

ABSTRACT

SATO, AI. Chemical Constituents of Sweetpotato Genotypes in Relation to Textural Characteristics of Sweetpotato French Fries. (Under the direction of Dr. Van-Den Truong).

Sweetpotato (SP) is an important economic crop and a highly nutritious vegetable due to the high contents of carotene, dietary fiber and vitamins. Currently, consumer demands of sweetpotato French fries (SPFF) have been increasing. However, SPFF are relatively new products, and information on the effects of chemical composition on SPFF textural properties are limited. This study aimed to investigate the relationship between chemical components of different types of SP varieties and textural characteristics of SPFF. Sixteen SP genotypes with varying flesh color (orange, yellow, cream) were evaluated on 1) chemical constituents in raw SP and SPFF, 2) instrumental measurement of textural properties and sensory textural characteristics of the SPFF, and 3) relationship between chemical components, instrumental texture measurements and sensory attributes.

Processing method of SPFF included tempering the whole roots, cutting into strips, blanching, pre-drying, par-frying at 185°C for 75 seconds, and freezing at -20°C. The frozen strips were fried at 177°C for 150 seconds, and cooled to 60°C for assessment of textural properties. Peak force and overall hardness of SPFF were measured using a texture analyzer equipped with a 2 mm cylinder probe, and a French fry rig, respectively. Dry matter (DM), alcohol insoluble solid (AIS), starch, sugars (glucose, fructose, sucrose,

maltose) and oil contents were analyzed in raw SP and SPFF samples. Alpha-amylase and beta-amylase activities were measured in raw SP. For sensory evaluation, 10 attributes were evaluated by a trained panel. Descriptive sensory analysis (DSA) was conducted and the DSA data was analyzed using analysis of variance and principal component analysis.

Dry matter content in raw SP of the 16 genotypes were in a range of 18.6 to 37.2%, AIS 11.6 to 36.7 g/100g, starch 6.0 to 23.4 g/100g, total sugars 1.2 to 6.5 g/100g, α -amylase activity 12.8 to 130.5 CU/100g, and β -amylase activity 3.9 to 618.9 U/100g fresh weight. Moisture contents in SPFF were in a range of 35.7 to 58.3%, AIS 30.8 to 64.2 g/100g fw, starch 11.6 to 41.4 g/100g, total sugar 0.3 to 10.2 g/100g, and oil 6.7 to 12.6%. Sensory textural characteristics of 8 orange-fleshed genotypes SPFF were similar to each other and were described as oily, moist, smooth and cohesive. SPFF from 3 yellow fleshed genotypes had similar characteristics that were characterized by outer crispness, high fracturability, hardness and rough surface. DM, AIS and starch contents in raw SP were positively correlated with instrumental peak force ($r = 0.41-0.52$, $p < 0.01$) and overall hardness ($r = 0.57-0.68$, $p < 0.01$), and with sensory overall hardness, fracturability and outer crispness ($r = 0.63-0.90$, $p < 0.01$). Total sugar contents in raw SP were correlated with sensory texture of inner smoothness and inner moistness ($r = 0.76-0.77$, $p < 0.01$), and negatively correlated with instrumental peak force ($r = -0.62$, $p < 0.01$) and overall hardness ($r = -0.69$, $p < 0.01$). Activities of amylases and oil content

had no/weak correlation with instrumental and sensory textural properties of SPFF. For the relationship between instrumental measurements and sensory characteristics, sensory overall hardness, fracturability and outer crispness were positively correlated ($r = 0.68-0.96$) with the peak force and overall hardness. Negative correlations ($r = -0.61 - -0.91$) were found between values of the instrumental measurements (peak force and overall hardness) and four sensory attributes including surface oiliness, inner smoothness, inner moistness and cohesiveness of mass. Therefore, DM, AIS, starch and total sugar contents and instrumental measurements could be used as tool to select SP genotypes for producing SPFF. These results would be beneficial to the breeding program in developing new SP varieties with improved SPFF quality to meet the increasing consumer demands.

© Copyright 2016 by Ai Sato

All Rights Reserved

Chemical Constituents of Sweetpotato Genotypes in Relation to Textural Characteristics
of Sweetpotato French Fries

by
Ai Sato

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Food Science

Raleigh, North Carolina

2016

APPROVED BY:

G. Craig Yencho, Ph.D.

Suzanne Johanningsmeier, Ph.D.

Van-Den Truong, Ph.D.
Chair of Advisory of Committee

DEDICATION

To my family – I sincerely appreciate your unconditional love, trust and support throughout my life.

BIOGRAPHY

Ai Sato was born and grew up in Tokyo, capital city of Japan. During her childhood, she loved anything related to foods such as cooking, eating and gardening. She often helped cooking at home and went for picking fruits and vegetables with her family. With these experiences, she decided to major in agriculture for her undergraduate program at Tokyo University of Agriculture (TUA) in Japan where she studied basic elements of plant nutrition and agriculture. In her junior year at TUA, she was selected to participate in the exchange student program and she studied at the National Chung Hsing University (NCHU) in Taiwan for one year. It was a valuable experience for her to conduct experiments for a research project on alpha-amylase inhibitor in common beans, to learn Chinese and to take agricultural courses at NCHU. She liked doing the experiment, and this experience has motivated her to pursue a career in food science. After graduation from TUA with a Bachelor degree in Agricultural Sciences, she pursued a Master's Degree in Food Science under the direction of Dr. Van-Den Truong at North Carolina State University. Her research for master's thesis focused on textural properties of sweetpotato French fries. She is very eager to continue her education for a Ph.D. program in Japan after graduation. She is excited to take a new step toward a bright future.

ACKNOWLEDGEMENTS

I would first like to sincerely thank my advisor, Dr. Van-Den Truong, for advice, understanding and support during my time at North Carolina State University. I am glad to have the wonderful opportunity to work on the sweetpotato project under his direction. In addition to Dr. Truong, I would like to appreciate my other committee members, Dr. Suzanne Johanningsmeier, Dr. G. Craig Yencho, and Mr. Kenneth Pecota. Dr. Johanningsmeier, thank you for serving on my committee, and advising and assisting the sensory test in my research project. Dr. G. Craig Yencho, and Mr. Kenneth Pecota, thank you for serving on my committee, for providing sweetpotato samples and for advice and support.

I would also like to thank all sweetpotato lab members, Rong Reynolds, Morgan Caudill, Sarah Chilungo and Carrie Xiao Qiu for your heartwarming support for everything. I could not complete my experiment without all of you.

I would also like to appreciate all members of USDA-ARS Food Science Research Unit for their support.

TABLE OF CONTENTS

LIST OF TABLES.....	vii
LIST OF FIGURES.....	ix
CHAPTER 1: Introduction.....	1
1.1 Introduction.....	2
1.2 References.....	7
CHAPTER 2: Literature Review.....	10
2.1 Sweetpotatoes.....	11
2.1.1 Chemical Composition and Health Benefits of Sweetpotatoes.....	12
2.1.2 Processing of Sweetpotato French Fries.....	17
2.2 Chemical Composition of Sweetpotato French Fries.....	23
2.3 Relationship between Chemical Composition and Textural Properties of Sweetpotato French Fries.....	27
2.4 Relationship between Instrumental Measurement and Sensory Evaluation of Texture of Sweetpotato French Fries.....	30
2.5 References.....	34
CHAPTER 3: Instrumental Textural Properties of Sweetpotato French Fries in Relation to Chemical Components.....	43
3.1 Abstract.....	44
3.2 Introduction.....	45
3.3 Materials and Methods.....	46
3.3.1 Materials.....	46
3.3.2 Sample Preparation for Chemical Analysis.....	48
3.3.3 Instrumental Measurement of Texture.....	51
3.3.4 Statistical Analysis.....	51
3.4 Results and Discussion.....	52
3.4.1 Chemical Component of Raw Sweetpotato and Sweetpotato French Fries.....	52
3.4.2 Instrumental Measurement.....	59

3.4.3 Relationship between Chemical Components and Instrumental Measurement.....	61
3.5 Conclusion.....	64
3.6 References.....	65
CHAPTER 4: Sensory Texture Characteristics of Sweetpotato French Fries.....	80
4.1 Abstract.....	81
4.2 Introduction.....	83
4.3 Materials and Methods.....	86
4.3.1 Materials.....	86
4.3.2 Sensory Analysis.....	87
4.3.3 Statistical Analysis.....	89
4.4 Results and Discussion.....	90
4.4.1 Texture Characteristics of Sweetpotato French Fries.....	90
4.4.2 Relationship between Sensory Texture Attributes and Chemical Components.....	93
4.4.3 Relationship between Sensory Texture Attributes and Instrumental Measurement.....	96
4.5 Conclusion.....	98
4.6 References.....	100
APPENDICES.....	112
Appendix A: Correlations and statistical analysis described in Chapter 3.....	113
Appendix B: Sensory panel training, DSA data without outliers, and statistical result described in Chapter 4.....	115
Appendix C: Sensory textural characteristics of commercial white potato French fries and commercial sweetpotato French fries.....	125

LIST OF TABLES

CHAPTER 2

Table 2-1. Nutrient content of sweetpotato in 5 inch long (130g) raw sweetpotato root.....	42
--	----

CHAPTER 3

Table 3-1. Chemical components of raw sweetpotatoes.....	68
Table 3-2. Chemical components of sweetpotato French fries.....	69
Table 3-3. Correlation coefficients (r) between chemical components on dry weight basis.....	70
Table 3-4. Correlation coefficients (r) between chemical components and instrumental texture measurement of SPFF of 16 genotypes.....	71

CHAPTER 4

Table 4-1. Sensory attributes with definitions and techniques for evaluation of sweetpotato French fries.....	102
Table 4-2. Texture attributes of sweetpotato French fries from 16 genotypes.....	104
Table 4-3. Correlation coefficients (r) between sensory attributes of sweetpotato French fries.....	106
Table 4-4. Factor loading in principal component analysis.....	107
Table 4-5. Correlation coefficients (r) between chemical components and sensory attributes of sweetpotato French fries of DSA panel produced from 16 genotypes.....	108
Table 4-6. Correlation coefficients (r) between instrumental measurement and sensory attributes of sweetpotato French fries from 16 genotypes.....	110

APPENDICES

Table A-1. Correlation coefficients (r) between chemical components and instrumental texture measurement of sweetpotato French fries produced from 15 genotypes (except NC13-487 which had unique texture).....	113
Table B-1. List of foods used for training.....	115
Table B-2. Panel mean of DSA of sweetpotato French fries calculated without individual outlier scores.....	116
Table B-3. p-value of correlation between chemical components and sensory attributes of sweetpotato French fries produced from 16 genotypes.....	118
Table B-4. Correlation coefficients (r) between chemical components and sensory attributes of sweetpotato French fries produced from 15 genotypes (except NC13-487 which had unique texture).....	119

Table B-5. Correlation coefficients (r) between instrumental measurement and sensory attributes of sweetpotato French fries produced from 15 genotypes (except NC13-487 which had unique texture).....	121
Table B-6. Analysis of Variance (ANOVA) table for DSA data.....	122

LIST OF FIGURES

CHAPTER 3

Figure 3-1. Sugar profile of raw sweetpotatoes.....	72
Figure 3-2. Sugar profile of sweetpotato French fries.....	73
Figure 3-3. Changes in sugar content after frying.....	74
Figure 3-4. Amount of decreased starch after frying.....	75
Figure 3-5. Comparison between replication 1 and 2 of oil content.....	76
Figure 3-6. Peak force of sweetpotato French fries.....	77
Figure 3-7. Overall hardness of sweetpotato French fries.....	78
Figure 3-8. Raw sweetpotato strips.....	79

CHAPTER 4

Figure 4-1. Principal Component Analysis of sweetpotato French fries accounting for 83% of the variability in all texture attributes.....	111
---	-----

APPENDICES

Figure A-1. Correlation between dry matter content in raw SP and peak force of sweetpotato French fries.....	114
Figure B-1. Score sheet of DSA panel.....	123
Figure C-1. Sensory textural characteristics of commercial white potato French fries and commercial sweetpotato French fries.....	126

CHAPTER 1

Introduction

1.1 Introduction

The origin of sweetpotato (SP) (*Ipomoea batatas* L.) is in tropical America and SP has been domesticated over 5000 years (Loebenstein 2009). Sweetpotato is currently an important economic crop with over 104 million metric tons in the world (FAOSTAT 2014). In terms of annual production, SP ranks seventh in world food production after maize, rice, wheat, potato, cassava, and barley (FAOSTAT 2013).

Sweetpotato is a highly nutritious vegetable and its consumption has been increased in various parts of the world in recent years. According to USDA survey, SP consumption in the US increased from 1.9 kg to 3.4 kg per capita annually between 2000 and 2014 (Johnson et al. 2015). North Carolina has ranked as the top SP producing state and produces about 50% of the US supply (Johnson et al. 2015). In the US, orange-fleshed cultivars occupy over 90% of SP production area (Carpena 2009).

Sweetpotato is an excellent source of carotene, dietary fiber, vitamins and minerals (Woolfe 1993). Orange-fleshed SP is rich in β -carotene which is a vitamin A precursor (Burri 2011). Absorption of β -carotene is enhanced when consumed with oil because β -carotene is oil-soluble (Van het Hof et al. 1999). Consumption of orange-fleshed SP helps to prevent vitamin A deficiency that is a public health problem in many countries, especially in Sub-Saharan Africa and south Asia (Stevens et al. 2015). On the other hand, purple-fleshed SP contains anthocyanins, which have high anti-oxidant activity. The anti-oxidants such as anthocyanins and β -carotene scavenge active oxygen radicals and prevent carcinogenesis (Kano et al. 2005). Therefore, there is great interest both in developed and developing countries on SP as a health food.

There are numerous SP genotypes with different sensory characteristics such as taste, texture, and flesh color (white, cream, yellow, orange, purple). The varieties with high dry matter (DM) content have firm and mealy texture after cooking while those with

low DM content have soggy texture after cooking (Truong et al. 2011). Common ways of eating SP are boiling, steaming and baking while common processed SP products are starches, juices and purees (Truong and Avula 2010). Meanwhile, processed SP products such as French fries and chips have been developed in the past decades (Walter and Hoover 1986; Walter et al. 1997). Recently, consumer demands of sweetpotato French fries (SPFF) have been increased and many potato processing companies have ventured into SPFF processing. The new products contribute to increasing sales for SP farmers (U.S. Sweet Potato Council, 2013). With these trends, the SP breeding programs have been focusing on development of new varieties suitable for both fresh root markets and processed products, particularly French fries and chips (U.S. Sweet Potato Council, 2011). To be highly acceptable in the market, texture and flavor of SPFF would be the key factors for consumer acceptance. However, limited information is available on suitable SP varieties, postharvest handling, and processing techniques affecting the product quality. Currently, SPFF are processed using the existing SP cultivars that were developed for fresh root market.

On the other hand, white potato French fries (WPF) is the most popular processed product from white potato (WP) around the world. White potato French fries accounted for 50% of total processed WP product (National Agricultural Statistics Service, USDA 2014). The consumption of frozen WP product, mostly WPF was 20.8 kg per capita annually in 2014 in the US (Economic Research Service, USDA 2016). Production of frozen WP product amounted to about 35% of total potato production in the US in 2014 (Economic Research Service, USDA 2016). The traditional way of preparing commercial WPF includes washing, peeling, cutting into strips, blanching, par-frying for 1-3 min, and freezing. The frozen strips are packed and sold at grocery stores and various food chains. The frozen strips are final-fried for 2-3 min at 180-195°C before consumption

(Miranda and Aguilera 2006; Pedreschi et al. 2016).

Since WFFF has been highly popular in the market for a long time, many studies were conducted over the past 60 years to develop various processes for WFFF and provide understanding on the factors including raw materials and postharvest handling affecting the product quality and consumer acceptability. Kirkpatrick (1956) reported that consumers prefer WFFF with leathery, gummy, and crispy without hard texture, and the desirable interior texture is mealy like baked potato and not watery and mushy. For textural properties of WFFF, many investigators revealed that chemical components including moisture, starch, pectin and oil affect textural characteristics of WFFF (Johnston et al. 1970; Du Pont et al. 1992; Tajner 2003; Kita and Lisińska 2005; Lisińska and Gołubowska 2005; Gołubowska 2005; Sanz et al. 2007). Moreover, relationship between instrumental measurement and sensory characteristics of WFFF was also well studied (Johnston et al. 1970; Du Pont et al. 1992; Kita and Lisińska 2005; Van Loon et al. 2007). However, information on WFFF may not be suitable for SPFF because the two commodities are different botanically and chemically. Sweetpotato is *Ipomoea batatas* L. and a root vegetable while WP is *Solanum tuberosum* L. and a tuber vegetable. Therefore, studies on SPFF including the factors affecting the product quality such as texture and flavor, and consumer acceptability are necessary for commercial success.

In the previous studies on SPFF, processing conditions of SPFF in relation to product qualities have been studied by several investigators (Walter and Hoover 1986; Walter et al. 1992; Walter et al. 2002; Oner and Wall 2012; Truong et al. 2014). Increased firmness of SPFF could be achieved by SP tissue acidification (Walter et al. 1992). In a study on purple-fleshed SPFF, SPFF without blanching treatment had the highest crust hardness although the SPFF had poor texture quality which was hard or rubbery (Oner and Wall 2012). Additionally, pre-drying of the blanched strips before frying resulted in

increases of DM content and improvement of the French fry texture (Walter and Hoover 1986; Truong et al. 2014).

Physico-chemical properties of SP varieties had profound effects on SPFF textural properties and sensory profiles. For the relationship between chemical components and textural properties, a negative correlation was observed between the DM content in SPFF and sensory intensity of the first-bite hardness of SPFF while AIS content and sugar content in SPFF was highly correlated with sensory intensity of first-bite moistness (Walter et al. 1997). Low DM and oil contents were related to perceived softness of SPFF (Oner and Wall 2012). Cell size, intercellular volume and specific gravity did not affect instrumental firmness of SPFF (Walter et al. 1997).

Sensory characteristics of boiled or baked SP and preferences of consumers on different types of SP varieties have been investigated (Laurie et al. 2013; Leksrisonpong et al. 2012). For SPFF, Walter et al. (1997) reported that the product processed from soft-sweet type SP was softer, moister, fewer particles, higher degree of mass cohesion, easier to swallow, and oily mouthfeel, and that consumers prefer caramel flavor and dislike starch flavor, and first-bite moistness and cohesiveness of mass in texture. In a study on restructured SPFF, sensory hardness and density were highly correlated with the value of instrumental measurements while cohesiveness, oiliness and moistness were negatively correlated with the value of instrumental measurements (Walter et al. 2002). However, there is no report used well-trained sensory panel and used comprehensive sensory texture attributes and evaluation techniques. In addition, no study was conducted on description of sensory characteristics of SPFF.

Overall, information on chemical and textural properties of SPFF processed from different SP varieties is limited. The lack of information in these aspects would hinder the efforts of SP breeders and processors in the development of SPFF with good quality to

meet the demands of the consumers.

Therefore, this study aimed to investigate the relationship between chemical components of different types of SP varieties and textural characteristics of SPFF. Sixteen SP genotypes with varying flesh color (orange, yellow, cream) were evaluated on 1) chemical constituents in raw SP and SPFF, 2) instrumental textural properties and sensory textural characteristics of the SPFF, and 3) relationship between chemical components, instrumental texture measurements and sensory attributes.

1.2 Reference

- Burri, B.J. 2011. Evaluating sweet potato as an intervention food to prevent vitamin A deficiency. *Comprehensive Reviews in Food Science and Food Safety*, 10(2), 118-130.
- Carpena, A.L. 2009. Important cultivars, varieties, and hybrids. In *The sweetpotato*. Springer Netherlands, 27-40
- Du Pont, M.S., Kirby, A.R. and Smith, A.C. 1992. Instrumental and sensory tests of texture of cooked frozen french fries. *International journal of food science & technology*, 27(3), 285-295.
- Economic Research Service, USDA. 2016. *Economic Research Service Vegetable and Pulses Yearbook*. Washington, DC: US Department of Agriculture
- Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). 2013. Retrieved from <http://faostat3.fao.org>
- Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). 2014. Retrieved from <http://faostat3.fao.org>
- Gołubowska, G. 2005. Changes of polysaccharide content and texture of potato during French fries production. *Food chemistry*, 90(4), 847-851.
- Johnson, T., Wilson, N., Worosz, M. R., Fields, D. and Bond, J. K. 2015. *Commodity Highlight: Sweet Potatoes*.
- Johnston, F.B., Kenkars, E. and Nunes, A.C. 1970. Starch and dry matter content of Netted Gem in relation to french fry texture. *American Potato Journal*, 47(3), 87-93.
- Kano, M., Takayanagi, T., Harada, K., Makino, K. and Ishikawa, F. 2005. Antioxidative activity of anthocyanins from purple sweet potato, *Ipomoea batatas* cultivar Ayamurasaki. *Bioscience, biotechnology, and biochemistry*, 69(5), 979-988.
- Kirkpatrick, M.E. 1956. *French-frying quality of potatoes: as influenced by cooking methods, storage conditions, and specific gravity of tubers (Vol. 1142)*. US Dept. of Agriculture.
- Kita, A. and Lisińska, G. 2005. The influence of oil type and frying temperatures on the texture and oil content of French fries. *Journal of the Science of Food and Agriculture*, 85(15), 2600-2604.
- Laurie, S.M., Faber, M., Calitz, F.J., Moelich, E.I., Muller, N. and Labuschagne, M.T. 2013. The use of sensory attributes, sugar content, instrumental data and consumer acceptability in selection of sweet potato varieties. *Journal of the Science of Food and Agriculture*, 93(7), 1610-1619.
- Leksrisonpong, P.P., Whitson, M.E., Truong, V.D. and Drake, M.A. 2012. Sensory attributes and consumer acceptance of sweet potato cultivars with varying flesh colors.

- Journal of Sensory Studies, 27(1), 59-69.
- Lisińska, G. and Gołubowska, G. 2005. Structural changes of potato tissue during French fries production. *Food chemistry*, 93(4), 681-687.
- Loebenstein, G. 2009. Origin, distribution and economic importance. In: *The sweetpotato*. Springer Netherlands, 9-12.
- Miranda, M.L. and Aguilera, J.M. 2006. Structure and texture properties of fried potato products. *Food Reviews International*, 22(2), 173-201.
- National Agricultural Statistics Service, USDA. 2014. Potatoes 2013 Summary. Washington, DC: US Department of Agriculture
- Oner, M.E. and Wall, M.M. 2012. Processing conditions for producing french fries from purple-fleshed sweetpotatoes. *Transactions of the ASABE*, 55(6), 2285-2291.
- Pedreschi, F., Mariotti, S.M. and Cortés, P. 2016. Fried and dehydrated potato products. In: *Advances in Potato Chemistry and Technology*, 2nd Edition; Singh, J., Kaur, L., Eds.; Elsevier: New York, 459-474.
- Sanz, T., Primo-Martín, C. and Van Vliet, T. 2007. Characterization of crispness of French fries by fracture and acoustic measurements, effect of pre-frying and final frying times. *Food Research International*, 40(1), 63-70.
- Stevens, G.A., Bennett, J.E., Hennocq, Q., Lu, Y., De-Regil, L.M., Rogers, L., Danaei, G., Li, G., White, R.A., Flaxman, S.R. and Oehrle, S.P. 2015. Trends and mortality effects of vitamin A deficiency in children in 138 low-income and middle-income countries between 1991 and 2013: a pooled analysis of population-based surveys. *The Lancet Global Health*, 3(9), e528-e536.
- Tajner-Czopek, A. 2003. Changes of pectic substances concentration in potatoes and French fries and the effect of these substances on the texture of the final product. *Food/Nahrung*, 47(4), 228-231.
- Truong, V.D. and Avula, R.Y. 2010. Sweet potato purees and powders for functional food ingredients. In: Ray RC, Tomlins KI, editors. *Sweet potato: Post harvest aspects in food, feed and industry*. New York: Nova Science Publishers, Inc. p 117-161.
- Truong, V.D., Avula, R.Y., Pecota, K. and Yencho, C.G. 2011. Sweetpotatoes. In: *Handbook of Vegetables and Vegetable Processing*, 717-737.
- Truong, V.D., Pascua, Y.T., Reynolds, R., Thompson, R.L., Palazoğlu, T.K., Atac Mogol, B. and Gökmen, V. 2014. Processing treatments for mitigating acrylamide formation in sweetpotato French fries. *Journal of agricultural and food chemistry*, 62(1), 310-316.
- U.S. Sweet Potato Council. 2011. National Sweet Potato News Letter. Retrieved from <http://sweetpotatousa.org/wp-content/uploads/2014/02/SPCNSummer2011.pdf>

- U.S. Sweet Potato Council. 2013. National Sweet Potato News Letter. Retrieved from <http://sweetpotatousa.org/wp-content/uploads/2014/02/SPCNSummer2013.pdf>
- Van het Hof, K.H., Brouwer, I.A., West, C.E., Haddeman, E., Steegers-Theunissen, R.P., van Dusseldorp, M., Weststrate, J.A., Eskes, T.K. and Hautvast, J.G. 1999. Bioavailability of lutein from vegetables is 5 times higher than that of β -carotene. *The American journal of clinical nutrition*, 70(2), 261-268.
- Van Loon, W.A., Visser, J.E., Linssen, J.P., Somsen, D.J., Klok, H.J. and Voragen, A.G. 2007. Effect of pre-drying and par-frying conditions on the crispness of French fries. *European Food Research and Technology*, 225(5-6), 929-935.
- Walter, W.M., Collins, W.W., Truong, V.D. and Fine, T.I. 1997. Physical, compositional, and sensory properties of French fry-type products from five sweetpotato selections. *Journal of Agricultural and Food Chemistry*, 45(2), 383-388.
- Walter, W. M., Fleming, H.P. and McFeeters, R. F. 1992. Firmness Control of Sweetpotato French Fry - Type Product by Tissue Acidification. *Journal of food science*, 57(1), 138-142.
- Walter, W.M. and Hoover, M.W. 1986. Preparation, Evaluation and Analysis of a French - Fry - Type Product from Sweet Potatoes. *Journal of Food Science*, 51(4), 967-970.
- Walter, W. M., Truong, V. D. and Espinel, K. R. 2002. Textural measurements and product quality of restructured sweetpotato French fries. *LWT-Food Science and Technology*, 35(3), 209-215.
- Woolfe, J. 1993. *Sweet potato: An untapped food resource*. Cambridge: Cambridge University Press.

CHAPTER 2

Literature Review

2.1 Sweetpotatoes

The origin of sweetpotato (SP) is from tropical America and SP has been domesticated over 5000 years (Loebenstein 2009). Sweetpotato (*Ipomoea batatas* L.) is produced in many countries around the world, and it is an important economic crop produced over 104 million metric tons of edible food products in the world (FAOSTAT 2014). Sweetpotato is a highly nutritious vegetable. There are lots of genotypes with different sensory characteristics such as taste and texture, and flesh color (white, cream, yellow, orange, purple).

In terms of annual production, SP ranks the seventh in the world food production after maize, rice, wheat, potato, cassava, and barley (FAOSTAT 2013). Annual per capita SP consumption is high in places where SP are consumed as a staple food such as the Solomon Islands at 174.9 kg, Rwanda at 71.3 kg, Uganda at 61.7kg, Angola at 46.1kg, and Uganda at 61.8 kg. The average annual per capita SP consumption is estimated at 9.4kg in Asia, 13.2 kg in Africa, and 18.2 kg in Caribbean (FAOSTAT 2011).

Sweet potatoes have been an important part of the diet in the United States for most of its history. According to a USDA survey, SP consumption in the US increased from 1.9 kg to 3.4 kg per capita annually between 2000 and 2014 (Johnson et al. 2015). Orange-fleshed SP genotypes occupy about 90% of the SP production area in the US (Carpena 2009). North Carolina has ranked as the top SP producing state and produces about 50% of the US supply (Johnson et al. 2015). In North Carolina, the Covington variety had the biggest share which was about 80% of total SP production in 2015.

Sweetpotato industry processes SP into liquid and semi-solid food products such as beverages, soups, baby foods, ice cream, baked products, restructured fries, fried chips and French fries, breakfast cereals, and various snack and dessert items in the US (Truong et al. 2011). In Japan, about 48% of SP are for fresh market, 28% for making alcohol,

15% for making starch, and 6% for other food processing in 2014 (Agriculture & Livestock Industries Corporation 2016).

2.1.1 Chemical Composition and Health Benefits of Sweetpotatoes

Chemical components of SP vary in different cultivars. Genotype background, growing condition, maturity, storage condition and duration, and processing condition also affect chemical components. Sweetpotato is one of the healthiest foods because of the high content of nutrients, especially carotene and dietary fiber thereby there is great interest both in developed and developing countries on SP as healthy foods. Table 2-1 shows nutrient content when consuming a 5 inches of SP root (130g) (USDA National Nutrient Database, and 2015-2020 Dietary Guidelines for Americans).

