunjukkan karakteristik jaringan umbi yang "mentah", sedangkan pengukusan lebih dari 10 menit menghasilkan jaringan "matang" yang berpengaruh nyata terhadap karakteristik tekstur umbi kukusnya. Tingkat kekerasan umbi menurun secara signifikan seiring dengan lama waktu pengukusan dan nilai keduanya relatif sama setelah pengukusan selama 15 menit. Umbi kukus dari kultivar ubijalar putih memiliki daya rekat dan nilai kekenyalan lebih rendah dibandingkan dengan ubijalar kuning, juga kurang elastis. Hal ini menunjukkan bahwa penggunaan ubijalar putih sebagai bahan baku produk pasta memiliki keunggulan, antara lain mudah dihaluskan, tidak mudah lengket pada peralatan masak yang digunakan, dan elastisitasnya rendah.

Kata kunci: daging ubi, pengukusan, tekstur, ubi jalar

INTRODUCTION

Cooking is a generic term for all hydrothermal treatments. Cooked products present a large diversity of structural, sensory and functional properties according to the methods and intensity of cooking. Such effects were reported on sweet potato tubers (Bahado-Singh *et al*. 2011; Ellong *et al*. 2014; Owusu-Mensah *et al*. 2016; Ogliari *et al*. 2020), in relation to a wide characteristic variation of the flesh colors. Different heat treatment methods, such as open cooking, pressure cooking, and baking, gave different profiles of sweet potato texture (Nwosisi *et al*. 2019). Blanching sweet potato at 62°C for 30-45 min before canning was beneficial in improving sensory acceptability, and retaining firmness and wholeness of canned sweet potato (Truong *et al*. 1998). On baking, the texture profile parameters were influenced by the storage period of tubers (Ando *et al*. 2018), whereas roots baked at 180, 200, and 230 °C were significantly less resistant to compression than at 150 °C (Losh *et al*. 1981). Controlling the pH of sweet potato strips prior to frying using acid and base treatments were reported as an attempt to increase the firmness of cooked sweet potato sticks and chips (Utomo 2009, Fadhil 2018).

The texture is an essential factor of the food quality attribute of many foods, including tuber crops. It is an important factor in consumers' perception of quality and acceptability (Tunick 2011; Sajeev *et al*. 2012; Lillford 2018). A great deal of research has been conducted on potato to explain the causes of textural differences among varieties and processed products (Fauster *et al*. 2018; Park *et al*. 2020; Halim 2020). Similar studies were also performed for sweet potato (Nafeesa *et al*. 2012; Sajeev *et al*. 2012; Laryea *et al*. 2019; Nwosisi 2019), as well as the effect of cooking, such as steaming and boiling on the texture of sweet potato (Rosanna *et al*. 2015).

Uniaxial test and Texture Profile Analysis (TPA) were employed to determine textural properties of most solid foods and to establish a correlation between instrumental and sensory measurements (Goldner *et al*. 2012; Brenner and Nishinari 2014; Li *et al*. 2020). The parameters of TPA were correlated with sensory texture attributes of restructured products from sweet potato puree (Utomo and Rahman 2015). Different cooking times may result in different texture profile characteristics of sweet potato tubers (Shaliha *et al*. 2018). The textural properties of cooked tubers also significantly vary between white, cream, and orange sweet potato (Sajeev *et al*. 2012). Therefore, this study was performed to determine the texture profile characteristics of sweet potato having yellow-fleshed and white-fleshed colors treated with different steaming times. This information would be useful for food processing industries, particularly those which use steamed and mashed sweet potato tubers as ingredients for the products.

MATERIALS AND METHODS

The yellow-fleshed (YF) and white-fleshed (WF) sweet potatoes were purchased from Pasar Borong Selangor, Malaysia. These cultivars are usually available throughout the year. The research activity was conducted at the Food Processing Technology Laboratory, Faculty of Food Science Technology, University Putra Malaysia.

A middle portion of each raw tuber was cut transversely to the long axis into 3.5 cm thick slab. Using a cork borer with 1.35 cm diameter (No. 10, Cork borer, Ambala, India) cylindrical samples were taken from each slab. Samples were taken at the inner tissue of the tubers at an approximately 1 cm distance from the tuber skin. The cylinders were then steamed at 100 °C for 5, 10, 15, and 20 min using a universal steamer (CPC 61, Rational, Germany). The steamed cylindrical specimens were trimmed to 2.2 cm height before texture measurement.

The moisture content of both raw and cooked samples was determined using an oven method (AOAC 2005). Approximately 4 g of samples were dried at 105 °C in an aluminum cup overnight or until a constant weight was achieved. The percentage of weight loss was calculated as the moisture content. The determination was repeated three times for each individual sample.

