ABSTRACT

ULUS, HANDE ZEYNEP. Baked Sweet Potato Chip Nutrition and Processing. (Under the direction of Dr. Jonathan C Allen).

With increasing production, demand, and product variety, the sweet potato market is growing. Due to its unique nutritional qualities, sweet potato is a staple food that provides food security in times of famine, natural disasters, and war. Sweet potato is also an underutilized versatile food that is gaining a relatively new interest in the industry that is driven by the demand for healthier snacks.

Orange-fleshed sweet potato is a good source of β-carotene, a vitamin A precursor. β-carotene is heat, light, and oxygen labile, therefore the β-carotene retention during the heat processing is affected by the method of cooking. Acrylamide is an unwanted by-product that is formed during heat treatment in food and it is classified as a "probable human carcinogen" and a neurotoxin. This study aimed to evaluate the effect of cooking method and time-temperature combination on moisture content, β-carotene retention, color, texture, acrylamide formation, and carbohydrate digestion of sweet potato chips.

In this study, we used Covington variety orange-fleshed sweet potato to prepare chips. Chips were cooked with air fryers, radiant ovens, convection ovens, and a microwave and were compared to the commercial deep-fried sweet potato chips. Moisture content was determined by oven drying. Color measurement was done with ColorFlex EZ Spectrophotometer (Hunter Associates Laboratory Inc., VA, USA) to obtain L*, a*, and b* values. β-carotene measurement was carried out by acetone:hexane extraction and absorbance measurement at 450 nm. Proximate analysis was done by Microbac Laboratories (Warrendale, PA). Texture analysis was completed with TA.TX2 Texture Analyzer (Stable Micro Systems, Godalming, UK). Acrylamide was measured with Acrylamide-ES ELISA, Microtiter Plate (Eurofins – Abraxis, Warminster, USA).

Multimode SPE column and Biotage ENV+ SPE columns were used for the clean-up procedure. *In vitro* Carbohydrate digestion was based on a previously developed procedure by Argyi et. al. with modifications. Data were analyzed by using *stats, rstatix, tidyverse, ggpubr,* and *ggplot2* packages in R Statistical Software to perform one-way, two-way, and three-way mixed ANOVA.

First part of our study showed that based on the moisture content, air fryers produced more consistent chips when compared to oven baking and microwaving across the temperature levels. We also observed that air-fried chips were similar to deep-fried chips in terms of texture. Proximate analysis results showed that, baked, air fried, and microwaved chips have less fat than commercial fried chips. Our analysis showed that microwaved chips retained more β-carotene compared to other cooking methods, which agrees with the literature on microwave treatment and retention of nutrients. Our results indicated that acrylamide levels were significantly higher when chips were cooked at a higher temperature for a shorter time. Even though it is not statistically significant, commercial chips formed more acrylamide than all other cooking treatments. Carbohydrate digestion results showed that commercial fried chips yielded more bioaccessible glucose than baked, air fried, and microwaved chips.

Baked Sweet Potato Chip Nutrition and Processing

by
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DEDICATION

This dissertation is dedicated to my family. My parents, Hayriye and Rahmi, and my sister Ozge. Thank you for your endless support and encouragement. I love and appreciate you.

BIOGRAPHY

Hande Ulus was born in Samsun, Turkey. She moved to the capital of Turkey, Ankara, to study Nutrition and Dietetics. Upon graduating in 2015, she moved to Raleigh to study Nutrition Science at North Carolina State University with a Fulbright scholarship. She continued her studies in Nutrition Science at NCSU to obtain a Ph.D. While doing her research she completed the requirements to become an International Board-Certified Lactation Consultant. A few years, kilos of sweet potato, and a pandemic later she is completing the workload for her Ph.D. She will continue to do research at *Plants for Human Health Institute* as a postdoctoral researcher in Eroglu Lab.

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CHAPTER 1: INTRODUCTION

Sweet potato (Ipomoea batatas [L.] Lam) is an important crop both nutritionally and economically. It is the fifth most important food crop worldwide after rice, maize, wheat, and potatoes in 2020 with world production volume of 89.49 million tons and the global market value of 42.75 billion US dollars (FAOSTAT, 2022; Statista, n.d.). Sweet potato is versatile, resilient, and underutilized. It can be harvested year around in frost-free climates. It has edible storage roots, leaves, and shoots that provide nutrition for people and livestock (Bovell-Benjamin, 2007; Low, 2018). It can grow in the altitudes up to 2500 m (CIP, n.d.). It tolerates severe weather and poor soil conditions well, compared to other staple foods sweet potato loses much less of its yield due to drought stress (Loebenstein & Thottappilly, 2009; Motsa et al., 2015).

Sweet potato requires less input, less maintenance, and matures fast compared to other staple crops and is a good source of nutrition, especially for people in developing countries (Woolfe, 1992). As a biofortified food, 100 grams of orange-fleshed sweet potato can provide enough provitamin-A to meet a preschooler's needs (Low et al., 2017; Mbabu et al., 2012; Stathers et al., 2013). Vitamin A has important roles in cellular differentiation, immunity, metabolism, growth and development, vision, and reproductive functions (Hodge & Taylor, 2022).

Sweet potato has a unique nutritional matrix. The roots contain large amounts of starch and is rich in minerals and vitamins such as potassium, phosphorus, calcium, magnesium, iron, copper, thiamin, riboflavin, niacin, pantothenic acid, folic acid, vitamin E, a variety of phenolic compounds, carotenoids and bioactive components that have numerous health benefits such as

antioxidant, hepatoprotective, anti-inflammatory, antitumor, antidiabetic, antimicrobial, and antiobesity effects (Truong et al., 2018; Wang et al., 2016; Woolfe, 1992)

In contrast to sweet potato use as a main source of nutrition in developing countries, it is commonly used as a side dish or a snack in developed countries. In the U.S. sweet potato production increased significantly for the last 20 years and reached 30.67 million hundredweight in 2020 with an estimated value of $726.2 million (AGMRC, 2021). Sweet potato consumption nearly doubled between 1999 to 2019 and from 3.8 pounds/year/per capita 7.1 pounds/year/per capita (USDA, 2020).

Sweet potatoes are consumed boiled, steamed, baked, dried, and fried or added to other recipes in home settings. In industry, especially in China, half of the sweet potato production is used to extract starch. Sweet potato starch is extracted to be added into staple food such as traditional noodles, vermicelli, bread, pancakes, or converted into glucose syrup. Sweet potatoes make a variety of snack foods. Sweet potato chips, roasted sweet potatoes, mashed sweet potatoes, biscuits, extruded snacks, and dried slices; bakery products such as bread, puffs, muffins, cakes, and doughnuts are produced from sweet potatoes (Mu & Singh, 2019; Mu et al., 2017).

One concern with the production of starchy snack foods is the potential creation of acrylamide during processing. Acrylamide ($CH2 = CHONH_2$) is a water-soluble, vinyl monomer. In 1994, acrylamide was classified as a “probable human carcinogen” and a neurotoxin by IARC due to its carcinogenic effect on animals and neurological symptoms of workers who handled acrylamide (Smith et al., 1991; Tornqvist, 2005). In 2002, presence of acrylamide was reported in food (Mottram et al., 2002; Tareke et al., 2002).

Acrylamide is produced in the food mainly due to the Maillard reaction between asparagine and reducing sugars at high temperatures (above 120 ˚C / 250 ˚F) (Mogol & Gökmen, 2016). Unfortunately, asparagine is in abundance in potato tubers. Therefore, french fries and chips are on the top of the list of foods that yield acrylamide and are the main source of acrylamide in diets. FDA published a guideline to reduce acrylamide production in industry and at-home settings however, currently there are no regulations on the acrylamide content of food in the U.S. In 2017, The European Commission set benchmark levels for certain food products. These levels are not enforced yet but in 2019 they started a program to set maximum levels on certain foods.

There is research effort on mitigation of acrylamide content for many food products. Type of oil, cooking temperature, pre-thawing, vacuum frying and air frying are among the interventions that showed reduction in acrylamide content (Granda & Moreira, 2005; Lim et al., 2014; Palazoğlu & Gökmen, 2008; Sansano et al., 2015; Tuta et al., 2010).

Majority of the sweet potato snack foods available in the market are deep-fried sweet potato chips or par-fried sweet potato fries. At home, ovens, air friers and microwaves can be used to make sweet potato snack food that would contain less acrylamide as well as less oil. Cooking method affects the taste, texture, appearance, nutrient retention, and nutrient availability of foods. Each cooking method has its advantages and limitations. Air friers are advertised for making low-fat fries that have similar taste, texture and appearance as their deep-fried counterparts (McFadden, 2006). Microwaves on the other hand are energy-efficient, less time-consuming, faster heating, and require less maintenance (Sumnu, 2001). Microwave processing can increase nutrient retention as well, but its caveat is uniform heating (Datta et al., 2001; Tian et al., 2016). Cooking method also affects glucose availability. Glycemic index of sweet potato

was shown to change with cooking method (Allen et al., 2012). Comparison of the in vitro digestion of different cooking methods could give us an idea about how cooking method affects glucose release.

Therefore, the objectives of this study were: (1) Investigate alternative methods for processing sweet potato into a baked chip with lower fat content. (2) Contrast the nutrient content of sweet potato chips that were processed with different cooking methods and commercially available fried sweet potato chips. (3) Quantify the effects of these processing methods on nutrient claims made for marketing NC Sweet Potatoes. (4) Measure acrylamide levels of the chips that were processed with different cooking methods. (5) Subject the sweet potato chips to an in vitro digestion procedure and compare glucose levels of chips produced with different cooking methods.

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CHAPTER 2: LITERATURE REVIEW

Sweet Potato

Origin

Sweet potato (*Ipomoea batatas* [L.] Lam) is a dicotyledonous plant with storage roots in the *Convolvulaceae (*Morning glory*)* botanical family. Sweet potatoes are not to be confused with potato (*Solanum tuberosum*) which is a thickened stem in the *Solanaceae* family and botanically unrelated although their uses can be similar. Orange-fleshed sweet potatoes are often referred to as yams in the US even though they are different from true yams (*Dioscorea* sp.) (Mu & Singh, 2019). Sweet potato is believed to originate in tropical America between the Yucatan Peninsula (Mexico) and Orinoco River (Venezuela) 5000 years ago (Austin, 1987). The sweet potato then was introduced to Europe in 1492 by Columbus and to Africa, India, Southeast Asia, and the East Indies in the 16th century by Portuguese explorers (Loebenstein & Thottappilly, 2009).

Importance and Characteristics

In 2020, sweet potato was ranked the fifth most important food crop worldwide after rice, maize, wheat, and potatoes (*FAOSTAT*, 2022). Sweet potatoes vary enormously in physical properties such as leaf shape and color, vine structure, taste, texture, resistance to pests and diseases, and yield (Stathers et al., 2013). It has very nutritious roots that have skin that is yellow, red, orange, purple, brown, or beige and has flesh that is white, red, pink, violet, yellow, orange, purple, or beige depending on the cultivar (Loebenstein & Thottappilly, 2009).

Sweet potato is an important, underutilized, versatile crop. Storage roots, leaves, and shoots are edible and most of the parts can be used in a variety of ways for both human and

livestock consumption. Sweet potato vines can provide a high protein animal feed for dairy animals. Vines and small roots can be used to make silage to store for months and provide a high protein animal feed throughout the year (Low, 2018). In developing countries, as a biofortified crop with high β-carotene content, orange-fleshed sweet potato has a significant role in the fight against Vitamin A deficiency (Low et al., 2017; Neela & Fanta, 2019). One hundred grams of orange-fleshed sweet potato provides enough provitamin A to meet a preschooler's needs and reduces the risk of infection, failure to growth, eye problems, and death (Low et al., 2017; Mbabu et al., 2012; Stathers et al., 2013). Even at low yields, orange-fleshed sweet potato can provide enough vitamin A for a family of 5 on a 500 m^2 field. It also contains more protein compared to other staple foods per unit growing area (Heck & Barker, 2020).

Sweet potato plays an important role in providing food security in developing countries, especially in Sub-Saharan Africa. Sweet potato is a resilient crop that is also drought resistant. Compared to other staple crops such as maize which yields 50% less or total failure, sweet potato loses 25% of the annual yield due to drought stress (Motsa et al., 2015). Sweet potato, tolerates poor soil and severe weather conditions well. It can grow in altitudes between 0 – 2500 m (CIP, n.d.-c). In frost-free areas, sweet potatoes can be planted and harvested year-round (Bovell-Benjamin, 2007; Motsa et al., 2015). Relative to the other staple foods it requires less input and maintenance, matures fast, and is rich in nutrients. However, it does not tolerate cold weather. Sweet potato can grow in regions that have a minimum of five frost-free months. It is very suitable for tropical soils without fertilizer or irrigation (Loebenstein & Thottappilly, 2009). These qualities are making the sweet potatoes known not only as the "poor man's crop" but also as the "protector of children" in Eastern Africa or "the crop that is there when maize fails". It is commonly the first available nutrition source after a natural disaster that keeps people from

starvation. The effort to emphasize the importance of orange-fleshed sweet potato in diets should continue and research should be directed at ensuring that sweet potato is available as an emergency nutrition source (Loebenstein & Thottappilly, 2009; Low et al., 2017; Woolfe, 1992).

History

Sweet potato has a long and rich history of providing food security and famine relief. In Japan, when typhoons and drought destroyed rice fields in Okinawa islands and Southern Kyushu, they cultivated sweet potato because it was tolerant to such natural disasters. The Japanese government recommends sweet potatoes as an emergency crop when people suffer from famine. The sweet potato was used as an emergency crop in China in the 1600s and in the 1960s to prevent starvation during the famine. In Uganda, in the 1990s cassava supply perished due to a virus and sweet potato came in to rescue. In Mozambique, after a flood and subsequent tropical cyclones in 2000, sweet potatoes provided food security. In the U.S., during the American Revolutionary War, World War I, and Civil War, sweet potato was an important staple food (Bovell-Benjamin, 2007; CIP, n.d.-c; Kapinga et al., 2005; Loebenstein & Thottappilly, 2009; Low, 2018; Mu & Singh, 2019).

Production Value and Consumption

In 2020, the world sweet potato production volume was 89.49 million ton and the global market value was 42.75 billion US dollars (*FAOSTAT*, 2022; Statista, n.d.). The majority of the production was in Asia with 63.4%, followed by Africa at 31.2%, and 4.3% in the Americas **(Figure 2.1)**. China alone produced 54.9% of the total global production. The top 10 sweet potato producing countries are China, Malawi, United Republic of Tanzania, Nigeria, Angola, Ethiopia, United States of America, Uganda, Indonesia, and Vietnam respectively (*FAOSTAT*,

2022). The top 10 sweet potato producing countries and yields for 2018, 2019, and 2020 are shown in **Table 2.1**.

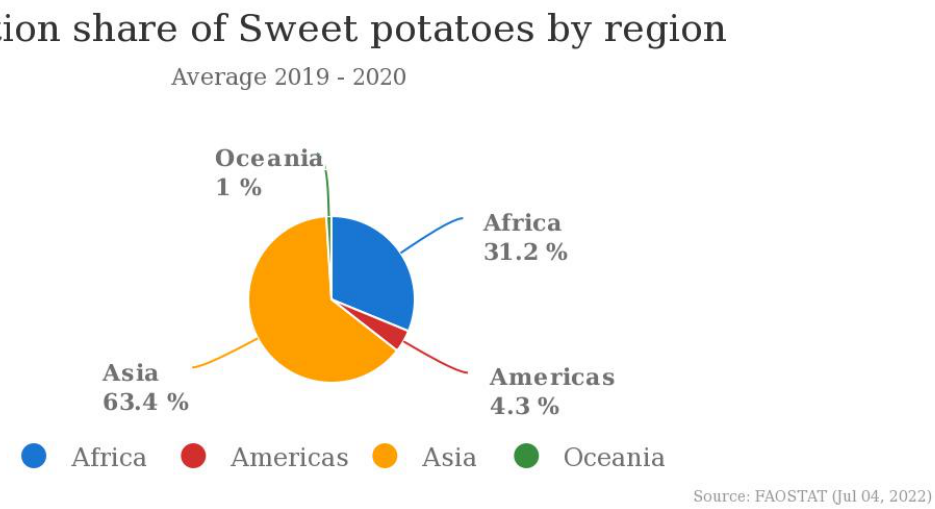

Figure 2.1 Production Share of Sweet Potatoes by Region

Table 2.1 Top 10 Sweet potato producers of the world in 2018, 2019, and 2020 *(In million ton)*

2018		**2019**		**2020**	
China, mainland	52.37	China, mainland	50.34	China, mainland	48.95
Malawi	6.02	Malawi	6.64	Malawi	6.92
Nigeria	3.88	United Republic of Tanzania	4.18	United Republic of Tanzania	4.44
United Republic of Tanzania	3.83	Nigeria	3.88	Nigeria	3.87
Angola	1.68	Angola	1.7	Angola	1.73
Indonesia	1.66	Ethiopia	1.68	Ethiopia	1.6
Ethiopia	1.63	United States of America	1.59	United States of America	1.56
Uganda	1.49	Uganda	1.51	Uganda	1.54
United States of America	1.43	Indonesia	1.5	Indonesia	1.49
Viet Nam	1.4	Viet Nam	1.4	Viet Nam	1.37

In the U.S, sweet potato production has been increasing rapidly for the last two decades **Figure 2.2** and **Figure 2.3** reached 30.67 million hundredweight in 2020 with an estimated value

of $726.2 million (AGMRC, 2021). Sweet potato consumption in the U.S. increased from 3.8 pounds/year/per capita in 1999 to 7.1 pounds/year/per capita in 2019 (USDA, 2020). In 2018, the production had a 20% dip compared to 2017 due to the low sweet potato prices in 2017, seasonal weather conditions, and Hurricane Florence (*FAOSTAT*, 2022; Miller, 2018). North Carolina has been the leading sweet potato producing state in the U.S since 1971, producing nearly 60% of all sweet potatoes in the country (AGMRC, 2021).