Generally, dry matter (DM) content in SP is widely ranged from 13 to 45% (Aina et al. 2009; Mensah et al. 2016; Brabet et al. 1998). Dry matter in SP is mainly consisted of carbohydrates which are starch, sugars, pectins, cellulose, and hemicellulose. Hagenimana et al. (1998) analyzed DM content of SP with different colors, and reported that general DM contents in orange-fleshed and purple-fleshed were ranged from 20.4 to 27.8% and 20.3 to 30.2% respectively. They also reported that cream-, yellow- and white-fleshed SP generally had high DM contents. Dry matter contents of Beauregard and Covington, which are the common orange-fleshed SP genotypes in the US, were 18.7% and 19.7% (Yencho et al. 2008).

Dry matter content decreases during storage because SP roots are metabolically active and utilized carbohydrates as an energy source and because of respiration and transpiration during storage (Walter and Hoover 1986; Truong et al. 2014). Alcohol insoluble solid (AIS) is a main component of DM, and it consists of substances that are not soluble in alcohol, primarily starch. Walter et al. (1997) measured AIS of four

genotypes, and AIS content in SP is ranged from 14.5-23.7%.

Starch is a main component of AIS. Generally, starch accounts for 60-70% of DM (Padmaja 2009). Starch content of SP is in a range of 6.9-33.5% (Tian et al. 1991; Brabet et al. 1998). Starch is composed of amylose and amylopectin, and the ratio varies in different genotypes. Amylose and amylopectin ratio influences textural properties, and it is widely known that viscosity increases with increasing amylopectin content. Sweetpotato starch contains up to 38% of amylose (Tian et al. 1991; Wolfe 1993; Zhu and Wang 2014). Katayama et al. (2006) measured amylose contents in 812 genotypes introduced from 11 different countries and areas and reported a range of 8.9-16.1%. Sweetpotatoes from Indonesia generally have high amylose contents. Tian et al. (1991) noted that amylose content in SP was less than potato, and that SP starch granule size was smaller than potato. Starch content decreased during storage although the reduction rate varied among genotypes (Zhang et al. 2002; Miyazaki 1990; Walter and Hoover 1986). Generally, gelatinization temperature of SP starch is 60-80°C (Zhu and Wang 2014). Nakamura et al. (2010) reported that gelatinization temperature did not affect mealiness and sogginess of steamed sweetpotatoes.

Gelatinization temperature of Japanese SP cultivar named Quick Sweet, which was registered as a new cultivar in 2002, is about 20°C lower than other SP cultivars (Katayama et al. 2003). Onset, peak and conclusion temperatures of gelatinization of the Quick Sweet are 37.4°C, 42.9°C and 54.4°C respectively. Quick sweet starch has higher proportion of short chain in amylopectin and has cracking on the hilum of starch granules. These characteristics would be the factors for the low gelatinization temperature (Katayama et al. 2002; Katayama et al. 2003). Another Japanese SP cultivar named Konamizuki was registered as a new cultivar in 2012, and this cultivar also has low gelatinization temperature such as Quick Sweet (Katayama et al. 2012).

Sweetpotatoes contain much more sugar than white potatoes. The amount of sugar varies widely among different genotypes and postharvest treatments. Total sugar ranged from 1.8 to 38% on dry weight basis (dw) (Truong et al. 1986; Zhang et al. 2002; Aina et al. 2009). Sugar in raw SP roots is composed of glucose, fructose and sucrose, and a proportion of each sugar also varies with genotypes. Zhang et al. (2002) reported that glucose, fructose and sucrose are in a range of 2.4-6.2%, 0.3-4.9% and 0.4-5.6% dw respectively while Truong et al. (2014) reported that glucose, fructose and sucrose are in a range of 1.0%, 0.8% and 4.2% respectively on fresh weight basis (fw). Zhang et al. (2002) reported that sugar content increased after 60 days of storage but maintained relatively constant levels after 120 days although Walter et al. (1975) reported that sugar content increased after 71 days of storage. Curing immediately after harvest increased sucrose content up to two folds (Miyazaki 1990). Raw SP contains trace amount of maltose. Maltose is increased during heating because β -amylase hydrolyzes starch.

Besides starch and sugars, SP contains high amount of dietary fiber. Dietary fiber in SP roots ranged from 1.9-26.6% dw (Wang et al. 2016). Based on USDA National Nutrition Database, adult female and male gain 14-18% and 12-14% of recommended amount of dietary fiber respectively by consuming a SP root of 130 g (Table 2-1). Dietary fiber reduces postprandial glucose response and beneficially influences certain blood lipids (Weickert and Pfeiffer 2008). Therefore, dietary fiber helps to prevent type 2 diabetes, cardiovascular disease and coronary heart disease (Kaczmarczyk et al. 2012; Pereira et al. 2004).

SP contains α -amylase and β -amylase (Woolfe 1993). Alpha-amylase plays an important role in starch degradation during storage (Zhang et al. 2002). Alpha-amylase randomly hydrolyzes α 1, 4 glycosidic bonds in amylose and amylopectin, the two main components in starch. Beta-amylase hydrolyzes gelatinized SP starch but it is unable to

hydrolyze native SP starch (Ohnishi et al. 1985). Beta-amylase hydrolyzes the second α 1, 4 glycosidic bonds from the non-reducing end, and cleaves off two glucose units which is maltose. Consequently, the production of maltose during heating is due to the hydrolysis of gelatinized starch by β -amylase.

Optimum temperature of SP α -amylase is 70 to 75°C (Ikemiya and Deobald 1966; Mensah et al. 2016). Zhang et al. (2002) reported that α -amylase activity ranged from 0.41 to 1.73 Ceralpha unit/g dw while Mensah et al. (2016) reported 60 to 90 U/g dw at 75°C. Sweetpotato β -amylase activity is optimal at 50°C, and it gradually decreases above 50°C then deactivates at 80°C (Tsuyukubo and Ishii 2011). Mensah et al. (2016) noted that β -amylase activity of SP was relatively stable at 65°C and the activity decreased with increasing heating time and temperature. Its optimum temperature is lower than those of other food such as soy bean and Japanese radish. Optimum temperature of the β -amylase from other foods is around 60°C, and β -amylase can be still active up to 70°C (Ohnishi et al. 1985). Nakamura et al. (2014) reported that β -amylase activity of SP ranged from 0.108-0.281 units (m mole maltose / min / mg protein). Dzedzoave et al. (2010) measured β -amylase activity of SP grown in a forest zone and a savannah zone at different maturity levels, which ranged from 176.6-601.9 units/g. They found that SP from the forest zone had higher β -amylase activity than those from the savannah zone.

Sweetpotato has certain amount of protein although it is not high. Most varieties of SP contain 1.3-10% dw protein (Padmaja 2009; Aina et al. 2009). Sporamins A and B account for over 80% of soluble protein in SP (Maeshima et al. 1985). In addition, SP contains 0.2-2.1% dw of fat and 1.9-4.4% dw of ash (Ravindran et al. 1995; Aina et al. 2009).

Sweetpotato is also a good source of β -carotene and vitamins such as vitamin B₆. Orange-fleshed SP is rich in β -carotene, which is vitamin A precursor (Burri 2011).

Hagenimana et al. (1998) reported β -carotene content from traces to 6.3 mg/100g in fresh roots of 32 SP cultivars. Deep orange-fleshed SP had the highest β -carotene, and white-fleshed had the lowest β -carotene. Other investigators reported 170-804 μ g RAE/100g fw from β -carotene in SP, and the β -carotene content decreased 20-24% after frying and 8-81% after boiling, baking, steaming (Van Jaarsveld et al. 2006; Bengtsson et al. 2008; Dincer et al. 2011). Five inches long of the orange-fleshed SP (130 g) meet the recommended dietary allowance of vitamin A based on dietary guidelines which is 700 to 900 μ g RAE (USDA National Nutrient Database, and 2015-2020 Dietary Guidelines for Americans). Beta-carotene which is converted to vitamin A in the human body helps to prevent diseases associated with vitamin A deficiency such as night blindness. Beta-carotene itself works as anti-oxidant and helps to prevent lifestyle related diseases such as heart disease and stroke. As for vitamin B₆, adult female and male gain 18-21% and 16-18% of recommended amount of dietary fiber respectively by consuming 130 g SP (Table 2-1). Vitamin B₆ in conjunction with vitamin B₁₂ and folic acid can help reducing blood levels of homocysteine which results in decreasing the risk of cardiovascular diseases (Padmaja 2009). Sweetpotato also contain ascorbic acid (vitamin C) in a range of 17.3-34.5 mg/100 g fw (Bradbury and Singh 1986). However, according to Grace et al. (2014), amount of vitamin C decreased by about half after 4 months in storage and by 65-84% after 8 months storage which was 2.7-11.1 mg/100g fw. The amounts of vitamin C of SP stored for 8 month are close to those of National Nutrient Database by US Department of Agriculture.

Purple-fleshed SP are rich in anthocyanins, which have anti-oxidant activity to scavenge active oxygen radicals and to prevent carcinogenesis (Kano 2005). According to a study on serum hepatic biomarker of 38 healthy adult men (30-54 years old), the group that consumed purple-fleshed SP beverage (400 mg anthocyanins/day) significantly

decreased serum hepatic biomarkers (Suda et al. 2008). The authors inferred that the purple-fleshed SP beverage may have potential capacity for hepatoprotection against oxidative stress. Anthocyanin content is in range of 32-1390 mg/100g dw, and cyanidin derivatives accounts for 19-92% of total monomeric anthocyanins measured by acid hydrolysis method (Truong et al. 2010; Truong et al. 2012; Xu et al. 2015). Some cooking treatments (steaming, pressure cooking, microwaving, frying) reduce 8–16% of total anthocyanin contents (Xu et al. 2015).

2.1.2 Processing of Sweetpotato French Fries

White potato French fries (WPF) is one of the most important white potato (WP) derived products and very popular around the world. White potato French fries accounted for 50% of total processed WP product (National Agricultural Statistics Service, USDA 2014). The traditional way of preparing WPF is cutting fresh WP into strips and frying in oil. For commercial scale, there are three types of WPF, which are 1) deep-frozen completely fried strips, 2) deep-frozen partially fried strips that require additional frying before eating, and 3) refrigerated partially fried strips that have a short shelf life and need additional frying (Pedreschi et al. 2016). Standard preparation method of WPF in food industries includes washing raw WP, peeling and cutting into strips. The strips are blanched to obtain uniform color after frying and to gelatinize starch to limit oil absorption and improve texture. The blanched strips are dehydrated until 20-30% of weight loss from initial weight. Then, the partially dried strips are par-fried for 1-3 min at around 190°C. The par-fried strips are frozen at around -18°C. The frozen strips are final-fried at home for 2-3 min at 180-195°C (Miranda and Aguilera 2006; Pedreschi et al. 2016).

Since sweetpotato French fries (SPFF) are a relatively new product, limited

information is available on processing conditions of SPFF. The preparation method of SPFF is similar to that of WPF. General preparation method of SPFF at home is just cutting raw SP and frying, or seasoning and coating strips with starch and then fry at 180-200°C. Conversely, food industries take more processing steps to improve the product quality and to prevent deterioration during storage and distribution. Standard preparation method of SPFF in food industries includes washing, peeling, pre-treatment (tempering, pH adjustment), cutting into strips, blanching, par-drying, par-frying, freezing and final frying. As for peeling, some did not peel SP skins (Oner and Wall 2012). Sweetpotatoes are cut into 9×9 mm to 9.5×9.5 mm strips and the length of strips is 50-90 mm or not controlled. All processing steps may affect texture of French fries. Texture of potato was changing during the technological process due to water losses and damage of potato tissue (Lisińska and Gołubowska 2005).

a) Pre-treatment (Tempering and Vacuum Infiltration)

Orange-fleshed SP are commonly preferred by consumers in the US. However, orange-fleshed SP are normally soft after cooking due to high moisture content. Therefore, SP needs to undergo pre-treatment to improve texture of SPFF. Tempering of the roots and pH acidification of SP strips by vacuum infiltration are applied to increase firmness of the processed products.

Tempering is a food processing operation to make vegetables and fruits firmer by soaking the raw materials in warm water before processing (LaBelle 1971; Aguilera-Carbó et al. 1999; He et al. 2014). The reason for the increase in firmness is the effect of pectin methylesterase (PME) on pectic substances. PME catalyzes de-esterification of carboxyl groups and forms cross-links between pectin polymers with divalent cations resulting in high molecular weight pectin with new non-methoxy ester linkages (Kohli et al. 2015; Buren 1979; Ni et al. 2005; Truong et al. 1998). Optimal

temperature for tempering of SP is 60°C (Fuchigami and Konishi 1978; Truong et al. 1998).

Vacuum infiltration treatment is performed by having solutions of different substances penetrating into SP. Walter et al. (1992) applied vacuum infiltration to decrease pH of SP tissue before blanching. They reported that tissue pH decreased by vacuum infiltration with a series of organic and mineral acids increased the force required to shear the SP strips. They also reported that tissue firmness increased as water soluble pectin content decreased. One possible reason of the firmness increase was that the middle lamella was less disrupted at lower pH due to less amount of solubilization. Another reason was that the starch degrading enzymes, α - and β -amylase, were inhibited because of the low pH in the acidified tissue.

b) Blanching

Blanching is a thermal treatment commonly practiced in processing of a variety of vegetable products including French fries. The process is important because blanching causes starch gelatinization impacting the texture and reducing oil absorption in fried products (Canet and Alvarez 2011; Pedreschi et al. 2016; Miranda and Aguilera 2006). Blanching also reduces sugars that cause undesirable color and acrylamide formation due to Maillard reaction during frying (Truong et al. 2014).

For SPFF, strips are blanched in boiling water or boiling water containing 1% sodium pyrophosphate for up to 10 min (Walter and Hoover 1986; Walter et al. 1997; Oner and Wall 2012). Blanching treatment caused a decrease in DM content because the sugars and other water-soluble materials were partially extracted by the hot water (Walter and Hoover 1986; Truong et al. 2014). Walter and Hoover (1986) reported that blanched treatment also decrease the amount of sucrose, fructose and glucose in raw SP strips. Oner and Wall (2012) reported the processing conditions for processing of purple-fleshed

SPFF. Crust hardness was the highest when purple-fleshed SP strips were not blanched and par-fried during processing although strips without blanching had poor texture quality which was hard or rubbery (Oner and Wall 2012). They reported that purple-fleshed SPFF with 10 min blanching had lower peak force than those of 0 and 5 min blanching although SPFF with a combination of 10 min blanching and par-frying significantly increased peak force.

Blanching treatment for white potato French fries (WPF) was more extensively researched. As for number of blanching time, Agblor and Scanlon (1998) reported that blanching 2 times (70°C for 10 min then 97°C for 2 min) increased instrumental peak force than blanching once (70°C for 10 min). Effect of low-temperature blanching on textural quality of WPF was also studied. Aguilar et al. (1997) found that low-temperature blanching (55-70°C) increased puncture force compared to unblanched strips, and hardness, chewiness and cohesiveness also increased. They postulated that the action of PME increased these attributes. They also reported that limpness and oil absorption were decreased. According to the results, the best condition of blanching for French fries texture was blanching for 30-45 min at 60-65°C. He et al. (2014) also studied on low-temperature blanching of SP before steam-cooking. They reported that low-temperature blanching increased tissue firmness and strength of cell wall. They also implied that blanching in water at 60°C for 30 min have a good effect on PME activity to hydrolyze methyl ester linkages in pectin molecules and accelerate forming cross-linkages between pectin polymers with divalent cations. Under this low-temperature blanching condition, PME activity of SP decreased by 87.8%, and polygalacturonase and β -amylase activity decreased 69.4% and 7.4% respectively.

On the other hand, Gołubowska (2005) worked on WPF and reported that changes in non-starch polysaccharide content during blanching and frying steps affect the product

texture. Effect of calcium addition to water during blanching was also studied. Jaswal (1970) reported that blanching in 0.5% calcium chloride solution at 70°C for 15 min was most effective to increase firmness of WFFF. Tajner (2003) focused on pectic substances to clarify the reason of the texture improvement. He found that blanching in water decrease the pectic substances in final fried WFFF while blanching in calcium and magnesium solutions prevent further loss of pectic substances. The calcium and magnesium ions bind to pectin substances in the potato tissue, which resulted in the texture improvement.

c) Pre-drying

Pre-drying of the blanched strips before frying resulted in increases of DM content and improvement of the French fry texture (Walter and Hoover 1986; Truong et al. 2014). In the studies conducted by Walter and Hoover (1986) and Walter et al. (1997), SP strips were dried by using forced air dryer at 121°C for 5 min while Truong et al. (2014) applied air-drying at 65±5°C for 10 min to obtain up to 10-15% weight loss. Walter and Hoover (1986) reported that SPFF with 5.7 min drying at 121°C had highest score evaluated by untrained sensory panel although the percentage of weight loss was not reported.

In the research of par-drying for WFFF, Van Loon et al. (2007) reported that strips which pre-dried until 10 and 15% weight loss increased crispness. A study on pre-drying (until 60% fw of moisture) for potato chip showed that pre-drying treatment decreased oil absorption and increase crispness of potato chip (Pedreschi and Moyano 2005).

d) Par-frying and freezing

Commercial SPFF is par-fried and sold as a frozen product in the market. The purpose of the par-frying treatment is to reduce final frying time. Generally, strips are par-fried for about 1 min at 165-180°C followed by quick freezing and packaging for storage and distribution (Oner and Wall 2012; Truong et al. 2014). However, par-frying

was not applied in some studies (Walter and Hoover 1986; Walter et al. 1997). Moisture content decreases with increasing par-frying time (Truong et al. 2014). Van Loon et al. (2007) reported that par-frying increased the crispness of WFFF while Oner and Wall (2012) showed that firmness of purple-fleshed SPFF was not consistent with par-frying regardless of blanching time and cooking method.

Regarding par-frying treatment for WFFF, effects of par-frying time and temperature on texture of WFFF were revealed. Optimal par-frying time is 60 seconds since 60 to 90 seconds par-frying slightly decrease crispness of WFFF (Sanz et al. 2007). For par-frying temperature, par-frying at 180°C rather than 160°C and 170°C increased crispness due to water evaporation from the strip surfaces (Van Loon et al. 2007).

Par-fried strips are normally frozen at -18 - -20°C (Miranda and Aguilera 2006; Truong et al. 2014). In a study on WFFF, water evaporation and oil absorption of frozen WP strips was higher than raw or blanched WP strips during final frying (Kato 1997). She implied that cell structure of WP strips was destroyed due to freezing, and this caused the high amount of water evaporation and oil absorption. O'Connor et al. (2001) also reported that WFFF undergone frozen storage before final frying had higher oil content in the inner core than those had been either chilled or prepared freshly for frying.

e) Final frying

Frying contributes to crust formation on the surface of French fries. The surface color of the French fries is also developed into golden yellow to brown during frying due to Maillard reaction. When strips are put into hot oil, temperature of outer layer of the strips reaches to 100°C rapidly, and water in the strips evaporate from the surface. The hot oil penetrates into the crevices where water is evaporated. The change between oil and water is occurred on the strip surfaces (Miranda and Aguilera 2006; Kato 1997), and oil penetrates into the French fries for about 0.3 to 0.4 mm (O'Connor et al. 2001).

Observation by confocal laser scanning microscopy (CLSM) shows that oil is placed as an egg-box arrangement surrounding intact potato cells (Miranda and Aguilera 2006).

Generally, strips are fried at 165-180°C for 2-5 min (Walter and Hoover 1986; Walter et al. 1997; Oner and Wall 2012; Truong et al. 2014). Temperature of 165°C was selected for both par-frying and final frying in the study by Truong et al. (2014) because high frying temperature causes undesirable brown color and high acrylamide formation. The European Food Safety Authority (EFSA) (2015) indicated that the frying temperature in oil-fried products should not exceed 170-175°C.

Numerous studies have been conducted on the effect of final frying time and temperature on the quality of WFFF. The frozen strips are usually fried at 180-195°C for 2-3 min (Aguilera and Gloria-Hernandez 2000; Miranda and Aguilera 2006; Pedreschi et al. 2016). Oil migration into intercellular spaces plays an important role for crust formation, which are significantly formed during frying. Du Pont et al. (1992) studied the relationship between frying time and oil absorption and they reported that increase of frying time resulted in decrease moisture content and increased oil content.

In a research focused on oil type, it was found that type of oil and frying temperature influence oil absorption and texture of WFFF (Kita and Lisińska 2005). For oil type, sunflower oil had high absorption, followed by soybean, palm, rapeseed and olive oils. Increase of frying temperature decreased oil absorption and hardness. WFFF with good texture was obtained by frying with rapeseed oil.

2.2 Chemical Composition of Sweetpotato French Fries

a) Dry Matter

Moisture in SP strips is evaporated during frying resulting in increases of DM. Moisture evaporation during frying is greater than in oven baking. According to the study

of purple-fleshed sweetpotato French fries (SPFF) by Oner and Wall (2012), purple-fleshed SPFF with final deep-fat frying contains 20-35.5% moisture, and those with final oven baking contains 39-60% moisture. They reported that the combination of blanching, no par-frying and oven baking to raw strips increased moisture content of purple-fleshed SPFF. In case of orange-fleshed SP, DM content of SPFF ranges from 50-68% (Truong et al. 2014).

Moreover, it was reported that increase of par-frying and final frying time increases DM content of WPF (Sanz et al. 2007). O'Connor et al. (2001) reported par-fried strips contained 28-37% DM. They also reported that the DM content of strips further increased by 10-23% during final frying. For commercial WPF, raw WP with 21-23% DM has mealy texture and suited for WPF (Pavlista and Ojala 1997).

b) Oil

Oil absorption occurs during frying and it forms crust on surfaces of strips. Oil is mainly located on the surface of strips, and surrounded potato cells (Bouchon and Aguilera 2001). The reported oil contents in SPFF in previous papers are not consistent because oil content differs depending on genotypes and processing conditions. Walter and Hoover (1986) reported 15.6 to 19.6% oil content in SPFF fried at 175°C for 2.5 min while Oner and Wall (2012) reported 9.5 to 37.9% dw oil content in purple-fleshed SPFF fried at 180°C for 3 min.

Effect of type of heat treatment was also studied. In research that compared deep-fat frying and oven baking as the final processing step, purple-fleshed SPFF fried at 180°C for 3 min contained 9.5 to 37.9% of oil, and purple-fleshed SPFF baked at 180°C for 8 min contained 0.3 to 12.4% oil (Oner and Wall 2012). Oil absorption varied depending on treatment before final frying. SPFF without blanching and par-frying contained 0.3% oil while SPFF with 10 min blanching and 1 min par-frying contained

12.4% dw oil (Oner and Wall 2012).

The amount of oil absorption increased with increasing moisture content of the unfried strips (Walter and Hoover 1986). Long blanching time damaged the surface of the strips, increasing water evaporation and thereby increased oil absorption (Oner and Wall 2012). Oil absorption of WFFF has been studied by many investigators. Oil content in WFFF normally ranged from 9 to 15% (Van Loon et al. 2007; Miranda and Aguilera 2006). Kita and Lisińska (2005) studied on the effect of frying temperature (150-190°C) and oil type (sunflower, soybean, rapeseed, olive, palm and modified oil) on oil absorption. Oil absorption varies depending on type of oil and frying temperature, and it ranged from 7.4 to 10.1%. Increase of frying temperature decreased the oil content of WFFF. As for type of oil, sunflower oil produced WFFF with the highest oil content (9.4% oil), followed by soybean, palm, rapeseed and olive (8.2% oil) oils. Oil content increases with increasing unsaturated fatty acids and decreasing saturated fatty acid content (Kita et al. 2005).

Processing treatment before final frying also influences oil content. O'Connor et al. (2001) reported strips processed without blanching, drying and freezing contained only 5.8% oil while WFFF processed with blanching, drying, par-frying and freezing contained 7.1-10.9% oil. Moreover, increase of frying time increases oil content and decrease moisture content (Du Pont et al. 1992). The oil content was 10.8% fw after 2 mins frying and was 23.8% after 9 min frying at 187°C. Oil content inside of WFFF was also studied. According to Aguilera and Gloria-Hernandez (2000), approximately 25% of the total oil in the crust in WFFF was structured oil that migrates into the crust during frying, and 75% was surface oil after frying. Oil absorption into the outer 1 mm layer is significantly higher than that into the inner core of the strips (O'Connor et al. 2001). Also, WFFF that had undergone frozen storage had higher oil content in the inner core than

those had been either chilled or prepared freshly for frying.

c) Carbohydrate (Starch, Sugar, Pectin, Alcohol insoluble Solid)

Starch is gelatinized by thermal processing. During frying, starch granules in WP are rapidly gelatinized, fragmented and compacted into one mass which occupies the whole volume of the cell (Aguilera et al. 2001). Starch in WP tubers and French fries has been extensively studied. Since growing rate of tubers and accumulation of starch are not consistent among tubers, starch content of WP may vary up to 10% within and among the tubers of the same variety (Komiyama et al. 2002; Komiyama et al. 2007). Mohr (1972) reported that starch contents in pit and perimedullary region of mealy variety were 21.2 and 6.5% while those in soggy variety were 32.1 and 16.1%, respectively. According to Komiyama et al. (2002), WPF with higher starch content was softer and had more floury texture. They reported that WPF with 16% starch in raw WP were preferred by consumers. The quality of SPFF as affected by starch content in SP roots has not been studied.

For sugars, although maltose content in raw SP is very low or not detectable (Kiribuchi and Kubota 1976), maltose is produced due to of the hydrolysis of gelatinized starch by β -amylase during thermal processing (Ohnishi et al. 1985). Sugar profile in SPFF fries is composed of glucose, fructose, sucrose and maltose. Sugar content of SPFF was 3-4 times higher than those of raw strips because of maltose formation and water evaporation during frying. Truong et al. (2014) reported that total reducing sugars (glucose, fructose and maltose) in SPFF were 5-6% and sucrose levels were 5.2-7.0% fw. Sugar has water-holding capacity so it may affect texture of SPFF.

The type of pectin and its content can affect the textural properties of the processed products. Water soluble galacturonic acid concentration in raw SP was 0.25-0.37%, and it was decreased by approximately half between raw and fried strips (Walter et al. 1997).

The reason of this phenomenon is not revealed. Regarding pectin content in WPF, Jaswal (1969) reported a range of 4.51-4.63% dw as anhydrouronic acids while Tajner (2003) measured galacturonic acids as pectin which ranged from 1.55-1.69% fw in WPF. Gołubowska (2005) did not clearly describe the procedure for pectin determination, but she reported that WPF contained 3.48% dw of pectin and 6.46% dw of cellulose. There is no significant difference in total pectin, protopectin and water-soluble pectin content among potato varieties with low and high specific gravity (Jaswal 1969).

2.3 Relationship between Chemical Composition and Textural Properties of Sweetpotato French Fries

Information on the relationship between chemical composition and textural property of SPFF is limited while many studies were conducted on WPF.

Oner and Wall (2012) noted that the perceived softness of SPFF due to weak crust and moist interior was related to low DM and low oil contents. The research on the relationship between DM content and textural property of WPF was conducted by many investigators. Dry matter content in the outer layers of the strip is a good indicator for crispness on the crust of WPF (Sanz et al. 2007). Changes in WP texture during processing are associated with water loss, damage of potato tissue and non-starch polysaccharide and lignin contents. The cells of the outer layers of WPF were much smaller than those of unprocessed potato strips due to water evaporation. The ultimate texture of French fries was developed during frying by oil penetration into the outer layer of strips (Lisińska and Gołubowska 2005).

Oil content in SPFF was related to perceived softness, low oil content resulting in a weak crust and moist interior texture (Oner and Wall 2012). Similarly, oil and frying temperature have influences on texture of WPF. Absorbed oil content was correlated

with hardness of WPF (Kita and Lisińska 2005). Type of fatty acids in frying oil also affects texture. Hardness of WPF increased with the increase of saturated fatty acids and decrease of unsaturated fatty acids and trans-isomers fatty acids (Kita et al. 2005). Kita and Lisińska (2005) reported that increase of frying temperature decreased oil content resulting in decrease of instrumental hardness and interior sensory oiliness, and increase of sensory crispness. The reason for this phenomenon was not revealed. Moreover, frying time influences texture due to moisture evaporation and oil absorption. According to Du Pont et al. (1992), sensory crispness of the outer layer, mealiness of center, softness texture of inside strip, and darker color were increased with frying time, while perceived oiliness was decreased with frying time. They assumed that moisture in the WPF is concentrated towards the center of strips, and the further loss of moisture is inhibited by oil entering outer layer of the strips during frying.

Heat treatment during SP processing causes starch gelatinization that fill the volume of the cell affecting the texture of processed products. Moisture content in raw SP is generally about 60-84% so starch can be gelatinized during heat treatment without water addition during processing. Walter et al. (1992) studied the effect of tissue acidification on firmness of SP and reported that starch hydrolysis would be inhibited by tissue acidification resulting in firmer tissue. Sugar content of SP was also highly correlated with sensory intensity of first-bite moistness of SP ($r = 0.97$) (Walter et al. 1997).

As for WP, soggy variety had lower starch content than mealy variety but varietal differences in WPF texture did not correspond precisely with total starch content (Mohr 1972). The following factors may affect texture of WPF: size of starch granules, amylose/amylopectin ratio, other factors affecting hydration properties of gelled starch, and the role of amylose, polyuronide and multivalent cations in intercellular adhesion.