An uniaxial compression test was performed using a Texture Analyzer TA.TX2i (Stable Microsystems, Godalming, Surrey, United Kingdom). The steamed cylindrical pieces were compressed longitudinally. A cylindrical flat-end probe with 50 mm diameter (P/50 probe) was used. The constant test speed was 1 mm/s, and the compression traveled 75% of its initial height. The peak force-deformation curves were obtained for 15 replicates per sample.

Texture profile analysis (TPA) was performed using a Texture Analyzer TA.TX2i (Stable Microsystems, Godalming, Surrey, United Kingdom). The instrument was fitted with a TA-50 probe (50 mm diameter cylinder). The specimens were compressed longitudinally for two cycles. The test conditions were: pre-test speed 2 mm/s, test speed 1 mm/s, post-test speed 2 mm/s, the time between two cycles 5 seconds, and degree of compression 35% of its initial height. TPA parameters were then calculated (Nishinari *et al*. 2013).

Data collection and analysis were accomplished by the EXTRAD Dimension Software that was supplied with the Texture Analyzer. For the Uniaxial compression test, the data of peak force or firmness, was obtained from the force deformation curves. Hardness, adhesiveness, springiness, and chewiness were measured by the Texture Profile Analysis (TPA) method (Nishinari *et al*. 2013).

The study was performed using the factorial completely randomized design with two factors, the first factor was the sweet potato flesh color (white and yellow), while the second factor was steaming time of 5, 10, 15, and 20 min and the study was repeated 15 times. The data collected were analyzed using an analysis of variance (ANOVA), and significant differences among means were determined by Duncan's Multiple Range Test (DMRT) using MSTAT-C statistical software.

RESULTS AND DISCUSSION

Force Deformation of Fresh Tubers

The force-deformation curve of the uniaxial compression test for two fresh sweet potato flesh colors is shown in Fig. 1. Regarding the uniaxial test, the data obtained is the peak force-deformation when the sample breaks. This value shows the force required for deforming the sample and expressed in Newton (N). The fresh sweet potato generated curves with a steep slope and a sharp peak force at fracture. The peak force-deformation of WF was found to be higher than that of YF. The maximum force needed to deform the specimen of WF was 349.36 N, whereas it was 298.15 N for YF. Sajeev *et al*. (2012) also noted a higher firmness of white-fleshed varieties (90.19-106.01 N) relative to cream-fleshed varieties (88.47-89.76 N). The differences in peak force-deformation values might be affected by moisture content or the structure of internal cell of sweet potato flesh tissue.

Fig. 1 exhibits a typical deformation pattern of rigid plant materials under loading. The fracture was the shear-type along 45° rupture plane (Truong *et al*. 1997). It has been recognized that in raw plant tissue, cell turgor pressure and cell wall strength account for tissue stiffness and the mode of failure (Singh *et al*. 2014, Nwosisi *et al*. 2019). Similar force-deformation curves and fracture type under uniaxial compression have been reported in fresh apples and potatoes (Khan and Vincent 1993). In raw sweet potato, the thickness of cell walls is about 838 nm, and it is approximately half of carrot cell walls thickness (Zhang *et al*. 2018). The cell walls show extensive folding, and the primary cell wall consists of fibrous substructure, probably cellulose fibrils, which are loosely woven together in a pattern and embedded in an amorphous matrix (Harris and Smith 2006).

Numerous intercellular spaces were observed, and the lower the number of intercellular spaces, the lower the water filling the space, and the firmer the tissue. Sweet potatoes with high dry matter content or low moisture content (both are negatively correlated) normally have a firmer and harder texture than those with higher moisture content (Nwosisi *et al*. 2019). This fact probably supported the consequence that WF generated a higher peak force-deformation than YF due to its lower moisture content. Based on the laboratory analysis, the moisture content of WF and YF fresh tubers was 73.35% and 78,04%, respectively. Lower moisture contents in the white-fleshed varieties (70.16-73.02%) were also recorded by Sajeev *et al*. (2012) than those of the cream-fleshed varieties (76.47-76.77%), suggesting the typical moisture content of sweet potato based on the flesh color.

Moisture Content of Steamed Sweet Potato

Changes in moisture contents of both sweet potatoes treated with different steaming times are presented in Table 1.

The moisture content showed a significant difference ($P<0.05$) between WF and YF. WF had lower moisture contents both for the fresh and steamed tubers than those of YF. Even though there was a tendency for the moisture content to increase along with the steaming time, however, the effects were not significant ($P>0.05$) within each flesh color.