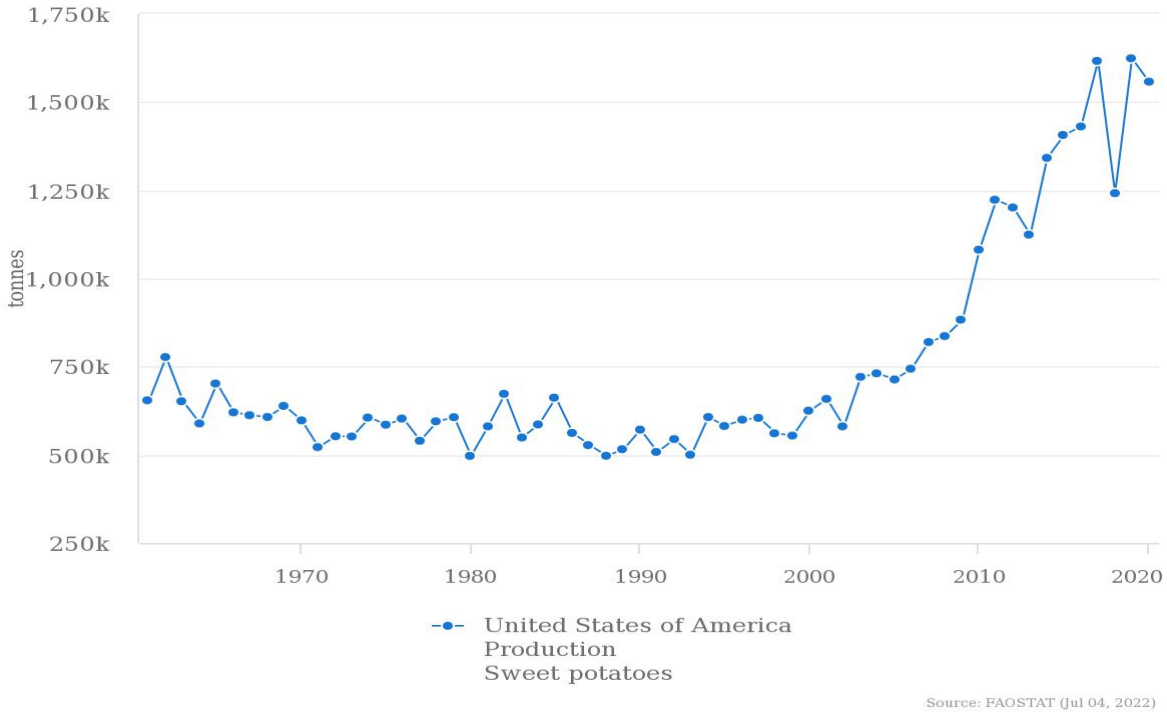

Figure 2.2 US Sweet potato production

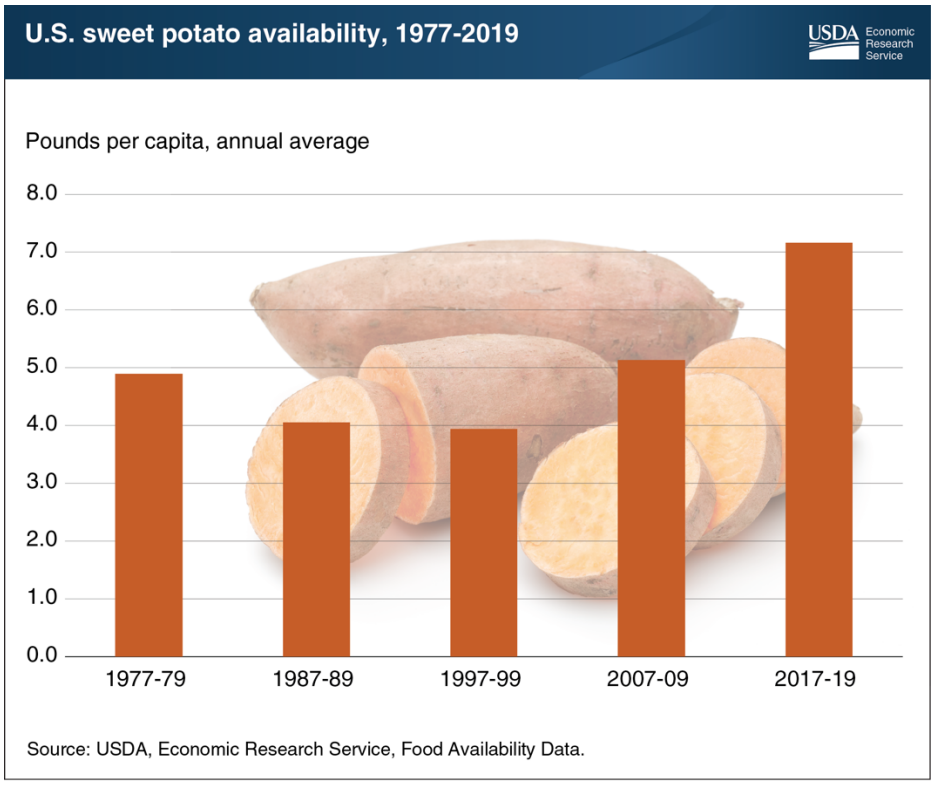

Figure 2.3 US sweet potato consumption

Sweet Potato Species and Development

Sweet potatoes originated more than 5000 years ago and it has spread across the world since. Currently, sweet potato is cultivated in 119 countries (*FAOSTAT*, 2022). Sweet potato reproduces in three ways: from seed, from the storage roots, or vines. The reproduction method can be selected depending on the climate conditions (CIP, n.d.-b).

There are thousands of sweet potato varieties across the world. Breeding is used to produce sweet potato varieties with a higher yield, drought, disease, and pest tolerance, higher nutrient content, uniformity, longer storability, and shorter harvest time (Stathers et al., 2013). International Potato Center maintains a cultivated sweet potato Genebank with over 5500 accessions, which makes it one of the largest in the world (CIP, n.d.-a). Sweet potato breeding is usually done by traditional breeding methods although two innovative processes is aiming to

improve the development of new cultivars (Campos & Caligari, 2017). The first one, Accelerated Breeding System (ABS), is a conventional method that allows the selection and release of the varieties in four years instead of seven to eight years with the regular conventional system. This system is used in a variety of ways, works well, and has been shown to improve Vitamin A, iron, zinc, drought tolerance, and virus disease resistance (Mwanga et al., 2021). The second one, Marker-Assisted Breeding employs the use of genetic and genomic tools to improve sweet potato qualities (NCSU, n.d.). Genomic Tools for Sweet potato Improvement project is led by North Carolina State University.

Even though there are thousands of cultivars in the Genebanks one or two varieties usually dominate each market. In the US these varieties are Beauregard (released by Lousiana State University in 1987) and Covington (released by NC State in 2005) (Loebenstein & Thottappilly, 2009). Covington is the top variety in North Carolina and grows on 85% of North Carolina's sweet potato acres. North Carolina is the leading state in sweet potato production and produced 61% of the whole US production in 2019 (Bogdan, 2021). Covington is an orange-fleshed sweet potato that is derived from "Regal" by North Carolina State University. A comparison of nutrient components for Covington and Beauregard roots is shown in **Table 2.2** Covington is very similar to Beauregard in terms of yield but it takes 5-10 days more for Covington to mature. Covington produces more uniform roots **(Figure 2.4)** and is more resistant to diseases with similar or better taste (Yencho et al., 2008).

Figure 2.4. Covington (top) and Beauregard (bottom) sweet potatoes grown in North Carolina (Yencho et al., 2008)

Table 2.2 Nutrient content of Covington and Beauregard storage roots (Yencho et al., 2008)

Nutrient components	Covington	Beauregard
Dry matter (%)	20.0	18.7
Ash (%)	0.91	0.88
Fat (%)	0.30	0.24
Protein (%)	1.8	1.4
Total carbohydrates (%)	17	16.2
Total dietary fiber (%)	2.2	2.1
Degree Brix	10.9	9.7
Starch (g/100 g fresh weight)	9.5	8.9
Total sugars (g/100 g fresh weight)	5.2	4.9
Sucrose	3.8	3.4
Reducing sugars (g/100 g fresh weight)	1.4	1.6
Glucose	0.88	1.0
Fructose	0.55	0.57
Maltose	ND	ND
B-carotene (mg/100 g fresh weight)	9.1	9.5

Note: Harvested roots were cured at 30 C, 80% to 90% relative humidity for 7 d.

ND = not detectable.

(*FoodData Central*, 2019)

Products from Sweet potato

Sweet potatoes are consumed boiled, steamed, baked, dried, and fried in household settings. In the industry, sweet potato starch is used to produce different staple foods and products such as traditional noodles, vermicelli, bread, pancakes, or converted into glucose syrup. Sweet potatoes have been used to produce snack foods such as sweet potato chips, roasted sweet potatoes, mashed sweet potatoes, biscuits, extruded snacks, and dried slices; bakery products such as bread, puffs, muffins, cakes, and doughnuts (Mu & Singh, 2019; Mu et al., 2017). Sweet potato is used to make distilled alcoholic beverages and fermented products such as Japanese liquor Shochu, vodka, wine, beer, red vinegar, yogurt, curd, fermented beverages, and

probiotic milk- sweet potato drink. Sweet potatoes are used to make purees, juices, frozen and canned products, flakes and flour, and fried products (Truong et al., 2018).

Chemistry and Nutrients

Sweet potato is used as the main dish in developing countries whereas in developed countries it is often a side dish or a snack. Mainly, the roots and the leaves of sweet potatoes are used for human consumption. The nutrient content of sweet potato leaves and roots varies depending on the variety, growing conditions, storage, and cooking methods(Truong et al., 2018). Sweet potato leaves are consumed as a green vegetable in Asia and Africa. Sweet potato leaves are a very good source of β-carotene, thiamin (B_1), riboflavin (B_2), folic acid, lutein, Vitamin C, calcium, potassium, iron, and magnesium (Truong et al., 2018; Woolfe, 1992). Sweet potato leaves contain 25-37% protein on dry weight basis and ~ 3g protein on fresh weight basis (Truong et al., 2018; Woolfe, 1992).

Sweet potato roots have a high moisture content that varies widely, depending on the cultivar, between 55 % - 87 % (Truong et al., 2018). The most abundant nutrient in sweet potato is carbohydrates, primarily starch, and sugars and in lesser amounts pectin, cellulose, and hemicellulose. Starch accounts for 60-70% of dry weight and it contains amylose and amylopectin. Sweet potato starches are commonly extracted to use as a functional additive in food in Asia. More than half of the sweet potato produced is used to extract starch in China although this has been changing over the last decade. Chinese government closed the factories that extract starch due to the detrimental effects of the by-products on the environment which in turn resulted in a reduction in the production of sweet potatoes (Mu & Singh, 2019). Sweet potato sugars are made up of sucrose, glucose, and fructose when it is raw. Baking changes the sugar composition significantly, amylases form maltose from starch, making maltose the major

sugar component (Chan et al., 2014). As with all the other nutrients, sugar amounts in sweet potatoes vary by cultivar (Truong et al., 2018). The Glycemic index for steamed, baked and microwaved sweet potato samples were determined as 63, 64, and 66 respectively. This indicates that sweet potato is a moderate glycemic index food when cooked by these methods (Allen et al., 2012).

Even though the protein amount in sweet potato is not regarded as a high protein food in the U.S., it is considered an important protein source in other parts of the world. Sweet potato contains 1.73 % - 9.14% protein on a dry weight basis and is rich in non-protein nitrogen (Bovell-Benjamin, 2007; Truong et al., 2018). Sweet potato protein primarily consists of sporamins (80%). Sporamins are rich in essential amino acids that make sweet potato proteins comparable to high-quality vegetable proteins. Sporamins have antioxidant and proteinase inhibitor activity that may have anticarcinogenic properties (Maloney et al., 2014). However, there is a lot of nutrient loss in the sweet potato industry due to sweet potato protein being discarded during the starch extraction process (Mu & Singh, 2019). Sweet potato lipids, especially glycolipids, have been shown to have certain anticancer effects (Mu & Singh, 2019). **Table 2.3** shows the nutrient content of raw sweet potato (*FoodData Central*, 2019).

Sweet potatoes contain a unique nutritional matrix. In addition to the macronutrients, sweet potato roots are a good source of potassium, phosphorus, calcium, magnesium, iron, copper, thiamin, riboflavin, niacin, pantothenic acid, folic acid, vitamin E, a variety of phenolic compounds, carotenoids and bioactive components that have numerous health benefits such as antioxidant, hepatoprotective, anti-inflammatory, antitumor, antidiabetic, antimicrobial, and antiobesity effects (Truong et al., 2018; Wang et al., 2016; Woolfe, 1992). Orange fleshed sweet potatoes are rich in β-carotene (Yencho et al., 2008) (**Table 2.2)**.

Table 2.3. Nutritional composition of sweet potato *(FoodData Central, 2019).*

Name	Amount	Unit
Water	77.3	g
Energy	86	kcal
Energy	359	kJ
Protein	1.57	g
Total lipid (fat)	0.05	g
Ash	0.99	g
Carbohydrates, by difference	20.1	g
Fiber, total dietary	3	g
Sugars, total including NLEA	4.18	g
Sucrose	2.52	g
Glucose	0.96	g
Fructose	0.7	g
Starch	12.6	g
Calcium, Ca	30	mg
Iron, Fe	0.61	mg
Magnesium, Mg	25	mg
Phosphorus, P	47	mg
Potassium, K	337	mg
Sodium, Na	55	mg
Zinc, Zn	0.3	mg
Copper, Cu	0.151	mg
Manganese, Mn	0.258	mg
Selenium, Se	0.6	µg
Vitamin C, total ascorbic acid	2.4	mg
Thiamin	0.078	mg
Riboflavin	0.061	mg
Niacin	0.557	mg
Pantothenic acid	0.8	mg
Vitamin B-6	0.209	mg
Folate, total	11	µg
Choline, total	12.3	mg
Vitamin A, RAE	709	µg
Carotene, β	8510	µg
Carotene, alpha	7	µg
Vitamin A, IU	14200	IU
Vitamin E (alpha-tocopherol)	0.26	mg
Vitamin K (phylloquinone)	1.8	µg
Fatty acids, total saturated	0.018	g
Fatty acids, total monounsaturated	0.001	g
Fatty acids, total polyunsaturated	0.014	g
Tryptophan	0.031	g

Table 2.3 (continued)

Threonine	**0.083**	**g**
Isoleucine	0.055	g
Leucine	0.092	g
Lysine	0.066	g
Methionine	0.029	g
Cystine	0.022	g
Phenylalanine	0.089	g
Tyrosine	0.034	g
Valine	0.086	g
Arginine	0.055	g
Histidine	0.031	g
Alanine	0.077	g
Aspartic acid	0.382	g
Glutamic acid	0.155	g
Glycine	0.063	g
Proline	0.052	g
Serine	0.088	g

Vitamin A Deficiency and Orange-Fleshed Sweet Potatoes

Vitamin A is a lipid-soluble essential nutrient that plays an important role in cellular differentiation, immunity, metabolism, growth and development, vision, and reproductive functions (Hodge & Taylor, 2022). Vitamin A can be obtained as preformed vitamin A from animal products (liver, eggs, dairy) or as provitamin A from plant sources (leafy green vegetables, orange, and yellow-colored fruit and vegetables). Among the provitamin A carotenoids, β-carotene has the highest vitamin A activity (**Figure 2.5**) (Haskell, 2012). Provitamin A is converted to retinol in the intestine by oxygenase and reductase enzymes (Harrison, 2012). Vitamin A is absorbed in the duodenum after hydrolysis from esters of retinol to retinol by pancreatic and intestinal enzymes. Then, free retinol is taken up by the mucosal cell. The majority of it is stored in the hepatic stellar cells (Hodge & Taylor, 2022).

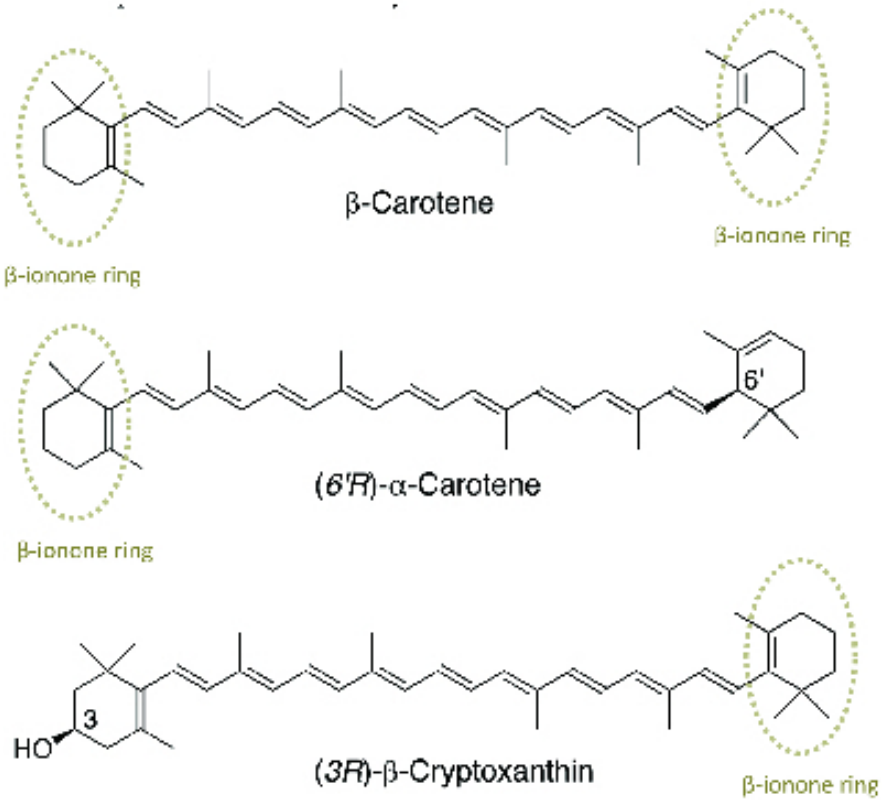

Figure 2.5 Chemical structures of provitamin A carotenoids *(de Moura et al., 2015).*

Deficiency of vitamin A is rare in developed countries (estimated at 0.3% in the US) where the preformed vitamin A is the main source, providing more than 70% of daily vitamin A intake (Tang, 2010). In the United States, toxicity is more common than deficiency and deficiency is usually due to malabsorption or an excessively restricted diet (Hodge & Taylor, 2022). In contrast to that, in low-income countries ~80% of daily vitamin A intake is provided by dietary carotenoids (Haskell, 2012) where vitamin A deficiency is a public health concern. Globally most cases of vitamin A deficiency happen in children less than 5 years of age and pregnant/lactating women. Approximately, 30% of children suffer from vitamin A deficiency and it accounts for 2% of all death of children less than 5 years of age (Hodge & Taylor, 2022). In India, 62% of preschool children in rural areas had vitamin A deficiency (Laxmaiah et al., 2012). In Ethiopia, 76% percent of lactating women had low vitamin A in their breastmilk which

indicates vitamin A deficiency for both lactating women and children (Abebe et al., 2019). To eliminate vitamin A deficiency and meet the requirements, 42 varieties of orange-fleshed sweet potatoes have been introduced to Sub-Saharan Africa since 1995 (Low et al., 2017). **Figure 2.6** shows Vitamin A deficiency as a public health problem in preschool children (WHO, 2009) and **Figure 2.7** shows night blindness as a public health problem in pregnant women (WHO, 2009)

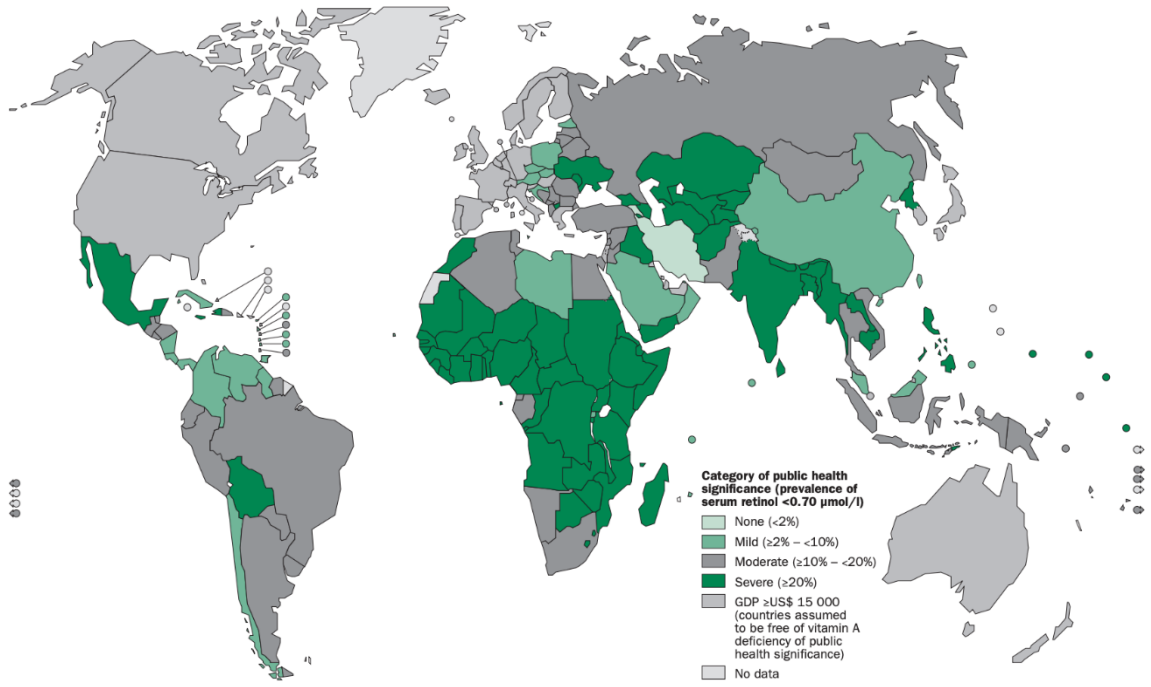

Figure 2.6 Vitamin A deficiency as a public health problem in preschool children

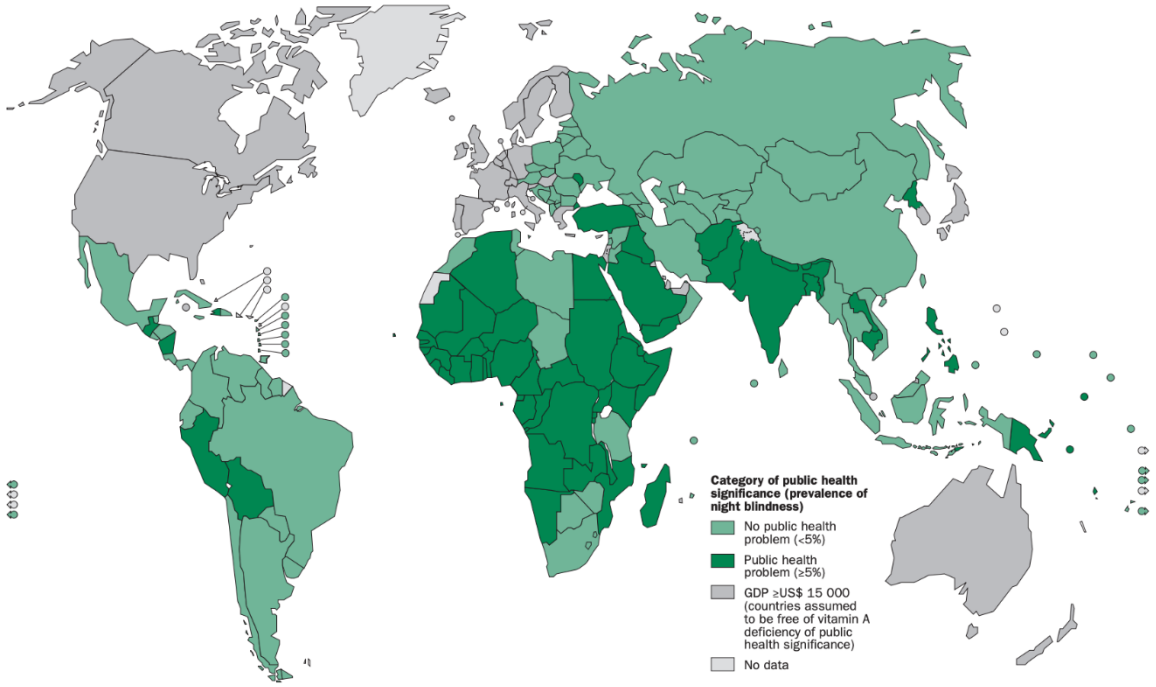

Figure 2.7 Night blindness as a public health problem in pregnant women

Heat Processing

Manley defines an oven as, "An oven is a hot box or tunnel which is designed to provide the desired conditions of heat and temperature for the dough pieces and to allow removal of moisture" (Manley, 1998). An oven is designed to have a regulated environment for heat transfer into food. Heat transfer into food occurs in three ways; conduction, convection, and radiation. Heat processing applications use more than one or all of these ways but in an optimized way to increase effectiveness. Conduction is the movement of thermal energy between molecules that are in contact with each other, in the direction of high energy to low energy (Fellows, 2017). Energy is provided by a fuel source that can be gas, oil, or electricity. In terms of baking, energy transfer occurs between the baking surface and food product. Conduction baking is commonly used in industry for the baking of crackers and saltines (Davidson, 2016b).