Johnston et al. (1970) studied starch granular size and reported that the percentages of starch fractions with 31-44 and 22-31 micron granules were positively correlated with specific gravity, DM and starch content. However, no correlation was found with the +53, 44-53, and -22 micron fractions. Sensory score on texture was also positively correlated with specific gravity, DM and starch content and 31-44 and 22-31 micron starch granules. They also reported that greater starch viscosity and swelling power caused poor texture while longer heating time required reaching maximum viscosity improved the product texture.

Heat treatment causes degradation of the structures of the pectic substances. Walter et al. (1992) reported that the structures of the pectic substances affected firmness of SPFF. Structural degradation of pectic substances causes softness of SPFF. Relationship between the amount of pectin and texture was also studied. Walter et al. (1997) reported that water soluble galacturonic acid in SPFF was negatively correlated with sensory intensity of mastication cohesiveness and mastication particles ($r = -0.90$ and $r = -0.95$ respectively) and the reason is unknown.

More detailed study on relationship between pectin and texture of WPF is available. Gołubowska (2005) reported that texture of WPF was mainly affected by pectin and cellulose among non-starch polysaccharide, and correlation coefficients between the texture and pectin and cellulose contents were 0.63 and 0.84 respectively. Jaswal (1969) found that strips with low specific gravity had poor texture. This is because protopectin of low specific gravity potatoes has weaker cross linkages, and is easy to break down during frying which results in the weakness of cell wall. Blanching with CaCl_2 , MgCl_2 and Ca-citrate improved the texture of WP tubers having low specific gravity (Jaswal 1970). Tajner (2003) found that WPF blanched in calcium and magnesium salts solution makes the bindings of cell walls in the middle lamella firm and

stiff resulting in increase of hardness of WPF. Calcium and magnesium ions bind to pectic substances in the potato tissue. She also reported that strips with higher pectin content were firmer than that with lower content of water-soluble pectins and protopectins.

Cell size, intercellular volume and specific gravity of SP roots do not affect instrumental firmness measured as shear force of SPFF (Walter et al. 1997). SPFF from the soft-sweet type SP was softer, moister, fewer particles, higher degree of mass cohesion, easier to swallow, and oily mouthfeel. As for WPF, inner strips of potato have lower specific gravity and had higher peak force than outer strips (Agblor and Scanlon 1998). A “balloon-like” appearance due to the pressure of starch gelling was observed in the cells of the outer strips by microstructural analysis.

2.4 Relationship between Instrumental Measurement and Sensory Evaluation of Texture of Sweetpotato French Fries

Sensory characteristics and preferences of consumers on different types of SP varieties have been investigated by few investigators (Laurie et al. 2013; Leksrisonpong et al. 2012). Laurie et al. (2013) studied the instrumental and sensory characteristics of boiled SP as affected by the chemical components. They reported poor correlation coefficients between sensory firmness and instrumental firmness ($r = 0.47$), sensory wateriness with starch ($r = -0.54$) and DM ($r = -0.60$), maltose content with sweet flavor ($r = 0.51$). They also found that sweet flavor was positively correlated with consumer acceptability ($r = 0.73$). Leksrisonpong et al. (2012) studied sensory evaluation of baked SP, and reported that consumers like smooth texture, brown sugar and dried apricot flavor and sweet taste while they dislike bitter and umami taste, astringent mouthfeel, vanilla aroma and residual fiber texture. In this study, the orange-fleshed SP (Beauregard,

Covington, Carolina Ruby) and Puerto Rican (yellow-fleshed) were preferred by consumers among 12 varieties of SP.

There are only a few studies on the relationship between instrumental measurement and sensory evaluation of texture of SPFF. Walter et al. (2002) studied the texture of restructured SPFF made from SP puree mixed with alginate and calcium sulfate. Descriptive sensory test and instrumental measurements including puncture, three-point bending and Kramer shear tests were conducted. Four sensory attributes, including springiness, hardness, density and mastication shear, were highly correlated with instrumental measurement ($r = 0.80-0.91$). On the other hand, cohesiveness, oiliness, moistness and compression while chewing were negatively correlated with instrumental measurement ($r = -0.80 - -0.92$).

Panel should be trained very well in order to evaluate sensory attributes properly. Walter et al. (1997) conducted two 3 hours training and applied 14 point intensity scale for assessing sensory attributes of SPFF in relation to the physical and chemical properties of 5 SP varieties. They reported that sensory first-bite moistness and first-bite hardness were not related to instrumental shear force. Oner and Wall (2012) applied 9 point hedonic scale to evaluate the sensory characteristics of SPFF. They reported that sensory hardness was in agreement with the instrumental hardness, however, correlation coefficient was not provided. No information on sensory attributes was available.

Similar to SP, the information about relationship between instrumental measurement and sensory evaluation of WFFF is limited. Van Loon et al. (2007) used a wedge-shaped probe to measure texture of French fries. For sensory test in this study, three experts of testing WFFF evaluated the product, and the panel used a structured scale from 4 to 8 for evaluation. The results showed that the instrumental measurement was highly correlated with the sensory crispness ($r = 0.76$). Kita and Lisińska (2005)

measured maximum shear force necessary to cut WPF strips as instrumental measurement and the results were highly correlated with sensory attributes. However, sensory test conditions such number of panelist, trained/not trained and correlation coefficient with the instrumental measurement were not reported in details.

Du Pont et al. (1992) used trained panel (training level is unknown) and use 0-100 scale for evaluation. As for instrumental measurement, high strain rate pendulum and low strain rate methods were used. They reported that the best correlation between sensory and instrumental measurements was on crispness and mechanical strength. Correlation coefficient between crispness and variance in impact was $r = 0.86$ and with flexural strength was $r = 0.82$.

Johnston et al. (1970) measured the resistance to the probe expressed as H/D_t for instrumental measurements. Sensory panel consisted 3 panelists, and 9 point scale (1 = very poor, and 9 = very good) was applied for evaluation in this study. They reported that results from instrumental measurements were agreed with those from the sensory panel scores.

Overall, information about chemical components of various SP varieties is available in the literature. However, limited information is available on the chemical and textural properties of SPFF processed from different SP varieties. Furthermore, there are only two published reports relating the chemical constituents with the instrumental and sensory properties of SPFF. In addition, no study was conducted on description of sensory characteristics of SPFF. For sensory evaluation of SPFF, sensory training and techniques are important and sensory panel should be well trained before evaluating products. Otherwise, inappropriate sensory training/evaluation would cause misleadingness of relationship between instrumental measurement and sensory evaluation. The lack of

information in these aspects would hinder the efforts of SP breeders and processors in the development of SPFF with good quality to meet the demands of the consumers.

2.5 References

- Agblor, A. and Scanlon, M.G. 1998. Effects of blanching conditions on the mechanical properties of french fry strips. *American Journal of Potato Research*, 75(6), 245-255.
- Agriculture & Livestock Industries Corporation. 2016. Sweet Potato Consumption by Use. <http://www.alic.go.jp/starch/japan/data/jdata.html>
- Aguilar, C.N., Anzaldua - Morales, A., Talamás, R. and Gastelum, G. 1997. Low-temperature Blanch Improves Textural Quality of French - fries. *Journal of Food Science*, 62(3), 568-571.
- Aguilera-Carbó, A., Montañez, J.C., Anzaldúa-Morales, A., Reyes, M.L., Contreras-Esquivel, J. and Aguilar, C.N. 1999. Improvement of color and limpness of fried potatoes by in situ pectinesterase activation. *European Food Research and Technology*, 210(1), 49-52.
- Aguilera, J.M., Cadoche, L., López, C. and Gutierrez, G. 2001. Microstructural changes of potato cells and starch granules heated in oil. *Food Research International*, 34(10), 939-947.
- Aguilera, J.M. and Gloria-Hernandez, H. 2000. Oil absorption during frying of frozen parfried potatoes. *Journal of Food Science*, 65(3), 476-479.
- Aina, A.J., Falade, K.O., Akingbala, J.O. and Titus, P. 2009. Physicochemical properties of twenty-one Caribbean sweet potato cultivars. *International journal of food science & technology*, 44(9), 1696-1704.
- Bengtsson, A., Namutebi, A., Alminger, M.L. and Svanberg, U. 2008. Effects of various traditional processing methods on the all-trans- β -carotene content of orange-fleshed sweet potato. *Journal of food composition and analysis*, 21(2), 134-143.
- Bouchon, P. and Aguilera, J.M. 2001. Microstructural analysis of frying potatoes. *International journal of food science & technology*, 36(6), 669-676.
- Brabet, C., Reynoso, D., Dufour, D., Mestres, C., Arredondo, J. and Scott, G. 1998. Starch content and properties of 106 sweetpotato clones from the world germplasm collection held at CIP, Peru. *CIP Program Report 1997-98*, 279-286.
- Bradbury, J. H. and Singh, U. 1986. Ascorbic acid and dehydroascorbic acid content of tropical root crops from the South Pacific. *Journal of Food Science*, 51(4), 975-978.
- Buren, J.V. 1979. The chemistry of texture in fruits and vegetables. *Journal of Texture Studies*, 10(1), 1-23.
- Burri, B.J. 2011. Evaluating sweet potato as an intervention food to prevent vitamin A deficiency. *Comprehensive Reviews in Food Science and Food Safety*, 10(2), 118-130.
- Canet, W. and Alvarez, M.D. 2011. Quality and safety of frozen vegetables. In: *Handbook*

of Frozen Food Processing and Packaging, second ed. CRC Taylor & Francis Group, Boca Raton, London, New York, 387-434.

Carpena, A.L. 2009. Important cultivars, varieties, and hybrids. In *The sweetpotato*. Springer Netherlands, 27-40

Dietary Guidelines for Americans 2015-2020, The US Departments of Health and Human Services (DHHS) and Agriculture (USDA)
<https://health.gov/dietaryguidelines/2015/guidelines/>

Dincer, C., Karaoglan, M., Erden, F., Tetik, N., Topuz, A. and Ozdemir, F. 2011. Effects of baking and boiling on the nutritional and antioxidant properties of sweet potato [*Ipomoea batatas* (L.) Lam.] cultivars. *Plant foods for human nutrition*, 66(4), 341-347.

Du Pont, M.S., Kirby, A.R. and Smith, A.C. 1992. Instrumental and sensory tests of texture of cooked frozen french fries. *International journal of food science & technology*, 27(3), 285-295.

Dziedzoave, N.T., Graffham, A.J., Westby, A., Otoo, J. and Komlaga, G. 2010. Influence of variety and growth environment on β -amylase activity of flour from sweet potato (*Ipomea batatas*). *Food control*, 21(2), 162-165.

EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain). 2015. Scientific Opinion on acrylamide in food. *EFSA Journal* 2015;13(6):4104, 321 doi:10.2903/j.efsa.2015.4104

Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). 2011. <http://faostat3.fao.org>

Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). 2013. <http://faostat3.fao.org>

Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). 2014. <http://faostat3.fao.org>

Fuchigami, M. and Konishi, E. 1978. Studies on cooking of vegetables (part 3), Effects of temperature and time of preheating on firming of vegetables. *Bull. Okayama Prefectural Junior College*, 22, 45-53.

Gołubowska, G. 2005. Changes of polysaccharide content and texture of potato during French fries production. *Food chemistry*, 90(4), 847-851.

Grace, M.H., Yousef, G.G., Gustafson, S.J., Truong, V.D., Yencho, G.C. and Lila, M.A. 2014. Phytochemical changes in phenolics, anthocyanins, ascorbic acid, and carotenoids associated with sweetpotato storage and impacts on bioactive properties. *Food Chem* 145, 717-724.

Hagenimana, V., Carey, E.E., Gichuki, S.T., Oyunga, M.A. and Imungi, J.K. 1998. Carotenoid contents in fresh, dried and processed sweetpotato products. *Ecology of*

- Food and Nutrition, 37(5), 455-473.
- He, J., Cheng, L., Gu, Z., Hong, Y. and Li, Z. 2014. Effects of low-temperature blanching on tissue firmness and cell wall strengthening during sweet potato flour processing. *International Journal of Food Science & Technology*, 49(5), 1360-1366.
- Ikemiya, M. and Deobald, H.J. 1966. New Characteristic Alpha-Amylase in Sweet Potatoes. *Journal of Agricultural and Food chemistry*, 14(3), 237-241.
- Jaswal, A.S. 1969. Pectic substances and the texture of french fried potatoes. *American Potato Journal*, 46(5), 168-173.
- Jaswal, A.S. 1970. Effects of various chemical blanchings on the texture of French fries. *American Potato Journal*, 47(1), 13-18.
- Johnston, F.B., Kenkars, E. and Nunes, A.C. 1970. Starch and dry matter content of Netted Gem in relation to french fry texture. *American Potato Journal*, 47(3), 87-93.
- Johnson, T., Wilson, N., Worosz, M.R., Fields, D. and Bond, J.K. 2015. Commodity Highlight: Sweet Potatoes.
- Kaczmarczyk, M.M., Miller, M.J. and Freund, G.G. 2012. The health benefits of dietary fiber: beyond the usual suspects of type 2 diabetes mellitus, cardiovascular disease and colon cancer. *Metabolism*, 61(8), 1058-1066.
- Kano, M., Takayanagi, T., Harada, K., Makino, K. and Ishikawa, F. 2005. Antioxidative activity of anthocyanins from purple sweet potato, *Ipomoea batatas* cultivar Ayamurasaki. *Bioscience, biotechnology, and biochemistry*, 69(5), 979-988.
- Katayama, K., Komae, K., Kohyama, K., Kato, T., Tamiya, S., and Komaki, K. 2002. New sweet potato line having low gelatinization temperature and altered starch structure. *Starch - Stärke*, 54(2), 51-57.
- Katayama, K., Komae, K., Tamiya, S., Khoyama, K., Nakatani, M. and Komaki, K. 2006. Studies on the breeding for improving starch properties in sweet potato. *Japan Agricultural Research Quarterly: JARQ*, 40(2), 115-122.
- Katayama, K., Sakai, T., Kai, Y., Nakazawa, Y. and Yoshinaga, M. 2012. Konamizuki”: a new sweetpotato cultivar. *Bull. NARO Kyushu Okinawa Agric. Res. Cent*, 58, 15-36.
- Katayama, K., Tamiya, S., Kuranouchi, T., Komaki, K. and Nakatani, M. 2003. New sweet potato cultivar “Quick Sweet”. *Bulletin of the National Institute of Crop Science*, 3, 35–52.
- Kato, K. 1997. Factors affecting the quality of deep fried food on the change of oil from moisture. *Bulletin of Tokyo Kasei University*, 37(2), 33-38.
- Kiribuchi, H. and Kubota, K. 1976. Studies on cooking of sweet potato (Part 1) – Changes in sugar content and β -amylase activity during cooking –, *Journal of Home Economics of Japan*, 27, 418-422

- Kita, A. and Lisińska, G. 2005. The influence of oil type and frying temperatures on the texture and oil content of French fries. *Journal of the Science of Food and Agriculture*, 85(15), 2600-2604.
- Kita, A., Lisińska, G. and Powolny, M. 2005. The influence of frying medium degradation on fat uptake and texture of French fries. *Journal of the Science of Food and Agriculture*, 85(7), 1113-1118.
- Kohli, P., Kalia, M. and Gupta, R. 2015. Pectin methylesterases: A review. *Journal of Bioprocessing & Biotechniques*, 5(5), 1.
- Komiyama, S., Kato, J., Honda, H. and Matsushima, K. 2007. Development of Sorting System Based on Potato Starch Content Using Visible and Near-Infrared Spectroscopy, *Journal of Japanese Society for Food Science and Technology* 54(6), 304-309.
- Komiyama, S., Meguro, T., Kato, J., Yamamoto, A., Yamaguchi, A. and Yoshida, M. 2002. Effect of Starch Content on the Cooking Quality of Potato. *Journal of Cookery Science*, 32, 336-342.
- LaBelle, R.L. 1971. Heat and calcium treatments for firming red tart cherries in a hot - fill process. *Journal of Food Science*, 36(2), 323-326.
- Laurie, S.M., Faber, M., Calitz, F.J., Moelich, E.I., Muller, N. and Labuschagne, M.T. 2013. The use of sensory attributes, sugar content, instrumental data and consumer acceptability in selection of sweet potato varieties. *Journal of the Science of Food and Agriculture*, 93(7), 1610-1619.
- Leksrisonpong, P.P., Whitson, M.E., Truong, V.D. and Drake, M.A. 2012. Sensory attributes and consumer acceptance of sweet potato cultivars with varying flesh colors. *Journal of Sensory Studies*, 27(1), 59-69.
- Lisińska, G. and Gołubowska, G. 2005. Structural changes of potato tissue during French fries production. *Food chemistry*, 93(4), 681-687.
- Loebenstein, G. 2009. Origin, distribution and economic importance. In: *The sweetpotato*. Springer Netherlands, 9-12
- Maeshima, M., Sasaki, T. and Asahi, T. 1985. Characterization of major proteins in sweet potato tuberous roots. *Phytochemistry*, 24(9), 1899-1902.
- Mensah, E.O., Ibok, O., Ellis, W.O. and Carey, E.E. 2016. Thermal Stability of β -Amylase Activity and Sugar Profile of Sweet-Potato Varieties during Processing. *J Nutr Food Sci*, 6(515), 2.
- Miranda, M.L. and Aguilera, J.M. 2006. Structure and texture properties of fried potato products. *Food Reviews International*, 22(2), 173-201.
- Miyazaki, T. 1990. Effects of curing, storage conditions, and cooking on the composition of sweet potatoes [*Ipomoea batatas*]. *Journal of the Japanese Society for Horticultural*

Science.

Mohr, W.P. 1972. Soggy-centered French fries. *Canadian Institute of Food Science and Technology Journal*, 5(4), 179-183.

Nakamura, Y., Kuranouchi, T., Takada, A., Ishida, N., Koda, I., Iwasawa, N., Matsuda, T., and Kumagai, T. 2010. Cell Structure, Water Status and Starch Properties in Tuberos Root Tissue in Relation to the Texture of Steamed Sweetpotato (*Ipomoea batatas* (L.) Lam). *Japanese journal of crop science* 79(3), 284-295.

Nakamura, Y., Kuranouchi, T., Takada, A. and Katayama, K. 2014. The Effects of β -Amylase Activity and Starch Pasting Temperature on Maltose Generation in Steamed Storage Roots of Sweet Potato, *Nippon Shokuhin Kagaku Kogaku Kaishi*, 61(12), 577-585.

National Agricultural Statistics Service, USDA. 2014. Potatoes 2013 Summary. Washington, DC: US Department of Agriculture

National Nutrient Database for Standard Reference Release 28, The US Department of Agriculture
<https://ndb.nal.usda.gov/ndb/foods/show/3207?fgcd=&manu=&facet=&format=&count=&max=35&offset=&sort=&qlookup=sweet+potato>

Ni, L., Lin, D. and Barrett, D. M. 2005. Pectin methylesterase catalyzed firming effects on low temperature blanched vegetables. *Journal of food engineering*, 70(4), 546-556.

O'Connor, C.J., Fisk, K.J., Smith, B.G. and Melton, L.D. 2001. Fat uptake in French fries as affected by different potato varieties and processing. *Journal of food science*, 66(6), 903-908.

Ohnishi M., Okada G., Taniguchi H. and Sakano Y. 1985. β -amylase, Protein, Nucleic Acid and Enzyme, 30, 404-412.

Oner, M.E. and Wall, M.M. 2012. Processing conditions for producing french fries from purple-fleshed sweetpotatoes. *Transactions of the ASABE*, 55(6), 2285-2291.

Padmaja, G. 2009. Uses and nutritional data of sweetpotato. In *The sweetpotato*. Springer Netherlands, 189-234

Pavlista, A.D. and Ojala, J.C. 1997. Potatoes: Chip and French fry processing. *Processing Vegetables, Science and Technology*. Lancaster: Technomic Publishing, Inc, 237-284.

Pedreschi, F. and Moyano, P. 2005. Effect of pre-drying on texture and oil uptake of potato chips. *LWT-Food Science and Technology*, 38(6), 599-604.

Pedreschi, F., Mariotti, S.M. and Cortés, P. 2016. Fried and dehydrated potato products. In: *Advances in Potato Chemistry and Technology*, 2nd Edition; Singh, J., Kaur, L., Eds.; Elsevier: New York, 459-474.

Pereira, M.A., O'Reilly, E., Augustsson, K., Fraser, G.E., Goldbourt, U., Heitmann, B.L.,

- Hallmans, G., Knekt, P., Liu, S., Pietinen, P. and Spiegelman, D. 2004. Dietary fiber and risk of coronary heart disease: a pooled analysis of cohort studies. *Archives of internal medicine*, 164(4), 370-376.
- Ravindran, V., Ravindran, G., Sivakanesan, R. and Rajaguru, S. B. 1995. Biochemical and nutritional assessment of tubers from 16 cultivars of sweet potato (*Ipomoea batatas* L.). *Journal of agricultural and food chemistry*, 43(10), 2646-2651.
- Sanz, T., Primo-Martín, C. and Van Vliet, T. 2007. Characterization of crispness of French fries by fracture and acoustic measurements, effect of pre-frying and final frying times. *Food Research International*, 40(1), 63-70.
- Suda, I., Ishikawa, F., Hatakeyama, M., Miyawaki, M., Kudo, T., Hirano, K., Ito, A., Yamakawa, O. and Horiuchi, S. 2008. Intake of purple sweet potato beverage affects on serum hepatic biomarker levels of healthy adult men with borderline hepatitis. *European journal of clinical nutrition*, 62(1), 60-67.
- Tajner - Czopek, A. 2003. Changes of pectic substances concentration in potatoes and French fries and the effect of these substances on the texture of the final product. *Food/Nahrung*, 47(4), 228-231.
- Tian, S.J., Rickard, J.E. and Blanshard, J.M.V. 1991. Physicochemical properties of sweet potato starch. *Journal of the Science of Food and Agriculture*, 57(4), 459-491.
- Tsuyukubo M. and Ishii K. 2011. Effects of β -Amylase in Sweet Potato on Cooked Rice and Rice Gruel, *Journal of cookery science of Japan*, 44, 15-20.
- Truong, V.D., Avula, R.Y., Pecota, K. and Yencho, C.G. 2011. Sweetpotatoes. In: *Handbook of Vegetables and Vegetable Processing*, 717-737.
- Truong, V.D., Biermann, C.J. and Marlett, J.A. 1986. Simple sugars, oligosaccharides and starch concentrations in raw and cooked sweet potato. *Journal of agricultural and food chemistry*, 34(3), 421-425.
- Truong, V.D., Deighton, N., Thompson, R.L., McFeeters, R.F., Dean, L.L., Pecota, K.V., Yencho, G. 2010. Characterization of Anthocyanins and Anthocyanidins in Purple-Fleshed Sweetpotatoes by HPLC-DAD and LC-ESI/MS-MS. *Journal of agricultural and food chemistry*, 58, 404-410.
- Truong, V.D., Hu, Z., Thompson, R.L., Yencho, G.C., and Pecota, K.V. 2012. Pressurized liquid extraction and quantification of anthocyanins in purple-fleshed sweet potato genotypes. *Journal of food composition and Analysis*, 26(1), 96-103.
- Truong, V.D., Pascua, Y.T., Reynolds, R., Thompson, R.L., Palazoğlu, T.K., Atac Mogol, B. and Gökmen, V. 2014. Processing treatments for mitigating acrylamide formation in sweetpotato French fries. *Journal of agricultural and food chemistry*, 62(1), 310-316.
- Truong, V.D., Walter, W.M. and Bett, K.L. 1998. Textural properties and sensory quality of processed sweetpotatoes as affected by low temperature blanching. *Journal of food*

- science, 63(4), 739-743.
- Van Jaarsveld, P. J., Harmse, E., Nestel, P. and Rodriguez-Amaya, D. B. 2006. Retention of β -carotene in boiled, mashed orange-fleshed sweet potato. *Journal of Food Composition and Analysis*, 19(4), 321-329.
- Van Loon, W.A., Visser, J.E., Linssen, J.P., Somsen, D.J., Klok, H.J. and Voragen, A.G. 2007. Effect of pre-drying and par-frying conditions on the crispness of French fries. *European Food Research and Technology*, 225(5-6), 929-935.
- Walter, W.M., Collins, W.W., Truong, V.D. and Fine, T.I. 1997. Physical, compositional, and sensory properties of French fry-type products from five sweetpotato selections. *Journal of Agricultural and Food Chemistry*, 45(2), 383-388.
- Walter, W.M., Fleming, H.P. and McFeeters, R.F. 1992. Firmness Control of Sweetpotato French Fry - Type Product by Tissue Acidification. *Journal of food science*, 57(1), 138-142.
- Walter, W.M. and Hoover, M.W. 1986. Preparation, Evaluation and Analysis of a French - Fry - Type Product from Sweet Potatoes. *Journal of Food Science*, 51(4), 967-970.
- Walter, W.M., Purcell, A.E. and Nelson, A.M. 1975. Effects of amylolytic enzymes on "moistness" and carbohydrate changes of baked sweet potato cultivars. *Journal of food science*, 40(4), 793-796.
- Walter, W.M., Truong, V.D. and Espinel, K.R. 2002. Textural measurements and product quality of restructured sweetpotato French fries. *LWT-Food Science and Technology*, 35(3), 209-215.
- Wang, S., Nie, S. and Zhu, F. 2016. Chemical constituents and health effects of sweet potato. *Food Research International*.
- Weickert, M.O. and Pfeiffer, A.F. 2008. Metabolic effects of dietary fiber consumption and prevention of diabetes. *The Journal of nutrition*, 138(3), 439-442.
- Woolfe, J. 1993. *Sweet potato: An untapped food resource*. Cambridge: Cambridge University Press.
- Xu, J., Su, X., Lim, S., Griffin, J., Carey, E., Katz, B., Tomich, J., Smith, J.S. and Wang, W. 2015. Characterisation and stability of anthocyanins in purple-fleshed sweet potato P40. *Food chemistry*, 186, 90-96.
- Yencho, G.C., Pecota, K.V., Schultheis, J.R., VanEsbroeck, Z.P., Holmes, G.J., Little, B.E., Thornton, A.C. and Truong, V.D. 2008. 'Covington' Sweetpotato. *HortScience*, 43(6), 1911-1914.
- Zhang, Z., Wheatley, C.C. and Corke, H. 2002. Biochemical changes during storage of sweet potato roots differing in dry matter content. *Postharvest biology and technology*, 24(3), 317-325.

Zhu, F. and Wang, S. 2014. Physicochemical properties, molecular structure, and uses of sweetpotato starch. *Trends in Food Science & Technology*, 36(2), 68-78.

Table 2-1. Nutrient content of sweetpotato in 5 inch long (130g) raw sweetpotato root

	Female (31-50)	Male (31-50)
Energy	6%	5%
Protein	4%	4%
Total fat	0%	0%
Carbohydrate	20%	20%
Dietary fiber	15%	13%
Minerals		
Calcium, Ca	4%	4%
Iron, Fe	4%	10%
Magnesium, Mg	10%	8%
Phosphorus, P	9%	9%
Potassium, K	9%	9%
Sodium, Na	3%	3%
Zinc, Zn	5%	4%

	Female (31-50)	Male (31-50)
Vitamins		
Vitamin C	4%	3%
Thiamin	9%	8%
Riboflavin	7%	6%
Niacin	5%	5%
Vitamin B6	21%	21%
Folate	4%	4%
Vitamin B12	0%	0%
Vitamin A	132%	102%
Vitamin E	2%	2%
Vitamin D	0%	0%
Vitamin K	3%	2%

Percentages are proportion of sweetpotato (130g) to goal recommended in Dietary Guidelines for Americans (age of 31-50)

CHAPTER 3

Instrumental Textural Properties of Sweetpotato French Fries in Relation to Chemical Components

3.1 Abstract

Sweetpotato French fries (SPFF) are relatively new commercial products, and only limited information is available on the product quality, especially on textural properties. This study aimed to determine the effects of chemical constituents on the instrumental textural properties of SPFF processed from sixteen SP genotypes with varying flesh color. Processing of SPFF included tempering the whole roots, cutting into strips, blanching, pre-drying, par-frying at 185°C for 75 seconds, and freezing at -20°C. The frozen strips were fried at 177°C for 150 seconds, and cooled to 60°C for assessment of textural properties. Peak force and overall hardness of SPFF were measured using a texture analyzer equipped with a 2 mm cylinder probe and a French fry rig. Dry matter (DM), alcohol insoluble solid (AIS), starch, sugars (glucose, fructose, sucrose, maltose) and oil contents were analyzed in raw SP and SPFF samples. Alpha-amylase and beta-amylase activities were measured in raw SP.