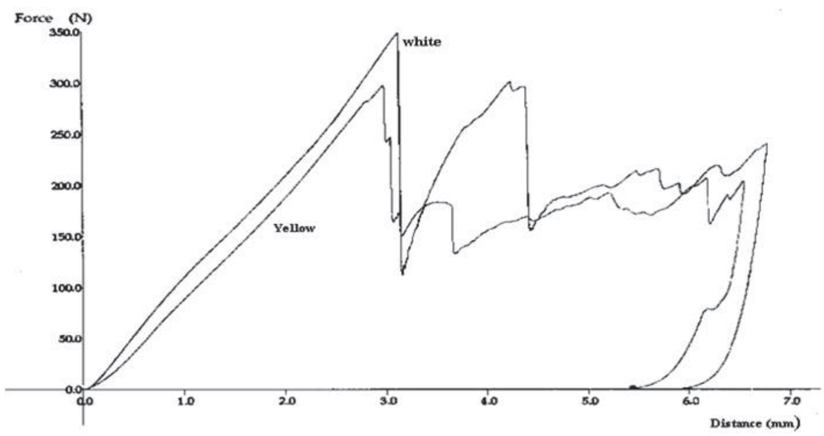

Figure 1. Force-deformation curve of uniaxial compression test for fresh sweet potato derived from two flesh colors.

Table 1. Interaction between flesh color and steaming time on moisture content and peak force deformation of steamed sweet potato

Flesh color	Steaming time (min)	Moisture (%)	Peak force deformation (N)
White (WF)	5	72.82 c	19.81 a
	10	73.59 c	6.98 c
	15	73.43 c	6.28 c
	20	74.84 b	5.07 c
Yellow (YF)	5	75.97 a	12.94 b
	10	76.95 a	5.09 c
	15	76.87 a	5.08 c
	20	76.31 a	4.71 c
CV (%)		0.77	35.67
DMRT		1.00	5.59

Means within a column followed by different letters are significantly different at P<0.05, N = Newton

A similar pattern of moisture content during steaming was observed for both flesh colors, except after 15 min of steaming. A slight decrease in moisture content occurred during the first 5 min of steaming that might be due to evaporation, especially in the surface of the specimen that took place immediately when it was subjected to steaming. The moisture content of WF decreased from 73.35% to 72.82%, whereas it was 78.04% to 75.97% for YF. This case was in agreement with the previous study proofing that water evaporation occur during steaming, resulting in a slight increase in dry matter content of cooked sweet potato (Truong *et al*. 1997).

The increase in moisture content after 5 to 10 min of steaming indicated that hydration and gelatinization were undergoing, even though it was not significantly different (P>0.05). The moisture content slightly increased, suggesting that the starch molecules continued to swell by absorbing water, and the gelatinization process was initialized (Li *et al*. 2013). The moisture content was increased by 0.77% and 0.99% for WF and YF, respectively. Steaming the sweet potato specimens for another 5 min might result in continued swelling and gelatinization of the starch granules. At the end of 15-min steaming, the moisture content was found to decrease slightly for both flesh colors. However, at the end of steaming (20 min), WF showed a significant (P<0.05) change of moisture content. This condition might be due to a higher dry matter/ starch or amylose content of WF than YF, thus it required more external water throughout the gelatinization process. Absorption of external water would be stopped once the cellular water was sufficient for the gelatinization process (Li *et al*. 2013). The previous study also noted an increase in moisture content of sweet potato tuber from 75.95% to 79.65% after steaming for 10 min and becoming 83.10% after boiling for 15 min (Eke-Ejiofor and Onyeso 2019).

Peak Force-deformation of Steamed Tubers

Texture attributes of samples were evaluated by two methods of measurement *i.e*. uniaxial compression test and TPA test. Uniaxial compression test was conducted to identify the hardness of the specimens when it was compressed until completely deformed. TPA was a non-destructive compression test producing rheological characteristics of solid samples (Nishinari *et al*. 2013; Nishinari and Fang 2018). Table 1 shows the changes of peak force-deformation in the samples during steaming. The decreasing of peak force-deformation occurred after the first 5-min of the heating process, however, prolonged the steaming time to 10 min up to 20 min did not significantly (P>0.05) affect the peak force-deformation for both flesh colors. WF generated a higher peak force deformation value in the first 5 min of steaming than YF. The peak force-deformation values of WF samples steamed for 10, 15, and 20 min were 3-fold lower relative to 5-min steaming, whereas it was 2.5-fold lower for YF. Incomplete gelatinization process until 5 min of steaming might be attributed to such differences; thereby, the texture of the tubers was yet firm.