Convection is the type of heat transfer that uses agitation of fluid to help transfer heat in the baking chamber. In convection ovens, air circulates in the oven by a fan to move air from the energy source to the product (Davidson, 2016b). The fan usually is located below the baking surface and blows hot air onto the product and removes moisture rapidly. Convection primarily affects the outside of the product at the surface level (Davidson, 2016a). Convection cooking is very efficient for removing moisture and it provides even heating on the surface of the product. However, it does remove a portion of the hot air during the cooking process and will cause energy loss. To maintain better energy efficiency, heat flux, and duct design, the location of the fan and the burner, and thermal conductivity of the insulation material are important factors that can be optimized (Park et al., 2018).

Air fryers were first introduced in 2005 and patented in 2006 (McFadden, 2006), so it is relatively a new product and cooking method. Air frying was marketed to produce low-fat food products that have a similar taste, texture, and appearance to their traditionally deep-fried-in-oil counterparts (McFadden, 2006). Air fryers use high-speed hot air circulation. Hot air flows through the metal food basket very rapidly and creates a crispy layer on the food with little to no oil (Tewari et al., 2015).

Microwave refers to the part of the electromagnetic spectrum from 300 MHz to 300 GHz and wavelength of 1 mm to 1 m **(Figure 2.8).** Generally, industrial and domestic microwaves operate on 915 – 2450 MHz (Verma et al., 2020). Microwaves are reflected by metal, pass through glass, plastic, and paper and interact with polar molecules which allows them to be used in the food industry (FDA, 2017; Sumnu, 2001). As opposed to all the prior cooking methods microwave ovens heat the food by agitating the water molecules and generating heat within food instead of heating the oven space (Ozkoc et al., 2014). Microwave ovens have advantages that

make them very appealing, such as fast start-up, energy efficiency, faster and volumetric heating, precise control ability, and less maintenance (Sumnu, 2001). Microwave processing results in more nutrient retention, possibly due to the quick process time (Tian et al., 2016). However, microwave processing has some disadvantages as well, the most significant one being non-uniform heating that results in hot and cold spots (Datta et al., 2001). A microwave oven cannot heat products that reflect or do not absorb microwave energy.

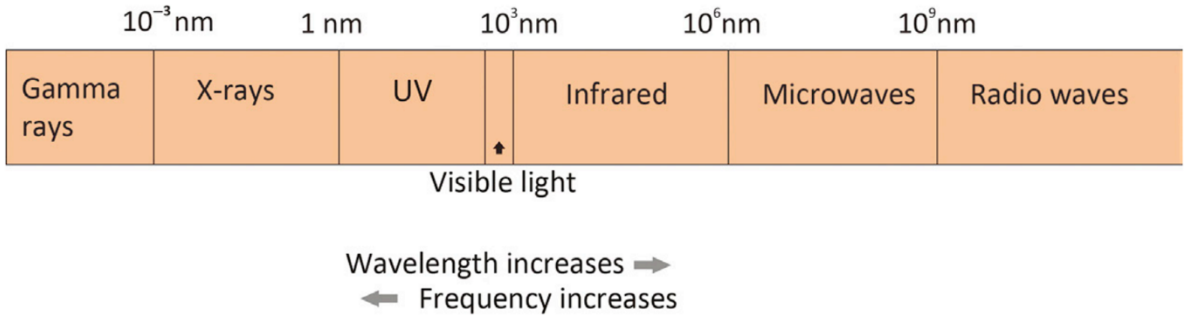

Figure 2.8 Electromagnetic spectrum *(Davidson, 2016a)*

Acrylamide

Acrylamide (CH_2=$CHONH_2$) is a highly water-soluble vinyl monomer and it was first produced in 1893 in Germany by hydration of acetonitrile with sulfuric acid mono hydrate at 90 – 100 ^{0}C. From the acrylamide monomers, polyacrylamide was produced and widely used in industry. Polyacrylamide was used in wastewater treatment, soil and sand treatment, crude oil production, and paper and pulp processing (Smith et al., 1991). It was not until the 1960s, that the toxicity of acrylamide was noticed. Workers who handled acrylamide started showing neurological symptoms (Smith et al., 1991). It was shown to have a carcinogenic effect on animals. It was classified as a "probable human carcinogen" and a neurotoxin by IARC in 1994 (Tornqvist, 2005).

In 2002, Swedish scientists reported the presence of acrylamide in a variety of heat-treated foods (Mottram et al., 2002; Tareke et al., 2002). Acrylamide is produced in food mainly due to the Maillard reaction **(Figure 2.9)** between asparagine and reducing sugars at temperatures above 120 ^{0}C / 250 ^{0}F. Acrylamide can also form by non-enzymatic browning, especially in roots, tubers, and bananas (Quayson & Ayernor, 2007). Fried potato products, pastries, and coffee were shown to have high levels of acrylamide (**APPENDIX A**). Both in the U.S. and Europe, policymakers investigated the impact of acrylamide on human health. In 2009, FAO/WHO Codex Alimentarius developed a "Code of Practice for the Reduction of Acrylamide in Foods" (Codex Alimentarius, 2009). In 2010, the Joint FAO/WHO Expert Committee on Food Additives concluded that acrylamide is a "human health concern" and recommended increasing efforts to monitor and reduce acrylamide levels in foods (WHO & FAO, 2011). In 2015, EFSA confirmed that the current dietary acrylamide levels indicate a concern due to its carcinogenic effects (EFSA, 2015). In 2016, FDA developed a "Guidance to Industry" and "Advice to Consumers" to provide information to the food industry and the general public on ways to reduce acrylamide levels in certain foods. In 2017, the EU Commission Regulation recognized that it is impossible to eliminate acrylamide in foods and established mitigation measures to keep acrylamide levels as low as reasonably achievable (the ALARA principle). They also introduced benchmark levels for certain food products **(Table 2.4)** (Commission Regulation (EU), 2017). In 2019, the EU Commission Regulation initiated a program to monitor acrylamide levels, evaluate previous recommendations, and set maximum levels on certain foods(Commission Regulation (EU), 2019). Currently, the effort is on setting a maximum level of acrylamide for processed cereal-based foods for infants and young children (European Commission, n.d.).

Table 2.4. Benchmark levels for the presence of acrylamide in foodstuffs *(Commission Regulation (EU) 2017/2158)*

Food	Benchmark level [μg/kg]
French fries (ready-to-eat)	500
Potato crisps from fresh potatoes and from potato dough Potato-based crackers and other products	750
Soft bread (a) Wheat based bread (b) Soft bread other than wheat-based bread	 50 100
Breakfast cereals (excl. porridge) — bran products and whole grain cereals, gun puffed grain — wheat and rye-based products — maize, oat, spelt, barley and rice-based products	 300 300 150
Biscuits and wafers Crackers with the exception of potato-based crackers Crispbread Ginger bread Products similar to the other products in this category	350 400 350 800 300
Roast coffee Instant (soluble) coffee	400 850
Coffee substitutes (a) coffee substitutes exclusively from cereals (c) coffee substitutes exclusively from chicory	 500 4000
Baby foods, processed cereal based foods for infants and young children excluding biscuits and rusks	40
Biscuits and rusks for infants and young children	150

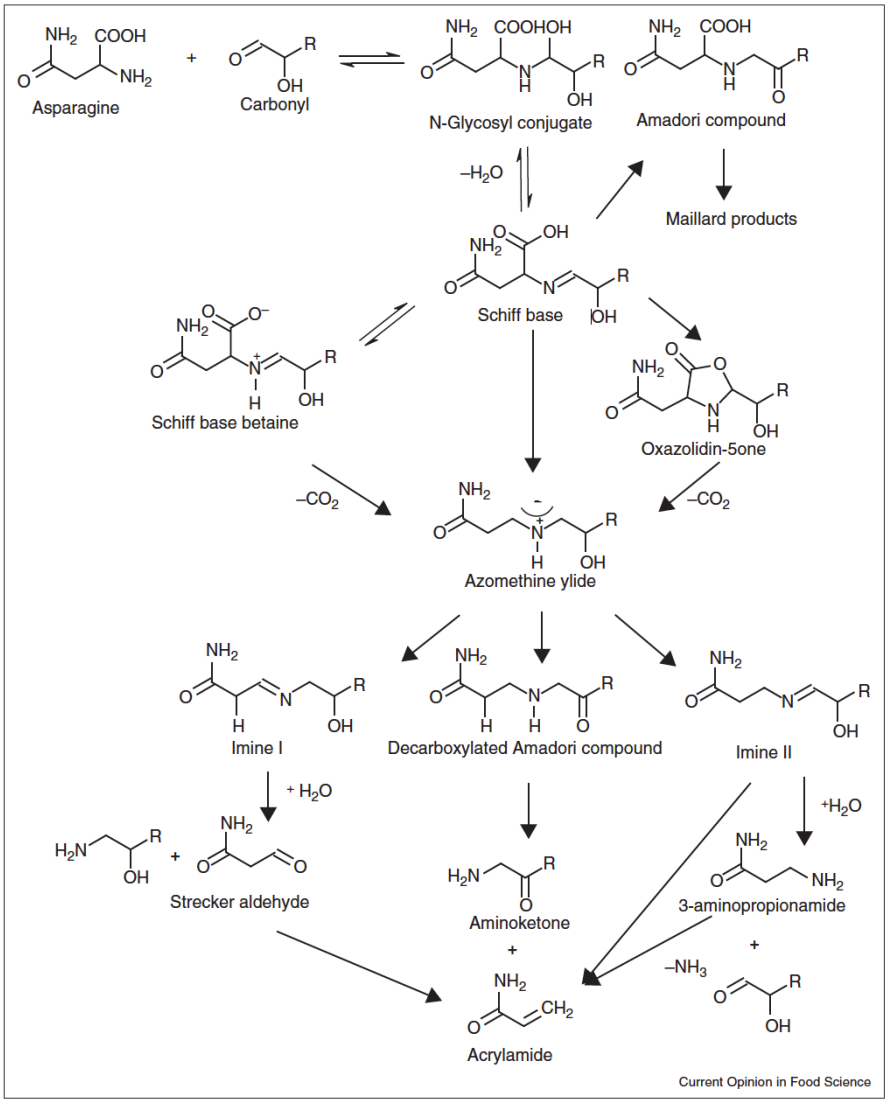

Figure 2.9 Maillard reaction of Asparagine and carbonyl group of reducing sugar *(Mogol & Gökmen, 2016)*

Research efforts focused on mitigation strategies to lower the production of acrylamide. Lim et al., (2014) suggested that type of vegetable oil affects acrylamide production and unsaturated oil yielded more acrylamide. Palazoğlu & Gökmen, (2008) demonstrated that by frying the chips in two steps; first high-temperature oil and then low-temperature oil, acrylamide levels can be lowered in half. Tuta et al., (2011) reduced the acrylamide level by 79% by using a microwave blanching step. Kocadağlı et al., (2012) showed a reduction in acrylamide up to 50%

by using radio frequency post-baking process in cookies. Truong et al., (2014) reported by using a water blanching step and soaking the sweet potato strips in sodium acid pyrophosphate, acrylamide levels can be reduced about 7 times in sweet potato french fries. Palazoglu et al., (2010) suggested frying potato chips at a low temperature (170 ^{0}C) yielded less acrylamide than baking by half, but at a higher temperature (190 ^{0}C) frying yielded 3 times more acrylamide than baking. Tuta et al., (2010) evaluated the effect of microwave prethawing on frozen french fries and showed an 89% reduction when sweet potato strips are cooked at 180 ^{0}C. Granda & Moreira, (2005) showed a 94% reduction in acrylamide when used vacuum frying compared to traditional frying. Sansano et al., (2015) compared air frying with deep frying and showed a 90% reduction in acrylamide with the use of air fryers.

Carbohydrate Digestion

Carbohydrates can be classified as monosaccharides, disaccharides, oligosaccharides and polysaccharides. Monosaccharides include glucose, galactose, and fructose. Disaccharides include sucrose, lactose, and maltose. Oligosaccharides contain 3 – 10 monosaccharide units and common oligosaccharides are trehalose, raffinose, and stachyose. Polysaccharides contain more than 10 units and common polysaccharides are starch, glycogen, cellulose, lignin, gums, and dietary fiber (Eggleston et al., 2018; Institute of Medicine, 2005). Starch is the most prominent nutrient globally and therefore an important source of energy (Copeland, 2020). Starch is made of hundreds to thousands of α-bonded glucose units. Most starches contain 20 – 30 % amylose which is the linear form of starch that is formed of α-(1,4) linkages of glucose and 70 – 80 % amylopectin that consist of both linear α-(1,4) linkages and branched α-(1,6) linkages of glucose (Copeland, 2020).

Carbohydrate digestion in the human body starts in the mouth with mastication and coating the food with saliva, then enzymatic hydrolyzation by salivary α-amylase(Nadia et al., 2021). Even though salivary α-amylase is a small portion of total amylase in the body, it is the most abundant protein in saliva and it cleaves interior α-(1,4) linkages of amylose and amylopectin and produces large oligosaccharides (α-limit dextrins), polysaccharides and disaccharides. (Peyrot des Gachons & Breslin, 2016; Scannapieco et al., 1993). Salivary α-amylase has a relatively short contact time with food and the level of starch digestion by the salivary α-amylase is not clear (Emmambux & Taylor, 2017) Once the food is swallowed, in the stomach, enzyme activity decreases within 15 – 30 minutes due to the low pH of the gastric juice. Even though there is no enzymatic carbohydrate digestion in the stomach, gastric digestion has been linked to the changes in glycemic response so it may be important not to skip gastric digestion in carbohydrate digestion (Nadia et al., 2021). The majority of the starch is digested by the pancreatic α-amylase, in the small intestine. Salivary and pancreatic α-amylase are 95% homologous. Therefore, they only hydrolyze starch down to maltose, maltotriose, and α-limit dextrins (Emmambux & Taylor, 2017). Further hydrolysis of the dextrin and disaccharides was completed at the brush border membrane of the small intestine by maltase-glucoamylase and α-dextrinase. Monosaccharides are absorbed by the first diffusion, then active transport by SGLT1 and GLUT2 or facilitated diffusion and transported to the liver by the portal vein (Emmambux & Taylor, 2017; Institute of Medicine, 2005).

The digestive process is very complicated and studying digestion is challenging due to the complexity of the gastrointestinal tract involving multiple enzymes and hormones controls digestion, variety in food matrices variability between people, and limitations of current techniques (Muttakin et al., 2019; Zhang et al., 2020). Mainly three methods are used to study

the digestive process; in vivo studies that involve the use of human or animals, in vitro studies that mimic the digestion outside of the body, and in silico studies that model and simulates the digestive process based on numerical and computational methods (Muttakin et al., 2019). Each method has its advantages and disadvantages. Therefore, it is important to select an appropriate digestion method for the aim of the study. In vivo methods give results that are more clinically relevant to human digestion. However, due to the logistical and practical limitations, in vivo models are not always feasible to conduct. In vivo methods include epidemiological studies, animal studies, and the use of imaging techniques, intubation, and measurement of biomarkers. On the contrary, in vitro methods allow researchers to create simple systems with more control ability but drawing clinical conclusions from in vitro studies requires caution and potentially further research (Bornhorst & Singh, 2014). In vitro models can be characterized as dynamic (mimics mastication, peristalsis, flow, mixing) or static; and can use multiple or only a single part of the digestive tract.

Digestion of starch has been studied in vivo, in vitro, and in silica research. In vivo starch digestion studies have been used to determine glycemic index and glycemic load. (Wolever et al., 1991) and (Brouns et al., 2005) established an in vivo method for the determination of glycemic index by measuring blood glucose after carbohydrate consumption that is commonly used. An in vitro digestion method is commonly used for starch digestion and estimation of the glycemic index of the food (Englyst et al., 1992; Englyst et al., 1999). In vitro methods focus on the use of α-amylase and amyloglucosidase to break down starches. The enzyme reactions are highly dependent on the pH and temperature. α-amylase is used as salivary (human) and/or pancreatic α-amylase (often porcine) and amyloglucosidase is usually sourced from *Aspergillus niger* (Zhang et al., 2020). In vitro starch digestibility is applied to quantify and compare glucose

release in different starchy food matrices such as bread(Ronda et al., 2012), rice (Khatun et al., 2018), oats (Brahma et al., 2016), and potatoes (Ek et al., 2014).

Glucose quantification after the digestion procedure can be done by several methods. HPLC, DNS, Fehling test, and enzymatic assays are available. However, these methods are expensive, time-consuming, labor intensive, and technically difficult (Choy et al., 2007). Glucometers use either glucose oxidase or pyrroloquinoline quinone glucose dehydrogenase to react with glucose to produce a small current that is proportional to glucose concentration. Glucometers are portable, quick, and inexpensive and are used in the biotechnological application by several studies before. Glucometers are used to determine the glucose concentration in the tissue culture media (Nayak & Herman, 1997), in wine (Cook et al., 1998), in fish (Iversen et al., 2005), in potato juice (Helgerud et al., 2016), in in vitro starch digestion of sorghum and wheat (Sopade & Gidley, 2009b), in vitro starch digestibility of rice (Khatun et al., 2018), in fermentation with *Trichoderma reesei* (Choy et al., 2007), and enzymic saccharification of maize stover (FitzGerald & Vermerris, 2005b). For screening and comparing similar samples glucometer can be used as a cheap, portable, convenient alternative for glucose measurement.

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CHAPTER 3: TIME – TEMPERATURE MATRIX

Introduction

Heat processing extends the storage life of food and minimizes the risk of food-borne diseases. However, it also reduces heat-labile nutrients (Lund, 1988). Therefore, the food industry is continuously looking for ways to optimize thermal processing and nutrient retention. Heat transfer can happen in three ways in the food context; conduction, convection, and irradiation. A conduction (radiant) oven cooks food by direct transfer of thermal energy from the cooking surface to food (Fellows, 2017). Convection employs a fan to agitate air in the oven and move air from energy source to food (Davidson, 2016b) and affects the food at the outside surface level (Davidson, 2016a) more evenly than the radiant oven. Convection cooking is very efficient in moisture removal however, the energy loss is greater during the cooking process (Park et al., 2018).