Results showed that DM content in raw SP of the 16 genotypes ranged from 18.6 to 37.2%, AIS 11.6 to 36.7 g/100g fw, starch 6.0 to 23.4 g/100g, total sugars 1.2 to 6.5 g/100g, α -amylase activity 12.8 to 130.5 CU/100g, and β -amylase activity 3.9 to 618.9 U/100g. Moisture contents in SPFF were in a range of 35.7 to 58.3%, AIS 30.8 to 64.2 g/100g fw, starch 11.6 to 41.4 g/100g, total sugar 0.3 to 10.2 g/100g, and oil 6.7 to 12.6%. The DM, AIS and starch contents in raw SP were positively correlated with peak force ($r = 0.41-0.52$, $p < 0.01$) and overall hardness ($r = 0.57-0.68$, $p < 0.01$). Total sugar contents in raw SP and SPFF were negatively correlated with SPFF peak force and overall hardness while activities of amylases and oil content were not correlated or had low correlation with SPFF peak force and overall hardness. These results would be beneficial to the breeding programs in developing new SP varieties with improved SPFF quality to meet the increasing consumer demands.

3.2 Introduction

Sweetpotato (SP) (*Ipomoea batatas* L.) is an important economic crop and ranked seventh in the world food production (FAOSTAT 2013). There are many SP varieties with different characteristics such as texture, flavor and flesh color (white, cream, yellow, orange, purple). In the United States, SP consumption per capita has increased by 80% in last 14 years (Johnson et al. 2015). Consumers consider SP as a highly nutritious vegetable because of the high contents of carotene, dietary fiber, vitamins and minerals. The absorption of β -carotene is enhanced when SP is consumed with oil since β -carotene is oil-soluble (Van het Hof et al. 1999). Therefore, fried products such as sweetpotato French fries (SPFF) would have high absorption of β -carotene. With these health benefits, consumer demands of SPFF have been increased recently, and many food companies have ventured into commercial production of SPFF.

Currently, SPFF are processed using the existing SP cultivars that were developed for fresh root markets. New SP varieties with good field performance and traits suitable for processing operation and quality of SPFF are being developed by the SP breeding and genetic programs. As other processed foods, texture, flavor and appearance of SPFF would be the key factors for good consumer acceptance. Therefore, it is important to study the factors affecting the SPFF quality.

Textural property is an important factor to consumer liking for French fries. Kirkpatrick (1956) reported that consumers prefer white potato French fries (WPF) with leathery, gummy, and crispy without hard texture, and the desirable interior texture is mealy like baked potato and not watery and mushy. For WPF, numerous studies on chemical components in white potato (WP) varieties in relation to the instrumental textural characteristics of the product have been conducted. Previous papers indicated that dry matter (DM), oil, and starch, pectin and cellulose contents were positively correlated

with hardness of WPF (Sanz et al. 2007; Kita and Lisińska 2005; Mohr 1972; Gołubowska 2005).

However, information on WPF may not be suitable for SPFF since they are different botanically and chemically. Generally, SP varieties with high DM content have firm and mealy texture after cooking while those with low DM content have sweet and soggy texture (Truong et al. 2011). In contrast to WPF, limited information is available on SPFF since it is relatively a new product being marketed at large scales. Several investigators have studied processing condition of SPFF in relation to product qualities (Walter and Hoover 1986; Walter et al. 1992; Walter et al. 2002; Oner and Wall 2012; Truong et al. 2014). Consumers disliked first-bite moistness and cohesiveness of mass in SPFF (Walter et al. 1997). For instrumental textural characteristics of SPFF, previous studies indicated that starch and pectic substances affected hardness of SPFF (Walter et al. 1992). Aside from the relationship between chemical components in the raw materials and textural properties of the processed product, information on chemical components of SPFF is also limited. Research in these aspects would facilitate the breeding efforts in developing new SP genotypes for SPFF with improved textural properties to meet the consumer demands.

This chapter aimed to 1) analyze the chemical components of raw SP and SPFF, and 2) determine the relationship between chemical components and instrumental texture measurement using 16 SP genotypes with varying flesh color.

3.3 Materials and Methods

3.3.1 Materials

All sweetpotatoes (SP) used in this study were grown at the experimental fields of the Sweetpotato Breeding Program (Clinton, NC, USA), North Carolina State University.

Sixteen genotypes with a wide range of dry matter content and flesh color were selected for the experiments (Table 3-1). Of those genotypes, 10 genotypes were orange-fleshed, one was orange/yellow-fleshed, another one was cream-fleshed, and 4 were yellow-fleshed. Nine genotypes (NC08-036, Evangeline, Beauregard, Covington, NC09-122, Porto Rico, NCDM04-197, Suwon122, NCDM04-001) were harvested in 2014 and stored for 7 month at 14°C, 85-90% relative humidity. Other 7 genotypes (NC13-487, NC05-198, NC13-1012, NC13-1001, NC13-1027, Bonita, NC13-1004) were harvested in 2015 and stored for 4 month under the same conditions.

Processing of Sweetpotato French Fries

Ten to twelve raw SP roots were randomly selected, washed, tempered as whole roots in tap water at 70°C for 45 minutes, and cut into 0.9 × 0.9 cm strips using a manual French fry cutter (model 29, Vollrath, Bloomfield, IN, USA). Strips with skin on the edges were not used in this study and the ends of strips with skins were cut off. The strips (1 kg) were blanched in tap water at 75°C for 7 minutes, pre-dried at 65°C for 10 minutes using a convection dryer (Food Dehydrator; The Sausage Maker inc., Buffalo, NY), par-fried in 22 L of canola oil at 185°C for 75 seconds using an electric fryer (1ER50 Series, Vulcan-Hart Co., Louisville, KY, USA), and drained on absorbent paper towels. The par-fried strips were frozen at -20°C until final frying. For final frying, the frozen strips were fried in canola oil at 177°C for 150 seconds using the electric fryer, and drained on absorbent paper towels. The experiment was conducted with two replications of SP roots taken from two different lots of each genotype grown in the experimental fields.

3.3.2 Sample Preparation for Chemical Analysis

For raw SP, dry matter (DM), sugar (glucose, fructose and sucrose), alcohol insoluble solid (AIS), starch contents and α - and β -amylase activities were measured. Moisture, oil, AIS, starch, sugar (glucose, fructose, sucrose and maltose) contents were measured for sweetpotato French fries (SPFF).

Dry Matter Content. Raw SP were peeled and cut into small chunk. The chopped SP (300g) was freeze-dried for several days using a VirTis Genesis 25XL freeze-dryer (Gadiner, NY, USA), operated at -35 to -40 °C, and DM content was determined by the weight difference before and after freeze-drying. The dried raw SP samples were pulverized using a mill (Foss Cyclotec, model 1093, Eden Prairie, MN, USA) and analyzed for sugars, AIS, starch and α - and β -amylases.

For SPFF, moisture content was determined by chopping SPFF samples into small chunk and the weighed samples were dried in a convection oven (Precision compact oven; Thermo-Scientific, Waltham, MA, USA) at 60°C until constant weight was obtained. Moisture content was calculated based on the difference in weight of the wet and dried samples. The dried samples were then ground using a Krups F203 electric spice and coffee grinder (Millville NJ, USA). The ground samples were used to measure oil, AIS, starch and sugar contents of SPFF.

Sugar and Alcohol Insoluble Solid Contents. One gram sample was mixed with 25 mL of hot 95% ethanol using a vortex mixer for one minute and centrifuged at 6500 rpm for 10 min. The precipitate was extracted one more time with 25 mL of 95% ethanol and centrifuged at 6500 rpm for 10 min. The obtained supernatants were combined and brought to 50 mL for sugar analysis as described by Pattee et al. (2000). The precipitate was dried until consistent weight and measured as AIS content. AIS was used for starch

analysis. Sugars were analyzed using a Shimadzu HPLC system equipped with a SIL-20AC HT autosampler, DGU-20a3 degasser, LC 20AD pump, CTO-20A column oven, and CBM-20A controller hooked to an Antec Leyden model Decade II electrochemical detector in the pulsed mode using a gold electrode and LabSolutions/LC Solution Acquisition software (Shimadzu Corp., Kyoto, Japan). Sugars are separated into glucose, fructose, sucrose and maltose using a 250 × 4 mm CarboPac-PA1 column attached to a 50 × 4 mm CarboPac guard column (Thermo Scientific, Waltham, MA, USA). The eluent was 0.2 N NaOH at a flow rate of 1 mL/min and temperature of 30°C. An external standard was used to determine glucose, fructose, sucrose and maltose contents by comparing peak heights of the sugars. The total sugar content was the summation of the individual sugars.

Starch Content. A Megazyme assay kit was used for total starch determination (Megazyme International, County Wicklow, Ireland). AIS sample was washed with 80% ethanol. Starch in the sample was hydrolyzed into D-glucose by thermostable α -amylase followed by amyloglucosidase. The D-glucose was oxidized by glucose oxidase to produce hydrogen peroxide and colored quinoneimine by a reaction with peroxidase, p-hydroxybenzoic acid, and 4-aminoantipyrine. Absorbance at 510 nm was measured against a reagent blank using a spectrophotometer (Cary 300 Bio UV-Visible Spectrophotometer, Varian Inc., Palo Alto, CA, USA), and starch content was calculated based on the absorbance of glucose standard.

Alpha-amylase Activity. Alpha-amylase activity was measured using a Megazyme assay kit based on the Ceralpha method (Megazyme International, County Wicklow, Ireland). Freeze-dried sample was mixed with an extraction buffer containing sodium malate,

sodium chloride and calcium chloride to extract the enzyme. Substrate (blocked *p*-nitrophenyl maltoheptaoside (BPNPG7)) was hydrolyzed by the extracted α -amylase followed by excess level of α -glucosidase into glucose and free *p*-nitrophenol. The reaction was stopped by adding alkaline solution, and yellow color was developed. The absorbance of the solution was read using a spectrophotometer at 400nm against distilled water to measure the activity of α -amylase. One unit of α -amylase activity is defined as the amount of enzyme required to release one micromole of *p*-nitrophenol from BPNPG7 in one minute.

Beta-amylase Activity. Beta-amylase activity was measured using a Megazyme assay kit of Betamyl-3 method (Megazyme International, County Wicklow, Ireland). Freeze-dried sample was mixed with Tris-HCl buffer to extract β -amylase. Betamyl-3[®] substrate (*p*-nitrophenyl- β -D-maltotrioside) was hydrolyzed by the extracted β -amylase followed by β -glucosidase into D-glucose and free *p*-nitrophenol. The reaction was stopped by adding alkaline solution, and yellow color was developed. The absorbance of the solution was read at 400 nm using a spectrophotometer against distilled water to measure the activity of β -amylase. One unit of β -amylase activity is defined as the amount of enzyme required to release one micromole of *p*-nitrophenol from the Betamyl-3[®] substrate in one minute.

Oil Content. Approximately five grams of oven dried sample were put in a thimble. Oil in the SPFF sample was Soxhlet extracted with hexane for 6 hours. The hexane remaining in a flask was evaporated and residue oil was measured as oil content (O'Connor et al. 2001).

3.3.3 Instrumental Measurement of Texture

The frozen SPFF samples were fried at 177°C for 150 sec. and the instrumental measurement was performed 3 minutes after final frying. Sample temperature was approximately 60°C. Peak force and overall hardness of SPFF were measured using a TA.XT2 Texture Analyzer equipped with a 2 mm cylinder puncture probe, and a French fry rig, respectively. Data was collected and analyzed using the Texture Expert software (version 6.1.3.0, Texture Technologies Corp., Hamilton, MA, USA). For peak force, the velocity of the cylinder probe was 3 mm/s and the force was measured using a 5 kg load cell. Peak force was determined as force (N) required penetrating the strip. Four strips were used to measure the peak force, and three measurements were performed for each strip. Twelve different values were collected for one replication. For overall hardness, a 50 kg load cell was used and the velocity of the French Fry Rig test was set at 3.0 mm/s. The area under the stress-strain curve (AUC) was determined as overall hardness (N.sec) which was the energy required to cut the strips. Five strips were used for each measurement of overall hardness and the measurement was conducted twice for each replication.

3.3.4 Statistical Analysis

The experiment was conducted with two replications and two samples were taken from each replicate for chemical analysis. Completely randomized design was applied for all experiments. The data was analyzed to determine differences among genotypes by Tukey's test ($\alpha=0.05$) using SAS software (version 9.4, SAS Institute, Inc., Cary, NC, USA). Pearson correlation coefficient was performed to calculate the correlations between chemical and instrumental data using SAS software. For the measurement of peak force, outliers were removed based on interquartile range (IQR) method. Data point

more than 1.5 interquartile ranges below the first quartile or above the third quartile was removed as an outlier (Ghasemi and Zahediasl 2012).

3.4 Results and Discussion

3.4.1 Chemical Component of Raw Sweetpotato and Sweetpotato French Fries

Dry Matter Content

Among the 16 genotypes, dry matter (DM) contents of raw SP were in a wide range of 18.6-37.2% (Table 3-1) which was representative of the DM range of 13-45% of the SP cultivars reported in previous studies (Aina et al. 2009; Mensah et al. 2016; Brabet et al. 1998). NC08-036 had the lowest DM content which was about half of that of NCDM04-001, the genotype with the highest DM content in this study. Ten genotypes were orange-fleshed, and 6 genotypes were orange/yellow-, cream- or yellow-fleshed. Except NC13-1027 (29.4% DM content), the DM content of the orange-fleshed SP ranged between 18.6-26.8% which were lower than the values of 26.9-37.2% in the cream- and yellow-fleshed SP. The results were consistent with a study by Hagenimana et al. (1998) that orange-fleshed SP generally had lower DM content (20.4-27.8%) than 'light orange' (32.3%), yellow- and cream-fleshed SP cultivars (27.7-34.6%). NC13-1027 had higher DM content than the other orange-fleshed SP genotypes.

As shown in Table 3-2, moisture content of SPFF ranged from 35.7% to 58.3%. Genotypes with lower DM content tended to have higher moisture content in SPFF. It was expected that blanching treatment slightly increased moisture content in SP strips while drying, par-frying and final frying treatment decreased the moisture content. Consequently, SPFF of all 16 genotypes had lower moisture content than raw SP. Truong et al. (2014) reported that moisture content of Covington SPFF was in a range of 50.1-67.7% depending on pre-treatments and frying time. The moisture content of 55.5%

in the Covington SPFF (Table 3-2) was in accordance with the previous study.

Sugar Content

On fresh weight basis, glucose, fructose and sucrose contents of raw SP were 0.05-2.26%, 0.03-1.43%, and 1.13-3.73%, respectively (Figure 3-1). Total sugar content (sum of glucose, fructose and sucrose) in raw SP was 1.22-6.49% (Table 3-1). NC08-036 had the highest total sugar content and it was about 5 times higher than NCDM04-001, the genotype with the lowest total sugar content. Total sugar content accounted for 3-35% of DM content, and the lower DM genotypes tended to contain higher sugars.

Sugar profile of SPFF consisted of glucose, fructose, sucrose and maltose. Maltose is produced by amylase hydrolysis of gelatinized starch during SP tempering, blanching and frying (Ohnishi et al. 1985). Total sugar content of SPFF was 0.35-10.16% fw (Table 3-2). Glucose, fructose, sucrose and maltose contents of SPFF were 0.003-3.245%, 0.01-2.16%, 0.34-4.03%, and 0.00-2.53% fw respectively (Figure 3-2). Maltose was not detected in SPFF of NC13-1027 and NCDM04-001. Similar to raw SP, SPFF of NC08-036 had the highest total sugar content and it was 29 times higher than the product from NCDM04-001 which had the lowest sugar content. Truong et al. (2014) reported that total sugar content of Covington SPFF was 10.3-12.6% fw. In our study, total sugar content of Covington SPFF was lower than the values reported by Truong et al. (2014) due to the difference in the processing treatments.

During frying, it is expected that sugar content in SPFF would be increased due to water evaporation. However, the apparent total sugar contents of SPFF from NC05-198, NC13-1027 and NCDM04-001 were respectively decreased by 3%, 46% and 71% fw (Table 3-1, Table 3-2). This implied that sugar content changed during processing. Glucose, fructose and sucrose are water soluble so they could be leaked into water during blanching. Optimum temperature of SP β -amylase is 50°C, and the β -amylase activity

decreased over 50°C then deactivate at 80°C (Tsuyukubo and Ishii 2011). Therefore, maltose is increased by β -amylase hydrolysis of gelatinized starch during tempering (70°C), blanching (75°C) and drying (65°C). Maltose was also increased until 80°C that is the point of β -amylase inactivation during par-frying (185°C).

The differences in the contents of maltose and other sugars in raw SP and fried strips on dry weight basis are shown in Figure 3-3. Glucose, fructose and sucrose contents of all 16 genotypes decreased by 1.5-13.5 g/100g dw after frying. NC08-036 had the largest decrease of sugar content, and NCDM04-197 had the lowest. Maltose was not detected in the SPFF from NC13-1027 and NCDM04-001 while other 14 genotypes had certain amount of maltose which was in a range of 2.5-4.9g/100g dw. Fried samples of NC13-1012 had the greatest and those from NC08-036 had the lowest amount of maltose among the 14 genotypes. When considering total sugar content (glucose, fructose, sucrose, maltose), only NCDM04-197 had an increase of 2.6g/100g dw (data not shown). The total sugar contents of all other 15 genotypes were decreased after processing. Total sugar reduction of Suwon 122 was the least (0.1 g/100g dw), and that of NC08-036 was the greatest (10.9 g/100g dw). Overall, the genotypes with higher total sugar content in raw SP had higher total sugar content after frying. NC08-036 marked the highest total sugar contents in SPFF although its sugar reduction by processing was the greatest.

Alcohol Insoluble Solid (AIS) and Starch

AIS is a residue of a sample after sugar extraction with ethanol. AIS content in raw SP was in a range of 11.6-36.7% fw (Table 3-1). AIS content of raw SP accounted for 62-99% of DM content, and the genotype with high DM content tended to have high AIS percentage. Similar to the DM content, NCDM04-001 had the highest AIS content, 36.7%, which was approximately 3 times higher than that of NC08-036. After processing, the AIS content in SPFF increased to 30.8-64.2% fw (Table 3-2) because of moisture

evaporation during pre-drying and frying. Similar to the AIS content of raw SP, SPFF from NC08-036 had the lowest AIS content, and SPFF from NCDM04-001 had the highest AIS content which was twice higher than NC08-036. The difference of AIS contents between raw SP and SPFF on dry weight basis varied in genotypes. AIS contents of NCDM04-197, Beaugard and Suwon 122 were decreased after frying, and the decreasing rates were 1.2%, 3.1% and 3.6% dw respectively. It is likely that leaching out of water-soluble substances during processing resulted in the AIS decreases. In contrast, AIS contents of other 13 genotypes increased after frying. Genotype with relatively low AIS increase was NCDM04-001 (1.3% dw), and genotypes with relatively high increasing rate were NC05-198 (20.3% dw) and NC13-1027 (19.2% dw). AIS increases of other genotypes were 3.8-16.5% dw. The reason of the increase of AIS content is unknown.

Starch content of raw SP was in a range of 6.0-23.4% fw (Table 3-1). Starch accounted for 32-69% and 52-78% of DM content and AIS content, respectively. Genotypes with higher DM and AIS contents contain more starch. Similar to DM and AIS contents, NC08-036 had the lowest (6.02%) and NCDM04-001 had the highest starch content (23.4%). Previous papers reported that starch content of raw SP in a range of 6.9-33.5% (Tian et al. 1991; Brabet et al. 1998; Zhu and Wang 2014).

Starch content of SPFF was in range of 11.6-41.4% fw (Table 3-2). As in the raw SP, SPFF from NC08-036 had the lowest and NCDM04-001 had the highest starch content. Differences of starch content between genotypes were about 17% fw in raw SP and up to 30% fw in SPFF. Therefore, the difference of starch content between raw SP and SPFF samples was compared based on dry weight basis. Starch content decreased by 0.8-19.0% after frying (Figure 3-4). Among the 16 genotypes, starch in SPFF from NC13-1012 and NC13-487 decreased the most while the decreased amount of starch in

SPFF from NCDM04-001 was much lower than the other SP genotypes. Starch leaks into water during blanching and the amount of starch leaking depends on strength of cell structure. SP cells can be strengthened by cross linking between pectin and calcium ion (LaBelle 1971). He et al. (2014) reported that blanching treatment of SP at 60°C increases the pectin methylesterase (PME) activity and decreases leaked starch content from 12.83% to 7.28%. Therefore, it is assumed that NC13-1012 and NC13-487 had low PME activity or low level of calcium ion resulting in great starch reduction. Low PME activity or low level of calcium ion would contribute to heat degradation of cell structure during blanching and made starch leaking into water easier. Conversely, it is considered that cells of NCDM04-001 were hardly weakened during blanching and the amount of starch leaking was low. Study on PME activity and cellular structure in tissues of the SP genotypes is required to provide an understanding on the variation on starch decreases during processing. Other possible reasons of the differences of starch reduction between genotypes could be initial starch content and amylase activities. NC08-036 had the lowest starch content that could result in lower amount of starch leaching out. Gelatinized starch in SP genotypes with higher amylase activities can be hydrolyzed into oligosaccharides and maltose resulting in higher starch reduction.

Amylases

Alpha-amylase activities varied widely among the 16 genotypes (Table 3-1). Covington had the highest α -amylase activity (130.5 CU/100g fw), and it was twice of the second highest genotype, NC13-1001 (63.0 CU/100g fw). NC13-1027 had the lowest α -amylase activity (12.8 CU/100g fw), and it was 10 times lower than that of Covington.

Beta-amylase activity was in range of 3.9-618.9 U/100g fw and varied widely between genotypes as α -amylase (Table 3-1). Beta-amylase activity of NC08-036 was the highest (618.9 U/100g fw), and it was 1.7 times higher than the second highest genotype

which was Porto Rico (372.6 U/100g fw). Among the 16 genotypes, NCDM04-001 and NC13-1027 had very low β -amylase activities which were 3.9 U/100g fw and 6.0 U/100g fw.

Beta-amylase plays an important role in maltose production. The optimum temperature of SP β -amylase is 50°C, and the activity gradually decreases with increasing temperature, then deactivates at 80°C (Tsuyukubo and Ishii 2011). The onset gelatinization temperature of SP starch from various genotypes is in a range of 66-75°C (Tian et al. 1991; Nakamura et al. 2010). As shown in Figure 3-3, maltose was not detected in the SPFF from NC13-1027 and NCDM04-001 which had low β -amylase activities (3.9-6.0 U/100g). However, NC13-1012 had the highest maltose content even though it had lower β -amylase activity (46.2 U/100g) than other genotypes. One possible reason of this phenomenon could be that β -amylase of NC13-1012 was not denatured in a wide range of elevated temperature. Another possible reason could be a lower gelatinization temperature of NC13-1012 starch. Beta-amylase hydrolyzes gelatinized SP starch but it is unable to hydrolyze native SP starch (Ohnishi et al. 1985). On the other hand, starch content is also important as well as β -amylase activity. NC08-036 produced smaller amount of maltose since it had low starch content even though it had the highest β -amylase activity (618.9 U/100g) among the genotypes. Therefore, a combination of β -amylase activity and starch content could be important for maltose production during SP processing.

Oil content in SPFF

Oil absorption occurs during par-frying and final frying treatments. Oil content of SPFF was in a range of 6.7-12.6% fw (Table 3-2). Since oil content in WPF is normally ranged from 9 to 15% (Van Loon et al. 2007; Miranda and Aguilera 2006), oil content in SPFF in our study was relatively lower than that of WPF. Among the 16 genotypes,

Suwon122 had the highest oil content and Bonita had the lowest.

This experiment was conducted with two replications and two samples were taken from each replication for analysis. When analyzing the data, it was found that oil content between the two replications of some genotypes especially Suwon122 and NCDM04-001 had the most variability (Figure 3-5). These two replications were separately prepared in the same day, and the processing conditions were carefully controlled. Also, samples were taken randomly, and chemical components of raw SP between replication 1 and 2 were not significantly different in all genotypes. Walter et al. (1997) observed the differences in physical properties such as intercellular volume, cell size and specific gravity among the genotypes affecting the oil absorption in the SPFF. Growing and storage conditions may have more impacts on the variation on these physical properties of SP roots such as Suwon122 and NCDM04-001 resulting in a large difference in oil content of SPFF processed from the two replicates. Therefore, it may be difficult to produce consistent oil content in SPFF from these genotypes.

Relationship between chemical components

Table 3-3 shows correlation coefficients between chemical components of raw SP and SPFF. Dry matter content in raw SP was positively correlated with AIS and starch contents. This could be because starch is the main component of AIS, and AIS is the main component of DM. These three chemical components were negatively correlated with total sugar content. Generally, DM consist of sugars and AIS including starch, and SP genotypes with high AIS and starch contents have low total sugar content. On the other hand, DM and AIS contents in raw SP were positively correlated with AIS contents in SPFF but the correlation coefficients were not high ($r = 0.63-0.67$). Therefore, it is considered that other chemical components such as pectic substances could contribute to

AIS content in SPFF. Alpha-amylase activity was not correlated with any of the measured chemical components in raw SP and SPFF. Beta-amylase activity was positively correlated with total sugar content in raw SP and SPFF ($r = 0.66-0.67$). Since total sugar content in SPFF is highly influenced by that in raw SP ($r = 0.92$), further studies will be required to determine if β -amylase activity affect total sugar content in SPFF. For oil, SP genotypes with higher starch content in raw roots had lower oil content in SPFF although the relationship was not so strong ($r = -0.67$). The degree of starch gelatinization might be related to the oil absorption as observed in WFFF (Pedreschi et al. 2016). During frying, heat in the oil is conducted to the surface of SP strips, and water is evaporated from the surface, and then oil is absorbed into the strips. High starch content genotypes had less water content resulting in low oil absorption during frying.

3.4.2 Instrumental Measurement

Peak force

Peak force is defined as the force required for a probe to penetrate through the surface of a sample. Peak force of SPFF from the 16 genotypes in this study was in a range of 0.5-3.1N (Figure 3-6(a)). Fried NC13-487 had the highest peak force and fried Evangeline had the lowest with the peak force of 6 times lower than that of the SPFF from NC13-487. Peak force of Evangeline French fries was not statistically different ($p < 0.05$) from other 10 genotypes (NC08-036, NC05-198, Beauregard, Covington, NC13-1012, NC09-122, NC13-1001, Porto Rico, Bonita and NC13-1004). Figure 3-6(b) is a box plot indicating the dispersion of 22-24 data points of peak force. A box indicates middle 50% of data points, a line under the box indicates a range of a minimum to 25% of data points, and a line above the box indicates a range of 75% to maximum of data points. Dispersions of peak force values of SPFF from NC13-487, Suwon122 and NCDM04-001

were high and much greater than the other genotypes. Conversely, smaller dispersion of peak force was exhibited in the samples from Evangeline and the 10 genotypes with lower peak force mentioned above.

As mentioned above, water in a strip evaporates from the tissue and hot oil comes into the empty space during frying, which results in the crust formation on the surface. Generally, peak force increases with decreases in moisture content. Based on this phenomenon, it is assumed that the variation in peak force among SPFF from the genotypes in this study was likely caused by the difference in the amount of water evaporated from the surface of the strips.

Overall Hardness

Overall hardness is the required energy to cut 5 fried strips placed in a French fry rig as described above, and it is calculated as the area under the stress-strain curve (AUC). The overall hardness of the 16 genotypes ranged from 136 to 577 N.sec (Figure 3-7a). Fried strips of NCDM04-001 had the highest overall hardness and those of Evangeline had the lowest value which was about 4 times lower than NCDM04-001. Similar to the result on peak force, no statistically significant difference was found between SPFF from Evangeline and other 8 genotypes (NC08-036, NC05-198, Beauregard, Covington, NC13-1012, NC09-122, NC13-1001 and NC13-1004). High correlation ($r = 0.97$) was found between overall hardness and peak force of SPFF from the 16 genotypes. Figure 3-7(b) is a box plot showing the dispersion of 4 data points. As the peak force, genotypes with higher overall hardness had larger dispersion of the data while genotypes with lower overall hardness had smaller dispersion. Study on microstructural analysis may provide an explanation for this phenomenon.

NC13-487 had unique textural characteristics. After tempering, the strips from NC13-487 were more flexible and elastic as compared to the brittleness of the samples

from other genotypes (Figure 3-8). After frying, peak force and overall hardness of SPFF from NC13-487 were very high although the chemical components of this genotype were similar to those of Evangeline. Cell wall properties and components such as water-soluble pectin could be related to the flexibility of the NC13-487 strips. Previous studies indicated that increase of water-soluble pectin content in the tissue resulted in soft texture of ripened or cooked fruits and vegetables (Komiya et al. 1979; and Fuchigami et al. 1993). Walter et al. (1997) reported a negative correlation between the content of water-soluble pectic substances and mastication cohesiveness of SPFF from 5 different SP genotypes. Regarding the hard texture of SPFF from NC13-487, amount of low methoxyl pectin in SPFF could affect the hardness. Previous study on pectin using 21 kinds of vegetables found that boiled vegetables with higher ratio of low methoxyl pectin were less softened (Fuchigami 2014). Pectic substances of raw SP and SPFF were not analyzed in the samples from the 16 genotypes in our study. Further research is required to provide better understanding on the relationship between cell wall components of SP roots and textural properties of fries and other processed products.