The force-deformation graphs of the steamed tubers are shown in Fig. 2 and Fig. 3. The curve was dissimilar compared with that of the fresh tuber (Fig. 1). Unsharp peak force-deformation indicated that no fracture was detected, and modification of cell and tissue occurred. The heat treatment on the specimens disrupted cell integrity and cell adhesion, resulting in a decrease in tissue rigidity. Steaming for 5 min remarkably decreased the peak force-deformation, indicating that physical changes occurred. Furthermore, the peak force-deformation continuously declined until 10 min of steaming due to major changes in texture for both flesh colors. The decline in textural attributes is composed of two first-order mechanisms, a quick and a slow softening (Farahnaky *et al*. 2012, Aamir *et al*. 2013, Dekker *et al*. 2014) that is caused by a decrease in cell stiffness as starch gelatinized and the cell wall bonding is weakened due to swelling pressure. Complete deformation of cell structure is accompanied by a considerable cellular collapse and disorganization of interface cells (Sajeev *et al*. 2012; Wang and Copeland 2013; Ai and Jane 2015). The proportion of amylopectin and amylose in the tuber

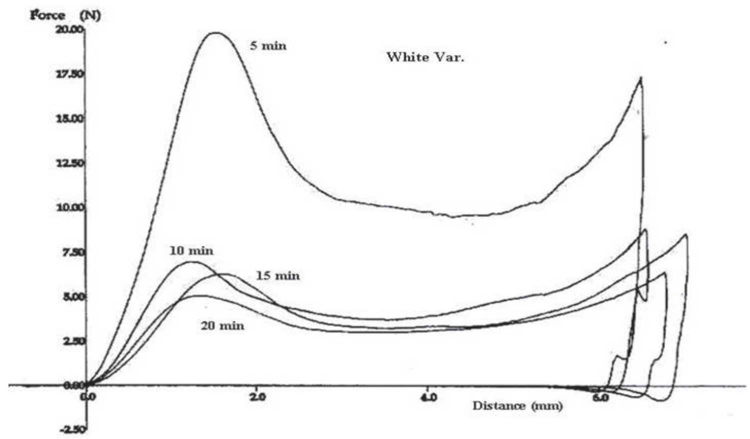

Figure 2. Force deformation curves of uniaxial compression test of WF (white flesh color) at different steaming time.

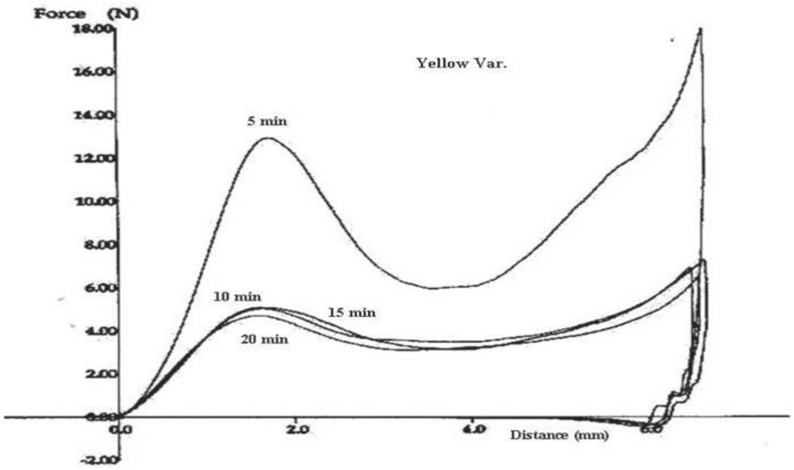

Figure 3. Force deformation curves of uniaxial compression test of YF (yellow flesh color) at different steaming time.

starch may thus account for the texture attributes in food products, including stickiness, resistance against shear stress, swelling of starch granules due to heat, solubility, tackiness, stability of gel, cold swelling, and retrogradation (Satin, 1998). Besides, the structure of starch granules is a major determinant of textural traits in the tuber and root crops (Charoenkul *et al.* 2011).

Texture Profile Analysis (TPA)

The TPA values, including hardness, adhesiveness, springiness, and chewiness of steamed tubers for 5 min up to 20 min are listed in Table 2. The interaction effects of flesh color and steaming time were significant, suggesting that both factors are essential in dictating the texture profiles of steamed sweet potato.