Air fryers are a relatively new product in the market. Air frying was marketed for producing low-fat fried food that is similar to deep-fried food (McFadden, 2006). The air fryer is similar to a convection oven but hot air flows through the basket more rapidly and creates a crispy layer on the food (Tewari et al., 2015). On the other hand, microwaves work in a different principle and heat the food by agitating water molecules within the food without heating the oven space (Ozkoc et al., 2014). Microwaves are more energy efficient, require less maintenance and counter space, and they heat faster with a fast start-up (Sumnu, 2001). However, microwaves heat less uniformly and can cause hot and cold spots (Datta et al., 2001).

Sweet potatoes are versatile staple crops. They are commonly boiled, steamed, baked, dried, and fried. A wide variety of food products are produced from sweet potatoes. Snack foods

such as sweet potato chips, roasted sweet potatoes, mashed sweet potatoes, biscuits, extruded snacks, and dried slices; bakery products such as bread, puffs, muffins, cakes, and doughnuts, are made of sweet potato as well as distilled alcoholic beverages, fermented products, purees, juices, frozen and canned products, flakes and flour, and fried products (Mu & Singh, 2019; Mu et al., 2017; Truong et al., 2018).

Sweet potatoes are very nutritious. They are rich in starch and contain a relatively high amount of protein in the form of sporamin that has bioactive properties (Bovell-Benjamin, 2007; Maloney et al., 2014; Truong et al., 2018). Sweet potatoes are rich in vitamins and minerals and they contain a variety of phenolic compounds, carotenoids, and bioactive components depending on the cultivar. Due to these bioactive components, sweet potatoes have numerous health benefits (Wang et al., 2016). Orange-fleshed sweet potatoes have significant importance because they are rich in β-carotene (Yencho et al., 2008). β-carotene is a provitamin A compound and it helps prevent vitamin A deficiency. Vitamin A deficiency is a public health concern in developing countries, and it causes a higher risk of infection, growth and development problems, eye problems, and death (Low et al., 2017). Therefore, retention of β-carotene with improved thermal processing is important.

Caetano et al., (2018) used oven-baked and air-fried chips to compare with deep-fried chips and suggested that oven-baked and air-fried chips have low-fat and moisture content. However, consumer acceptance was higher for deep-fried chips. Hagenimana et al., (1998) suggested that forced-air dried chips with higher b* colorimetry values retained more β-carotene. Therefore, the aims of this study were to: (1) determine the optimal cooking time-temperature for each oven type based on the moisture content; (2) compare β-carotene levels to optimize nutrient

retention with different cooking methods; (3) evaluate the correlation between colorimetry measurement and β-carotene levels.

Methods

Production of Sweet Potato Chips

Covington variety Orange Fleshed Sweet Potato was obtained from local farms. Sweet potatoes were sorted, cleaned and washed thoroughly. They were patted dry with paper towels. Sweet potatoes were not peeled. Then, they were sliced into 2 mm sweet potato chip (SPC) slices with a Presto Slicer. Slices were then lightly sprayed with canola oil and cooked with 7 different cooking methods: 2 air fryers, (Air fryer 1; Cook's Essential, CM15901,1500 W,) (Air fryer 2 NuWave, NuWave Brio, 1300 W); 2 radiant ovens, (Radiant oven 1; Krups, 571509, 1600W) (Radiant oven 2; Krups, 571505, 1600W): 2 convection ovens (Krups, 571509, 1600W) (KitchenAid, KCO253, 1440 W); and a microwave (Panasonic Inverter, NN-SD987S, 1250 W). Cooking times and temperatures were selected based on preliminary data and can be found in **Table 3.1**. For ovens and air fryers 4 temperature levels were selected: 250 ˚F/120 ˚C, 300 ˚F/ 150 ˚C, 350^{0}F/ 175 ˚C, 400^{0}F/205 ˚C. For microwave, 2 power levels were used, 100% and 50% and two different heating times. After cooking, SPC were allowed to equilibrate for 10 minutes. After ten minutes, chips underwent moisture content analysis and color analysis. Once moisture and color analysis samples were processed, the remainder of SPCs were stored in a -20 ˚C freezer and excluded from light.

Table 3.1 Oven types, times and temperature.

Time-temperature	250 F / 120 C		300 F / 150 C		350 F / 175 C	400 F / 205 C
Cooking Method	**ST**	**LT**	**ST**	**LT**		
Air fryer-1	25'	30'	12'	17'	10'	7'
Air fryer-2	25'	30’	12'	17'	10'	7'
Radiant oven-1	50’	55'	25’	30'	20’	15’
Radiant oven-2	50’	55'	25’	30'	15’	10’
Convection oven-1	55’	60'	25’	30'	15’	10’
Convection oven-2	60’	65'	25’	30'	15’	10’
Microwave	**2'**		**3'**		**3'**	**5'**
	100%		100%		50%	50%

Moisture Analysis

Moisture content was measured by oven drying using a convection oven at 70 ˚C to prevent nutrient degradation (Bradley, 2010). Approximately 5 g of sample was weighed and dried in aluminum pans until constant weight was achieved. Moisture content was calculated using the difference between the initial and final weight of sample and it is expressed as a percent moisture retained.

Color Measurement

Color was measured using ColorFlex EZ Spectrophotometer (Hunter Associates Laboratory Inc., VA, USA). The color meter was standardized every 4 to 8 hours with white and black tiles and each measurement is an average of three readings of different orientation per chip. Color was described based on L*, a*, and b* values. L* is a measure of light vs. dark (0 – 100) where lower values indicate dark and higher values indicate light. The a* value is a measure of red vs. green where positive values indicate red and negative values indicate green. The b* value

is a measurement of yellow vs. blue where positive values indicate yellow and negative values indicate blue (Hunter Associates Laboratory Inc., 2012).

Beta-carotene Measurement

A 0.5-g portion of ground SPC were weighed. Acetone, 10 mL, (A949-4, Fisher Chemical, NJ, USA) and 10 mL hexane. (H302-4, Fisher Chemical, NJ, USA) were added to the sample. This mixture was homogenized using a homogenizer (PRO Scientific, PRO250) and vortexed. Subsequently, an additional 10-mL acetone and 10-mL hexane portions were added and the sample was allowed to incubate for 5 minutes covered in foil at ambient. Samples then were centrifuged at 6000 x *g* for 5 minutes at 20 ˚C. The supernatant was retained and the pellet re-extracted two more times each time retaining the supernatant. The extract (combined supernatants) was transferred into a separatory flask and washed with 30 mL deionized water. Two mL saturated NaCl (Fischer Scientific, S271-500) was added to aid in separation of acetone and hexane layers. The extract was washed four times. Acetone/water layers were discarded after each wash. The remaining hexane layer then was collected and brought up to 100 mL. Absorbance was measured using a spectrophotometer (Genesys 10S UV-Vis spectrophotometer) set at 450 nm. β-carotene levels were calculated by Beer's law from the absorbance readings.

$A = E^{1\%/cm} * b * c$ where;

A = absorbance reading from the spectrophotometer

b = The pathlength of the cuvette (1 cm)

c= the concentration in g/dL

$E^{1\%/cm}$ = the extinction coefficient (2592 for β-carotene at 450 nm) (Scott, 2001)

Results

Two factors (*oven type* and *time-temperature*) are involved in the experiment of measuring the dependent variables, moisture content (%), β-carotene (mg/100g), and color of sweet potato chips. In total, 120 samples were collected from six different oven types and a microwave. In each oven type, the sweet potato samples were exposed to six different time-temperature combinations, except for the microwave. There were four power – time combinations for the microwave. **Table 3.1** shows the levels of each factor. Inner cells display the cooking times combined with the temperature in our study. For the analysis, the first column on 250 ^{0}F are labeled as 250-ST (short time), second column as 250-LT (long time). First column in 300 ^{0}F are labeled as 300-ST (short time), second column as 300-LT. Treatments at 350 ˚F are labeled as 350 and 400 ˚F was labeled as 400.

Table 3.2. Average moisture content for cooking treatments (%)

Time-temperature	**250 ˚F / 120 ˚C**		**300 ˚F / 150 ˚C**		**350 ˚F / 175 ˚C**	**400 ˚F / 205 ˚C**
Cooking Method	**ST**	**LT**	**ST**	**LT**		
Air fryer-1	1.63	3.69	2.62	2.62	8.9	8.51
Air fryer-2	3.77	4.25	9.81	5.7	3.84	8.07
Radiant oven-1	4.39	4.31	25.68	13.4	4.14	28.05
Radiant oven-2	2.49	4.04	5.54	4.18	5.56	19.85
Convection oven-1	6.7	5.03	11.29	4.16	12.35	14.7
Convection oven-2	5	6.14	16.26	8.62	11.88	18.78
Microwave	**2'**		**3'**		**3'**	**5'**
	8.57		4.37		18.57	8.31

Table 3.2 shows the average moisture content across treatments. Moisture content 5% and below is considered acceptable for a chip product. These values were used to select the

treatments that would be considered for further study. The table shows that some of the treatments did not yield moisture levels that are acceptable for chip making, especially at 400 ˚F. This was usually due to uneven charring, which resulted in high moisture retention.

The main objective of this study was to investigate the effect of the oven type and time-temperature on the moisture content, β-carotene, and color of sweet potatoes. We were also interested in whether the cooking method and time-temperature interact with each other and if there is any correlation between the moisture, β-carotene, and color of the sweet potatoes as a result of cooking treatment. For this purpose, we used the *stats* and *ggplot2* packages in R Statistical Software (version 4.0.5; R Foundation for Statistical Computing, Vienna, Austria) to perform a two-way ANOVA which examined the factors' effects. The two-way ANOVA assumed that the dependent variable is normally distributed and the population variances are equal in each group of the factors. Therefore, the dependent variables were transformed using a proper Box-Cox transformation to meet assumptions, and then the analysis was conducted on the transformed data.

The two-way ANOVA included the following research questions for the main effects and interaction effects:

(i) Does the cooking method influence the average moisture content, β-carotene and color of sweet potato chips?

(ii) Do temperature changes and different cooking times influence the average moisture content, β-carotene and color of sweet potato chips?

(iii) Does the effect of the cooking method on average moisture content, β-carotene and color depend on the time-temperature combination?

Moreover, the bivariate correlation analysis examined the research question of whether there is a significant correlation between the moisture content, β-carotene, and color.

Results for Moisture Content

A two-way ANOVA was performed to concurrently investigate the effect of the oven type and time-temperature on moisture levels. We also performed a one-way ANOVA to evaluate the effect of oven type across treatments including microwaved samples. The two-way ANOVA results for the moisture content are summarized in **Table 3.3** below.

Two-way ANOVA (Oven type and time-temperature ~ moisture content)

Table 3.3. Two-way ANOVA results for oven type and time-temperature interaction effect on moisture

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	5	1481.1	296.2	8.096	4.20e-06 *
Time_Temperature	5	2172.5	434.5	11.875	2.16e-08 *
Oven:Time_Temperature	25	738.8	29.6	0.808	0.72
Residuals	72	2634.5	36.6		

The asterisk (*) denotes the significant effect in ANOVA model (p<0.05).

The analysis revealed no statistically significant interaction effect between the oven type and time-temperature for the moisture content, F (25,72) = 0.808, p = 0.720. However, the main effects analysis showed that each factor statistically affected the moisture content (p < 0.001). We ran Tukey-adjusted post-hoc tests to assess whether the differences among average moisture contents for oven types and time-temperature levels were statistically significant.

Figures 3.1 and 3.2 illustrate each factor's estimated marginal means of the moisture content. Boxes indicate the expected marginal means, and error bars indicate the 95% confidence interval of the expected marginal means. Means sharing a letter were not significantly different.

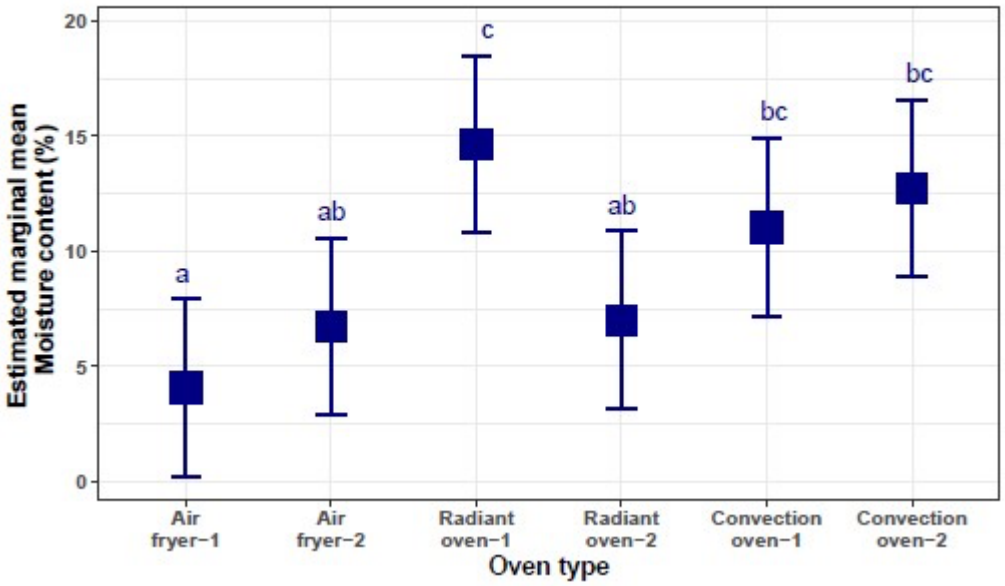

Figure 3.1 Post-hoc analysis for the oven type effect on moisture. *X-axis shows the different oven types and y-axis shows moisture content.*

In **Figure 3.1,** air fryer-1 and radiant oven-1 stand out with their lowest and highest mean moisture content, respectively. The Tukey test results also proved that these oven types significantly differed from others regarding their moisture rates. Furthermore, the average moisture contents obtained by air fryer-2 and radiant oven-2 were very close and not statistically different. Likewise, convection ovens 1 and 2 yielded similar moisture rates on average. Data suggest that air fryers yielded chips with the lowest moisture, which is desirable.

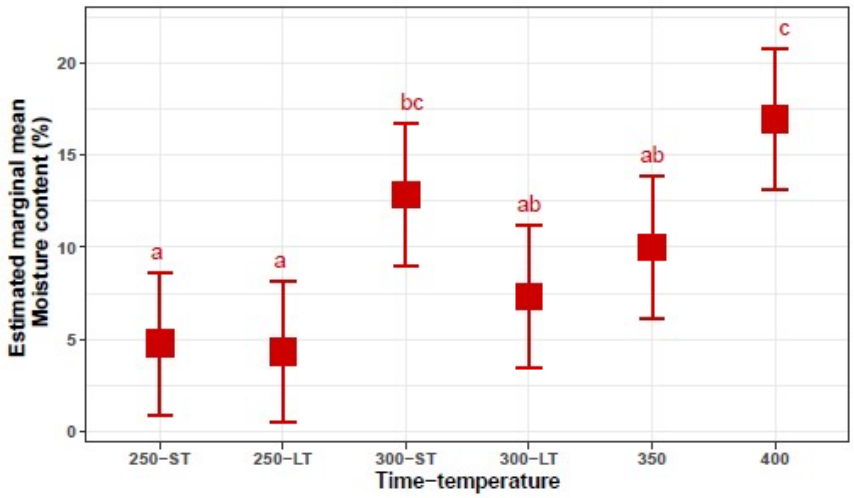

Figure 3.2 Post-hoc analysis for the time-temperature effect on moisture. *X-axis shows the different oven types and y-axis shows moisture content.*

The profile plot for the time-temperature factor **(Figure 3.2)** showed that the highest mean moisture rate was obtained at the maximum temperature (400). The lowest moisture for sweet potato samples were measured at the lowest temperature with a longer cooking time (250-LT). Additionally, sweet potatoes' moisture content significantly increased from low to mid-temperature (250-LT to 300-ST) and mid-high to high temperature (350 to 400). According to the post-hoc results, there was no significant difference between 250-ST and 250-LT. Hence, these combinations can be grouped as providing the lowest moisture content. However, we obtained the highest moisture at 400 F, and this temperature gave significantly different moisture rates from all other time-temperature levels.

One-way ANOVA (Moisture ~ Oven type)

Time and temperature options are different for the microwave oven type. It would not be proper to add microwave in two-way ANOVA since it does not share the same time-temperature levels with other oven types. Therefore, we preferred to omit the time-temperature factor and assess the performance of oven types only. In this section, time-temperature treatments were

combined for each oven and compared with the microwave. **Table 3.4** summarizes the one-way ANOVA results.

Table 3.4 One-way ANOVA results for oven type and moisture content

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	3	1067	355.7	6.105	0.000681 *
Residuals	116	6759	58.3		

The asterisk (*) denotes the significant effect in ANOVA model (p<0.05).

In one-way ANOVA, we compared the average moisture content through four different oven types. The oven type had a significant effect on the moisture content at α=0.05 level (F=6.105, p<0.001). Post-hoc comparisons using the Tukey HSD test **(Figure 3.3)** indicated that the mean moisture content for air fryer was significantly different from those for the other oven types. However, convection oven and microwave did not differ significantly. Convection oven and microwave were not significantly different from radiant oven. In summary, air fryer yielded the lowest amount of moisture, while radiant oven the highest. Convection oven and microwave provided similar moisture rates and were placed in between the two previously mentioned oven types.

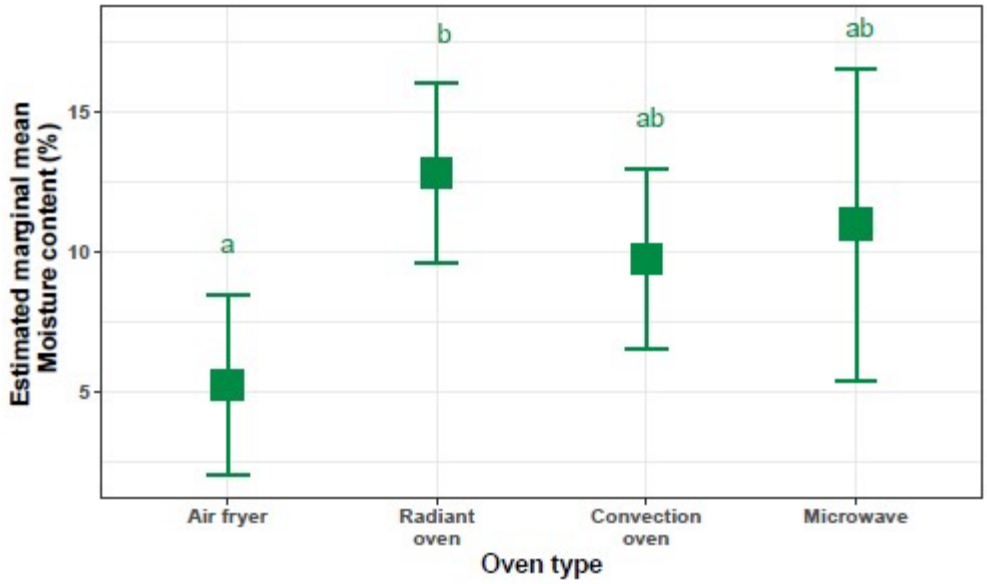

Figure 3.3 One-way ANOVA results for the effect of the oven type on moisture content. *X-axis shows the oven types and y-axis shows the moisture content.*

Results for Beta-Carotene

A two-way ANOVA was performed to concurrently investigate the effect of the oven type and time-temperature on β-carotene levels with appropriate post-hoc test. We also performed a one-way ANOVA to evaluate the effect of oven type across treatments including microwave and control samples.

Two-way ANOVA (Oven type and time-temperature ~ β-carotene)

Table 3.5 Two-way ANOVA results. Oven type and Time-temperature interaction effect on β-carotene

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven type	5	220.2	44.03	16.394	8.99e-11 *
Time_Temperature	5	128.7	25.74	9.584	4.85e-07 *
Oven:Time_Temperature	25	151.4	6.06	2.256	0.00394 *
Residuals	72	193.4	2.69		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

Table 3.5 shows the results of two-way ANOVA. Based on the results, the null hypotheses indicating neither the oven type nor the time-temperature combination had a prominent effect on β-carotene levels of sweet potato samples can be rejected at $\alpha=0.05$ ($p<0.001$). This means that the main effects of the factors were significant. Furthermore, we can conclude that there was also a statistically significant interaction effect between the oven type and time temperature, F (25,72)=2.256, p=0.004. In other words, the oven type impacts β-carotene levels for different time-temperature levels. Therefore, the β-carotene levels for oven types depends on the time and temperature levels at which sweet potato chips are cooked. In this case, it would be sufficient to interpret the interaction plot displayed in **Figure 3.4.** As can be seen, the lines are far from parallel, indicating that the oven types yield different β-carotene rates as the time-temperature combination changes.