3.4.3 Relationship between Chemical Components and Instrumental Measurement

Table 3-4 shows correlation coefficient between chemical components on fresh weight basis and peak force and overall hardness of SPFF processed from the 16 genotypes.

The DM, AIS and starch contents in raw SP were positively correlated with both peak force ($r = 0.41-0.52$, $p < 0.01$) and overall hardness ($r = 0.57-0.68$, $p < 0.01$). As mentioned above, NC13-487 had unique textural properties (Figure 3-8) among many genotypes developed by the SP breeding programs. Exclusion of the data from this unique genotypes resulted in higher correlation coefficients between chemical components and

instrumental measurements of SPFF processed from the 15 genotypes (Table A-1, Figure A-1). As shown in Table 3-3, genotypes with higher DM had higher AIS and starch contents ($r = 0.73-0.81$). For SPFF, correlation coefficients between starch and AIS contents of SPFF and hardness were increased ($r = 0.51-0.73$). Thus, it is implied that structure of starch was changed during French fry processing and this change contributed to the hardness of SPFF. Nakamura et al. (2010) reported that texture of steamed SP with higher starch content was prone to mealy, and that starch gelatinization temperature and amylose content were not related to mealy texture. Moreover, a study on white potato French fries (WPF) indicated that starch granule size and amylose content had no influence on mealiness of WPF (Mohr 1972). Starch is gelatinized during processing and form a gel. In a study on cellular structure of steamed SP tissue, Nakamura et al. (2010) observed that each cell was filled with starch gels and maintained its cell structure in the mealy SP while several cells were combined with starch gels which leaked from the cells in soggy SP, resulting in overall soggy texture of the SP cell. The authors assumed that water molecular motion is limited in the mealy SP as compared to the soggy SP. The moistness of soggy SP can be explained by the water dispersion in the entire structure. Therefore, in our study, it is expected that the same phenomena occurred during processing of SPFF, and the difference of density of gelling starch might affect the texture of SPFF rather than AIS. More researches are required to test this hypothesis.

Total sugar contents of raw SP and SPFF were negatively correlated with peak force and overall hardness ($r = -0.55 - -0.69$). Sugars have high water-holding capacity and attract water from the surrounding environment. Thus, it is expected that more sugar content attracts more water, resulting in soggy texture of SPFF. However, since SP genotypes with higher starch content had lower sugar content ($r = -0.88$), it is uncertain to conclude either starch or sugars affect the texture of SPFF. Further studies such as

controlling the amount of chemical components are required to determine which chemical components influence on the texture of SPFF.

Regarding amylases, peak force and overall hardness were not correlated with α -amylase activity ($r = -0.15$) and the p-values were high ($p = 0.15-0.16$). Therefore, α -amylase activity was not related to the hardness of SPFF. For β -amylase activity, p-values were less than 0.05 but correlation coefficients with the peak force and overall hardness were low ($r = -0.26 - -0.30$). In other words, β -amylase activity is related to the hardness of SPFF but is not key factor of the hardness.

Moisture content of SPFF was negatively correlated with peak force and overall hardness ($r = -0.59 - -0.72$), which means that moisture content contributes to soggy texture of SPFF. Moisture content in SP strips decreased during processing, especially during frying. Lisińska and Gołubowska (2005) reported that moisture in the surface layers of WP strips evaporated, so the cells of the skin of WPF are smaller than those of raw tubers. It is considered that the same phenomenon was occurred on SPFF. Kato (1997) indicated that amount of evaporated moisture of WP cultivars with high starch content is small because moisture in the cells is used for starch gelatinization and is hardly evaporated. In our study, it is expected that starch on strip surface was already gelatinized due to heat treatments such as blanching, and therefore moisture in the strips could not be easily evaporated during frying.

Oil content of SPFF had no effect on peak force and overall hardness ($r = -0.01 - -0.03$, $p > 0.05$). However, a study on white potato crisps using genotypes with different DM and starch contents indicated that potatoes with higher DM content had lower oil content and had crispy texture (Kita 2002). Moreover, a study on WPF using 7 oil types for frying one WP genotype, reported that hardness was increased with increasing oil content (Kita and Lisińska 2005). Amount of oil absorption into surface layer and inner

part of WP strips were significantly different (O'Connor et al. 2001). Therefore, it is necessary to consider relationship between oil content and texture of SPFF based on a measurement of oil content of outer and inner layers separately in future study.

3.5 Conclusion

The high correlations between DM, AIS and starch content in raw SP with peak force and overall hardness of SPFF indicated that these chemical components can be used to select SP genotypes for processing SPFF. Total sugar is also useful for the selection since the peak force and overall hardness of SPFF were negatively correlated with total sugar content. The relationship between chemical components in raw SP, instrumental hardness and sensory characteristics of SPFF would be helpful to plant breeders in developing new SP varieties suitable for processing into a fried product that meets the increasing consumers' demand.

3.6 References

- Aina, A. J., Falade, K. O., Akingbala, J. O., and Titus, P. 2009. Physicochemical properties of twenty-one Caribbean sweet potato cultivars. *International journal of food science & technology*, 44(9), 1696-1704.
- Brabet, C., Reynoso, D., Dufour, D., Mestres, C., Arredondo, J. and Scott, G. 1998. Starch content and properties of 106 sweetpotato clones from the world germplasm collection held at CIP, Peru. CIP Program Report 1997-98, 279-286.
- Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). 2014. <http://faostat3.fao.org>
- Fuchigami, M. 2014. Changes in Pectic Substances of Vegetables and Fruit during Cooking. *Journal of Home Economics of Japan*, 65(9), 479-491.
- Fuchigami M., Tamura S., Okuda H. 1993. Effects of cations and anions on the softening of cooked Japanese radish roots and on the pectic composition after cooking. *Journal of Home Economics of Japan*, 44(8), 649-654.
- Ghasemi, A. and Zahediasl, S. 2012. Normality tests for statistical analysis: a guide for non-statisticians. *International journal of endocrinology and metabolism*, 10(2), 486-489.
- Gołubowska, G. 2005. Changes of polysaccharide content and texture of potato during French fries production. *Food chemistry*, 90(4), 847-851.
- Hagenimana, V., Carey, E. E., Gichuki, S. T., Oyunga, M. A., and Imungi, J. K. 1998. Carotenoid contents in fresh, dried and processed sweetpotato products. *Ecology of Food and Nutrition*, 37(5), 455-473.
- He, J., Cheng, L., Gu, Z., Hong, Y. and Li, Z. 2014. Effects of low-temperature blanching on tissue firmness and cell wall strengthening during sweet potato flour processing. *International Journal of Food Science & Technology*, 49(5), 1360-1366.
- Johnson, T., Wilson, N., Worosz, M.R., Fields, D. and Bond, J.K. 2015. Commodity Highlight: Sweet Potatoes.
- Kato, K. 1997. Factors Affecting the Quality of Deep Fried Food on the Change of Oil from Moisture. *Bulletin of Tokyo Kasei University*, 37(2), 33-38.
- Kiribuchi, H. and Kubota, K. 1976. Studies on cooking of sweet potato (Part 1) – Changes in sugar content and β -amylase activity during cooking –, *Journal of Home Economics of Japan*, 27, 418-422
- Kirkpatrick, M.E. 1956. French-frying quality of potatoes: as influenced by cooking methods, storage conditions, and specific gravity of tubers (Vol. 1142). US Dept. of Agriculture.
- Kita, A. 2002. The influence of potato chemical composition on crisp texture. *Food*

Chemistry, 76(2), 173-179.

Kita, A. and Lisińska, G., 2005. The influence of oil type and frying temperatures on the texture and oil content of French fries. *Journal of the Science of Food and Agriculture*, 85(15), 2600-2604.

Komiyama, Y., Harakawa, M. and Ozawa, S. 1979. Changes in physical and chemical compositions of plums during maturation. *Nippon Shokuhin Kogyo Gakkaishi*, 26(7), 305-310.

LaBelle, R. L. 1971. Heat and calcium treatments for firming red tart cherries in a hot - fill process. *Journal of Food Science*, 36(2), 323-326.

Lisińska, G. and Gołubowska, G. 2005. Structural changes of potato tissue during French fries production. *Food chemistry*, 93(4), 681-687.

Mensah, E.O., Ibok, O., Ellis, W.O. and Carey, E.E. 2016. Thermal Stability of β -Amylase Activity and Sugar Profile of Sweet-Potato Varieties during Processing. *J Nutr Food Sci*, 6(515), 2.

Mohr, W.P. 1972. Soggy-centered French fries. *Canadian Institute of Food Science and Technology Journal*, 5(4), 179-183.

Nakamura, Y., Kuranouch, T., Takada, A., Ishida, N., Koda, I., Iwasawa, N., Matsuda, T. and Kumagai, T. 2010. Cell Structure, Water Status and Starch Properties in Tuberos Root Tissue in Relation to the Texture of Steamed Sweetpotato (*Ipomoea batatas* (L.) Lam). *Japanese journal of crop science* 79(3), 284-295.

O'Connor, C.J., Fisk, K.J., Smith, B.G. and Melton, L.D. 2001. Fat uptake in French fries as affected by different potato varieties and processing. *Journal of food science*, 66(6), 903-908.

Ohnishi, M., Okada, G., Taniguchi, H. and Sakano, Y. 1985. β -amylase, Protein, Nucleic Acid and Enzyme, 30, 404-412.

Oner, M.E. and Wall, M.M. 2012. Processing conditions for producing french fries from purple-fleshed sweetpotatoes. *Transactions of the ASABE*, 55(6), 2285-2291.

Pattee, H.E., Isleib, T.G., Giesbrecht, F.G., and McFeeters, R.F. 2000. Investigations into genotypic variations of peanut carbohydrates. *J. Agric. Food Chem.* 2000, 48, 750-756.

Pedreschi, F., Mariotti, S.M. and Cortés, P. 2016. Fried and dehydrated potato products. In: *Advances in Potato Chemistry and Technology*, 2nd Edition; Singh, J., Kaur, L., Eds.; Elsevier: New York, 459-474.

Sanz, T., Primo-Martín, C. and Van Vliet, T. 2007. Characterization of crispness of French fries by fracture and acoustic measurements, effect of pre-frying and final frying times. *Food Research International*, 40(1), 63-70.

Tian, S.J., Rickard, J.E. and Blanshard, J.M.V. 1991. Physicochemical properties of sweet

- potato starch. *Journal of the Science of Food and Agriculture*, 57(4), 459-491.
- Truong, V.D., Avula, R.Y., Pecota, K. and Yencho, C.G. 2011. Sweetpotatoes. In: *Handbook of Vegetables and Vegetable Processing*, 717-737.
- Truong, V.D., Pascua, Y.T., Reynolds, R., Thompson, R.L., Palazoğlu, T.K., Atac Mogol, B. and Gökmen, V. 2014. Processing treatments for mitigating acrylamide formation in sweetpotato French fries. *Journal of agricultural and food chemistry*, 62(1), 310-316.
- Tsuyukubo M. and Ishii K. 2011, Effects of β -Amylase in Sweet Potato on Cooked Rice and Rice Gruel, *Journal of cookery science of Japan*, 44, 15-20.
- Van het Hof, K.H., Brouwer, I.A., West, C.E., Haddeman, E., Steegers-Theunissen, R.P., van Dusseldorp, M., Weststrate, J.A., Eskes, T.K. and Hautvast, J.G. 1999. Bioavailability of lutein from vegetables is 5 times higher than that of β -carotene. *The American journal of clinical nutrition*, 70(2), 261-268.
- Walter, W.M., Collins, W.W., Truong, V.D. and Fine, T.I. 1997. Physical, compositional, and sensory properties of French fry-type products from five sweetpotato selections. *Journal of Agricultural and Food Chemistry*, 45(2), 383-388.
- Walter, W.M., Fleming, H.P. and McFeeters, R.F. 1992. Firmness Control of Sweetpotato French Fry - Type Product by Tissue Acidification. *Journal of food science*, 57(1), 138-142.
- Walter, W.M. and Hoover, M.W. 1986. Preparation, Evaluation and Analysis of a French - Fry - Type Product from Sweet Potatoes. *Journal of Food Science*, 51(4), 967-970.
- Walter, W. M., Truong, V. D. and Espinel, K. R. 2002. Textural measurements and product quality of restructured sweetpotato French fries. *LWT-Food Science and Technology*, 35(3), 209-215.
- Zhu, F. and Wang, S. 2014. Physicochemical properties, molecular structure, and uses of sweetpotato starch. *Trends in Food Science & Technology*, 36(2), 68-78.

Table 3-1. Chemical components of raw sweetpotatoes

Genotype	Flesh Color	Dry Matter (%)	AIS (g/100g)	Starch (g/100g)	Total Sugar (g/100g)	Alpha-amylase activity (CU/100g)	Beta-amylase activity (U/100g)
NC08-036	orange	18.59 ⁱ	11.58 ^k	6.02 ^k	6.49 ^a	20.96 ^{fgh}	618.91 ^a
Evangeline	orange	19.90 ^{hi}	13.54 ^j	7.99 ^j	5.40 ^b	34.34 ^{de}	228.81 ^{de}
NC13-487	orange	20.55 ^{gh}	16.33 ⁱ	10.55 ^{hi}	2.72 ^{gh}	29.16 ^{efg}	279.72 ^{cd}
NC05-198	orange	20.99 ^{gh}	16.36 ⁱ	12.36 ^g	3.42 ^{ef}	51.52 ^{bc}	354.48 ^b
Beauregard	orange	21.25 ^{gh}	19.06 ^h	10.87 ^h	3.74 ^{de}	16.15 ^h	151.78 ^{fg}
Covington	orange	22.00 ^g	17.17 ⁱ	9.74 ⁱ	4.69 ^c	130.54 ^a	128.09 ^{fg}
NC13-1012	orange	24.95 ^f	20.16 ^{gh}	14.26 ^f	3.47 ^{ef}	33.78 ^{de}	46.18 ^{hi}
NC09-122	orange	25.24 ^{ef}	20.20 ^{gh}	14.76 ^f	4.26 ^{cd}	18.27 ^{gh}	182.53 ^{ef}
NC13-1001	orange	26.08 ^{def}	22.27 ^f	16.45 ^e	3.04 ^{fg}	63.00 ^b	235.41 ^{de}
Porto Rico	orange/yellow	26.79 ^{de}	22.50 ^f	16.29 ^e	3.86 ^{de}	19.51 ^{gh}	372.65 ^b
Bonita	cream	26.90 ^d	23.65 ^e	17.69 ^d	2.71 ^{gh}	14.06 ^h	222.13 ^{de}
NC13-1027	orange	29.44 ^c	22.98 ^{ef}	17.95 ^d	4.54 ^c	12.83 ^h	5.97 ⁱ
NC13-1004	yellow	31.81 ^b	27.96 ^d	21.82 ^b	2.94 ^{fg}	51.60 ^{bc}	110.49 ^{gh}
NCDM04-197	yellow	32.88 ^b	31.42 ^c	20.18 ^c	1.37 ⁱ	20.65 ^{fgh}	313.71 ^{bc}
Suwon122	yellow	33.28 ^b	32.78 ^b	20.09 ^c	2.15 ^h	42.61 ^{cd}	224.99 ^{de}
NCDM04-001	yellow	37.20 ^a	36.65 ^a	23.40 ^a	1.22 ⁱ	30.78 ^{ef}	3.93 ⁱ

Values within the column having different letters are statistically different ($\alpha=0.05$).

All data are fresh weight basis.

Table 3-2. Chemical components of sweetpotato French fries

Genotype	Flesh Color	Moisture (%)	Oil (%)	AIS (g/100g)	Starch (g/100g)	Total Sugar (g/100g)
NC08-036	orange	57.58 ^{ab}	11.02 ^{abc}	30.82 ^k	11.56 ^g	10.16 ^a
Evangeline	orange	58.33 ^a	7.86 ^{cde}	33.07 ^j	12.74 ^g	7.74 ^b
NC13-487	orange	50.95 ^{cde}	7.73 ^{de}	47.08 ^{ef}	16.00 ^f	4.16 ^{fg}
NC05-198	orange	56.68 ^{ab}	6.75 ^e	42.54 ^g	17.89 ^{ef}	3.32 ^{gh}
Beauregard	orange	57.81 ^{ab}	9.88 ^{abcde}	36.52 ⁱ	18.88 ^e	5.65 ^{de}
Covington	orange	55.49 ^{abc}	10.46 ^{abcde}	36.42 ⁱ	15.79 ^f	6.85 ^{bc}
NC13-1012	orange	50.25 ^{de}	9.78 ^{abcde}	46.79 ^{ef}	19.00 ^e	5.20 ^{ef}
NC09-122	orange	54.74 ^{abcd}	8.63 ^{cde}	40.17 ^h	20.46 ^e	6.45 ^{cd}
NC13-1001	orange	45.06 ^f	9.23 ^{bcd}	53.66 ^c	25.16 ^d	4.39 ^{fg}
Porto Rico	orange/yellow	46.00 ^{ef}	12.41 ^{ab}	48.50 ^{ef}	25.25 ^d	5.75 ^{cde}
Bonita	cream	53.12 ^{bcd}	6.78 ^e	45.91 ^f	23.32 ^d	3.29 ^{gh}
NC13-1027	orange	47.15 ^{ef}	7.11 ^e	51.39 ^d	25.76 ^d	2.44 ^h
NC13-1004	yellow	43.66 ^f	8.16 ^{cde}	55.59 ^c	30.65 ^c	3.72 ^g
NCDM04-197	yellow	42.64 ^f	8.02 ^{cde}	54.13 ^c	31.25 ^c	3.89 ^g
Suwon122	yellow	36.91 ^g	12.61 ^a	59.76 ^b	35.48 ^b	4.03 ^g
NCDM04-001	yellow	35.73 ^g	8.90 ^{cde}	64.19 ^a	41.44 ^a	0.35 ⁱ

Values within the column having different letters are statistically different ($\alpha=0.05$).

All data are fresh weight basis.

Table 3-3. Correlation coefficients (r) between chemical components on dry weight basis

	DM (raw)	AIS (raw)	Starch (raw)	Sugar (raw)	Alpha (raw)	Beta (raw)	Moist (fried)	Oil (fried)	AIS (fried)	Starch (fried)	Sugar (fried)
DM (raw)											
AIS (raw)	0.81 0.0001										
Starch (raw)	0.73 0.0013	0.74 0.0010									
Sugar (raw)	-0.83 <.0001	-0.92 <.0001	-0.88 <.0001								
Alpha (raw)	-0.35 0.1891	-0.26 0.3301	-0.37 0.1611	0.29 0.2681							
Beta (raw)	-0.60 0.0141	-0.61 0.0126	-0.63 0.0091	0.66 0.0052	0.01 0.9719						
Moisture (fried)	-0.92 <.0001	-0.77 0.0005	-0.64 0.0072	0.80 0.0002	0.28 0.2912	0.47 0.0694					
Oil (fried)	-0.54 0.0290	-0.40 0.1288	-0.67 0.0044	0.65 0.0063	0.33 0.2126	0.47 0.0674	0.45 0.0824				
AIS (fried)	0.63 0.0082	0.68 0.0041	0.91 <.0001	-0.87 <.0001	-0.31 0.2485	-0.60 0.0137	-0.62 0.0103	-0.80 0.0002			
Starch (fried)	0.93 <.0001	0.90 <.0001	0.83 <.0001	-0.87 <.0001	-0.38 0.1441	-0.61 0.0119	-0.81 0.0002	-0.53 0.0335	0.71 0.0023		
Sugar (fried)	-0.78 0.0004	-0.78 0.0004	-0.87 <.0001	0.92 <.0001	0.29 0.2784	0.67 0.0045	0.75 0.0008	0.78 0.0004	-0.95 <.0001	-0.81 0.0001	

Values on the top are correlation coefficients. Values on the bottom are p-values.

DM: dry matter, AIS: alcohol insoluble solid, Sugar: total sugar, Alpha: alpha-amylase activity, Beta: beta-amylase activity.

Table 3-4. Correlation coefficients (r) between chemical components and instrumental texture measurement of SPFF of 16 genotypes

	Peak Force		Overall Hardness	
	Correlation Coefficient	p-value	Correlation Coefficient	p-value
Dry matter (raw)	0.47	<.0001	0.64	<.0001
AIS (raw)	0.52	<.0001	0.68	<.0001
Starch (raw)	0.41	0.0009	0.57	<.0001
Total sugar (raw)	-0.62	<.0001	-0.69	<.0001
Alpha-amylase activity (raw)	-0.15	0.1509	-0.15	0.1585
Beta-amylase activity (raw)	-0.26	0.0245	-0.30	0.0100
Moisture (fried)	-0.59	<.0001	-0.72	<.0001
Oil (fried)	-0.03	0.8276	-0.01	0.9541
AIS (fried)	0.61	<.0001	0.73	<.0001
Starch (fried)	0.51	<.0001	0.67	<.0001
Total Sugar (fried)	-0.55	<.0001	-0.64	<.0001

Correlation coefficients were determined on fresh weight basis

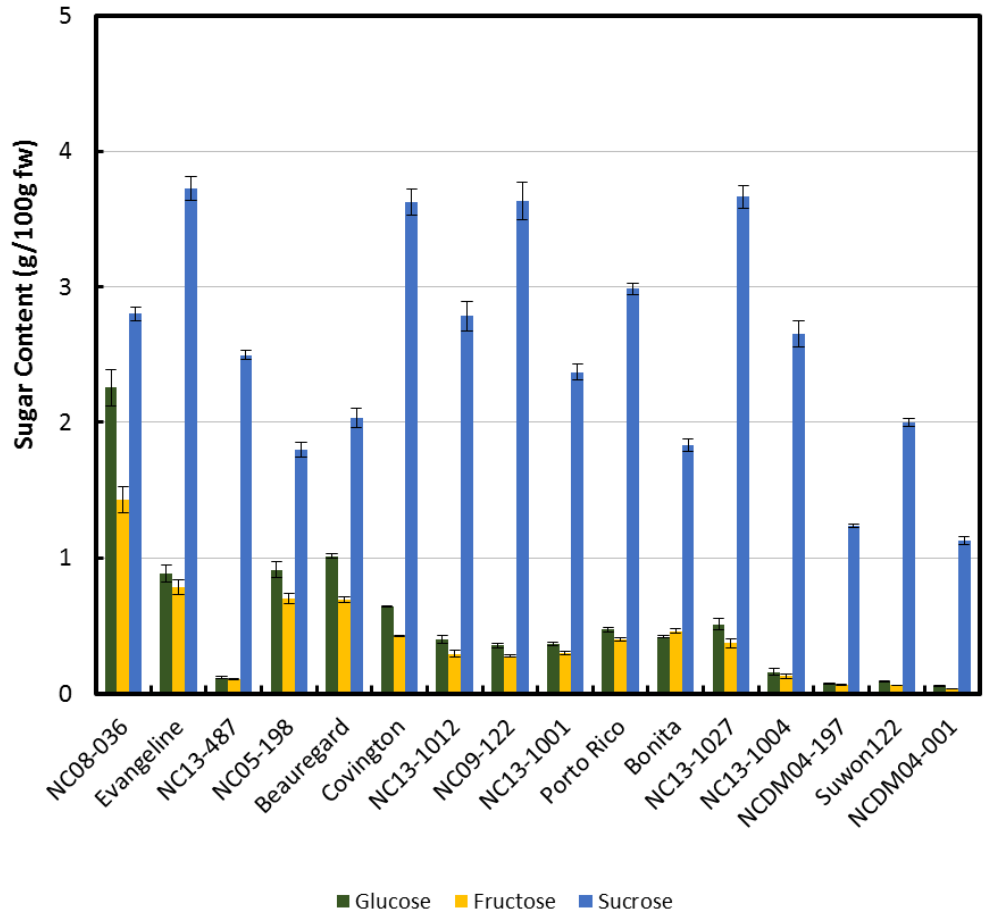


Figure 3-1. Sugar profile of raw sweetpotatoes

Error bars represents standard error.

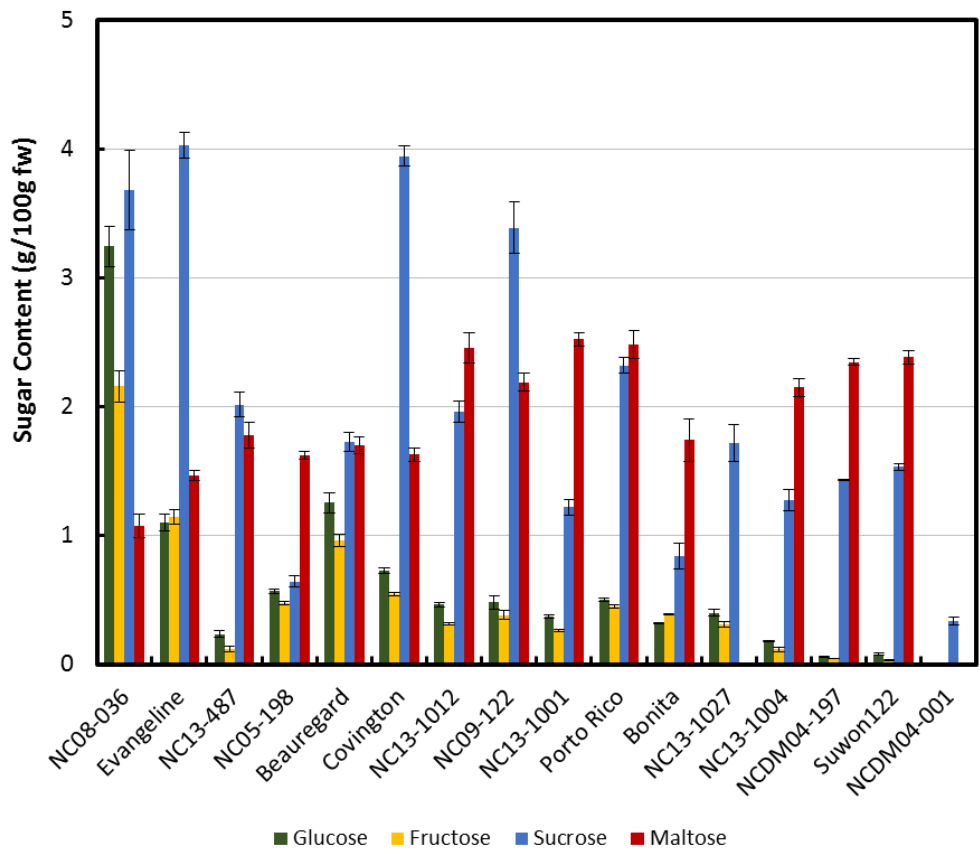


Figure 3-2. Sugar profile of sweetpotato French fries

Error bars represents standard error.

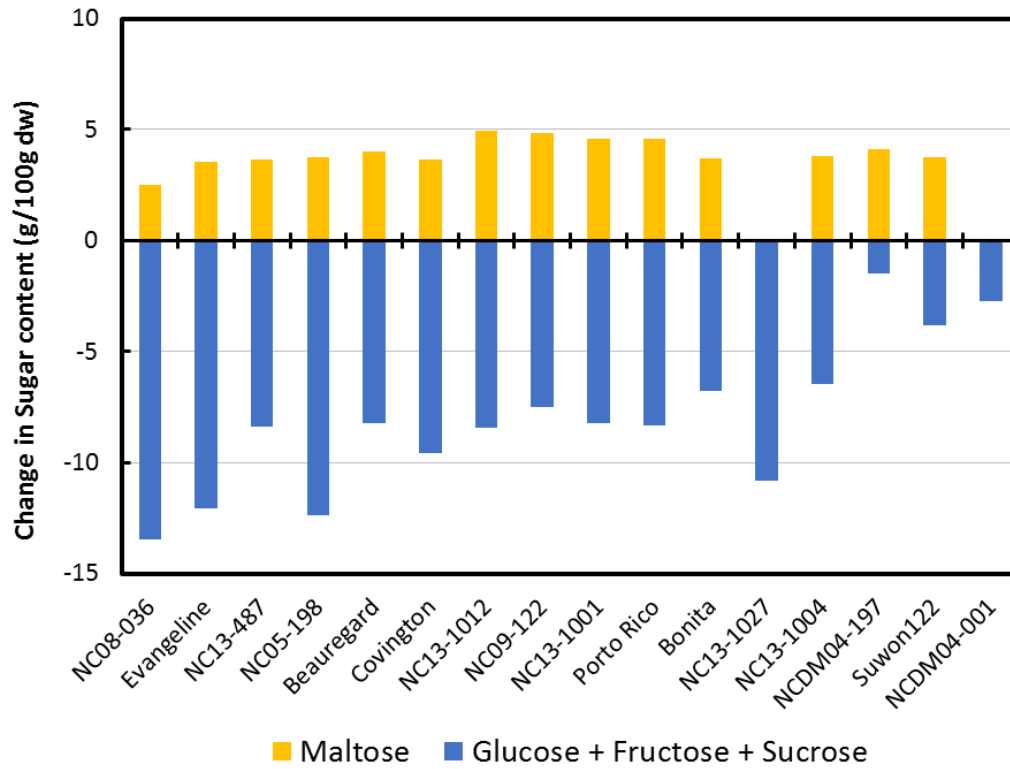


Figure 3-3. Changes in sugar content after frying

Set initial sugar content as zero in each genotype.