The hardness of both sweet potato flesh colors sharply declined during steaming. The hardness of WF was significantly ($P<0.05$) greater than YF for the first five and 10-min steaming, however afterward no significant difference was observed. Also, steaming for 5 min showed a significant hardness ($P<0.05$) compared to other steaming times within flesh color. The decrease in hardness was parallel with the increase in moisture content (Table 1); the lower the moisture content, the higher the hardness/ firmness (Nwosisi *et al.* 2019). Nicoletto *et al.* 2018 recorded 40% decrease in firmness/hardness after steaming the fresh tubers for 30-35 min. Greater hardness values relative to this study finding were noted for white and cream flesh colors originated from Kerala, India, *c.a.* 17.23-26.84 N and 9.36-16.06 N, respectively after 20 min-steaming (Sajeev *et al.* 2012). In the present study, a positive correlation ($r = 0.92$) between hardness and peak force-deformation was obtained, suggesting considerable textural changes of the tubers during the steaming process (Fig. 4). Yoon *et al.* 2018 revealed a positive correlation between the hardness of the cooked sweet potato tubers with the starch content ($r = 0.64$).

The adhesiveness changes were affected by different steaming times for both flesh colors. YF showed significantly greater adhesiveness ($P<0.05$) than that of WF, particularly after 10 min and 20-

Table 2. Interaction between flesh color and steaming time on texture profile of steamed sweet potato

Flesh color	Steaming time (min)	Hardness (N)	Adhesiveness (Ns)	Springiness (%)	Chewiness (N)
White (WF)	5	18.17 [a]	0.073 [d]	91 [a]	294.01 [b]
	10	11.55 [b]	0.104 [d]	83 [cd]	201.65 [c]
	15	7.18 [c]	0.143 [cd]	82 [cd]	120.47 [cd]
	20	4.96 [c]	0.129 [cd]	80 [d]	69.22 [d]
Yellow (YF)	5	16.78 [a]	0.136 [cd]	86 [ab]	321.30 [a]
	10	6.35 [c]	0.201 [bc]	90 [a]	155.91 [c]
	15	4.48 [c]	0.264 [ab]	88 [a]	114.25 [cd]
	20	4.48 [c]	0.287 [a]	86 [ab]	115.38 [cd]
CV (%)		33.67	16.70	50.08	54.24
DMRT		2.78	0.09	7.45	60.77

Mean within a column followed by different letters are significantly different at $P<0.05$. N = Newton, Ns = Newton second

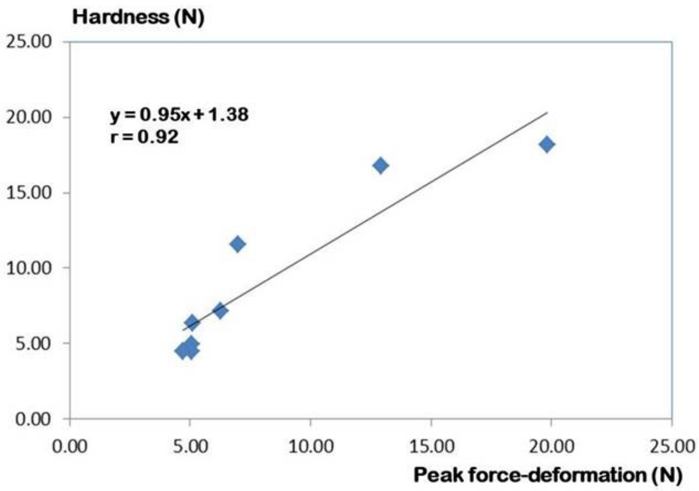

Figure 4. Correlation between hardness and peak force-deformation of two sweet potato flesh colors at different steaming time.

min steaming, while it was similar for 5 and 10-min steaming. The adhesiveness of YF increased significantly ($P<0.05$) during steaming. In contrast, it was not significant for WF, even though the values tended to increase when steamed for 10 min and 15 min and decreased at 20 min (Table 2). Adhesiveness was defined as "the work necessary to overcome the attractive forces between the surface of the samples and the surface of other materials with which the sample comes in contact" (Nishinari *et al*. 2019). In terms of sweet potato, adhesiveness relates with the stickiness of the tuber surface after cooking as a result of starch gelatinization. The level of adhesiveness might be linked to the dry matter content (Nicolette *et al*. 2018), which is associated with the components of starch (amylose and amylopectin). This may group sweet potato as dry or mealy, intermediate, and moist after cooking (Truong *et al*. 1997). The increase in adhesiveness was in line with the steaming time following the step of the gelatinization process. Negative adhesiveness values were reported by Sajeev *et al*. (2012) for white and cream flesh colors that ranged from -0.23 Ns up to -0.63 Ns and -0.33 Ns up to -0.47 Ns, respectively, suggesting that multiple breaks or fractures occurred, and no inherent stickiness was detected, thus giving a negative value of adhesiveness (Nishinari *et al*. 2019). The negative adhesive value written in this case may be due to the TPA adhesiveness image, which is depicted at the bottom of the X axis. However, the adhesiveness value is an absolute power required to remove the sample from the probe surface; thus the negative sign can be ignored.