The air fryer-2 gave the highest β-carotene level at low temperature and a longer cooking time (250-LT). β-carotene level obtained by air fryer-1 oven type increased as the temperature increase, especially from 300-ST to 350. We also observed that, except for the air fryer-2, β-carotene decreased as the temperature changes from 350 °F to 400 °F. Radiant ovens 1-2 and convection oven-1 provided similar β-carotene levels at 250-LT and 350. On the other hand, there was more variability between the oven types at the 300 °F to 400 °F. This was true regardless of the cooking time for 300 °F (300-ST and 300-LT). We also observed that air fryer retained more β-carotene for all time-temperature levels. Except for 300-ST and 300-LT radiant ovens retained the least β-carotene.

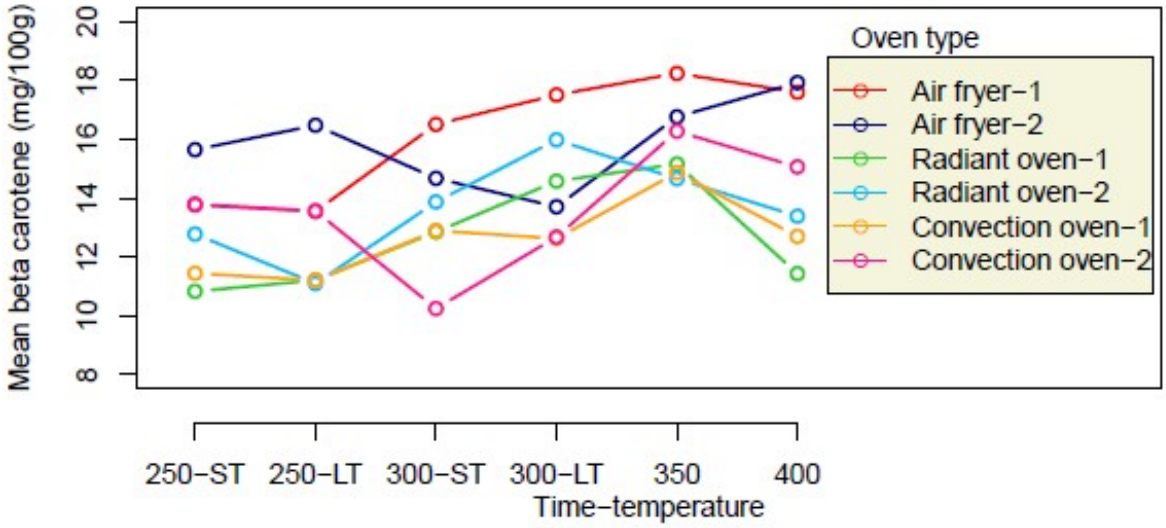

Figure 3.4 Two-way ANOVA results. Interaction effect between oven type and time-temperature on β-carotene. *X-axis shows the time-temperature levels and y-axis shows β-carotene. Cooking methods are represented by different colors on the plot.*

One-way ANOVA (Beta-carotene ~ Oven type)

Results from a one-way ANOVA **(Table 3.6)** suggest that the average β-carotene rates of the four oven types were not equal ($F\ (3,116) = 14.680$, $p < 0.001$). Pairwise comparisons of the means were illustrated in **Figure 3.5**. Based on the results, we would conclude that air fryer gives the highest average β-carotene rate, followed by microwave. The radiant oven obtained the lowest average β-carotene rate. Furthermore, there was a statistically significant difference between air fryer and all other oven types.

Table 3.6 One-way ANOVA results for the β-carotene and oven types

	Df	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Oven	3	232.5	77.50	14.68	3.61e-08 *
Residuals	116	612.2	5.28		

The asterisk (*) denotes the significant effect in ANOVA model ($p< 0.05$).

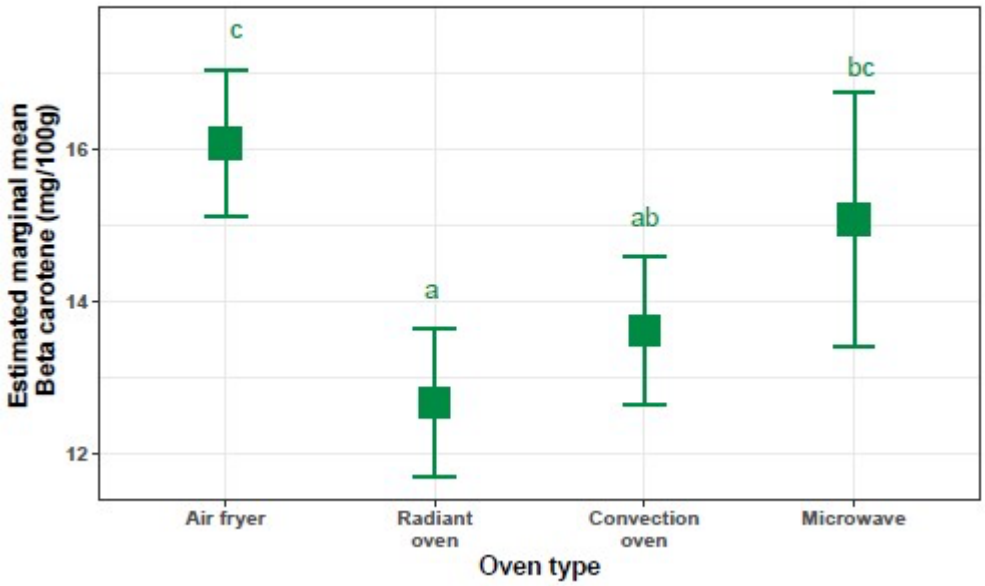

Figure 3.5 One-way ANOVA results for oven type and β-carotene. *X-axis shows the oven types and y-axis shows the β-carotene levels.*

Results for Color

Results for L*

L* represents light vs dark. A low value (0-50) indicates dark and a high number (51-100) indicates light. A two-way ANOVA was performed to concurrently investigate the effect of the oven type and time-temperature on L* levels with appropriate post-hoc test. We also performed a one-way ANOVA to evaluate the effect of oven type across treatments including microwaved samples. The following table shows the results of two-way ANOVA.

Table 3.7 Two-way ANOVA results for Oven type and Time-temperature interaction effect on L*

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Oven	5	256.9	51.39	3.603	0.00578 *
Time_Temperature	5	984.7	196.94	13.810	1.87e-09 *
Oven:Time_Temperature	25	478.8	19.15	1.343	0.16687
Residuals	72	1026.8	14.26		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

There was no significant interaction between the oven type and time-temperature, $F(25,72) = 1.343$, $p = 0.167$. On the other hand, the main effects of the oven type ($F(5,72) = 3.603$, $p = 0.006$) and cooking time-temperature ($F(5,72) = 13.810$, $p < 0.001$) impacted L* measurements significantly. Because the interaction did not exist, we can separate the effects of the factors and run a post-hoc analysis on each. **Figures 3.6 and 3.7** illustrate the estimated marginal means for each factor and Tukey-adjusted post-hoc comparisons.

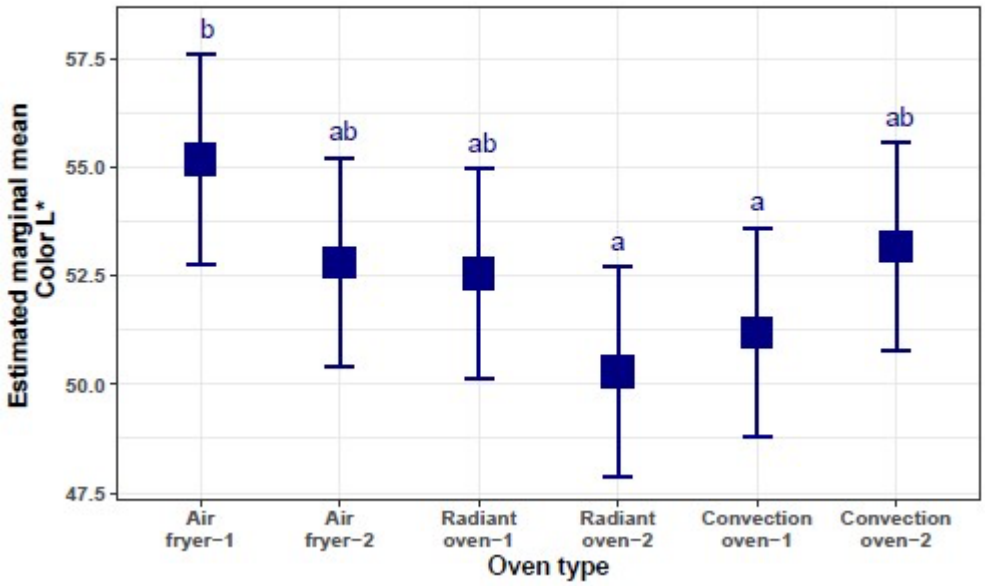

Figure 3.6 Post-hoc analysis for the oven type effect on L*. *X-axis shows the different oven types and y-axis shows L* readings.*

L* is an indicator of charring because more charring results in darker chips. Higher L* values indicate less charring. The highest average L* score was obtained by Air fryer-1, whereas radiant oven-2 obtained the lowest. Radiant oven-2 and convection oven-1 provided similar L* scores and can be grouped. Similarly, the difference between the mean L* scores for methods air fryer-2, radiant oven-1, and convection oven-2 were not statistically significant. The letter coding revealed that these three oven types can be grouped with the ones coded by "a" or "b." Unfortunately, the distinction among oven types was not very clear. However, we can confidently express that the air fryer -1 gave the highest L* score and was significantly different from radiant oven-2 and convection oven-1.

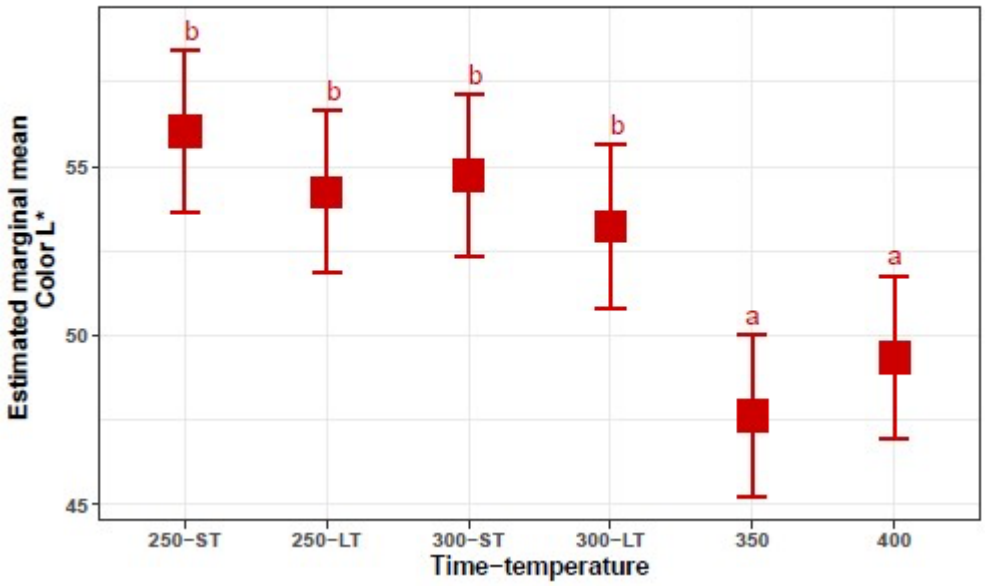

Figure 3.7 Post-hoc analysis for the time-temperature effect on L*. *X-axis shows the time-temperature levels and y-axis shows L* readings.*

In **Figure 3.7**, we observed a clear distinction among the levels of the time-temperature factor. Even though the 250-ST combination had the highest readings, it can be seen that the 250 $^{\circ}$F and 300 $^{\circ}$F levels, regardless of the cooking time, gave similar mean L* scores. Hence, the first four levels can be categorized together. On the other hand, the 350 ^{0}F and 400 ^{0}F

temperature levels can be grouped by yielding very close average L* scores. The sweet potato samples had lower average L* at 350 ˚F and 400 ˚F temperatures than at 250 ˚F and 350 ˚F temperature levels. In brief, these two groups (labeled with "a" and "b") were significantly different. Therefore we can conclude that high temperature treatments (350 ˚F – 400 ˚F) yielded chips with significantly more charring than low temperature treatments (250 ˚F – 300 ˚F).

One-way ANOVA (L* ~ Oven type)

A one-way ANOVA shows the effect of the oven type on L* is significant, F=3.934, p=0.0103.

Table 3.8 ANOVA results for oven type and L*

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Oven	3	317.1	105.70	3.934	0.0103 *
Residuals	116	3116.5	26.87		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

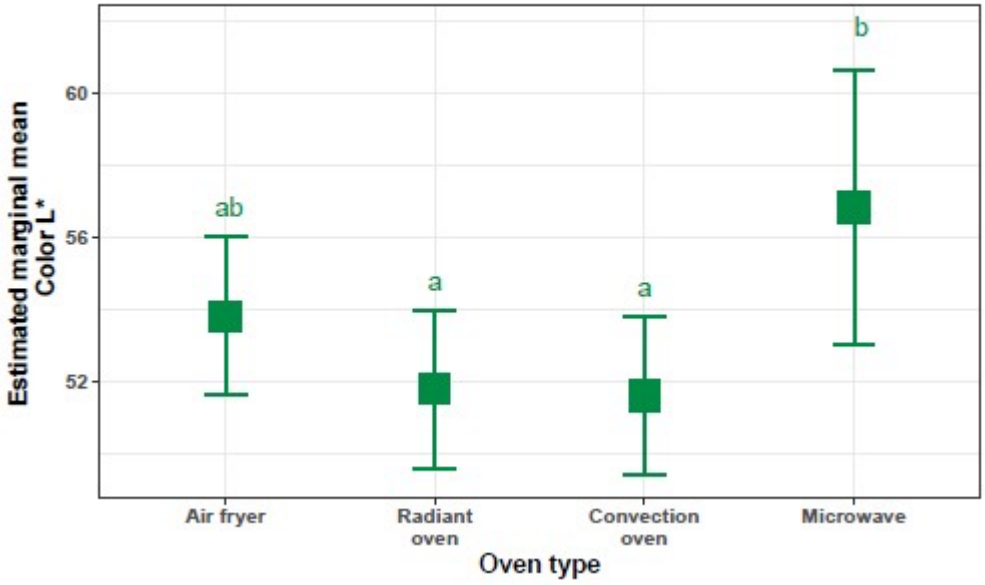

Figure 3.8 One-way ANOVA results for oven type and L*. X axis shows the oven types and Y axis shows the L* levels.

Post-hoc analyses using the Tukey HSD indicated that the average score of L* was significantly higher in microwave than in the other three oven types. Radiant oven and convection oven resulted in almost the same mean L* scores, and no significant difference was found between these two oven types. Air fried chips had higher L* values than radiant oven and convection oven, and lower than microwaves but these differences are not statistically significant. We can conclude microwave oven yielded chips with significantly less charring compared to radiant oven and convection oven.

Results for a*

The value for a* represents red vs. green. A positive number indicates red and a negative number indicates green. A two-way ANOVA is conducted to investigate the concurrent effects of the oven type and time-temperature combinations on a* measurements of sweet potato samples. The results from the ANOVA analysis revealed at least one significant difference among oven types ($F\ (5,72)$ = 10.473, $p < 0.001$) and time-temperature combinations ($F\ (5,72)$ = 6.595, $p < 0.001$). We observed no significant interaction effect between the factors ($F\ (25,72)$ =1.298, $p = 0.195$). Or, to say it another way, the type of oven did not have different effects on a* measurements for different cooking time-temperature levels.

Table 3.9 Two-way ANOVA results for oven type and time-temperature interaction effect on a*

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	5	332.3	66.45	10.473	1.41e-07 *
Time_Temperature	5	209.2	41.85	6.595	4.18e-05 *
Oven: Time_Temperature	25	205.9	8.23	1.298	0.195
Residuals	72	456.9	6.35		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

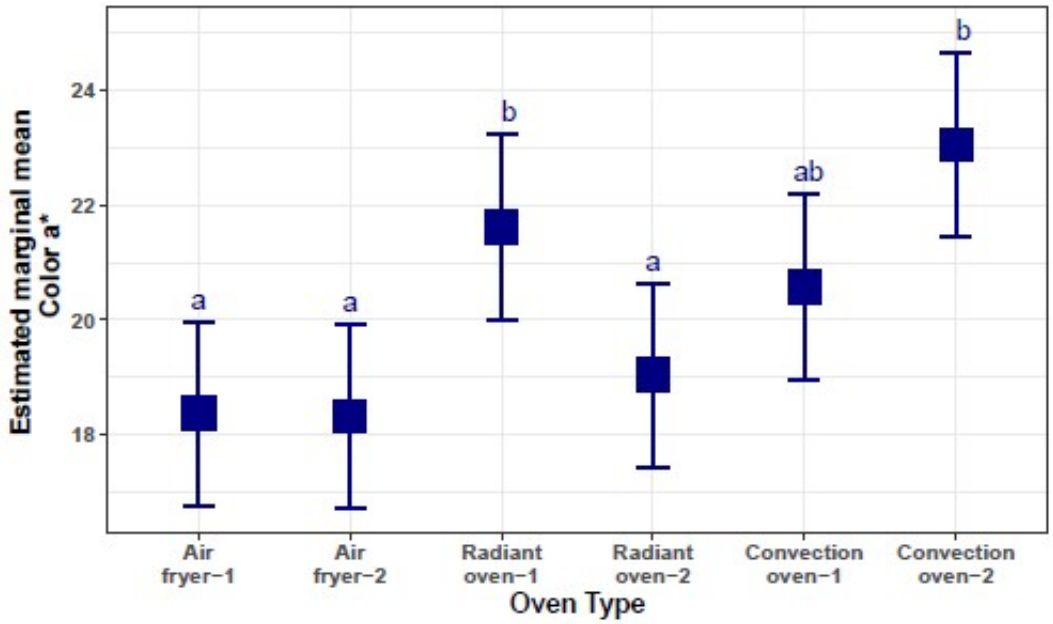

Figure 3.9 Post-hoc analysis for the oven type effect on a*. *X-axis shows the oven types and y-axis shows a* readings.*

The marginal means for the oven type are illustrated in **Figure 3.9**. We can say that all the samples were in the red side of the spectrum. The Tukey HSD results reveal that the mean a* scores for air fryers 1-2 and radiant oven-2 were not different with lowest a* measurements. Radiant oven-1 and convection oven-2 stand out as the two types with higher average a* scores. Convection oven-1 yields an average value that is not significantly different than any other treatment. We can also say that air fried chips were less red than the rest of the oven baked chips although it was only significantly different than radiant oven-1 and convection oven-2.

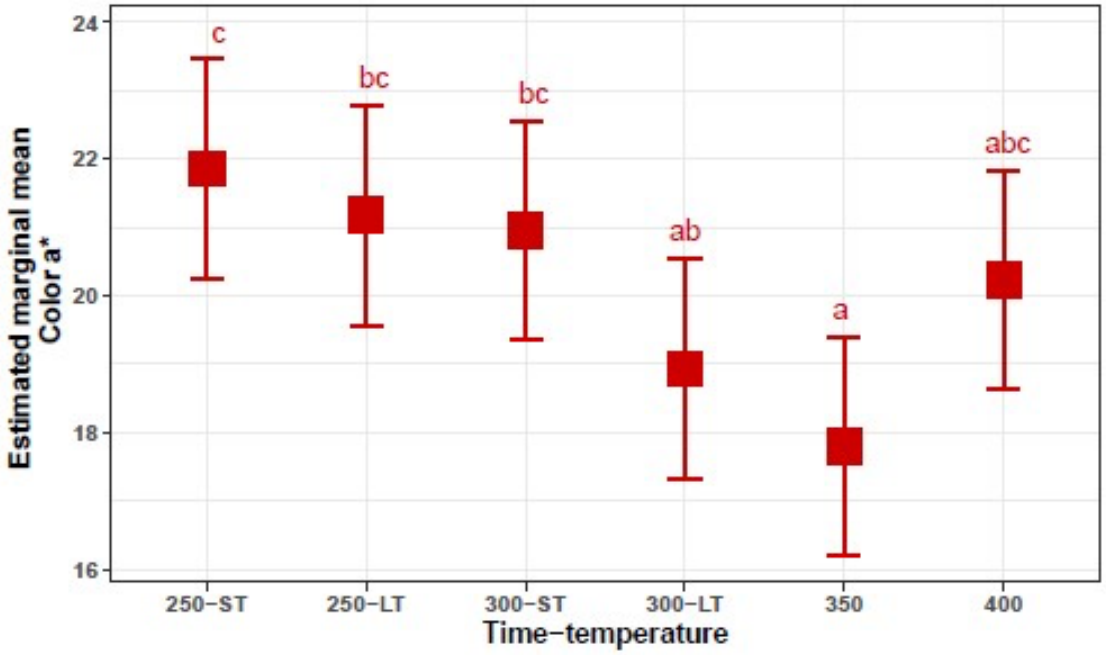

Figure 3.10 Post-hoc analysis for the time-temperature effect on a*. *X-axis shows the time-temperature and y-axis shows a* readings.*

Figure 3.10 shows that the estimated marginal means for a* decreased as the temperature increase from 250 ˚F to 350 ˚F. The level of 350 ˚F gave the lowest average a* score. The average a* score of the 250-ST was significantly higher than the other time-temperature levels. On the other hand, the levels 250-LT and 300-ST yielded close results to that for 250-ST. It would be proper to put the first three time-temperature levels in the same group. The 400 ˚F treatment was not significantly different than any other level.