Bar under the zero indicates the amount of decreased sugar after frying.

Bar above the zero indicates the amount of increased sugar after frying.

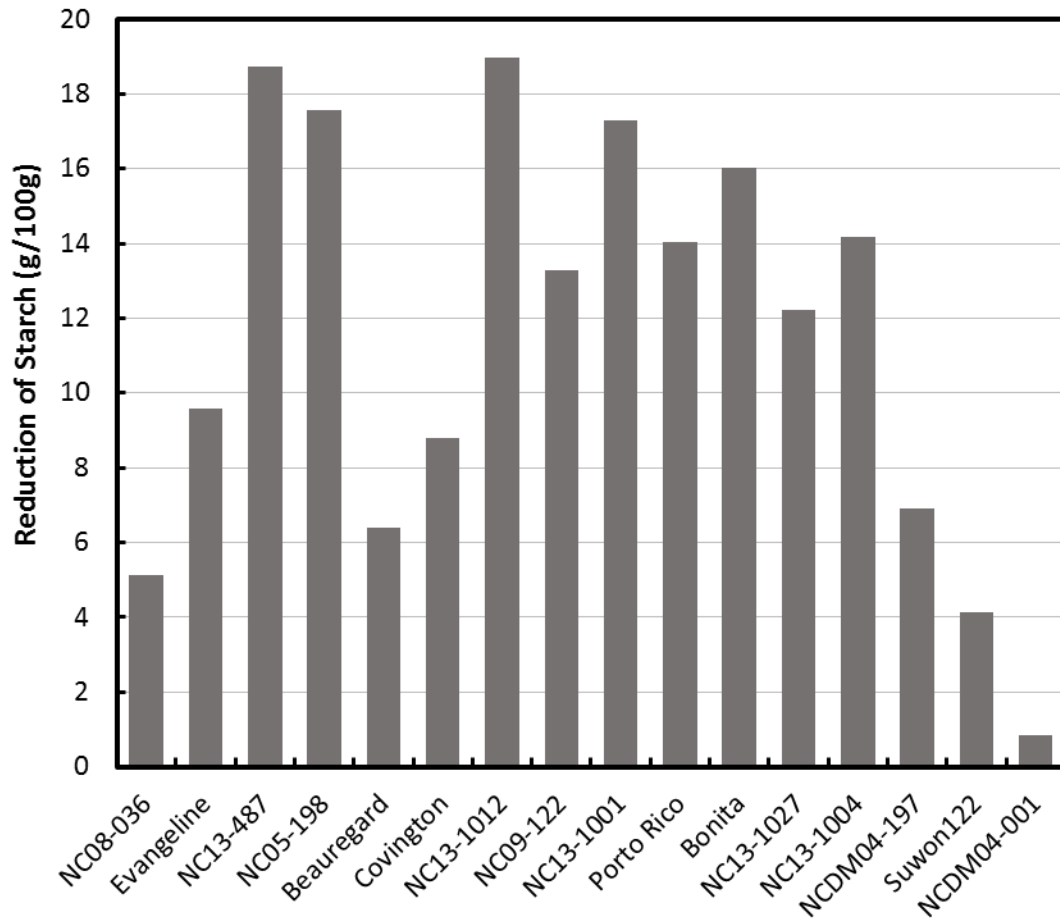


Figure 3-4. Amount of decreased starch after frying

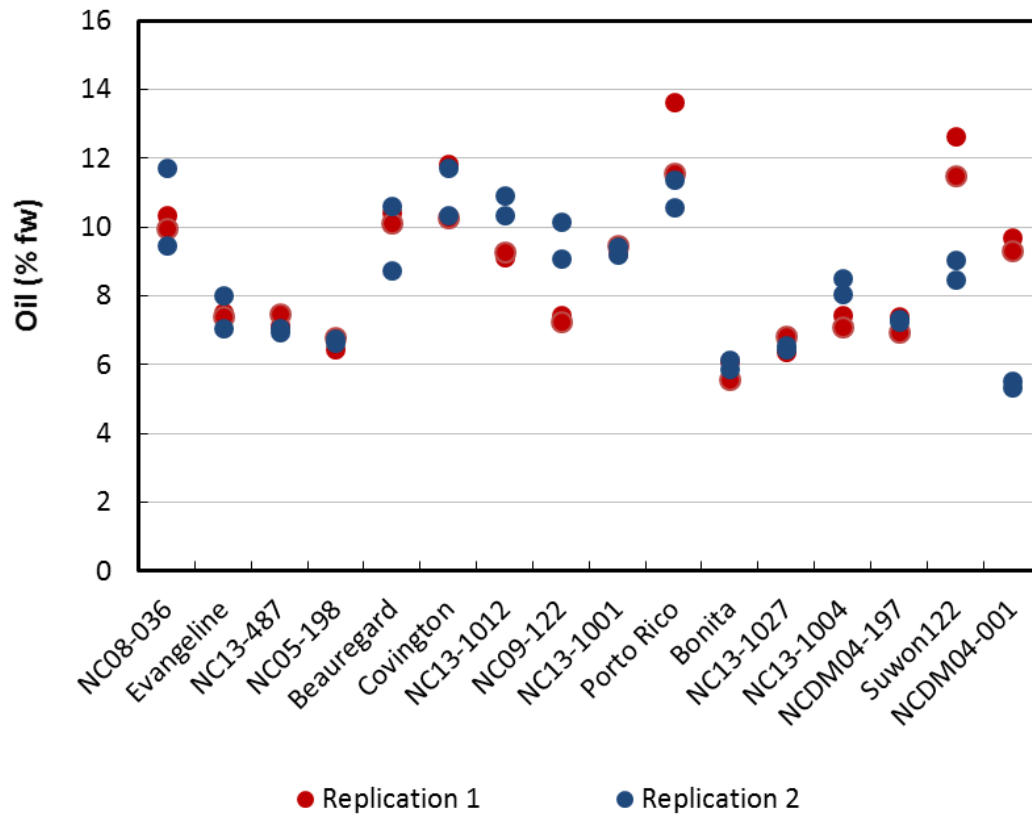


Figure 3-5. Comparison between replication 1 and 2 of oil content

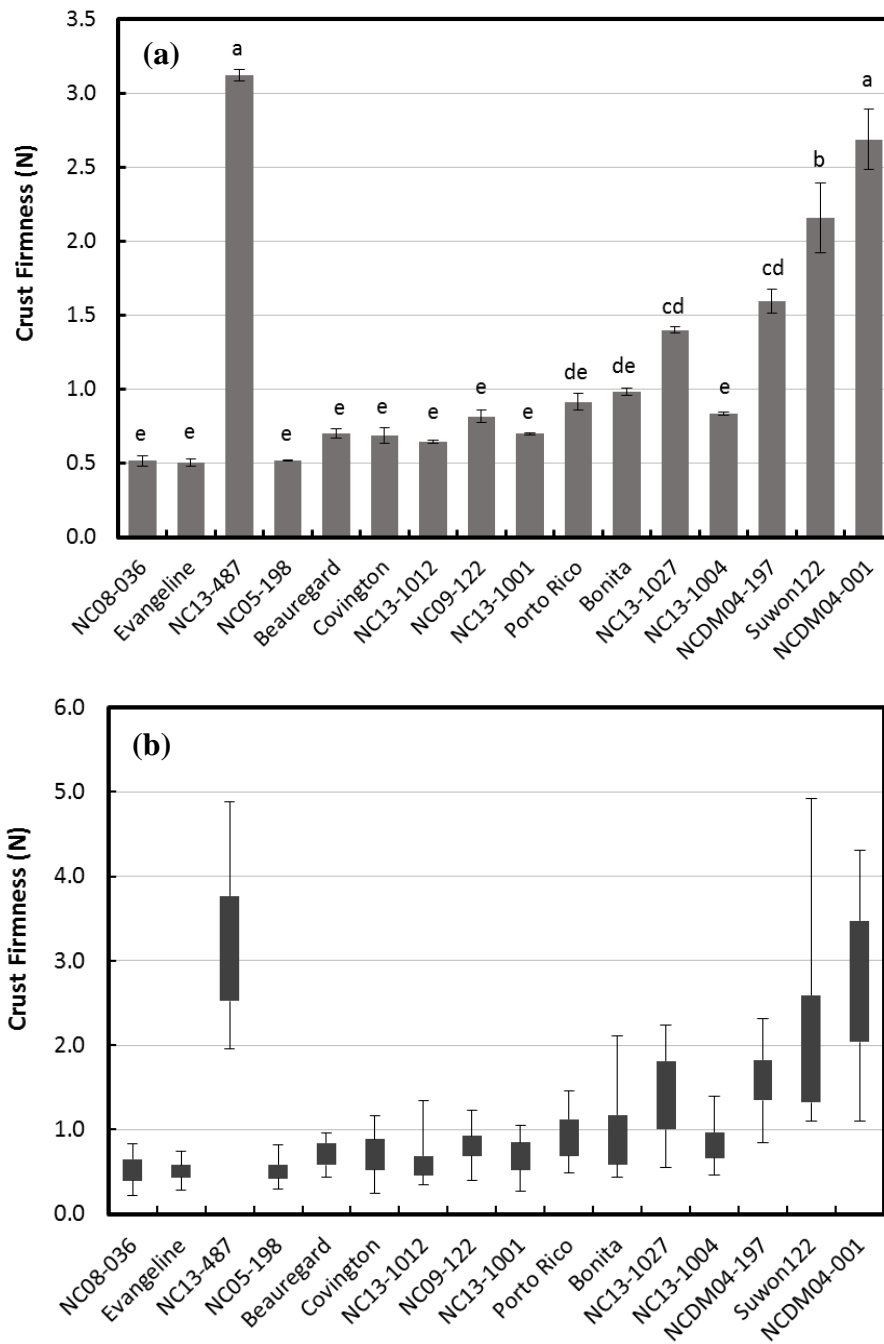


Figure 3-6. Peak force of sweetpotato French fries

(a): Average peak force. Different letters indicate a significant difference at $p < 0.05$.

(b): Dispersion of measured peak force.

n = 22-24

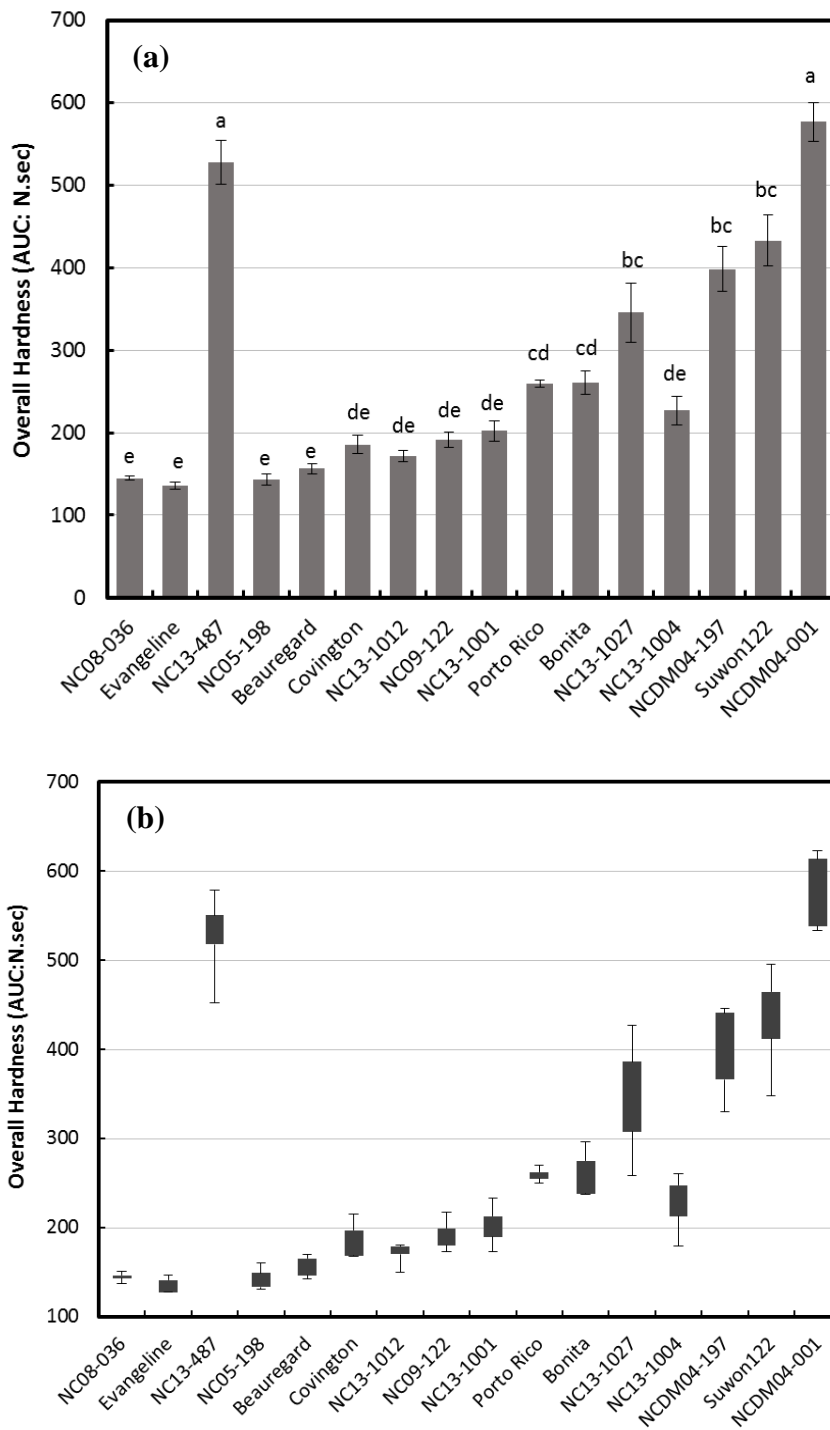


Figure 3-7. Overall hardness of sweetpotato French fries

(a): Average overall hardness. Different letters indicate a significant difference at $p < 0.05$.

(b): Dispersion of measured overall hardness.

$n = 4$



Figure 3-8. Raw sweetpotato strips

Strips on the left are NC13-487, and strips on the right are other 3 different genotypes (NC13-1001, NC05-198, Bonita).

CHAPTER 4

Sensory Texture Characteristics of Sweetpotato French Fries

4.1 Abstract

Consumer demand on sweetpotato French fries (SPFF) has been increasing recently. However, information on sensory characteristics of SPFF is limited since SPFF are relatively a new commercial product. This study aimed to evaluate the sensory characteristics of SPFF processed from various sweetpotato (SP) genotypes, and determine the relationship among sensory attributes, instrumental textural measurement (peak force, overall hardness) and chemical components of raw SP and SPFF. Sixteen SP genotypes with varying flesh color were used in this study. The preparation method of SPFF included tempering the whole roots, cutting into strips, blanching, pre-drying, par-frying at 185°C for 75 seconds, and freezing at -20°C. The frozen strips were fried at 177°C for 150 seconds, and cooled to 60°C for assessment of textural properties. For sensory evaluation, 10 attributes were evaluated by a trained panel. Descriptive sensory analysis (DSA) was conducted and the DSA data was analyzed using analysis of variance and principal component analysis.

Results showed that sensory characteristics of SPFF from 8 orange-fleshed genotypes were similar that characterized by surface oiliness, inner moistness, inner smoothness and cohesiveness of mass. SPFF from 3 yellow-fleshed genotypes had similar texture that was characterized by outer crispness, high fracturability, overall hardness and rough surface. Sensory hardness, fracturability and crispness were positively correlated (r

= 0.63-0.97) with dry matter (DM), alcohol insoluble solid (AIS) and starch contents in raw SP and SPFF. Total sugar contents in raw SP and SPFF were positively correlated to smooth and moist texture. Furthermore, sensory overall hardness, fracturability and outer crispness were positively correlated ($r = 0.68-0.96$) with the instrumental measurements. Negative correlations ($r = -0.61 - -0.91$) were found between the instrumental measurements and four sensory attributes (oiliness, smoothness, moistness, cohesiveness of mass). Therefore, DM, AIS, starch and total sugar contents and instrumental measurements can be used as tools to select SP genotypes for producing SPFF. These results would help SP breeders and processors in the development of SPFF with good quality to meet the demands of the consumers.

4.2 Introduction

Sweetpotato (SP) (*Ipomoea batatas* L.) is produced in many countries around the world and it is an important economic crop. In terms of annual production, SP ranks the seventh in the world food production after maize, rice, wheat, potato, cassava, and barley (FAOSTAT 2013). There are many varieties of SP with different flesh color (white, cream, yellow, orange, purple) and sensory characteristics such as taste and texture. In the US, orange-fleshed varieties occupy over 90% of SP production area (Carpena 2009).

Sweetpotato is considered as one of the highly nutritious vegetables because of the high contents in carotene, dietary fiber, vitamins and minerals. SP is usually boiled, steamed, fried or baked for home consumption. For processed SP product, sweetpotato French fries (SPFF) and SP chips as commercial products have been developed in recent years while flours, starch and purees have been in the markets in many countries. Recently, consumer demands of SPFF have been increased and many potato processing companies have ventured into SPFF processing. The new processed products partially contribute to recent increase in SP consumption of 3.4 kg or 7.5 pounds per capita (Johnson et al. 2015). With these trends, SP breeding programs have been focusing on development of new varieties suitable for both fresh root markets and processed products particularly SPFF and chips (U.S. Sweet Potato Council, 2011).

On the other hand, white potato French fries (WPF) are the most common and

popular processed white potato (WP) product for many years. Consumption of frozen WP product in the US, mostly WFFF, was 20.8 kg per capita in 2014 (Economic Research Service, USDA 2016). Production of frozen WP product amounted for about 35% of total potato production in the US (Economic Research Service, USDA 2016). Although SPFF is similar to WFFF, the SP product is more nutritious due to the high carotene level in the orange-fleshed SP. Besides, absorption of β -carotene is enhanced when the foods are consumed with oil because β -carotene is oil-soluble (Van het Hof et al. 1999). Therefore, it is expected that the demand of SPFF would increase in the market.

For SPFF, texture, flavor and appearance would be the key factors to receive good consumer acceptance. Consumers prefer WFFF with light-colored to golden color, leathery, gummy, and crispy without hard texture, and the desirable interior texture is mealy like baked potato and not watery and mushy (Miranda and Aguilera 2006; Kirkpatrick 1956). In previous studies on WFFF, it was reported that instrumental measurement was highly correlated with the sensory crispness (Van Loon et al. 2007; Du Pont et al. 1992). Kita and Lisińska (2005) also found that the results on instrumental measurement were highly correlated with sensory attributes. However, sensory test conditions such trained or untrained panel and correlation coefficient with the instrumental measurement were not reported in details. Walter et al. (1997) reported that SPFF processed from the soft-sweet type SP as compared to the mealy varieties was

softer, moister, fewer particles, higher degree of mass cohesion, easier to swallow, and oily mouthfeel. The authors also found that consumers prefer caramel flavor and dislike starch flavor, and first-bite moistness and cohesiveness of mass in texture.

About the relationship between chemical components and sensory characteristics of SPFF, positive correlation between sugar and alcohol insoluble solid (AIS) contents in SPFF and first-bite moistness was reported while dry matter (DM) in SPFF was negatively correlated with first-bite hardness (Walter et al. 1997). There are few studies on relationship between sensory characteristics and instrumental measurement on SPFF texture. In a study on restructured SPFF, Walter et al. (2002) reported that hardness and density were highly correlated with the value of instrumental measurements while cohesiveness, oiliness and moistness were negatively correlated with the value of instrumental measurements.

While there are some studies on sensory evaluation of WPF (Johnston et al. 1970; Du Pont et al. 1992; Kita and Lisińska 2005; Van Loon et al. 2007), the information on WPF may not be suitable for SPFF because the two commodities are different botanically and chemically. Nevertheless, information on comprehensive sensory attributes of SPFF evaluated by well-trained panel and the relationship with chemical components and instrumental textural measurement is limited. The lack of information in these aspects would hinder the efforts of SP breeders and processors in the development

of SPFF with good quality to meet the demands of the consumers.

This chapter aimed to evaluate sensory characteristics of SPFF processed from 16 SP genotypes with varying flesh color, and determine the relationship between sensory attributes, instrumental textural measurement and chemical components to reveal factors affecting textural properties of SPFF. Descriptive sensory analysis (DSA) was conducted and the DSA data was analyzed using principal component analysis to describe sensory characteristics of SPFF.

4.3 Materials and Methods

4.3.1 Materials

All sweetpotatoes (SP) used in this study were grown at the experimental fields of the Sweetpotato Breeding Program (Clinton, NC, USA), North Carolina State University (NCSU). Sixteen genotypes with a wide range of dry matter content and flesh color were selected for the experiments. Of those genotypes, 10 genotypes were orange-fleshed, one was orange/yellow-fleshed, another one was cream-fleshed, and 4 were yellow-fleshed. Nine genotypes (NC08-036, Evangeline, Beauregard, Covington, NC09-122, Porto Rico, NCDM04-197, Suwon122, and NCDM04-001) were harvested in 2014 and stored for 7 month at 14°C, 85-90% relative humidity. Other 7 genotypes (NC13-487, NC05-198, NC13-1012, NC13-1001, NC13-1027, Bonita, and NC13-1004) were harvested in 2015

and stored for 4 month under the same conditions.

Processing of Sweetpotato French Fries

Ten to twelve raw SP roots were randomly selected, washed, tempered in tap water at 70°C for 45 minutes, and cut into 0.9×0.9 cm strips using a manual French fry cutter (model 29, Vollrath, Bloomfield, IN, USA). Strips with skin on the edges were not used in this study and the ends of strips with skins were trimmed off. The strips (1 kg) were blanched in tap water at 75°C for 7 minutes, pre-dried at 65°C for 10 minutes using a convection dryer (Food Dehydrator; The Sausage Maker inc., Buffalo, NY), par-fried in 22 L of canola oil at 185°C for 75 seconds using an electric fryer (1ER50 Series, Vulcan-Hart Co., Louisville, KY, USA), and drained on absorbent paper towels. The par-fried strips were frozen at -20°C until final frying. For final frying, the frozen strips were fried in canola oil at 177°C for 150 seconds using the electric fryer, and drained on absorbent paper towels. SPFF were evaluated by a trained sensory panel 3 minutes after final frying, and the sample temperature was approximately 60°C.

4.3.2 Sensory Analysis

Descriptive sensory analysis (DSA) was conducted to evaluate the sensory textural properties of SPFF. The sensory evaluation was conducted in accordance with the NCSU Institutional Review Board for Human Subjects (IRB) approval. The IRB protocol number was 9010. Fifteen panelists consisting of NCSU graduate students, faculty and

staff were recruited for this study. The sensory panel was trained on sensory texture attributes of SPFF during 12 different days of 1 hour for each training session. During training, commercial SPFF (Alexia Foods, Long Island, NY, USA) and WFFF (Golden Fries, Ore-Ida, Kraft Heinz Co., Pittsburgh, PA, USA) products were provided to develop lexicons. Then, the panel was trained on all developed attributes using various foods to be familiar with the attributes, and then practice samples were shifted to French fries for practice in scaling the attribute intensities (Table B-1). Some attributes and definitions of texture of SPFF were described in previous papers (Walter et al. 1997; Walter et al. 2002). Ten sensory attributes for texture of SPFF were modified or developed by the panel. The ten attributes were grouped into 5 categories which were surface texture (oiliness, roughness), first bite/chew (overall hardness, fracturability, denseness), three chew (outer crispness), initial chewdown (inner smoothness, inner moistness, inner fibrousness), and chewdown (overall cohesiveness of mass) (Table 4-1).

Before conducting DSA for actual SPFF samples, the performance of each panelist including their reproducibility and ability to discriminate between samples was evaluated. Panelist performance was statistically analyzed using analysis of variance (ANOVA) for each attribute and panelist to find panelist interaction. Based on the analysis, 14 panelists were selected (12 women and 2 men, ages 21-56 years) for the sensory evaluation of experimental samples.

In the sample evaluations, 16 SPFF samples were evaluated using a balanced incomplete block (BIB) design for 2 sensory replications. Before evaluating in each session, panelists were calibrated with reference sample of established attributes intensities which was the commercial frozen SPFF product (Alexia Foods, Long Island, NY, USA). The reference sample was fried for 2.5 min at 177°C, drained and waited for 3 min before serving. Panelists evaluated 4 SPFF samples per session, and each sample had 3 random digit code. Napkins, wet wipes and water were provided to clean hands and refresh mouth between samples. For descriptive sensory evaluation, a 15-point numerical scale with 0 = low intensity, 15 = high intensity was adopted, and each panelist used one score sheet for each sample to avoid bias during evaluation (Figure B-1).

4.3.3 Statistical Analysis

Panel mean of DSA data was analyzed using 2 different methods: Analysis of variance (ANOVA) with means comparison by Tukey's test and principal component analysis (PCA). ANOVA and Tukey's test ($\alpha=0.05$) were conducted using SAS software (version 9.4, SAS Institute, Inc., Cary, NC, USA) to determine differences among genotypes for each sensory attribute. PCA using the correlation matrix was conducted to visualize proximity among genotypes based on differences between sensory attributes and samples. PCA was done using XLSTAT 2016 software (Addinsoft, Paris, France).

4.4 Results and Discussion

4.4.1 Texture Characteristics of Sweetpotato French Fries

The 16 SP genotypes produced SPFF with a wide range of sensory texture properties. The mean scores calculated using all data evaluated by the DSA panel for SPFF from the 16 SP genotypes are shown in Table 4-2. Table B-2 shows the mean scores of DSA panel without individual outlier scores which were removed based on the interquartile range (IQR) method. Scored intensities more than 1.5 IQR below the first quartile or above the third quartile was considered as an outlier (Ghasemi and Zahediasl 2012). For surface oiliness, overall hardness and inner moistness, DSA data without individual outlier scores distinguished better than using all DSA data. Meanwhile, all DSA data distinguished fracturability, denseness, outer crispness and inner smoothness better than DSA data without individual outlier scores. Generally, panel mean is calculated using all DSA data, and only scores evaluated by a panelist who has poor performance such as poor reproducibility and poor discrimination between samples are removed from the calculation of panel mean. In this study, some attributes showed better results using all DSA data while other attributes showed better results using DSA data without outlier. Therefore, panel means calculated using all individual panelist attribute scores were selected to discuss the results below since this method is commonly used.

Relationship among the sensory attributes of SPFF samples is shown in Table 4-3.

Overall hardness, fracturability and outer crispness were highly correlated with each other ($r = 0.84-0.96$). Surface oiliness, inner smoothness and inner moistness had positive correlation to each other ($r = 0.74-0.93$). High correlation was also found between inner smoothness and cohesiveness of mass. Meanwhile, overall hardness, fracturability and outer crispness had negative correlation with surface oiliness, inner smoothness and inner moistness. Surface roughness, denseness and fibrousness were not significantly related to all observed sensory attributes.

Figure 4-1 shows a PCA biplot of the SP genotypes based on SPFF texture attributes. A total of 83% of variability was explained by 62% of the principal component (PC) 1 and 20.94% of PC2. Surface oiliness, inner moistness, inner smoothness and cohesiveness of mass were positively loaded on PC1 while overall hardness, fracturability and outer crispness were negatively loaded on PC1. Meanwhile, denseness and fibrousness were positively loaded on PC2 (Table 4-4).

On the PCA biplot of Figure 4-1, SPFF of 8 orange-fleshed genotypes (NC08-036, Evangeline, Beauregard, Covington, NC13-1012, NC09-122, NC13-1001, Porto Rico) were located close together. This means that these 8 genotypes have similar sensory characteristics. These samples had more surface oiliness, inner moistness, inner smoothness and more cohesive in texture, and were less hard, less crispy and easy to be fractured. In addition to the samples from the 8 genotypes, SPFF of NC05-198 was also

loaded on the positive site of PC1, and characterized by high intensity of fibrousness, as well as oiliness, moistness, smoothness and cohesiveness of mass. Samples of Bonita, NC13-1027 and NC13-1004 were close to each other and loaded on the negative PC1 and positive on PC2 coordinates. They were more dense, hard, high fracturability and crispy, and they had less inner smoothness and moistness. Although three yellow fleshed genotypes (NCDM04-197, Suwon122, NCDM04-001) were not located very close to each other, they located on the lower left quadrant, the negative PC1 and negative PC2 coordinates of the PCA biplot. . These SPFF samples were characterized by crispness, fracturability, hardness and surface rough texture but they were not oily, fibrous and moist. On the other hand, the SPFF of NC13-487 was located far from the other genotypes. It means that sensory characteristics of SPFF from this genotype were completely different from other genotypes, and it was considered as a unique genotype. This sample was dense, hard, high fracturability, fibrousness and oiliness, while it was less cohesive. The sensory textural properties of commercial WPF were evaluated during panel training and the data are plotted in PCA. As shown the PCA biplot, WPF was not grouped with SPFF from 16 genotypes (Appendix C).