Springiness relates to "how well a product springs back after it has been deformed or to its un-deformed condition after the deforming force is removed", which indicates the elasticity of the product (Razavi and Karazhiyan 2012; Zhu and Sun 2019). Steaming for 5 min up to 20 min obviously had no significant effect ($P>0.05$) on springiness, particularly for the YF, while the effect was only seen at 5 min-steaming for WF (Table 2). Springiness did not differ for each flesh color when steamed for 10 min up to 20 min. This may relate to the gelatinization

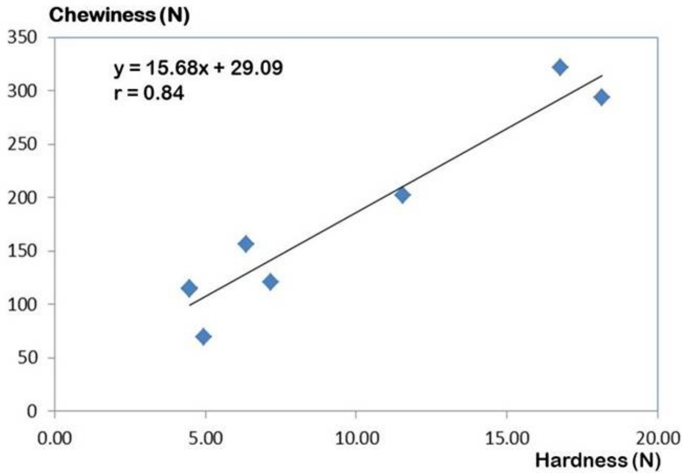

Figure 5. Correlation between chewiness and hardness of two sweet potato flesh colors at different steaming time.

process that occurred after 5 min of steaming. Furthermore, prolonged steaming time caused no significant change in moisture content, except it slightly increased at 20 min-steaming for WF (Table 1). This resulted in no significant differences noted in springiness (Table 2). Sajeev *et al*. (2012) also reported a similar springiness for both white and cream sweet potato varieties that ranged from 91.9-96.4%, slightly greater than the values obtained at the present study.

The chewiness was measured as the energy required masticating a solid food involving compressing, shearing, piercing, grinding, tearing, and cutting (Sajeev *et al*. 2012). The chewiness of both WF and YF was significantly ($P<0.05$) affected by the time of steaming (Table 2). Table 2 shows that the chewiness of WF decreased almost linearly during steaming, while it declined sharply for the first of 10 min for YF and slightly went down thereafter. Chewiness is a mathematical calculation of hardness, cohesiveness and springiness. In this study, chewiness was highly affected by hardness ($r = 0.84$), as presented in Fig 5, and hardness is closely related to moisture content of the steamed tubers as discussed previously. Smaller values of chewiness were previously reported in white and cream flesh colors, *c.a.* 4.56-5.89 and 1.80-4.21, respectively (Sajeev *et al*. 2012).

CONCLUSIONS

Both white (WF) and yellow (YF) sweet potato flesh colors exhibited different textural characteristics. The moisture content of WF was lower than YF, which could be declared as typical moisture content for both flesh colors. Steaming of the tubers for 5 min performed the “raw” properties tissue, whereas steaming for more than 10 min would generate “cooked” tissue that significantly affected the textural characteristics. The level of hardness decreased considerably along with the time of steaming and was similar for both flesh colors after 15-min steaming. The WF was less adhesive and less elastic but was less chewiness than YF. The use of WF as a raw material for mashed products would give several advantages, such as easiness to mash, less tendency to stick with the cooking tools, and low elasticity.

REFERENCES

AOAC. 2005. Official Methods of Analysis of AOAC International. Vol. I. Agricultural Chemicals, Contaminants, Drugs. AOAC International, Gaithersburs, Maryland, USA.

Aamir M, Ovissipour M, Sablani SS, Rasco B. 2013. Predicting the quality of pasteurized vegetables using kinetic models: a review. International Journal of Food Science article ID 271271, 29 pp.

Ai Y, Jane JL. 2015. Gelatinization and rheological properties of starch. Starch/Stärke 67(3-4):213-224.

Ando T, Yasuda M, Hisaka H. 2018. Effect of storage period on free sugar and starch contents of six sweet potato varieties with different taste on baking, and quantification of sweetness and texture. Horticultural Research (Japan) 17(4):449-457.