One-way ANOVA (a* ~ Oven type)

Table 3.10 shows the results from a one-way ANOVA, which revealed that at least one oven type yields significantly different a* scores, $F(3,116) = 7.035$, $p < 0.001$. **Figure 3.11** below displays the comparison of each oven type concerning a* measurements.

Table 3.10 One-way ANOVA results for oven type and a*

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Oven	3	209.3	69.76	7.035	0.000218 *
Residuals	116	1150.3	9.92		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

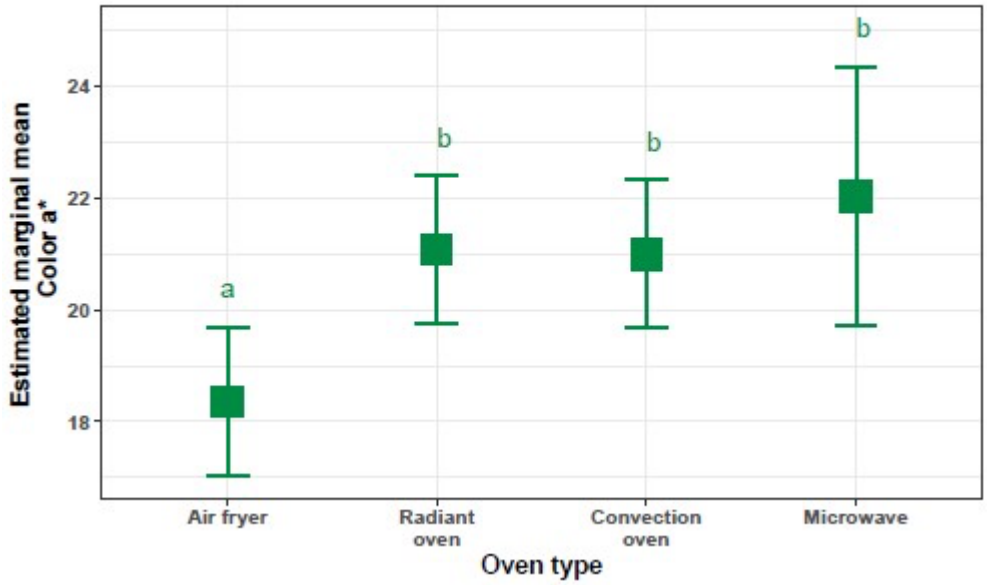

Figure 3.11 One-way ANOVA results for oven type and a*. *X-axis shows the oven types and y-axis shows the a* levels.*

Figure 3.11 shows the effect of oven on a* values. The Tukey HSD post-hoc test shows that air fryer's average a* score differed from other oven types. In addition, air fryer gave the lowest a* readings among all. Radiant oven, convection oven, and microwave measurements were significantly higher than air fryer. This means that radiant ovens, convection ovens and microwave yielded chips with similar redness.

Results for b*

The value for b* represents yellow vs. blue. A positive value indicates yellow and a negative value indicates blue. A two-way ANOVA revealed the main effects of the oven type

($F(5,72)$=7.509, p<0.001) and the time-temperature ($F(5,72)$ = 11.387, p < 0.001) were statistically significant. However, the interaction effect was insignificant, F (25,72) =1.652, p = 0.052, indicating that the oven types do not have different effects on levels of time-temperature.

Table 3.11 Two-way ANOVA results for Oven and Time-temperature interaction effect on b*

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	5	761.5	152.31	7.509	1.02e-05 *
Time_Temperature	5	1154.9	230.97	11.387	4.10e-08 *
Oven:Time_Temperature	25	837.8	33.51	1.652	0.0515
Residuals	72	1460.4	20.28		

The asterisk (*) denotes the significant effect in ANOVA model (p < 0.05).

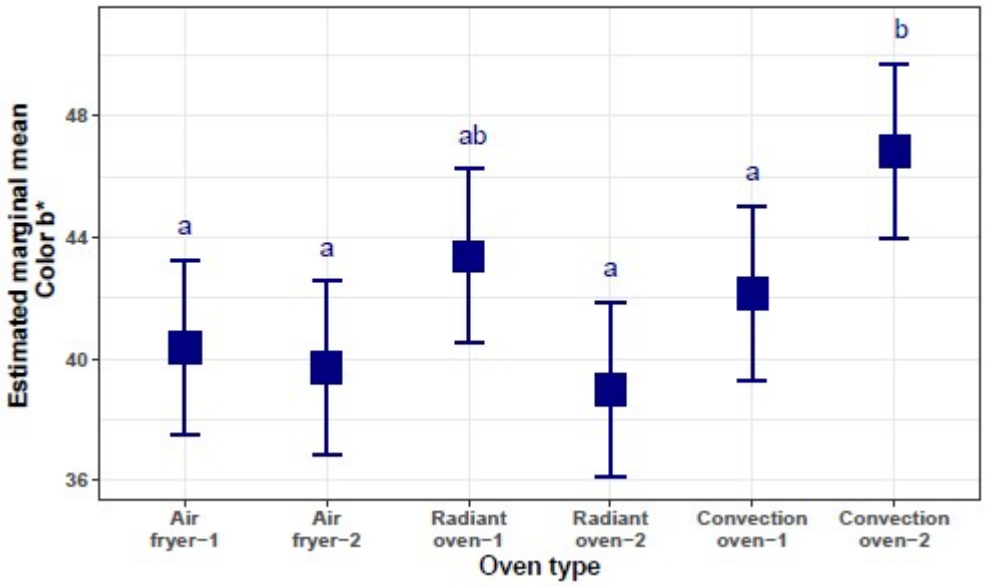

Figure 3.12 Post-hoc analysis for the oven type effect on b*. *X-axis shows the different oven types and y-axis shows b* readings.*

The Tukey post-hoc test results are displayed in **Figure 3.12** above. As can be seen, convection oven-2 gave the highest average b* score, followed by radiant oven-1. These two oven types differed significantly from the others. All other pair-wise comparisons between the oven types showed non-significant results.

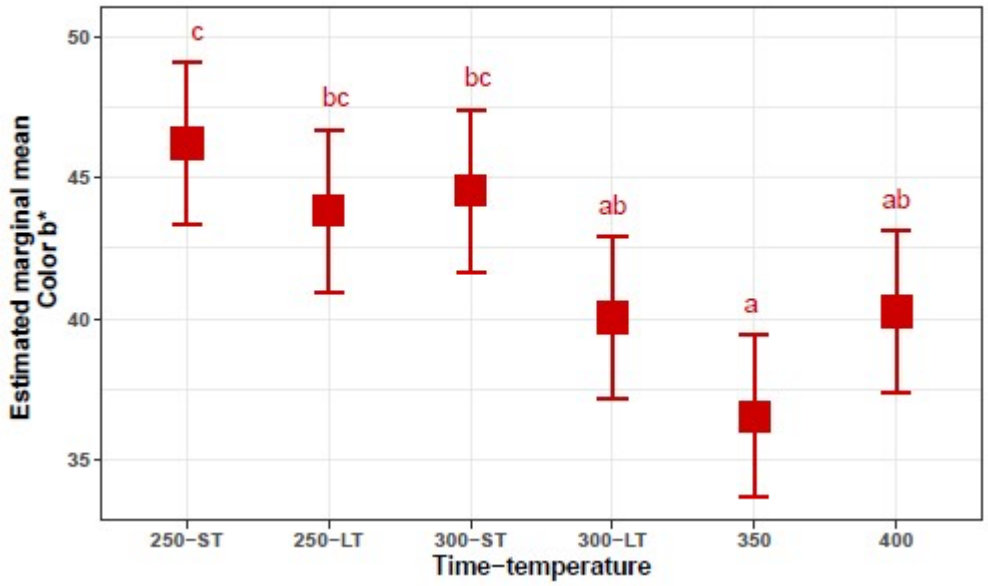

Figure 3.13 Post-hoc analysis for the time-temperature effect on b*. *X-axis shows the time-temperature levels and y-axis shows b* readings.*

The profile plot of the time-temperature factor, **Figure 3.13**, shows a very similar pattern as in a* scores (91.9% correlation between a* and b*). The estimated marginal means for b* decreased as the temperature increased from 250 ˚F to 350 ˚F. The 350 ˚F treatment gave the lowest average b* score overall. The average b* obtained by the 250-ST was the highest followed by 250-LT and 300-ST and they were significantly higher than the other time-temperature levels.

One-way ANOVA (b* ~ Oven type)

Table 3.12 shows the results from a one-way ANOVA, which reveals that at least one oven type yields significantly different b* scores, $F\ (3,116)$ =3.790, p=0.012. **Figure 3.14** below displays the comparison of each oven type concerning b* measurements.

Table 3.12 One-way ANOVA results for oven type and b*

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
OvenType	3	448	149.3	3.79	0.0123 *
Residuals	116	4570	39.4		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

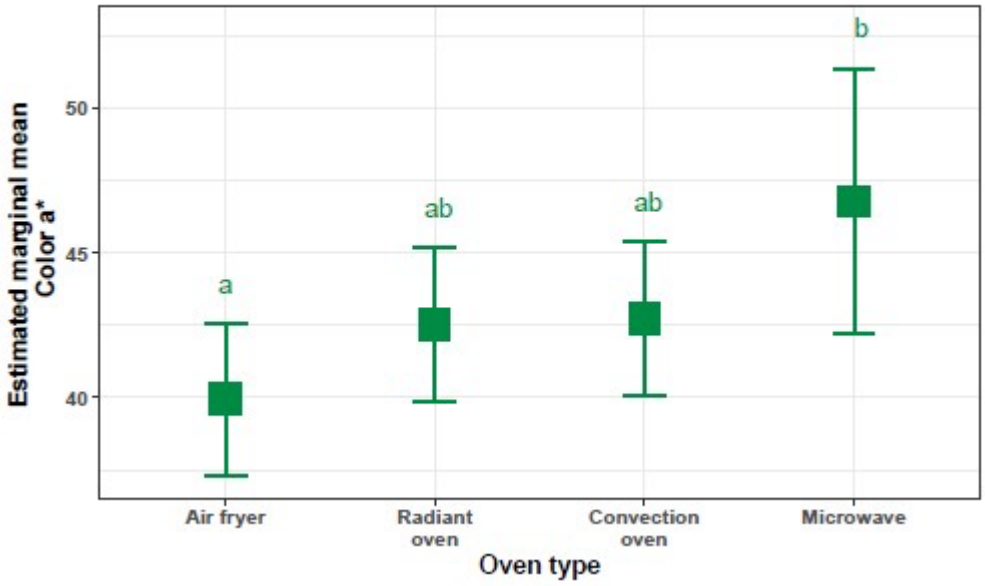

Figure 3.14 One-way ANOVA results for oven type and a* readings. X-axis shows the oven types and y-axis shows the a* levels.

The Tukey HSD post-hoc test showed that air fryer's average b* score differed from other oven types and was the lowest mean b* among all. Radiant oven and convection oven gave almost the same average amount and do differ from each other concerning b* scores. Microwave yielded a relatively higher amount of b* than other oven types.

Table 3.13 Correlation between variables

	Moisture	Beta-carotene	Color_L	Color_a	Color_b
Moisture	1.0000000	-0.1438561	-0.1425707	0.3701428	0.2030705
		p=0.1375	p=0.141	p<0.001*	p=0.03505*
Beta-carotene		1.0000000	-0.1645628	-0.4648901	-0.4082350
			p=0.08877	p<0.001*	p<0.001*

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

Discussion

In this section, our aims were to determine optimal cooking time-temperature, compare β-carotene levels to optimize nutrient retention and evaluate the correlation between color measurements and β-carotene. We applied different levels of time-temperature treatment to produce sweet potato chips with 7 different ovens (2 air fryers, 2 radiant ovens, 2 convection ovens, and 1 microwave). Chips that have moisture content 5% or below were considered acceptable. Based on the moisture content, air fryers yielded lower moisture content compared to other oven types across different time-temperature treatment. Lowest temperature level, 250 ˚F, produced chips with lowest moisture levels across oven types.

The interaction effect between oven type and time-temperature levels were significant for β-carotene. The results demonstrate that β-carotene levels were affected by cooking method as well as the time-temperature combination. In terms of temperature effect, β-carotene levels were the highest with the least variability at 350 ˚F. This could be due to the short time application as well as the high moisture content of the samples. Due to uneven cooking and charring at the high temperatures, cooking was incomplete in some sections of the sweet potato slices for some oven types. In terms of the interaction effect between time-temperature and cooking method, air fryers retained more β-carotene at higher temperatures (350 ˚F and 400 ˚F) than all other ovens. In terms of the oven type, highest β-carotene measurements were produced by air fryers followed

by microwave. Radiant oven resulted in the least β-carotene retention and it was significantly less than either microwave or air fryer, possibly due to the longer cooking time for both radiant oven and convection oven. For our study we used β-carotene as a representation of nutrient retention. Therefore, air fried chips retained significantly more β-carotene than those prepared in radiant and convection ovens. Microwaved chips were a close second and not significantly different than air fryers.

Color analysis showed that microwaved chips were on average less charred. The chips were on the light side of the spectrum rather than dark except for the chips that were cooked at 350 °F and 400 °F. The higher temperatures yielded chips with more charring. Based on the average moisture content of each treatment we selected cooking treatments for further analysis. Correlation analyses **(Table 3.13)** show a significant correlation between moisture content and color a* and b*. Similarly, β-carotene and color a* and b* have a significant correlation. This result suggests that color analysis might be further developed as a quick indicator of β-carotene and nutrient retention in baked sweet potato chips.

Tian (2016) used domestic cooking methods on purple-fleshed sweet potato to see if there is a difference between cooking methods. They compared boiling, baking, steaming, microwaving, frying, stir frying, and air frying. They observed that cooking method had an effect on the antioxidant activity and the phytochemical composition of potatoes. They showed that microwaving and steaming retained highest phytochemical and antioxidant activity. They also concluded that frying methods caused severe losses in phytochemicals and vitamin C except for use of an air frier. Air fried retained the highest level of antioxidant activity. Another significant result from their study is that air frying could yield chips that are lower fat but are similar to other frying methods in terms of sensory characteristic (Tian et al., 2016). Our results have

similarities with their study based on the higher β-carotene retention of chips made with air fryers. Caetano et al., (2018) showed that baking and air frying yields chips that are low-fat and low moisture content. However, their study showed consumers preferred fried chips.

In conclusion, air fryers produce chips that are evenly cooked chips more consistently compared to radiant, convection, or microwave cooking across different temperatures while retaining more β-carotene compared to radiant and convection oven. Similar β-carotene retention was observed with microwave. Correlation between β-carotene and color a* and b* is promising for a quick determination of nutrient retention by evaluating colorimetry results.

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CHAPTER 4: EVALUATION OF SWEET POTATO CHIPS

Introduction

Sweet potato (*Ipomoea batatas* [L.] Lam) is a nutritious storage root that provides a significant amount of starch, minerals (potassium, phosphorus, calcium, magnesium, iron, copper), vitamins (thiamin, riboflavin, niacin, pantothenic acid, folic acid, vitamin E), phenolic compounds, carotenoids, and bioactive components (Truong et al., 2018; Woolfe, 1992). Sweet potato composition varies widely depending on the variety. Orange fleshed sweet potatoes are biofortified due to their high β-carotene levels (Yencho et al., 2008).

Sweet potato production grew exponentially in the last two decades. Consumption increased by 86% between 1999 and 2019 climbing from 3.8 pounds/year/per capita to 7.1 pounds/year/per capita (USDA, 2020). North Carolina has been the leading state in sweet potato production since 1971 producing nearly 60% of all sweet potatoes in the country (AGMRC, 2021). Sweet potatoes are commonly consumed as a snack or as a side dish in the U.S and their popularity is increasing. Sweet potatoes can be boiled, steamed, baked, dried, and fried in a home setting. It is processed into french fries, chips, baby food, purees, juices, frozen and canned products, flakes, and flour (Truong et al., 2018).

The processing method is very important to retain nutrients and avoid unwanted by-products. Acrylamide is an unwanted by-product of processing sweet potatoes at high temperatures (over 120 ˚C). Acrylamide showed a carcinogenic effect on animals. It is classified as a "probable human carcinogen" and a neurotoxin by IARC (Tornqvist, 2005). Later, it was discovered in food, and the mechanism of production was described (Mogol & Gökmen, 2016; Mottram et al., 2002; Tareke et al., 2002).

The main mechanism for acrylamide production is the Maillard reaction between free asparagine and reducing sugar at high temperatures. Sweet potato is abundant in asparagine therefore, it is susceptible to acrylamide formation (Mogol & Gökmen, 2016). Several studies investigated mitigation strategies against acrylamide formation. Efforts focus on alternative cooking methods, improving the time-temperature variables of cooking, adding a thawing step for frozen products, and using newly developed systems. Palazoğlu & Gökmen, (2008) showed by frying at two steps acrylamide levels can be reduced in half. Tuta et al., (2011). used a microwave blanching step and reduced acrylamide production by 79%. Granda & Moreira, (2005) used a vacuum frying method and decreased the amount of acrylamide by 94%. Comparing air frying with deep frying, Sansano et al., (2015) yielded chips with 90% acrylamide reduction.

The main carbohydrate in sweet potato is starch. Starch makes up the majority of the dry matter. Starch digestion in the human body starts in the mouth with salivary α-amylase (Nadia et al., 2021). When the food is swallowed enzyme activity decreases in the stomach due to acidity. The majority of the digestion occurs in the duodenum with pancreatic α-amylase which hydrolyzes starch to maltose, maltotriose, and α-limit dextrins (Emmambux & Taylor, 2017). Further hydrolysis of dextrin and disaccharides was completed by maltase-glucoamylase and α-dextrinase at the brush border membrane of the small intestine. Monosaccharides are absorbed by diffusion, then active transport by SGLT1 and GLUT2 and transported to the liver (Emmambux & Taylor, 2017; Institute of Medicine, 2005).

Digestion is a complex process so to imitate and study how the gastrointestinal tract works there are three main methods. In vivo digestion, in vitro digestion, and in silica digestion (Muttakin et al., 2019). In vivo digestion occurs in a living organism therefore it is more

clinically relevant compared to in vitro digestion. In vitro digestion happens outside of the body and the researcher mimics a part of the digestive tract. In vitro digestion is easier to use but to be able to draw a clinical conclusion it should be supported by further research (Bornhorst & Singh, 2014). In vivo digestion is commonly used for the determination of the glycemic index and bioaccessibility of a food component (Brouns et al., 2005). In vitro digestion allows us to create simpler systems with more control ability.

Therefore, the objectives of this study were; (1) to compare the effect of different cooking methods and time-temperature treatments on β-carotene, color, texture, and acrylamide formation. (2) to evaluate the effect of cooking method and cooking time-temperature interaction on carbohydrate digestion. Moreover, the correlation between the variables was investigated as a potential method to monitor β-carotene and acrylamide levels.

Methods

Production of Sweet Potato Chips

Covington variety Orange Fleshed Sweet Potatoes were grown at the Horticultural Crops Research Station in Clinton, NC, provided by the Sweet Potato Breeding and Genetics Program at North Carolina State University. Sweet potatoes were sorted, cleaned, and washed thoroughly. They were patted dry with paper towels. Sweet potatoes were not peeled. They were sliced into 1.5 mm slices with a Hobart Slicer. Slices were then lightly sprayed with canola oil and cooked with 7 different cooking methods: 2 air fryers, (Air fryer 1; Cook's Essential, CM15901,1500 W) (Air fryer 2 Nuwave, NuWave Brio, 1300 W), 2 radiant ovens, (Radiant oven 1; Krups, 571509, 1600W) (Radiant oven 2; Krups, 571505, 1600W), 2 convection ovens (Krups, 571509, 1600W) (KitchenAid, KCO253, 1440 W) and a microwave (Panasonic Inverter, NN-SD987S, 1250 W).