For consumer preference of SPFF, Walter et al. (1997) reported that consumers prefer caramel flavor, dislike starch flavor, and dislike first-bite moistness and cohesiveness of mass in texture. However, there is no study reporting what textural

characteristics consumers specifically prefer. Sensory consumer preference test is required to find the sensory characteristics that consumers prefer in a future study.

4.4.2 Relationship between Sensory Texture Attributes and Chemical Components

Table 4-5 shows correlation between sensory attributes and chemical components of raw SP and SPFF. Overall hardness, fracturability and outer crispness of SPFF increased with increasing DM, AIS and starch contents in raw SP and SPFF ($r = 0.63-0.97$), while they were decreased with increasing moisture total sugar contents ($r = -0.72 - -0.97$). As presented in Chapter 3, SP genotypes with high DM also had high AIS and starch contents. SPFF with hard texture required more force to be fractured thus high fracturability was found in hard SPFF. Komiyama et al. (2002) reported that WFFF with higher starch content was softer and had more floury texture. According to them, WFFF with 16% starch preferred by consumers among WFFF processed from raw WP with 12%, 14% and 16% starch content in raw WP tubers. In our study, SPFF produced by SP genotypes with 16% starch in raw roots was characterized by high intensities of inner smoothness and cohesiveness of mass and low intensities of denseness, overall hardness and fracturability. Among 16 genotypes, starch contents from SP genotypes of NC13-1001 and Porto Rico were about 16%. Pavlista and Ojala (1997) reported that raw WP with 21-23% DM content had mealy texture and suited for WFFF. In our study, SP

genotypes of Beauregard and Covington had 21-22% DM and their starch contents were about 10%. The SPFF produced from these genotypes had soggy texture as indicated with higher scores on inner smoothness, inner moistness and cohesive and less intensities of denseness, overall hardness and fracturability. Therefore, the difference in starch content and properties between SP and WP varieties with similar DM content could have profound effect on the sensory characteristics of French fries

On the other hand, total sugar content in raw SP and SPFF correlated to smooth and moist texture ($r = 0.77-0.83$) while increase of DM, AIS and starch contents decreased with decreasing intensity of these attributes ($r = -0.78 - -0.91$). Sugars have high water-holding capacity and attract water from the surrounding area possibly explaining the positive correlation between total sugar content and sensory inner moistness. The moistness might associate with the smoothness of interior of SPFF. For fibrousness, DM and AIS contents of raw SP were negatively correlated with sensory fibrousness ($r = -0.71 - -0.72$) while AIS content of SPFF were not significantly correlated ($r = -0.42$). Walter et al. (1997) studied the sensory profile of SPFF, and reported that first-bite hardness was negatively correlated with DM content in SPFF ($r = -0.92$), and first-bite moistness was highly correlated with sugar and AIS contents of raw SP ($r = 0.94-0.97$). The relationships between sugar content and moistness were consistent with the results of our study. However, the sensory perception of texture in relation to DM and AIS contents

were not in agreement with our results. In a study on texture of boiled SP, correlation coefficients of sensory wateriness with DM, and starch contents were $r = -0.60$ and $r = -0.54$, respectively (Laurie et al. 2013). As shown in Table 4-5, the correlations between those chemical components and moistness were higher than the results in the previous study by Laurie et al. (2013).

Denseness was not correlated with any chemical components of raw SP and SPFF since correlation coefficients were low and $p > 0.05$ (Table 4-5, Table B-3). Surface roughness had positive correlation with DM, AIS and starch contents in raw SP and SPFF ($r = 0.56-0.63$, $p < 0.05$) while it was not correlated with total sugar contents in raw SP and SPFF ($r = -0.36 - -0.45$, $p > 0.05$). Although correlation was not strong, cohesiveness of mass was positively correlated with total sugar contents in raw SP and SPFF and moisture content in SPFF ($r = 0.51$, $p < 0.05$), and negatively correlated with AIS content in SPFF ($r = -0.51$, $p < 0.05$). The perception of sensory surface oiliness decreased with increasing DM, AIS and starch contents of raw SP and starch content of SPFF ($r = -0.62 - -0.77$, $p < 0.05$). Oil content in SPFF and sensory perception of surface oiliness showed no relationship to each other ($r = -0.15$, $p > 0.05$). Oil absorption occurs during frying and the oil penetrates into the crevices where water is evaporated. The movement of oil and water occurs on the surface of strips (Miranda and Aguilera 2006; Kato 1997). Amount of oil absorption of strip surface layer and inner is significantly different, and oil

absorption into the outer 1 mm layer is significantly higher than that into the inner core of the strips (O'Connor et al. 2001). Since sensory oiliness is associated with surface texture, it is necessary to examine the relationship between oil content and sensory oiliness of SPFF based on a separate measurement of oil content of the outer and inner layers in the future study. As well as oil content in SPFF, α - and β -amylase activities had no significant correlation with all evaluated sensory texture attributes ($p > 0.05$).

4.4.3 Relationship between Sensory Texture Attributes and Instrumental Measurement

Table 4-6 shows the correlation coefficient between the instrumental textural values (peak force, overall hardness) and 10 sensory attributes. Sensory overall hardness, fracturability and outer crispness were positively correlated with peak force and overall hardness ($r = 0.68-0.96$, $p < 0.05$), and surface oiliness, inner smoothness, inner moistness and cohesiveness of mass had negative correlation with both instrumental values ($r = -0.61 - -0.91$, $p < 0.01$). These high correlations indicate that instrumental measurement could be used as a tool to select genotypes for SPFF. On the other hand, surface roughness, denseness and inner fibrousness had no significant relationship with the values of instrumental measurements ($p > 0.05$). For boiled SP, Laurie et al. (2013) reported a poor correlation coefficients between sensory firmness and instrumental firmness, $r =$

0.47. Walter et al. (2002) studied the texture of restructured SPFF made from SP puree mixed with alginate and calcium sulfate. Sensory test and instrumental measurements including puncture, three-point bending and Kramer shear tests were conducted. They reported that hardness and density were highly correlated with all instrumental measurements ($r = 0.80-0.92$) while cohesiveness, oiliness and moistness were negatively correlated with all instrumental measurements ($r = -0.80 - -0.91$). Although the results of sensory attributes of hardness, cohesiveness, oiliness and moistness agreed with our results, denseness was not consistent with the study by Walter et al. (2002). Denseness had no significant correlation with the values of the instrumental measurements in our study. This could be due to the differences in the product type, restructured SPFF was used in the study by Walter et al. (2002) while SPFF was processed from raw SP in our study. A study on texture of WPFFF indicated that sensory crispness was also highly correlated ($r = 0.76$) with the instrumental measurement using a wedge-shaped probe (Van Loon et al. 2007), which was also consistent with the results of our study.

As mentioned above, NC13-487 had unique texture and it affected correlation between chemical components and sensory attributes, especially overall hardness and fracturability. When NC13-487 was excluded from the analysis, the correlation coefficients between chemical components (DM, AIS, starch, moisture) and sensory attributes of overall hardness and fracturability increased (Table B-4). Although sensory

perceptions of overall hardness, fracturability and outer crispness were correlated to each other, correlation of outer crispness did not change a lot even after removing NC13-487. This could be because the SPFF from NC13-487 were hard but not crispy, and the well-trained sensory panel was able to distinguish the difference. As well as the relationship between chemical components and sensory attributes, the unique texture of NC13-487 also affected correlation between instrumental measurements and sensory attributes. When NC13-487 was removed from the analysis, the correlations between 7 sensory attribute (surface oiliness, overall hardness, fracturability, outer crispness, inner smoothness, inner moistness, cohesiveness of mass) and the instrumental measurements became stronger (Table B-5). Aside from these 7 sensory attributes, sensory fibrousness had negative correlation with the instrumental measurements after removing NC13-487 from the data analysis ($r = -0.68$, $p < 0.01$).

4.5 Conclusion

This is the first study reporting sensory texture characteristics of SPFF evaluated by a well-trained panel and correlations of sensory attributes with chemical components of SP and instrumental texture measurement. Among 16 genotypes, SPFF from 8 orange-fleshed genotypes had similar texture characteristics including surface oiliness, inner moistness, inner smoothness and cohesiveness of mass. Three yellow fleshed

genotypes were characterized by higher crispness, fracturability, hardness and surface roughness. The SPFF sample from NC13-487 was unique as illustrated by the difference from all the other genotypes on the PCA biplot. This sample was perceived as having a burnt exterior with an undercooked interior.

Sensory overall hardness, fracturability and outer crispness were positively correlated with DM, AIS and starch contents of SP. Total sugar and moisture contents contributed to the smooth and moist texture. All measured chemical components had no significant effect on sensory denseness. Therefore, sensory characteristics of SPFF such as overall hardness, fracturability, outer crispness, inner smoothness and inner moistness were profoundly affected by DM, AIS, starch, moisture and total sugar contents in raw SP and SPFF.

Positive correlation was found between instrumental measurements and three sensory attributes including overall hardness, fracturability and outer crispness. Surface oiliness, inner smoothness, inner moistness and cohesiveness of mass were negatively correlated with the instrumental measurements. Therefore, the instrumental measurements can be used as a good tool to select genotype for SPFF.

4.6 References

- Carpena, A.L. 2009. Important cultivars, varieties, and hybrids. In *The sweetpotato*. Springer Netherlands, 27-40
- Du Pont, M.S., Kirby, A.R. and Smith, A.C. 1992. Instrumental and sensory tests of texture of cooked frozen french fries. *International journal of food science & technology*, 27(3), 285-295.
- Economic Research Service, USDA. 2016. *Economic Research Service Vegetable and Pulses Yearbook*. Washington, DC: US Department of Agriculture
- Ghasemi, A. and Zahediasl, S. 2012. Normality tests for statistical analysis: a guide for non-statisticians. *International journal of endocrinology and metabolism*, 10(2), 486-489.
- Kato, K. 1997. Factors affecting the quality of deep fried food on the change of oil from moisture. *Bulletin of Tokyo Kasei University*, 37(2), 33-38.
- Kita, A. and Lisińska, G. 2005. The influence of oil type and frying temperatures on the texture and oil content of French fries. *Journal of the Science of Food and Agriculture*, 85(15), 2600-2604.
- Kirkpatrick, M.E. 1956. *French-frying quality of potatoes: as influenced by cooking methods, storage conditions, and specific gravity of tubers (Vol. 1142)*. US Dept. of Agriculture.
- Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). 2013. Retrieved from <http://faostat3.fao.org>
- Johnson, T., Wilson, N., Worosz, M. R., Fields, D. and Bond, J. K. 2015. *Commodity Highlight: Sweet Potatoes*.
- Johnston, F.B., Kenkars, E. and Nunes, A.C. 1970. Starch and dry matter content of Netted Gem in relation to french fry texture. *American Potato Journal*, 47(3), 87-93.
- Laurie, S.M., Faber, M., Calitz, F.J., Moelich, E.I., Muller, N. and Labuschagne, M.T. 2013. The use of sensory attributes, sugar content, instrumental data and consumer

- acceptability in selection of sweet potato varieties. *Journal of the Science of Food and Agriculture*, 93(7), 1610-1619.
- Leksrisompong, P.P., Whitson, M.E., Truong, V.D. and Drake, M.A. 2012. Sensory attributes and consumer acceptance of sweet potato cultivars with varying flesh colors. *Journal of Sensory Studies*, 27(1), 59-69.
- Miranda, M.L. and Aguilera, J.M. 2006. Structure and texture properties of fried potato products. *Food Reviews International*, 22(2), 173-201.
- O'Connor, C.J., Fisk, K.J., Smith, B.G. and Melton, L.D. 2001. Fat uptake in French fries as affected by different potato varieties and processing. *Journal of food science*, 66(6), 903-908.
- Pavlista, A.D. and Ojala, J.C. 1997. Potatoes: Chip and French fry processing. *Processing Vegetables, Science and Technology*. Lancaster: Technomic Publishing, Inc, 237-284.
- U.S. Sweet Potato Council. 2011. National Sweet Potato News Letter. Retrieved from <http://sweetpotatousa.org/wp-content/uploads/2014/02/SPCNSummer2011.pdf>
- Van het Hof, K.H., Brouwer, I.A., West, C.E., Haddeman, E., Steegers-Theunissen, R.P., van Dusseldorp, M., Weststrate, J.A., Eskes, T.K. and Hautvast, J.G. 1999. Bioavailability of lutein from vegetables is 5 times higher than that of β -carotene. *The American journal of clinical nutrition*, 70(2), 261-268.
- Van Loon, W.A., Visser, J.E., Linssen, J.P., Somsen, D.J., Klok, H.J. and Voragen, A.G. 2007. Effect of pre-drying and par-frying conditions on the crispness of French fries. *European Food Research and Technology*, 225(5-6), 929-935.
- Walter, W.M., Collins, W.W., Truong, V.D. and Fine, T.I. 1997. Physical, compositional, and sensory properties of French fry-type products from five sweetpotato selections. *Journal of Agricultural and Food Chemistry*, 45(2), 383-388.
- Walter, W.M., Truong, V.D. and Espinel, K.R. 2002. Textural measurements and product quality of restructured sweetpotato French fries. *LWT-Food Science and Technology*, 35(3), 209-215.

Table 4-1. Sensory attributes with definitions and techniques for evaluation of sweetpotato French fries

	Attribute	Definition	Technique
Surface Texture	Oiliness	Lack of friction on surface	Press sample between thumb and index finger for 3 seconds (compress sample to 50% of original thickness). Then rub fingers together and evaluate the perception of oiliness.
	Roughness	The perception of deviations in the sample surface often influenced by the overall amount of small and large particles on the surface	Place sample against lips and move sample back and forth across lips; Take note of the perception of deviations in the sample surface.
First Bite / Chew	Hardness (overall)	Amount of force required to compress the sample	Place sample between back molars and compress sample with molars.
	Fracturability	The degree to which the sample fractures (breaks into distinct pieces)	Observe the sample while bending it to cause a break at the center of the fry. Then place sample between back molars and bite at a fast rate.
	Denseness	Compactness of cross section	Place sample between back molars and compress sample with molars. Take note of the perception of the amount/thickness of the material in the middle of the French fry that is not air.
Three Chew	Crispness (outer)	Multiple, higher pitched sounds produced as the sample is crushed with the molar teeth	Place sample between back molars and compress sample slowly. Repeat compression 3 times with the same sample.

Table 4-1(continued). Sensory attributes with definitions and techniques for evaluation of sweetpotato French fries

	Attribute	Definition	Technique
Initial	Smoothness	The degree to which the chewed mass	Break the fry in half and bite from the center portion of fry. Evaluate the texture of the inner part of the fry sample by pressing the mass against palate with tongue and ignoring parts of the mass that are from the fry exterior. Evaluate the perception of the surface texture.
Chewdown	(inner)	surface/surface of individual particles is smooth	
	Moistness	The extent to which the inner section of the fry has a moist or wet texture during mastication	
	(inner)		Break the fry in half and bite from the center portion of fry. Evaluate the texture of the inner part of the fry sample by pressing the mass against palate with tongue and ignoring parts of the mass that are from the fry exterior. Evaluate the perceived amount of moisture in the sample.
	Fibrousness	Amount of stringy fibers perceived in the bolus	Break the fry in half and bite from the center portion of fry. Evaluate the texture of the inner part of the fry sample by pressing the mass against palate with tongue and ignoring parts of the mass that are from the fry exterior. Evaluate the perception of fibers.
	(inner)		
Chewdown	Cohesiveness	The degree to which the chewed sample	Break the fry in half and bite from the center portion of fry. Chew sample five times with molars and use tongue to evaluate the degree to which the pieces of the chewed mass stick to each other.
	of mass	holds together in a mass	
	(overall)		

Table 4-2. Texture attributes of sweetpotato French fries produced from 16 genotypes

Genotype	Flesh color	Surface Oiliness	Surface Roughness	Overall Hardness	Fracturability	Denseness
Reference	orange	12.0	11.0	5.5	2.5	7.5
NC08-036	orange	11.3 ^{abc}	3.8 ^d	1.8 ^g	1.2 ^f	6.0 ^d
Evangeline	orange	10.5 ^{abc}	5.0 ^{abcd}	2.1 ^g	1.6 ^{ef}	5.9 ^d
NC13-487	orange	11.4 ^{abc}	4.3 ^{cd}	9.0 ^a	5.7 ^a	11.0 ^a
NC05-198	orange	12.8 ^a	4.2 ^{cd}	3.1 ^{efg}	1.7 ^{ef}	6.9 ^{bcd}
Beauregard	orange	10.6 ^{abc}	4.4 ^{bcd}	2.8 ^{fg}	2.0 ^{def}	5.8 ^d
Covington	orange	11.3 ^{abc}	4.1 ^d	2.8 ^{fg}	1.1 ^f	6.3 ^d
NC13-1012	orange	11.8 ^{ab}	4.9 ^{abcd}	3.6 ^{efg}	2.0 ^{def}	6.6 ^{bcd}
NC09-122	orange	9.4 ^{bcd}	4.3 ^{cd}	3.8 ^{defg}	2.2 ^{def}	6.4 ^{cd}
NC13-1001	orange	11.4 ^{abc}	6.1 ^a	4.9 ^{cdef}	2.9 ^{cdef}	6.9 ^{bcd}
Porto Rico	orange/yellow	10.6 ^{abc}	5.7 ^{abc}	4.9 ^{cdef}	2.8 ^{cdef}	6.5 ^{bcd}
Bonita	cream	10.5 ^{abc}	4.4 ^{bcd}	5.1 ^{cdef}	2.7 ^{cdef}	8.0 ^b
NC13-1027	orange	9.3 ^{bcd}	5.4 ^{abcd}	6.5 ^{bc}	3.9 ^{bc}	7.8 ^{bc}
NC13-1004	yellow	11.2 ^{abc}	4.5 ^{abcd}	5.4 ^{cde}	3.0 ^{cde}	7.8 ^{bc}
NCDM04-197	yellow	8.9 ^{cd}	5.9 ^{ab}	6.1 ^{bcd}	3.6 ^{bcd}	6.4 ^{cd}
Suwon122	yellow	7.7 ^{de}	5.8 ^{abc}	7.2 ^{abc}	5.2 ^{ab}	6.1 ^d
NCDM04-001	yellow	5.3 ^e	5.0 ^{abcd}	8.4 ^{ab}	6.8 ^a	6.0 ^d

Values within the column having different letters are statistically different ($\alpha=0.05$).

All attributes were evaluated by DSA panel using 15 point scale.

Reference is commercial sweetpotato French fries used for calibration of panelists.

Table 4-2 (continued). Texture attributes of sweetpotato French fries produced from 16 genotypes

Genotype	Outer Crispness	Inner Smoothness	Inner Moistness	Inner Fibrousness	Cohesiveness of Mass
Reference	6.5	10.0	8.0	4.5	8.0
NC08-036	0.8 ^e	10.9 ^a	10.0 ^a	2.9 ^{abc}	7.6 ^{ab}
Evangeline	1.0 ^e	10.7 ^a	9.5 ^{ab}	3.3 ^{abc}	8.1 ^{ab}
NC13-487	2.9 ^{cde}	7.1 ^c	6.6 ^{abc}	5.2 ^a	4.1 ^c
NC05-198	1.7 ^{cde}	9.8 ^a	9.2 ^{efgh}	4.9 ^{ab}	7.9 ^{ab}
Beauregard	1.4 ^{de}	10.4 ^a	7.7 ^{bcdef}	2.7 ^{bc}	9.0 ^a
Covington	1.3 ^{de}	10.7 ^a	8.5 ^{abcde}	3.5 ^{abc}	9.2 ^a
NC13-1012	2.5 ^{cde}	10.2 ^a	8.8 ^{abcd}	3.1 ^{abc}	8.2 ^{ab}
NC09-122	2.0 ^{cde}	10.3 ^a	6.7 ^{defgh}	2.7 ^{bc}	9.0 ^a
NC13-1001	3.8 ^{abc}	9.6 ^{ab}	7.9 ^{abcdef}	3.5 ^{abc}	9.1 ^a
Porto Rico	3.5 ^{bcd}	9.5 ^{ab}	7.2 ^{cdefg}	3.3 ^{abc}	8.2 ^{ab}
Bonita	2.6 ^{cde}	7.2 ^c	5.7 ^{fghi}	2.0 ^c	7.8 ^{ab}
NC13-1027	4.0 ^{abc}	7.0 ^c	5.1 ^{ghi}	3.0 ^{abc}	7.3 ^{ab}
NC13-1004	3.6 ^{bcd}	7.7 ^{bc}	5.9 ^{fghi}	2.0 ^c	8.4 ^{ab}
NCDM04-197	3.6 ^{bcd}	7.2 ^c	4.6 ^{hi}	1.9 ^c	7.1 ^{ab}
Suwon122	5.5 ^{ab}	6.3 ^c	4.2 ^{ij}	1.8 ^c	6.4 ^b
NCDM04-001	6.1 ^a	3.8 ^d	2.4 ^j	1.6 ^c	3.6 ^c

Values within the column having different letters are statistically different ($\alpha=0.05$).

All attributes were evaluated by DSA panel using 15 point scale.

Reference is commercial sweetpotato French fries used for calibration of panelists.

Table 4-3. Correlation coefficients (r) between sensory attributes of sweetpotato French fries

Attribute	Surface Oiliness	Surface Roughness	Overall Hardness	Fracturability	Denseness	Outer Crispness	Inner Smoothness	Inner Moistness	Inner Fibrousness	Cohesiveness of Mass
Oiliness										
Roughness	-0.38									
Hardness	-0.57	0.40								
Fracturability	-0.71	0.39	0.96							
Denseness	0.28	-0.17	0.55	0.38						
Crispness	-0.72	0.65	0.84	0.86	0.09					
Smoothness	0.74	-0.34	-0.90	-0.92	-0.30	-0.87				
Moistness	0.83	-0.42	-0.83	-0.84	-0.13	-0.87	0.93			
Fibrousness	0.68	-0.28	-0.14	-0.22	0.48	-0.46	0.43	0.60		
Cohesiveness	0.57	-0.07	-0.79	-0.87	-0.41	-0.58	0.79	0.59	0.02	

Values in bold indicate strong relationship.

Table 4-4. Factor loading in principal component analysis

Sensory attribute	PC1	PC2
Surface Oiliness	0.82	0.43
Surface Roughness	-0.48	-0.35
Overall Hardness	-0.92	0.35
Fracturability	-0.96	0.22
Denseness	-0.23	0.90
Outer Crispness	-0.93	-0.13
Inner Smoothness	0.97	-0.08
Inner Moistness	0.94	0.15
Inner Fibrousness	0.46	0.76
Cohesiveness of Mass	0.77	-0.42

Table 4-5. Correlation coefficients (r) between chemical components and sensory attributes of sweetpotato French fries of DSA panel produced from 16 genotypes

Attribute	Raw sample					
	DM	AIS	Starch	Sugar	α -amylase activity	β -amylase activity
Surface Oiliness	-0.77	-0.77	-0.62	0.49	0.26	0.37
Surface Roughness	0.58	0.56	0.56	-0.45	-0.13	-0.17
Overall Hardness	0.67	0.68	0.67	-0.75	-0.20	-0.33
Fracturability	0.68	0.71	0.63	-0.72	-0.25	-0.33
Denseness	-0.11	-0.12	0.02	-0.21	-0.10	-0.04
Outer Crispness	0.90	0.90	0.88	-0.76	-0.14	-0.41
Inner Smoothness	-0.81	-0.82	-0.78	0.77	0.24	0.38
Inner Moistness	-0.90	-0.91	-0.86	0.77	0.25	0.47
Inner Fibrousness	-0.72	-0.71	-0.62	0.33	0.23	0.28
Cohesiveness of Mass	-0.39	-0.42	-0.30	0.51	0.27	0.09

All chemical components are fresh basis. DM; dry matter, AIS; alcohol insoluble solid, Sugar; total sugar.

Table 4-5 (continued). Correlation coefficients (r) between chemical components and sensory attributes of sweetpotato French fries of DSA panel produced from 16 genotypes

Attribute	Fried sample				
	Oil	Moisture	AIS	Starch	Sugar
Surface Oiliness	-0.15	0.69	-0.60	-0.77	0.47
Surface Roughness	0.22	-0.68	0.63	0.58	-0.36
Overall Hardness	-0.12	-0.77	0.82	0.69	-0.75
Fracturability	-0.04	-0.79	0.80	0.73	-0.72
Denseness	-0.46	-0.01	0.16	-0.12	-0.30
Outer Crispness	0.13	-0.97	0.97	0.93	-0.77
Inner Smoothness	0.18	0.80	-0.84	-0.83	0.83
Inner Moistness	0.07	0.82	-0.84	-0.90	0.77
Inner Fibrousness	-0.21	0.52	-0.42	-0.66	0.21
Cohesiveness of Mass	0.12	0.51	-0.51	-0.43	0.51

All chemical components are fresh basis. AIS; alcohol insoluble solid, Sugar; total sugar.

Table 4-6. Correlation coefficients (r) between instrumental measurement and sensory attributes of sweetpotato French fries produced from 16 genotypes

Sensory Attribute	Instrumental Measurement			
	Peak Force	p-value	Overall Hardness	p-value
Surface Oiliness	-0.61	0.0121	-0.70	0.0024
Surface Roughness	0.21	0.4293	0.33	0.2134
Overall Hardness	0.92	<.0001	0.95	<.0001
Fracturability	0.94	<.0001	0.96	<.0001
Denseness	0.48	0.0573	0.40	0.1256
Outer Crispness	0.68	0.0040	0.78	0.0003
Inner Smoothness	-0.82	<.0001	-0.90	<.0001
Inner Moistness	-0.73	0.0013	-0.83	<.0001
Inner Fibrousness	-0.06	0.8097	-0.20	0.4503
Cohesiveness of Mass	-0.91	<.0001	-0.89	<.0001

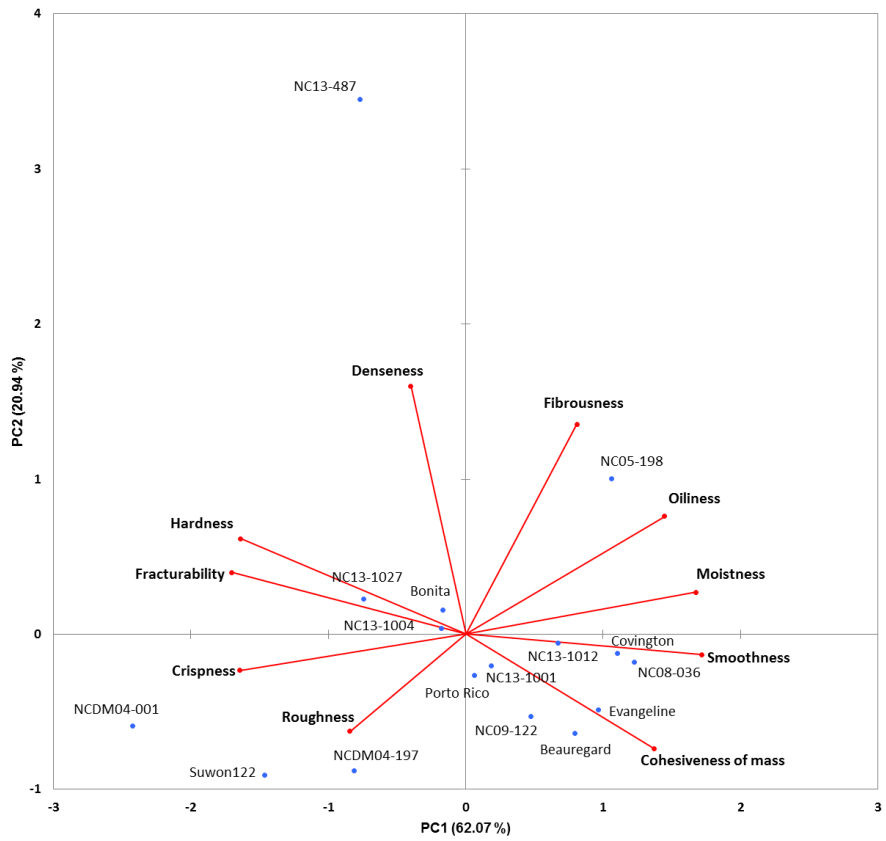


Figure 4-1. Principal Component Analysis of sweetpotato French fries accounting for 83% of the variability in all texture attributes

APPENDICES

Appendix A: Correlations and statistical analysis described in Chapter 3

Table A-1. Correlation coefficients (r) between chemical components and instrumental texture measurement of sweetpotato French fries produced from 15 genotypes (except NC13-487 which had unique texture)

	Peak Force		Overall Hardness	
	Correlation		Correlation	
	Coefficient	p-value	Coefficient	p-value
Dry matter (raw)	0.87	<.0001	0.90	<.0001
AIS (raw)	0.89	<.0001	0.91	<.0001
Starch (raw)	0.74	<.0001	0.79	<.0001
Total sugar (raw)	-0.69	<.0001	-0.71	<.0001
Alpha-amylase activity (raw)	-0.15	0.1849	-0.14	0.2032
Beta-amylase activity (raw)	-0.39	0.0011	-0.37	0.0019
Moisture (fried)	-0.82	<.0001	-0.85	<.0001
Oil (fried)	0.11	0.4207	0.08	0.5340
AIS (fried)	0.78	<.0001	0.82	<.0001
Starch (fried)	0.88	<.0001	0.90	<.0001
Total Sugar (fried)	-0.66	<.0001	-0.68	<.0001

Following SAS code was used to determine correlation discussed in the thesis.