Bahado-Singh PS, Riley CK, Wheatley AO, Lowe HI. 2011. Relationship between processing method and the glycemic indices of ten sweet potato (*Ipomoea batatas*) cultivars commonly consumed in Jamaica. Journal of Nutrition and Metabolism 2011 , Article ID 584832, 6 pp. doi:10.1155/2011/584832

Brenner T, Nishinari K. 2014. A note on instrumental measures of adhesiveness and their correlation with sensory perception. Journal of Texture Studies 45(1):74-79.

Charoenkul N, Uttapap D, Pathipanawat W, Takeda Y. 2011. Physicochemical characteristics of starches and flours from cassava varieties having different cooked root textures. LWT -Food Science and Technology 44(8): 1774–1781.

Dekker M, Dekkers E, Jasper A, Baár C, Verkerk R. 2014. Predictive modelling of vegetable firmness after thermal pre-treatments and steaming. Innovative Food Science and Emerging Technologies 25:14-18. doi: 10.1016/j.ifset.2013.10.015

Eke-Ejiofor J, Onyeso BU. 2019. Effect of processing methods on the physicochemical, mineral and carotene content of orange fleshed sweet potato (OFSP). Journal of Food Research 8(3):50-58.

Ellong EN, Billard C, Adenet S. 2014. Comparison of physicochemical, organoleptic and nutritional abilities of eight sweet potatoes (*Ipomoea batatas*) varieties. Food and Nutrition Sciences 5(2):196-211.

Fadhil R., Nurba D. 2018. Penilaian organoleptik keripik ubi jalar ungu (*Ipomoea batatas* L.) pasca penggorengan menggunakan metode non-numeric MP-MCDM. Jurnal Keteknikan Pertanian 6(2):165-170.

Farahnaky A., Azizi R, Gavahian M. 2012. Accelerated texture softening of some root vegetables by Ohmic heating. Journal of Food Engineering 113(2):275-280.

Fauster T, Schlossnikl D, Rath F, Ostermeier R, Teufel F, Toepfl S, Jaeger H. 2018. Impact of pulsed electric field (PEF) pretreatment on process performance of industrial French fries production. Journal of Food Engineering 235:16-22. doi: 10.1016/j.jfoodeng.2018.04.023

Goldner MC., Pérez OE, Pilosof AM, Armada M. 2012. Comparative study of sensory and instrumental characteristics of texture and color of boiled under-exploited Andean tubers. LWT -Food Science and Technology 47(1):83-90.

Halim L. 2020. Aplikasi *pre-heating* dan *edible coating* untuk peningkatan kualitas keripik kentang varietas Granola. [Skripsi]. Fakultas Sains dan Teknologi, Universitas Pelita Harapan, Tangerang.

Harris PJ, Smith BG. 2006. Plant cell walls and cell wall polysaccharides: structures, properties and uses in food products. International Journal of Food Science and Technology 41:129-143.

Khan AA, Vincent JFV. 1993. Compressive stiffness and fracture properties of apple and potato parenchyma. Journal of Texture Studies 24(4):423-435.

Laryea D, Koomson D, Oduro I, Carey E. 2019. Evaluation of 10 genotypes of sweet potato for fries. Food Science and Nutrition 7(2):589-598.

Li Q, Xie Q, Yu S, Gao Q. 2013. New approach to study starch gelatinization applying a combination of hot-stage light microscopy and differential scanning calorimetry. Journal of Agricultural and Food Chemistry 61(6):1212-1218.

Li P, Wu G, Yang D, Zhang H, Qi X, Jin Q, Wang X. 2020. Applying sensory and instrumental techniques to evaluate the texture of French fries from fast food restaurant. Journal of Texture Studies 51(3):521-531.

Lillford P. 2018. Texture and breakdown in the mouth: An industrial research approach. Journal of Texture Studies 49(2):213-218.

Losh JM, Phillips JA, Axelson JM, Schulman RS. 1981. Sweet potato quality after baking. Journal of Food Science 46(1):283-290.

Nafeesa A, Kolawole OF, John OA. 2012. Effect of cultivar on quality attributes of sweet potato fries and crisps. Food and Nutrition Sciences 3(2), Article ID: 17523 , 9 pp. doi: 10.4236/fns.2012.32033

Nicoletto C, Vianello F, Sambo P. 2018. Effect of different home cooking methods on textural and nutritional properties of sweet potato genotypes grown in temperate climate conditions. Journal of the Science of Food and Agriculture 98(2):574-581.

Nishinari K, KohyamaK, Kumagai H, Funami T, Bourne MC. 2013. Parameters of texture profile analysis. Food Science and Technology Research 19(3):519-521.