Cooking times and temperatures were selected based on the cooking matrix study and can be found in **Table 4.1**. For ovens and air fryers 2 temperature levels were selected one low temperature long time and one high temperature short time. For microwave 1 level was selected (100% 3 minutes). After cooking SPCs were allowed to rest for 10 minutes. After the rest, chips underwent moisture content analysis, color analysis, β-carotene analysis, texture analysis, acrylamide analysis, and carbohydrate digestion SPCs underwent moisture and color analysis directly following preparation. The remaining SPCs were stored away from light at -20 °C until the β-carotene, acrylamide, glucose digestion, and texture measurements were completed. Proximate analysis of SPCs was completed for each cooking method. Moisture content, color, and β-carotene were measured as explained in **pages 51 and 52.**

Table 4.1. Oven types, times and temperature.

Cooking method	**Cooking temperature & time**	**Cooking temperature & time**
Airfryer 1 (1)	250 ^{0}F / 25’	300 ^{0}F / 17’
Airfryer 2 (2)	250 ^{0}F / 25’	350 ^{0}F / 10’
Radiant oven 1 (3)	250 ^{0}F / 50’	350 ^{0}F / 20’
Radiant oven 2 (4)	250 ^{0}F / 50’	300 ^{0}F / 30’
Convection oven 1 (5)	250 ^{0}F / 60’	300 ^{0}F / 30’
Convection Oven 2 (6)	250 ^{0}F / 60’	
Microwave (7)	100 % / 3’	

Proximate Analysis

Proximate analysis was performed by Microbac Laboratories (Warrendale, PA). SPC from each cooking method were batched before sending in for the proximate analysis. One sample was analyzed for each cooking method.

Texture Analysis

Four individual different sweet potato chips were tested from each sample with TA.TX2 Texture Analyzer (Stable Micro Systems, Godalming, UK) equipped with 25 kg load cell, Heavy Duty Platform and 18 mm Crisp Fracture Rig (HDP/CFS) and with 1/2" diameter ball probe. The texture analyzer was calibrated with 2 kg and 5 kg load cells. Test speed was set to 1 mm/sec and trigger force was set to 5 g. Travel distance of the probe was set to 3 mm. Each sample was selected randomly from the bag just before the analysis and placed on the fracture rig. Data acquisition rate was 500 points per second. Peak positive force (fracture force) and positive area under the curve were used to interpret the data.

Figure 4.1 Illustration of texture analyzer setup

Acrylamide Measurement

Acrylamide content was measured with Acrylamide-ES ELISA, Microtiter Plate (Franek et al., 2014) (PN 515680, Eurofins – Abraxis, Warminster, USA). Biotage Multimode SPE

column and Biotage ENV+ SPE columns were used for clean-up procedure. Samples and standards were prepared following the manufacturer instructions as follows. Approximately 1.5 g of sample was used for sample extraction in duplicate. Acrylamide was extracted with water by mixing the sample with deionized water, vortexing, incubating, filtering, and centrifugation. The extract then underwent a clean-up process using Multimode SPE column and ENV+ SPE columns (Biotage, USA) conditioned with 100% methanol and deionized water by centrifugation at 40 x *g* (500 rpm). Deionized water and 60% methanol solution were used for the clean-up process. Prior to assaying, controls and standards (0, 2.5, 5, 10, 25, 50, 200 ng/mL (ppb)) underwent a derivatization procedure. Subsequently, the assay procedure was performed. The assay was a direct competitive ELISA. Acrylamide conjugated with the enzyme competes for the binding sites of rabbit anti-acrylamide antibodies. The acrylamide antibodies then were bound by the second antibody (goat anti-rabbit) and immobilized on the plate. Then a substrate was added to create blue color signal. The intensity of blue color was inversely proportional to the acrylamide concentration. The absorbance was read at 450 nm within 15 minutes after the stop solution was added. Data were evaluated with a four-parameter logistic curve and average concentration of each sample was calculated.

Carbohydrate Digestion

In vitro digestion was based on previously developed procedures (Argyri et al., 2016; Germaine et al., 2008; Sopade & Gidley, 2009) with minor modifications. Samples were ground with a coffee grinder (SHARDOR Coffee & Spice Grinders, CG628B) into a powder. Samples calculated to contain 0.25 g of carbohydrate (Samples weight = 0.354 – 0.447 g) were weighed into mini vials in duplicate and mixed with equal amount of phosphate buffer. Then, samples were incubated with α-amylase (185 U/g available carbohydrate, 1194 U/mg, dissolved in 0.02

M phosphate buffer, α-amylase from human saliva, (type XIII-A A1031-5KU, Sigma-Aldrich, St. Louis, MO, USA) at 37 ˚C for 15 min in a shaking water bath (Thermo Scientific Precision, Waltham, MA, USA) to simulate the oral digestion step. After the oral digestion, pH was adjusted to 2.5 with 0.1 M HCl and the total volume was brought to 2 mL with deionized water (pH adjusted to 2.5 with 0.1 M HCl) for gastric digestion. Pepsin, 0.1 mL, of was added to each vial (porcine pepsin preparation, suspended in 4 g/100 mL in 0.1 M HCl, porcine pepsin, P-7000, Sigma-Aldrich, St. Louis, MO, USA). Vials were placed in the shaking water bath and were incubated for 2 hours at 37 ˚C to mimic the gastric phase of digestion. After the incubation, 2 mL of 0.1 M PIPES buffer, pH 6.5 (Piperazine-N,N′-bis(2-ethanesulfonic acid), Piperazine-1,4-bis(2-ethanesulfonic acid), 1,4-Piperazinediethanesulfonic acid) (dissolved in 10 N NaOH, PIPES ≥ 99% (titration), P6757, Sigma-Aldrich, St. Louis, MO, USA) was added to the digesta to increase pH to prepare for the intestinal digestion. After adding PIPES buffer, vials were placed back in the water bath and incubated for 30 minutes at 37 ˚C. After this incubation, 40 µL amyloglucosidase (82 U/mg, in 0.01 M acetate buffer, amyloglucosidase from *Aspergillus niger*, 10115-1G-F, Sigma-Aldrich, St. Louis, MO, USA) and 0.5 mL of a pancreatin – bile salt mixture (0.2 g Pancreatin from porcine pancreas, (P-1625 Sigma-Aldrich, St. Louis, MO, USA), and 1.2 g bile extract (B-8756 Sigma-Aldrich, St. Louis, MO, USA) were dissolved into 100 mL 0.1 M $NaHCO_3$) was added to each vial. Vials were placed back in the shaking water bath for 2 hours with aliquots removed for glucose concentration measurement with a glucometer every 30 minutes.

For glucose measurement OneTouch Verio IQ Glucometers (LifeScan, Miltipas, CA) were used with OneTouch Verio test strips. Glucometers are intended for self-testing blood glucose to monitor diabetes. OneTouch VerioIQ can measure a blood glucose range of 20 – 600

mg/dL. The test utilizes flavin adenine dinucleotide dependent glucose dehydrogenase (FAD-GDH) for oxidation of glucose to gluconolactone in 0.4 µL of blood sample. This oxidation reaction creates a small electric current proportional to the glucose concentration of the sample. (FitzGerald & Vermerris, 2005a). A control test was performed with each box of strips with control solutions. Readings were recorded at the time of initiation of intestinal digestion and was taken every 30 minutes (0, 30, 60, 90, 120 min).

Ground samples that contain 0.25 g carbohydrate are weighed
Mix with equal weight of phosphate buffer
Incubate with α-amylase for 15 min at 37 ˚C in shaking water bath
Adjust the pH to 2.5 with 0.1 M HCl and bring the volume up to 2 mL
Add 0.1 mL pepsin and incubate for 2 hours at 37 ˚C in shaking water bath
Add 2 mL 0.1 M PIPES pH=6.5; incubate for 30 minutes
Add 40 µL of amyloglucosidase and 0.5 mL pancreatin-bile salt mixture
Take a glucose reading immediately and every 30 minutes

Figure 4.2 Flowchart for glucose bioaccessibility assay

Results

Two factors (*oven type* and *time-temperature*) are involved in the experiment of measuring the dependent variables, moisture content, β-carotene (mg/100g), color, texture, acrylamide, and glucose readings of carbohydrate digestion of sweet potato chips. In total, there were 36 samples collected from six different oven types and a microwave. In each oven type, the sweet potato samples were exposed to one or two different time-temperature combinations.

There was one power-time combinations for the microwave. **Table 4.1** shows the levels of each factor. Inner cells display the cooking times and temperatures. For the analysis, first column was labeled as Low-LT (low temperature-long time) and second column was labeled as High-ST (high temperature-short time). We also had two brands of commercially available deep-fried sweet potato chips to compare with our samples as a control.

The main objective of this study was to investigate the effect of the oven type and time-temperature on the moisture content, β-carotene, color, texture, acrylamide levels, and carbohydrate digestion of sweet potatoes. We were also interested in whether the cooking method and time-temperature interact with each other and if there is any correlation between the moisture, β-carotene, color, texture, acrylamide levels, and carbohydrate digestion of the sweet potatoes as a result of cooking treatment. For this purpose, we used the *stats, rstatix, tidyverse, ggpubr* and *ggplot2* packages in R Statistical Software (version 4.0.5; R Foundation for Statistical Computing, Vienna, Austria) to perform one-way, two-way and mixed ANOVA which examined the factors' effects. Air fryers, radiant ovens and convection ovens were evaluated in the two-way ANOVA. Microwaved chips and control (commercially available deep-fried sweet potato chips) are not included in the two-way ANOVA due to the incompatibility in time-temperature levels. The two-way ANOVA assumed that the dependent variable is normally distributed and the population variances are equal in each group of the factors. Therefore, the dependent variables were transformed using a proper Box-Cox transformation to meet assumptions, and then the analysis was conducted on the transformed data.

The two-way ANOVA included the following research questions for the main effects and interaction effects:

(i) Does the cooking method influence the average moisture content, β-carotene, color, texture, acrylamide levels, and carbohydrate digestion of sweet potato chips?

(ii) Do temperature changes and different cooking times influence the average moisture content, β-carotene, color, texture, acrylamide levels, and carbohydrate digestion of sweet potato chips?

(iii) Does the effect of the cooking method on average moisture content, β-carotene and color depend on the time-temperature combination?

Moreover, the bivariate correlation analysis examined the research question of whether there is a significant correlation between the β-carotene, color, texture, and acrylamide levels.

Table 4.2 Proximate analysis results of each cooking method.

	Microwaved SPC	**Air Fried SPC**	**Baked SPC**	**Commercial SPC***
Calories	464 kcal/100g	507 kcal/100g	513 kcal/100g	535 kcal/100 g
Carbohydrate	69.6 g/100g	63.9 g/100g	65.1 g/100g	57.1 %
Fiber	3.00%	3.10%	3.10%	NA
Ash	2.83%	2.83%	2.67%	NA
Fat	19.10%	26.40%	26.70%	32.1 %
Moisture	4.95%	3.45%	4.95%	NA
Protein	3.51%	3.46%	3.14%	3.6 %

NA = Not Available

Results for Moisture Content

One-way ANOVA (Moisture ~ Oven type)

We combined time-temperature treatments for each oven and compared them to see if there is any difference between oven types. **Table 4.3** shows the ANOVA results for the moisture content. The analysis revealed moisture content for cooking methods were not significantly different across oven types $F(4,33) = 0.807$, $p = 0.530$. Moisture content of each

group is given below in **Table 4.4.** Average moisture content across samples were 2.93%. Moisture content 5% and below is considered acceptable for a chip product. **Table 4.3** shows that on average all ovens and all temperature levels yielded acceptable chips in terms of moisture content on average.

Table 4.3 One-way ANOVA for oven type and moisture content

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	4	7.80	1.949	0.807	0.53
Residuals	33	79.73	2.416		

Table 4.4. Average moisture content for cooking treatments (%)

Cooking method	**Moisture content (%)**	**Moisture content (%)**
	Low-LT	**High-ST**
Airfryer 1 (1)	2.26	1.31
Airfryer 2 (2)	4.02	3.29
Radiant oven 1 (3)	4.47	3.34
Radiant oven 2 (4)	3.95	1.89
Convection oven 1 (5)	1.66	3.25
Convection Oven 2 (6)	2.02	
Microwave (7)	3.47	
Control	3.18	

Results for β-Carotene

A two-way ANOVA was performed to concurrently investigate the effect of the oven type and time-temperature on β-carotene levels. We performed a one-way ANOVA to evaluate the effect of oven type across treatments including microwaved and control samples. The following table shows the results of two-way ANOVA.

Two-way ANOVA (Oven type and time-temperature ~ β-carotene)

Table 4.5 Two-way ANOVA results. Oven type and time-temperature interaction effect on β-carotene

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	2	8.44	4.222	3.030	0.0566
Time_Temperature	1	0.00	0.000	0.000	0.9967
Oven:Time_Temperature	2	6.19	3.097	2.222	0.1182
Residuals	54	75.25	1.394		

Table 4.5 shows the two-way ANOVA results for β-carotene. The analysis revealed no significant interaction effect between the oven type and time-temperature for the β-carotene levels, F (2,54) = 2.222, p = 0.118. Additionally, the main effects of the oven type (F (2,54) = 3.030, p = 0.057) and time-temperature (F (1,54) < 1, p = 0.9967) did not contribute to the ANOVA model significantly. Therefore, we can say oven type, time-temperature or the interaction of the oven type and the time-temperature did not significantly affect β-carotene retention of air fried and baked sweet potato chips. We continued with a one-way ANOVA test to evaluate the β-carotene retention across all cooking methods.

One-way ANOVA for (β-carotene ~ oven type)

In this section, we investigated only the effect of the oven type by adding microwave and control levels to the model. **Table 4.5** shows the results from the one-way ANOVA. The oven type had a significant effect on the moisture content at α=0.05 level (F *(4,65)* = 6.41, p < 0.001), meaning that at least one oven type yielded chips with significantly difference β-carotene levels.

Table 4.6 One-way ANOVA results for the β-carotene and oven types.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Oven	4	46.03	11.508	6.41	0.000207 *
Residuals	65	116.70	1.795		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

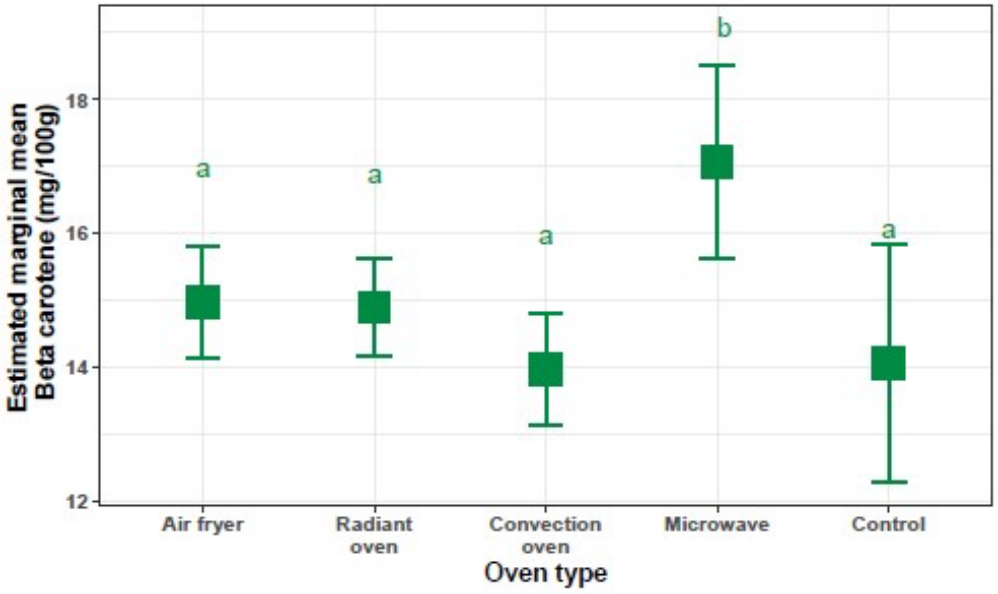

Figure 4.3 One-way ANOVA results for oven type and β-carotene. *X-axis shows the oven types and y-axis shows the β-carotene levels.*

We compared the average β-carotene levels through four different oven types and the control. Post-hoc comparisons using the Tukey HSD test **(Figure 4.3)** indicate that microwave yields the highest average β-carotene rate and differs significantly from the other oven types and the control. However, air fryer, radiant oven, and convection oven did not differ significantly from each other.

Results for Color

Results for L*

L* represents light vs dark. A low value (0-50) indicates dark and a high number (51-100) indicates light. A two-way ANOVA was performed to investigate the effect of the oven type and time-temperature on L* levels with appropriate post-hoc test. We also performed a one-way ANOVA to evaluate the effect of oven type across treatments including microwaved samples. The following table shows the results of two-way ANOVA.

Table 4.7 Two-way ANOVA results for Oven and Time-temperature interaction effect on L*

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	2	19.72	9.86	1.148	0.33214
Time_Temperature	1	87.57	87.57	10.202	0.00355 *
Oven:Time_Temperature	2	21.40	10.70	1.247	0.30344
Residuals	27	231.75	8.58		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

There was no significant interaction between the oven type and time-temperature, ($F_{(2,27)} = 1.247$, $p = 0.303$). Main effect of oven type did not affect ANOVA significantly either ($F_{(2,27)} = 1.148$, $p = 0.332$). Though, the main effect of cooking time-temperature ($F_{(1,27)} = 10.202$, $p = 0.003$) impacted L* measurements significantly. Since the interaction between oven type and time-temperature did not exist, we separated the effects of the factors and ran a post-hoc analysis on time-temperature. **Figure 4.4** illustrates the estimated marginal means for each factor and Tukey-adjusted post-hoc comparisons.

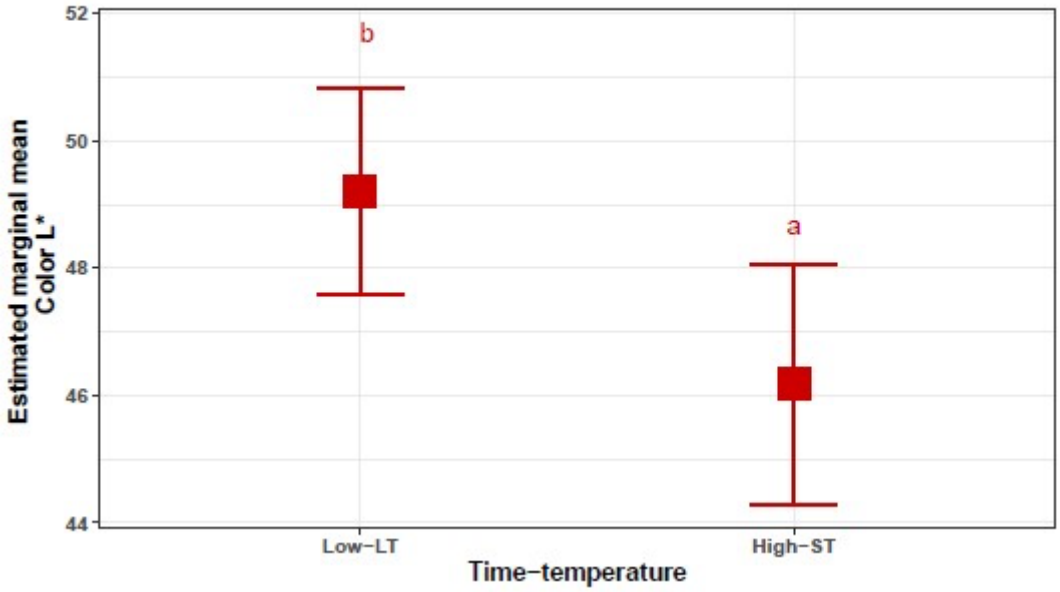

Figure 4.4 Post-hoc analysis for the time-temperature effect on L*. *X-axis shows the time-temperature levels and y-axis shows L* readings.*

In **Figure 4.4**, we observed a clear distinction among the levels of the time-temperature factor. L* is an indicator of charring because more charring results in darker chips. Higher L* values indicate less charring. Low temperature, long time treatment yielded chips with significantly less charring compared to the high temperature, short time treatment.