SAS Code:

```
Proc corr;
run;
```

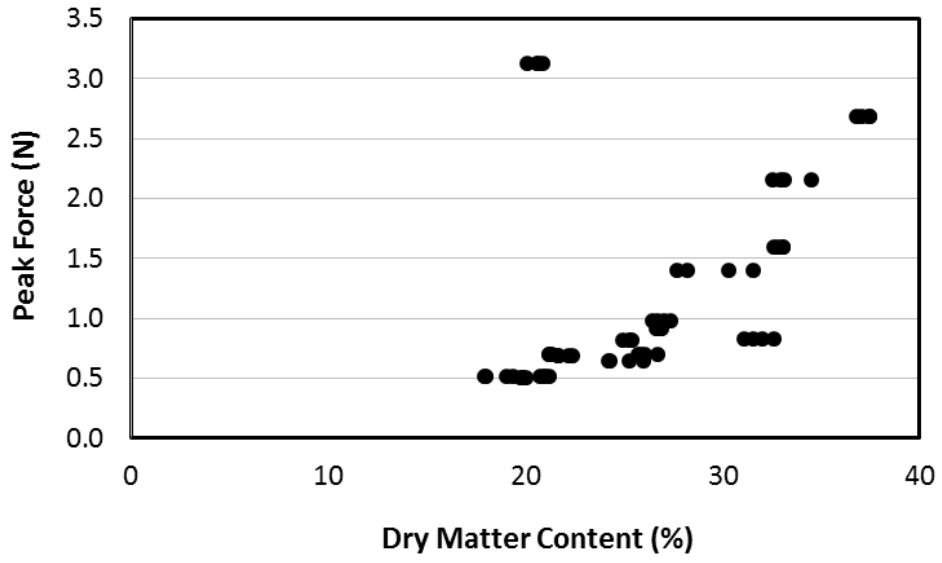


Figure A-1. Correlation between dry matter content in raw SP and peak force of sweetpotato French fries

Appendix B: Sensory panel training, DSA data without outliers, and statistical result described in Chapter 4

Table B-1. List of foods used for training

Sensory Attribute	Practice samples
Surface Oiliness	Water, Mayonnaise, Oil, Chicken nugget, Avocado
Surface Roughness	Gelatin dessert, Potato chip, Fresh orange peel, Hard granola bar, Melba toast
Overall Hardness	Cream cheese, Hebrew National Hotdog, Almonds, American processed cheese, Peanuts
Fracturability	Corn muffin, Graham crackers, Ginger snaps, Life Saver
Denseness	Cool whip, Malted milk ball, Frankfurter, Marshmallow Fluff, Fruit jellies
Outer Crispness	Gala apple, Water chestnut, Granola bar, Corn flakes
Inner Smoothness	Parmesan cheese, Muenster cheese, Process cheese, Cheddar cheese, Gelatin dessert, Crouton, Nature's Own whole wheat bread
Inner Moistness	Baked potato, Baked orange sweetpotato, Banana, Avocado, Peer in jar,
Inner Fibrousness	Silken tofu, Baked orange sweetpotato, Boiled asparagus (bottom 3 inches), Gelatin dessert, Celery
Cohesiveness of Mass	Licorice, Frankfurter, Fig Newton, Baby carrots, American processed cheese

The practice samples were used to be familiar with each sensory attribute during training sessions. No specific degree of intensity (number) was not provided.

Table B-2. Panel mean of DSA of sweetpotato French fries calculated without individual outlier scores

Genotype	Surface	Surface	Overall	Fracturability	Denseness
	Oiliness	Roughness	Hardness		
NC08-036	11.4 ^{ab}	3.8 ^c	1.6 ^g	0.8 ^e	6.0 ^e
Evangeline	10.5 ^{abc}	5.0 ^{abc}	1.8 ^g	1.1 ^e	5.8 ^e
NC13-487	11.4 ^{ab}	4.5 ^{abc}	8.7 ^a	5.5 ^{ab}	11.0 ^a
NC05-198	12.8 ^a	4.2 ^{abc}	3.0 ^{efg}	1.7 ^{de}	7.1 ^{bcde}
Beauregard	10.6 ^{abc}	4.4 ^{abc}	2.8 ^{fg}	1.6 ^{de}	5.8 ^e
Covington	11.3 ^{ab}	4.1 ^{bc}	2.8 ^{fg}	1.1 ^e	6.3 ^{cde}
NC13-1012	11.9 ^{ab}	5.2 ^{abc}	3.6 ^{defg}	2.0 ^{de}	6.8 ^{bcde}
NC09-122	9.7 ^{bc}	4.3 ^{abc}	3.8 ^{defg}	2.2 ^{de}	6.4 ^{cde}
NC13-1001	11.7 ^{ab}	6.1 ^a	4.5 ^{cdef}	2.9 ^{cde}	6.6 ^{bcde}
Porto Rico	10.5 ^{abc}	5.7 ^{abc}	4.9 ^{cdef}	2.7 ^{cde}	6.7 ^{bcde}
Bonita	10.5 ^{abc}	4.1 ^{bc}	5.1 ^{bcde}	2.6 ^{de}	8.1 ^b
NC13-1027	9.3 ^{bc}	5.4 ^{abc}	6.4 ^{bc}	3.5 ^{bcd}	7.8 ^{bcd}
NC13-1004	11.2 ^{ab}	4.2 ^{abc}	5.4 ^{bcd}	3.3 ^{cd}	7.9 ^{bc}
NCDM04-197	9.1 ^{bc}	5.9 ^{ab}	6.2 ^{bc}	3.6 ^{bcd}	6.4 ^{cde}
Suwon122	7.7 ^{cd}	5.8 ^{abc}	7.3 ^{ab}	4.7 ^{abc}	6.1 ^{de}
NCDM04-001	5.0 ^d	5.0 ^{abc}	8.8 ^a	6.8 ^a	6.6 ^{bcde}

Values within the column having different letters are statistically different ($\alpha=0.05$).

Table B-2 (continued). Panel mean of DSA of sweetpotato French fries calculated without individual outlier scores

Genotype	Outer Crispness	Inner Smoothness	Inner Moistness	Inner Fibrousness	Cohesiveness of Mass
NC08-036	0.8 ^e	10.9 ^a	10.1 ^a	2.9 ^{abcd}	7.6 ^{abc}
Evangeline	0.9 ^{de}	11.2 ^a	9.5 ^{ab}	3.3 ^{abcd}	8.1 ^{abc}
NC13-487	2.9 ^{bcde}	7.6 ^{bc}	6.8 ^{cdef}	5.2 ^a	4.0 ^d
NC05-198	1.5 ^{bcde}	9.9 ^{ab}	9.2 ^{abc}	4.9 ^{ab}	7.9 ^{abc}
Beauregard	1.3 ^{bcde}	11.1 ^a	7.7 ^{bcd}	2.5 ^{bcd}	9.0 ^{ab}
Covington	1.0 ^{cde}	10.8 ^a	8.5 ^{abc}	3.5 ^{abc}	9.3 ^a
NC13-1012	2.5 ^{bcde}	10.2 ^{ab}	8.8 ^{abc}	3.0 ^{abcd}	8.4 ^{abc}
NC09-122	1.9 ^{bcde}	10.4 ^a	6.9 ^{cdef}	2.7 ^{abcd}	9.0 ^{ab}
NC13-1001	3.8 ^{ab}	10.0 ^{ab}	7.9 ^{abcd}	3.5 ^{abc}	8.8 ^{ab}
Porto Rico	3.5 ^{abcd}	9.9 ^{ab}	7.2 ^{bcde}	3.1 ^{abcd}	8.0 ^{abc}
Bonita	2.6 ^{bcde}	7.2 ^c	5.7 ^{defg}	1.9 ^{cd}	7.8 ^{abc}
NC13-1027	3.7 ^{ab}	7.0 ^c	5.1 ^{efg}	3.0 ^{abcd}	7.1 ^{bc}
NC13-1004	3.6 ^{abc}	7.7 ^{bc}	5.9 ^{defg}	2.0 ^{cd}	8.6 ^{ab}
NCDM04-197	3.6 ^{abc}	7.2 ^c	4.4 ^{fgh}	1.7 ^{cd}	7.0 ^{bc}
Suwon122	5.6 ^a	6.0 ^{cd}	4.2 ^{gh}	1.8 ^{cd}	6.4 ^c
NCDM04-001	5.8 ^a	3.8 ^d	2.4 ^h	0.9 ^d	3.4 ^d

Values within the column having different letters are statistically different ($\alpha=0.05$).

Table B-3. p-value of correlation between chemical components and sensory attributes of sweetpotato French fries produced from 16 genotypes

Attribute	Raw sample						Fried sample				
	DM	AIS	Starch	Sugar	α -amylase activity	β -amylase activity	Oil	Moisture	AIS	Starch	Sugar
Surface Oiliness	0.0005	0.0004	0.0109	0.0536	0.3320	0.1556	0.5803	0.0032	0.0148	0.0005	0.0631
Surface Roughness	0.0193	0.0230	0.0246	0.0809	0.6189	0.5297	0.4138	0.0037	0.0088	0.0178	0.1719
Overall Hardness	0.0048	0.0038	0.0048	0.0009	0.4496	0.2082	0.6655	0.0004	<.0001	0.0030	0.0009
Fracturability	0.0038	0.0022	0.0085	0.0015	0.3490	0.2105	0.8939	0.0003	0.0002	0.0014	0.0017
Denseness	0.6935	0.6524	0.9410	0.4402	0.7186	0.8760	0.0725	0.9592	0.5423	0.6704	0.2614
Outer Crispness	<.0001	<.0001	<.0001	0.0007	0.6128	0.1122	0.6317	<.0001	<.0001	<.0001	0.0005
Inner Smoothness	0.0001	0.0001	0.0004	0.0004	0.3705	0.1443	0.4942	0.0002	<.0001	<.0001	<.0001
Inner Moistness	<.0001	<.0001	<.0001	0.0005	0.3411	0.0680	0.7875	<.0001	<.0001	<.0001	0.0005
Inner Fibrousness	0.0018	0.0022	0.0099	0.2152	0.3827	0.2947	0.4326	0.0407	0.1079	0.0054	0.4391
Cohesiveness of Mass	0.1372	0.1091	0.2561	0.0449	0.3170	0.7450	0.6629	0.0432	0.0428	0.0982	0.0433

All chemical components are fresh basis. DM is dry matter. AIS is alcohol insoluble solid. Sugar is total sugar.

Table B-4. Correlation coefficients (r) between chemical components and sensory attributes of sweetpotato French fries produced from 15 genotypes (except NC13-487 which had unique texture)

Attribute	Raw sample				α -amylase activity	β -amylase activity
	DM	AIS	Starch	Sugar		
Surface	-0.76	-0.77	-0.60	0.53	0.28	0.36
Oiliness	0.0010	0.0008	0.0174	0.0422	0.3196	0.1856
Surface	0.55	0.54	0.54	-0.50	-0.15	-0.15
Roughness	0.0323	0.0366	0.0394	0.0595	0.5863	0.5893
Overall	0.97	0.94	0.94	-0.79	-0.20	-0.45
Hardness	<.0001	<.0001	<.0001	0.0005	0.4852	0.0905
Fracturability	0.91	0.91	0.84	-0.74	-0.24	-0.42
	<.0001	<.0001	0.0001	0.0016	0.3790	0.1188
Denseness	0.23	0.13	0.41	-0.15	-0.07	-0.25
	0.4166	0.6565	0.1268	0.5909	0.7990	0.3733
Outer	0.94	0.92	0.90	-0.76	-0.14	-0.42
Crispness	<.0001	<.0001	<.0001	0.0009	0.6256	0.1239
Inner	-0.92	-0.90	-0.87	0.76	0.23	0.41
Smoothness	<.0001	<.0001	<.0001	0.0010	0.4070	0.1249
Inner	-0.94	-0.94	-0.89	0.77	0.25	0.47
Moistness	<.0001	<.0001	<.0001	0.0007	0.3629	0.0743
Inner	-0.72	-0.73	-0.62	0.52	0.34	0.27
Fibrousness	0.0026	0.0021	0.0143	0.0493	0.2179	0.3335
Cohesiveness	-0.67	-0.67	-0.54	0.52	0.28	0.18
of Mass	0.0058	0.0062	0.0390	0.0486	0.3193	0.5200

All chemical components are fresh basis. DM is dry matter. AIS is alcohol insoluble solid. Sugar is total sugar.

Values on the top show correlation coefficient. Values on the bottom show p-value.

Table B-4 (continued). Correlation coefficients (r) between chemical components and sensory attributes of sweetpotato French fries produced from 15 genotypes (except NC13-487 which had unique texture)

Attribute	Fried sample				
	Oil	Moisture	AIS	Starch	Sugar
Surface Oiliness	- 0.12	0.69	- 0.61	- 0.76	0.50
	0.6705	0.0044	0.0164	0.0010	0.0603
Surface Roughness	0.19	- 0.69	0.65	0.56	- 0.38
	0.5074	0.0047	0.0091	0.0292	0.1581
Overall Hardness	- 0.02	- 0.93	0.95	0.96	- 0.83
	0.9496	<.0001	<.0001	<.0001	0.0001
Fracturability	0.06	- 0.90	0.89	0.94	- 0.76
	0.8405	<.0001	<.0001	<.0001	0.0009
Denseness	- 0.55	- 0.11	0.29	0.15	- 0.44
	0.0322	0.7077	0.2991	0.5945	0.0991
Outer Crispness	0.13	- 0.97	0.97	0.96	- 0.77
	0.6372	<.0001	<.0001	<.0001	0.0008
Inner Smoothness	0.15	0.83	- 0.86	- 0.91	0.83
	0.5929	0.0001	<.0001	<.0001	0.0001
Inner Moistness	0.07	0.83	- 0.84	- 0.93	0.77
	0.8104	0.0002	0.0001	<.0001	0.0007
Inner Fibrousness	- 0.12	0.60	- 0.52	- 0.66	0.31
	0.6730	0.0186	0.0467	0.0069	0.2639
Cohesiveness of Mass	0.01	0.65	- 0.61	- 0.69	0.57
	0.9810	0.0083	0.0156	0.0042	0.0268

All chemical components are fresh basis. DM is dry matter. AIS is alcohol insoluble solid. Sugar is total sugar.

Values on the top show correlation coefficient. Values on the bottom show p-value.

Table B-5. Correlation coefficients (r) between instrumental measurement and sensory attributes of sweetpotato French fries produced from 15 genotypes (except NC13-487 which had unique texture)

Sensory Attribute	Instrumental Measurement			
	Peak Force	p-value	Overall Hardness	p-value
Surface Oiliness	- 0.93	<.0001	- 0.91	<.0001
Surface Roughness	0.45	0.0920	0.50	0.0580
Overall Hardness	0.89	<.0001	0.93	<.0001
Fracturability	0.96	<.0001	0.96	<.0001
Denseness	0.11	0.6992	0.01	0.9645
Outer Crispness	0.87	<.0001	0.89	<.0001
Inner Smoothness	- 0.91	<.0001	- 0.94	<.0001
Inner Moistness	- 0.91	<.0001	- 0.93	<.0001
Inner Fibrousness	- 0.68	0.0055	- 0.67	0.0059
Cohesiveness of Mass	- 0.87	<.0001	- 0.86	<.0001

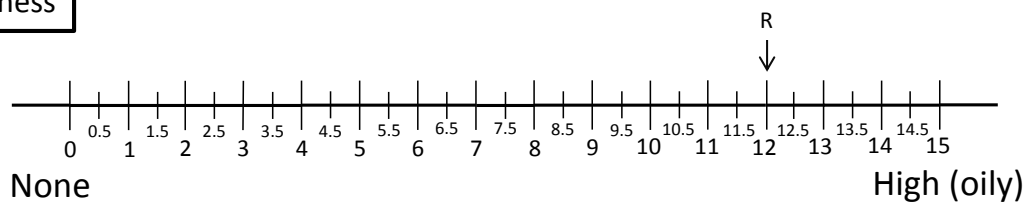
Table B-6. Analysis of Variance (ANOVA) table for DSA data

Attribute	ANOVA Sum				
	DF	of Squares	Mean Square	F Value	Pr > F
Surface Oiliness	15	97.7087500	6.5139167	14.38	<.0001
Surface Roughness	15	15.69968750	1.04664583	6.55	0.0003
Overall Hardness	15	15.69968750	1.04664583	6.55	0.0003
Fracturability	15	82.30968750	5.48731250	28.74	<.0001
Denseness	15	50.16468750	3.34431250	24.72	<.0001
Outer Crispness	15	71.29875000	4.75325000	12.89	<.0001
Inner Smoothness	15	129.5921875	8.6394792	28.65	<.0001
Inner Moistness	15	133.7887500	8.9192500	29.98	<.0001
Inner Fibrousness	15	31.20875000	2.08058333	5.84	0.0006
Cohesiveness of Mass	15	81.51000000	5.43400000	17.35	<.0001

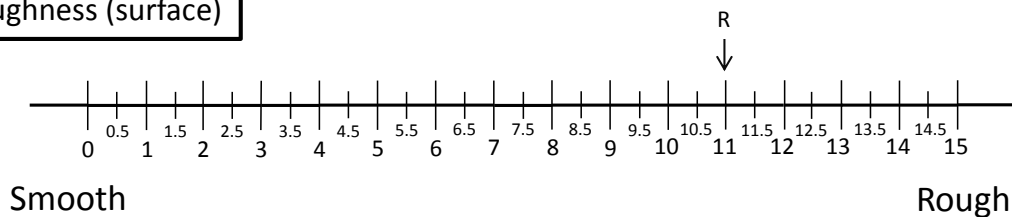
Sample ID: 738

Panelist #: _____

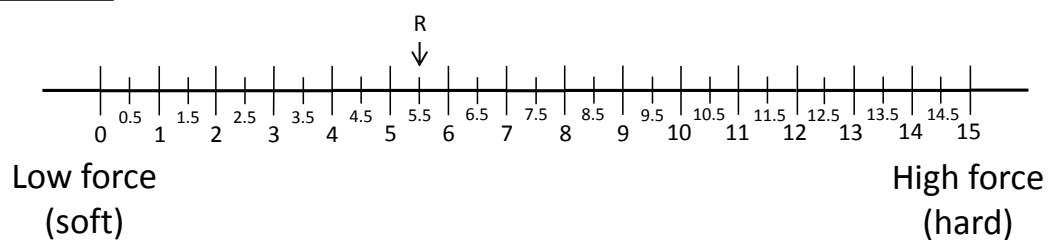
Oiliness



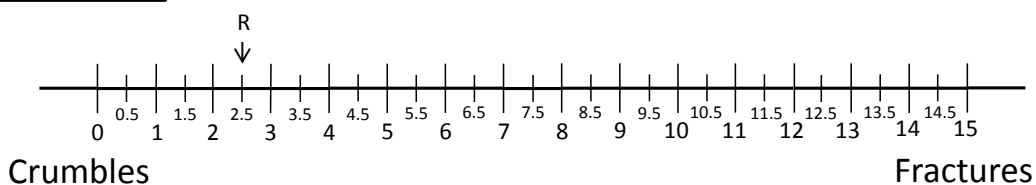
Roughness (surface)



Hardness



Fracturability



Denseness

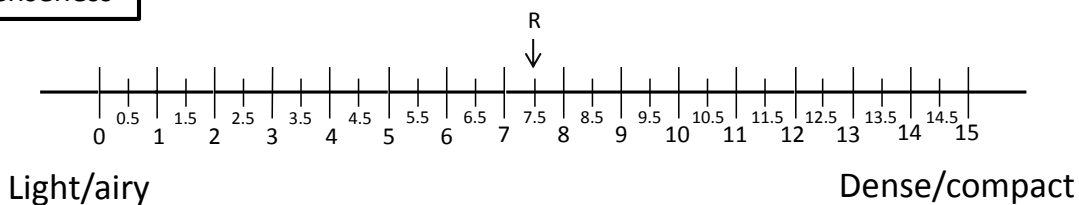
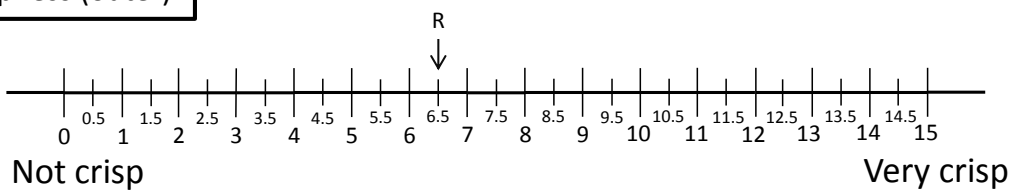


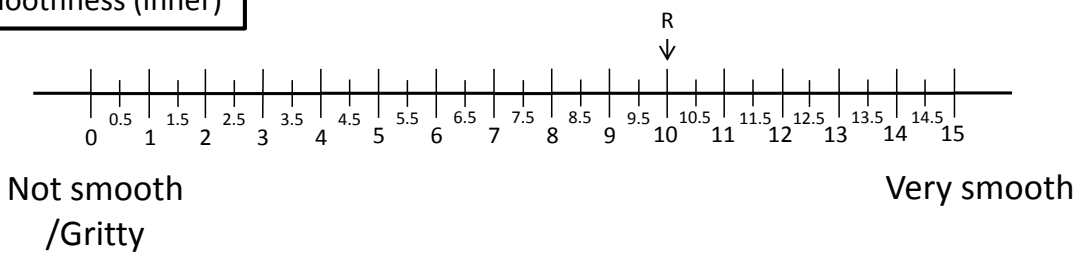
Figure B-1. Score sheet of DSA panel

R is a reference sample used for calibration.

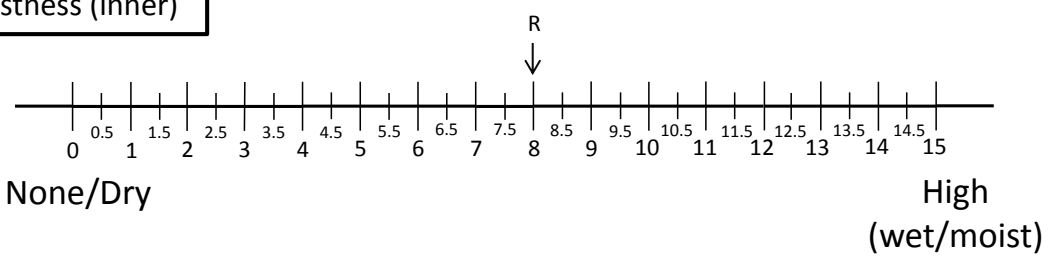
Crispness (outer)



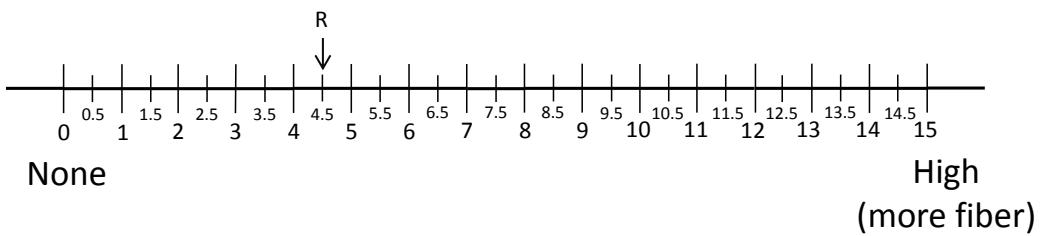
Smoothness (inner)



Moistness (inner)



Fibrousness (inner)



Cohesiveness of mass

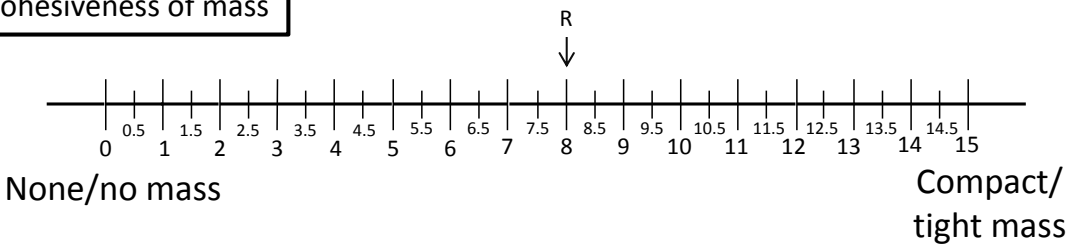
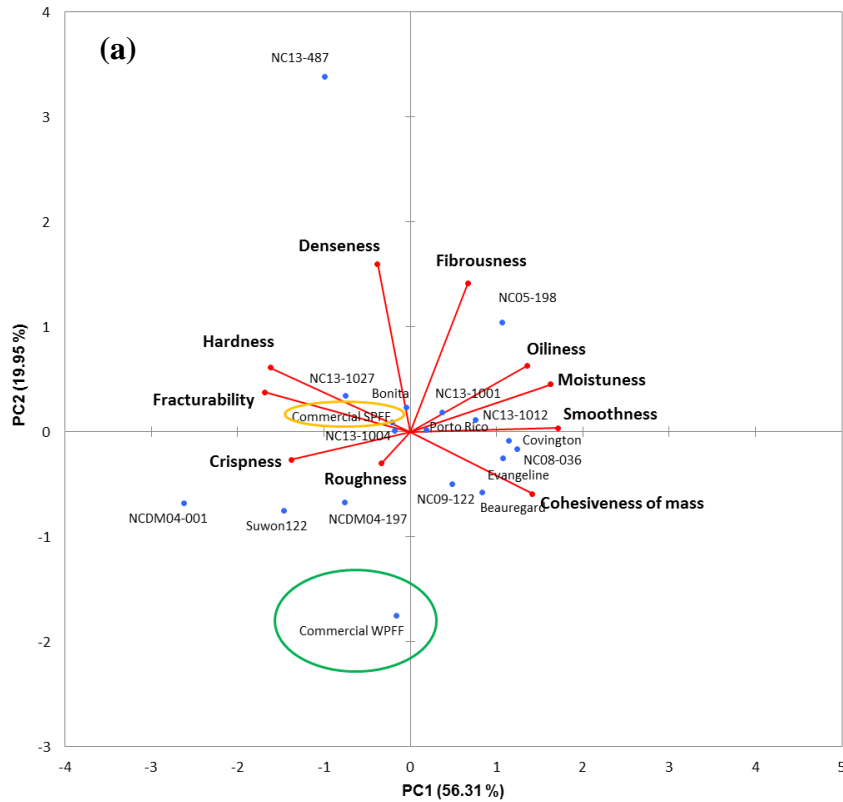


Figure B-1 (continued). Score sheet of DSA panel

R is a reference sample used for calibration.

Appendix C: Sensory textural characteristics of commercial white potato French fries and commercial sweetpotato French fries

The commercial sweetpotato French fries (SPFF) (Alexia Foods, Long Island, NY, USA) were used as a reference sample to calibrate panelists before sample evaluations and the intensities of sensory attributes of the commercial SPFF were established. The commercial white potato French fries (WPF) (Golden Fries, Ore-Ida, Kraft Heinz Co., Pittsburgh, PA, USA) were evaluated during panel training, and the panelists were semi-trained (not fully trained) at the point. Therefore, Figure C-1 just gives some ideas of textural properties of the WPF. The sample was evaluated by 15 semi-trained panel (13 women and 2 men, ages 21-56 years).



(b)

Genotype	Surface Oiliness	Surface Roughness	Overall Hardness	Fracturability	Denseness	Outer Crispness	Inner Smoothness	Inner Moistness	Inner Fibrousness	Cohesiveness of mass
Commercial WPF	11.4	6.9	3.9	2.4	4.2	4.2	7.7	5.2	1.2	7.6
Commercial SPFF	12.0	11.0	5.5	2.5	6.5	6.5	9.0	7.5	4.5	8.0

Figure C-1. Sensory textural characteristics of commercial white potato French fries and commercial sweetpotato French fries

(a): Principal Component Analysis of DSA panel for of sweetpotato French fries and commercial white potato French fries

(b): Panel means of semi-trained DSA panel for commercial white potato French fries and commercial sweetpotato French fries

Sensory texture characteristics of the commercial SPFF (circled in orange color) were similar to those of SPFF produced from Bonita, NC13-1003 and NC13-1027, that were characterized by high intensities of overall hardness, fracturability and denseness.

The WPF (circled in green color) was crispy and has rough surface while it was

less oily, perceived fiber and moist. The characteristic of the WPFF was not similar to any of sweetpotato French fries (SPFF) from 16 genotypes since it located far from all other SP genotypes.

For SPFF, if the hardness was similar to each other, other sensory attributes such as smoothness and fibrousness were similar too, that resulted in similar overall texture. However, if WPFF had similar hardness to some of SPFF, other sensory attributes such as smoothness and fibrousness were different from those SPFF. This could be because white potato and sweetpotato are different botanically. White potato is a tuber while sweetpotato is a root. Therefore, sensory characteristic of the WPFF was not similar to the all SPFF.