Nishinari K, Fang Y. 2018. Perception and measurement of food texture: Solid foods. Journal of Texture Studies 49(2):160-201.

Nishinari K, Fang Y, Rosenthal A. 2019. Human oral processing and texture profile analysis parameters: Bridging the gap between the sensory evaluation and the instrumental measurements. Journal of Texture Studies 50(5):369-380.

Nwosisi S, Nandwani D, Ramasamy RAVÝ. 2019. Texture profile analysis of organic sweet potato (*Ipomoea batatas*) cultivars as affected by different thermal processing methods. International Journal of Agriculture Environment and Food Sciences 3(2):93-100.

Ogliari R, Soares JM, Teixeira F, Schwarz K, da Silva KA, Schiessel DL, Novello D. 2020. Chemical, nutritional and sensory characterization of sweet potato submitted to different cooking methods. International Journal of Research-GRANTHAALAYAH 8(10):147-156.

Owusu-Mensah E, Carey EE, Oduro I, Ellis WO. 2016. Cooking treatment effects on sugar profile and sweetness of eleven-released sweet potato varieties. Journal of Food Processing and Technology 7(4), Article ID 1000580, 6 pp. http://dx.doi.org/10.4172/2157-7110.

Park EY, Moon JH, Park HY, Lee HJ, Kim JY. 2020. Effect of thermal shock cycling on storage stability and quality of fresh-cut potato. Lebensmittel-Wissenschaft und-Technologie Food Science and Technology 121, 108972, 8 pp. doi: 10.1016/j.lwt.2019.108972

Razavi SM, Karazhiyan H. 2012. Rheological and textural characteristics of date paste. International Journal of Food Properties 15(2):281-291.

Rosanna, Oktora Y, Ahza AB, Syah D. 2015. Preheating improve the crispness of cassava and sweet potato chips. Jurnal Teknologi dan Industri Pangan 26(1):72-79.

Sajeev MS, Sreekumar J, Vimala B, Moorthy SN, Jyothi AN. 2012. Textural and gelatinization characteristics of white, cream, and orange fleshed sweet potato tubers (*Ipomoea batatas* L.). International Journal of Food Properties 15(4):912-931.

Satin M. 1998. Functional properties of starches. In Spolight tropical starch misses market. AGSI report, Agriculture 21: 1-9. FAO-Magazine p.11.

Shaliha LA, Abduh SBM, Hintono A. 2018. Aktivitas antioksidan, tekstur dan kecerahan ubi jalar ungu (*Ipomoea batatas*) yang dikukus pada berbagai lama waktu pemanasan. Jurnal Aplikasi Teknologi Pangan 6(4):141-144.

Singh OF, Katiyar VK, Singh BP. 2014. Analytical study of turgor pressure in apple and potato tissues. Postharvest Biology and Technology 89:44-48. doi: 10.1016/j.postharvbio.2013.11.007

Truong VD, Hamman DD, Walter Jr WM. 1997. Relationship between instrument and sensory parameters of cooked sweet potato texture. Journal of Texture Studies. 28(2):163-185.

Truong VD, Walter Jr WM, Bett KL. 1998. Textural properties and sensory quality of processed sweetpotatoes as affected by low temperature blanching. Journal of Food Science 63(4):739-743.

Tunick MH. 2011. Food texture analysis in the 21st century. Journal of Agricultural and Food Chemistry 59(5):1477-1480.

Utomo JS. 2009. Sweet potato as a food crop. Buletin Palawija No. 17:19-28.

Utomo JS, Rahman RA. 2015. Physical and chemical properties of restructured sweet potato stick from three sweetpotato cultivars. International Journal on Advance Science Engineering Information Technology 5(1):16-22.

Wang S, Copeland L. 2013. Molecular disassembly of starch granules during gelatinization and its effect on starch digestibility: a review. Food and Function 4(11):1564-1580.

Yoon H, No J, Kim W, Shin M. 2018. Textural character of sweet potato root of Korean cultivars in relation to chemical constituents and their properties. Food Science and Biotechnology 27(6):1627-1637.

Zhang Z, Wei Q, Nie M, Jiang N, Liu C, Liu C, Liu C, Li D, Xu L. 2018. Microstructure and bioaccessibility of different carotenoid species as affected by hot air drying: Study on carrot, sweet potato, yellow bell pepper and broccoli. LWT -Food Science and Technology 96:357-363.

Zhu F, Sun J. 2019. Physicochemical and sensory properties of steamed bread fortified with purple sweet potato flour. Food Bioscience 30, Article ID 100411, 38 pp. *doi:* 10.1016/j.fbio.2019.04.012