One-way ANOVA (L* ~ Oven type)

A one-way ANOVA shows the effect of the oven type on L* was not significant when microwave and control samples were added, $F\ (3,32)$=1.611, p=0.206. The oven type did not have an effect on L*. Therefore, we can conclude that charring was similar between baked, air fried, microwaved samples and controls.

Table 4.8 ANOVA results for oven type and L*

	Df	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Oven	3	60.0	20.00	1.611	0.206
Residuals	32	397.2	12.41		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

Results for a*

The value for a* represents red vs. green. A positive number indicates red and a negative number indicates green. A two-way ANOVA is conducted to investigate the concurrent effects of the oven type and time-temperature combinations on a* measurements of sweet potato samples with appropriate post-hoc test. We also performed a one-way ANOVA to evaluate the effect of oven type across treatments including microwaved samples. The following table shows the results of two-way ANOVA.

Table 4.9 Two-way ANOVA results for oven type and time-temperature interaction effect on a*

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	2	3.33	1.66	0.366	0.69706
Time_Temperature	1	47.47	47.47	10.439	0.00324 *
Oven:Time_Temperature	2	11.94	5.97	1.313	0.28575
Residuals	27	122.77	4.55		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

There was no significant interaction effect between the oven type and time-temperature, ($F\ (2,27)$ =1.313, p = 0.286). Main effect of oven type did not affect ANOVA significantly either ($F\ (2,27)$ = 0.366, p = 0.697). Only the main effect of time-temperature ($F\ (1,27)$ = 10.439, p = 0.003) impacted a* measurements significantly. Since the interaction between oven type and time-temperature was not significant, we did a post-hoc analysis on time-temperature. **Figure 4.5** illustrates the estimated marginal means for each factor and Tukey-adjusted post-hoc comparisons.

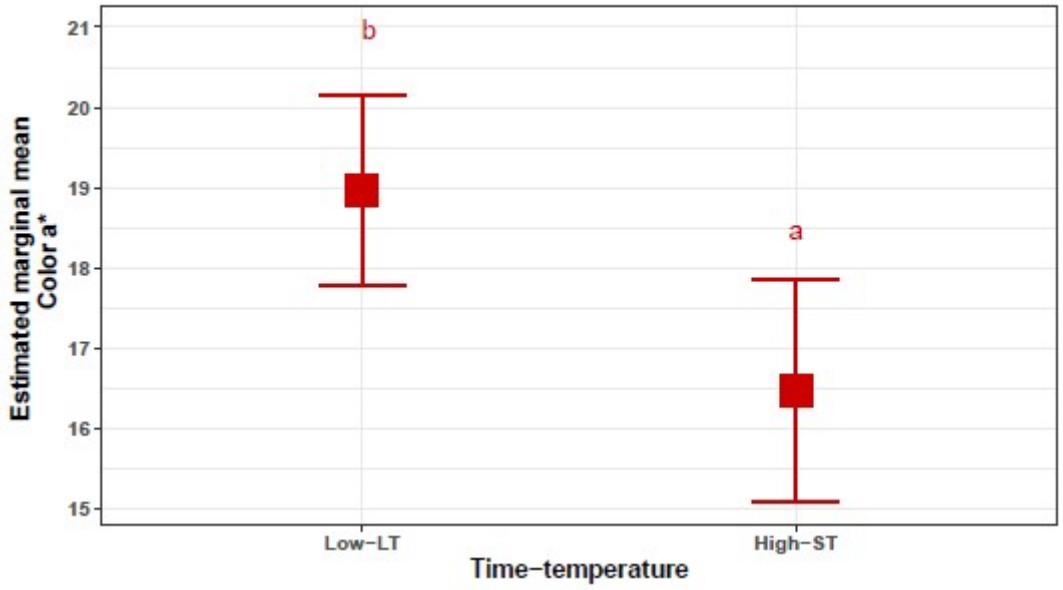

Figure 4.5 Post-hoc analysis for the time-temperature effect on a*. *X-axis shows the oven types and y-axis shows a* readings*

The Tukey post-hoc test results for are displayed in **Figure 4.5** above. All the chips were on the red side of the spectrum. The Tukey HSD results revealed that the mean a* scores for low temperature-long time treatment is significantly higher than those of high temperature-short time. Therefore, we can conclude that low temperature long time treatment yielded chips that are more red.

One-way ANOVA (a* ~ Oven type)

One-way ANOVA results are shown in **Table 4.10** The effect of the oven type on a* was not significant when microwave and control samples were added, $F\ (3,32) = 0.791$, $p = 0.508$. The oven type did not have an effect on a*. Therefore, we can conclude that redness of the chips was similar between baked, air fried, microwaved samples and controls.

Table 4.10 One-way ANOVA results for oven type and a*

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Oven	3	13.49	4.497	0.791	0.508
Residuals	32	181.85	5.683		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

Results for b*

b* represents yellow vs. blue. A positive value indicates yellow and a negative value indicates blue. A two-way ANOVA is conducted to investigate the interaction effect of the oven type and time-temperature combinations on b* measurements of sweet potato chips with appropriate post-hoc test. Furthermore, we used a one-way ANOVA to evaluate the effect of oven type across treatments including microwaved and control samples. The following table shows the results of two-way ANOVA.

Table 4.11 Two-way ANOVA results for oven and time-temperature interaction effect on b*

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Oven	2	24.3	12.13	0.882	0.4254
Time_Temperature	1	131.3	131.3	9.551	0.0046 *
Oven:Time_Temperature	2	40.9	20.44	1.487	0.2440
Residuals	27	371.2	13.75		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

Similarly with L* and a*, the interaction effect was not significant between the oven type and time-temperature, ($F\ (2,27) = 1.487$, $p = 0.244$). Main effect of oven type did not have a significant effect either ($F\ (2,27) = 0.882$, $p = 0.425$). Only the main effect of time-temperature ($F\ (1,27) = 9.551$, $p = 0.005$) impacted b* measurements significantly. Since the interaction between oven type and time-temperature was not significant, we did a post-hoc analysis only on

time-temperature levels. **Figure 4.6** shows the estimated marginal means for each time-temperature level and Tukey-adjusted post-hoc comparisons.

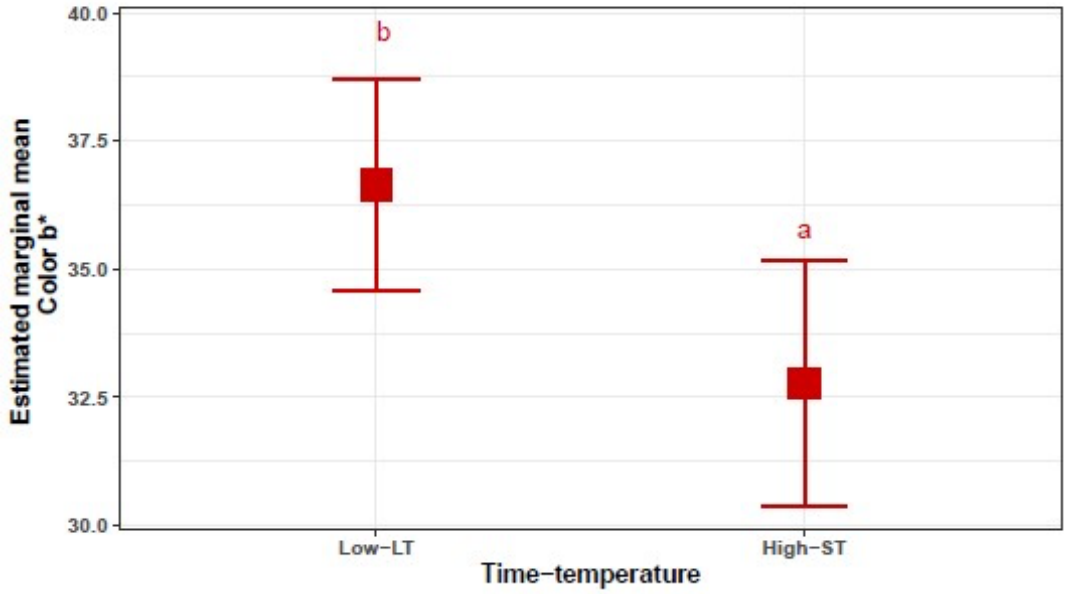

Figure 4.6 Post-hoc analysis for the time-temperature effect on b*. *X-axis shows the time-temperature levels and y-axis shows b* readings.*

Similarly with both L* and b* results, the mean a* scores for low temperature-long time treatment were significantly higher compared to high temperature-short time. All the chips were on the yellow side of the spectrum. Therefore, we can conclude that low temperature long time treatment yielded chips that are more yellow. We would also suggest that low temperature-short time treatment resulted in less charred and more orange-colored chips than high temperature-short time treatment.

One-way ANOVA (b* ~ Oven type)

Table 4.12 below, shows the results from a one-way ANOVA. The effect of the oven type on b* was not significant when microwave and control samples were added, $F\ (3,32) = 1.848$, $p = 0.158$. Therefore, we can conclude that yellowness of the chips was similar between baked, air fried, microwaved samples and controls.

Table 4.12 One-way ANOVA results for oven type and b*

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Oven	3	99.8	33.26	1.848	0.158
Residuals	32	576.0	18.00		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

Results for Texture

Peak positive force and positive area under the curve values were extracted from the texture analysis and evaluated similarly with previous variables, a two-way ANOVA was performed to investigate the interaction effect of the oven type and time-temperature on texture variables of air fried and baked sweet potato chips. We also performed a one-way ANOVA to evaluate the effect of oven type across treatments including microwaved chips and controls.

Two-way ANOVA for Peak Positive

A two-way ANOVA is performed to concurrently investigate the effect of the oven type and time-temperature on peak positive force. The following table shows the results of the two-way ANOVA

Table 4.13 Two-way ANOVA results. Oven type and Time-temperature interaction effect on peak positive force

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Oven	2	1402239	701120	13.396	4.86e-06 *
Time_Temperature	1	386779	386779	7.390	0.007408 *
Oven:Time_Temperature	2	992579	496290	9.482	0.000139 *
Residuals	137	7170511	52339		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

Based on the results, the null hypotheses indicating neither the oven type nor the time-temperature combination has a prominent effect on peak positive force would be rejected at α =

0.05 ($p < 0.001$). This means that the main effects of the factors were significant. Furthermore, we can conclude that there was also a statistically significant interaction effect between the factors, $F\ (2,137) = 9.482$, $p < 0.001$. In other words, the oven type's impact would depend on the temperature and cooking time. In this case, we are primarily interested in interpreting the interaction effect rather than the main effects. **Figure 4.7** illustrates the interaction plot between the factors. It is clear from the plot that the lines are far from parallel, indicating that the oven types have different average peak positive force through the levels of time-temperature. At the low temperature and longer cooking time combination, radiant oven and convection oven gave almost the same average peak positive force, which was considerably higher than the average peak force for the air fried chips. The mean peak positive rate for radiant and convection ovens decreased as the temperature increased and the cooking time decreased.

On the other hand, the average peak positive rate increased as the time-temperature combination changed from Low-LT to High-ST. The oven types gave very close mean values at a high temperature-short time combination. The oven type had little effect on peak positive force rates at the High-ST level.

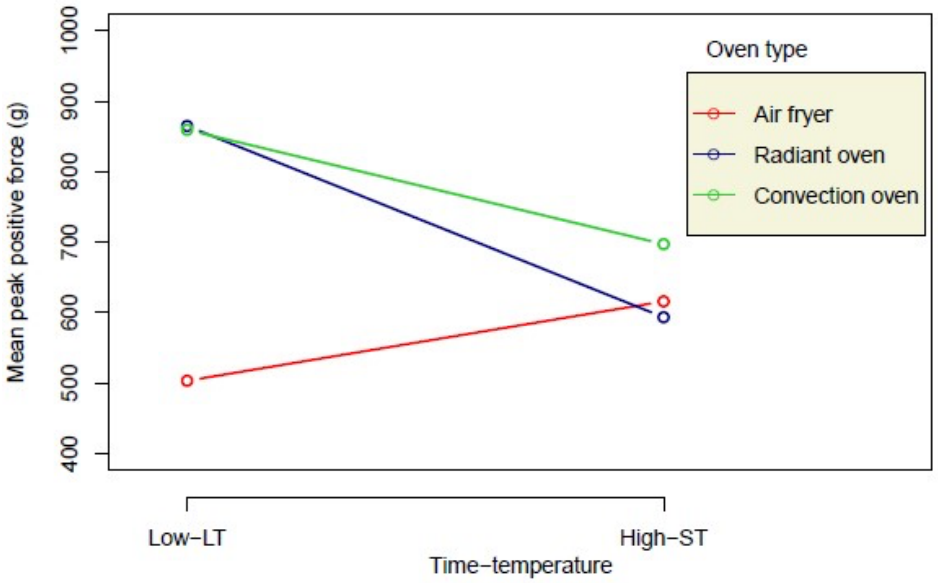

Figure 4.7 Two-way ANOVA interaction plot. Interaction effect of oven type and time-temperature on peak positive force. *X-axis shows the time-temperature levels and y-axis shows mean positive force. Cooking methods are represented by different colors on the plot.*

One-way ANOVA for Peak Positive

Results from a one-way ANOVA **(Table 4.14)** suggest that the average peak positive force rates of the oven types are not equal ($F\ (4,170) = 7.585$, $p < 0.001$). Pairwise comparisons of the means are illustrated in **Figure 4.8**. Based on the results, we would conclude that air fryer gives the lowest average peak positive force, followed by control. Air fryer and all other oven types had a statistically significant difference. The microwave oven type obtained the highest average force. Control was not significantly different from any of the cooking methods.

Table 4.14 One-way ANOVA results for the peak positive force and oven types.

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	4	1889044	472261	7.585	1.2e-05 *
Residuals	170	10584945	62264		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

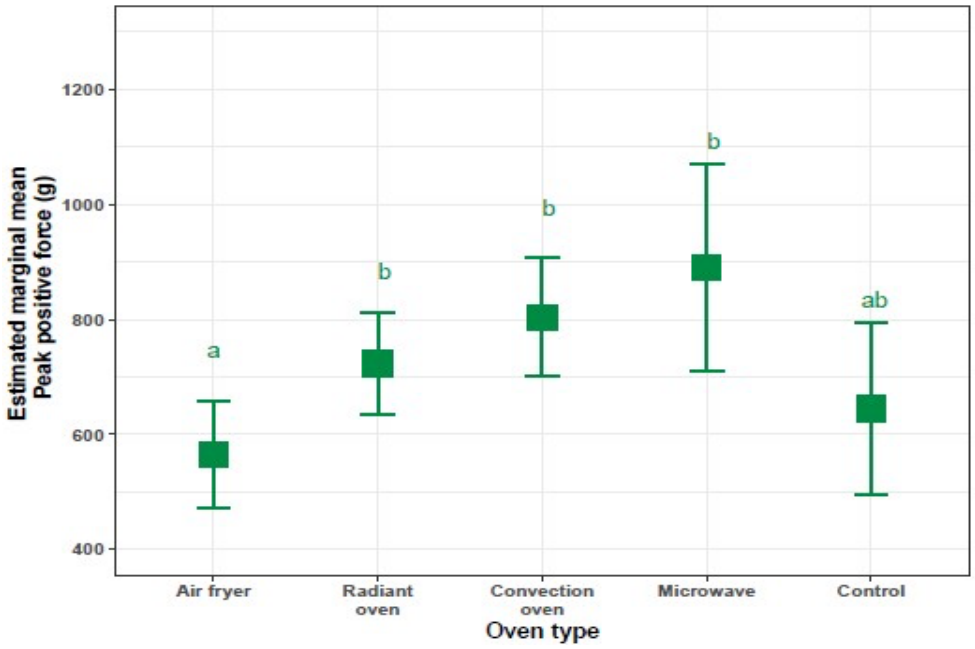

Figure 4.8 One-way ANOVA results for oven type and peak positive force. X-axis shows the oven types and y-axis shows the peak positive force values.

Two-way ANOVA for Positive Area under the curve

The resulting ANOVA table of the interaction model is shown in **Table 4.14.** We find that the interaction effect between the factors was statistically significant at an alpha level of 0.05 ($F\ (2,136) = 6.79$, $p = 0.002$). Therefore, the data suggested the oven types have different mean positive areas for Low-LT and High-ST levels. The interaction plot in **Figure 4.9** exemplifies that the average positive area was reduced for all oven types as the temperature increase and the cooking time decrease. Specifically, the lines represented by air fryer and convection oven were perfectly parallel, indicating that these oven types behaved nearly the same on each level of time-temperature. So, their contribution to the interaction effect was minimal.

Meanwhile, time-temperature change affected radiant oven differently than convection oven and air frier. Radiant oven had a higher average positive area under the curve than convection oven at low temperature-long time treatment. Radiant oven showed a rapid decline as

the temperature increases with a shorter cooking time, whereas convection oven and air fried remained almost constant. Then it yields a higher average area than Radiant oven at High-ST.

Table 4.15 Two-way ANOVA results. Oven type and Time-temperature interaction effect on positive area under the curve

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	2	26931129	13465564	22.84	2.81e-09 *
Time_Temperature	1	10066056	10066056	17.07	6.25e-05 *
Oven:Time_Temperature	2	8007517	4003759	6.79	0.00155 *
Residuals	136	80187703	589615		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

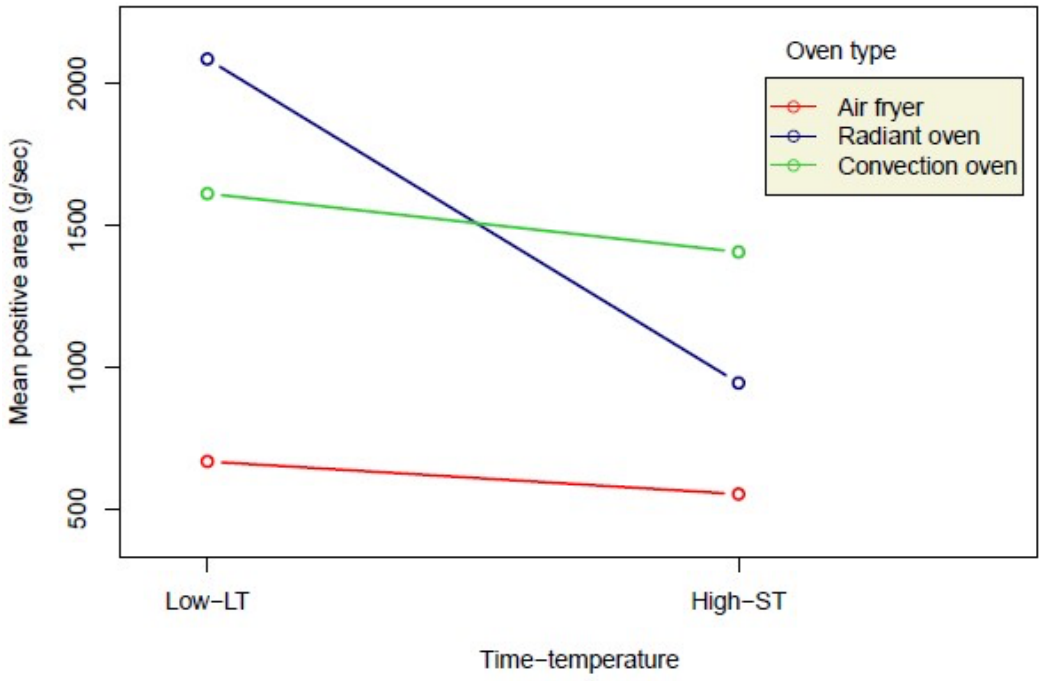

Figure 4.9 Two-way ANOVA interaction plot. Interaction effect of oven type and time-temperature on positive area under the curve. *X-axis shows the time-temperature levels and y-axis shows mean positive area under the curve. Cooking methods are represented by different colors on the plot.*

One-way ANOVA for Positive Area

Table 4.16 summarizes the one-way ANOVA results. The effect of the oven type was significant, $F\ (4,168) = 18.18$, $p < 0.001$. Post-hoc analyses using the Tukey HSD **(Figure 4.10)** indicate that the average positive area was significantly higher in microwave, radiant, and convection ovens. The control showed the lowest average area, followed by air fryer. Based on the letter coding, the microwave, radiant, and convection ovens were not significantly different, however they were significantly different from the air fryer and control with noticeably higher positive area under the curve measurements.

Table 4.16 One-way ANOVA results for the peak positive force and oven types

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	4	45272946	11318236	18.18	2e-12 *
Residuals	168	104595856	622594		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

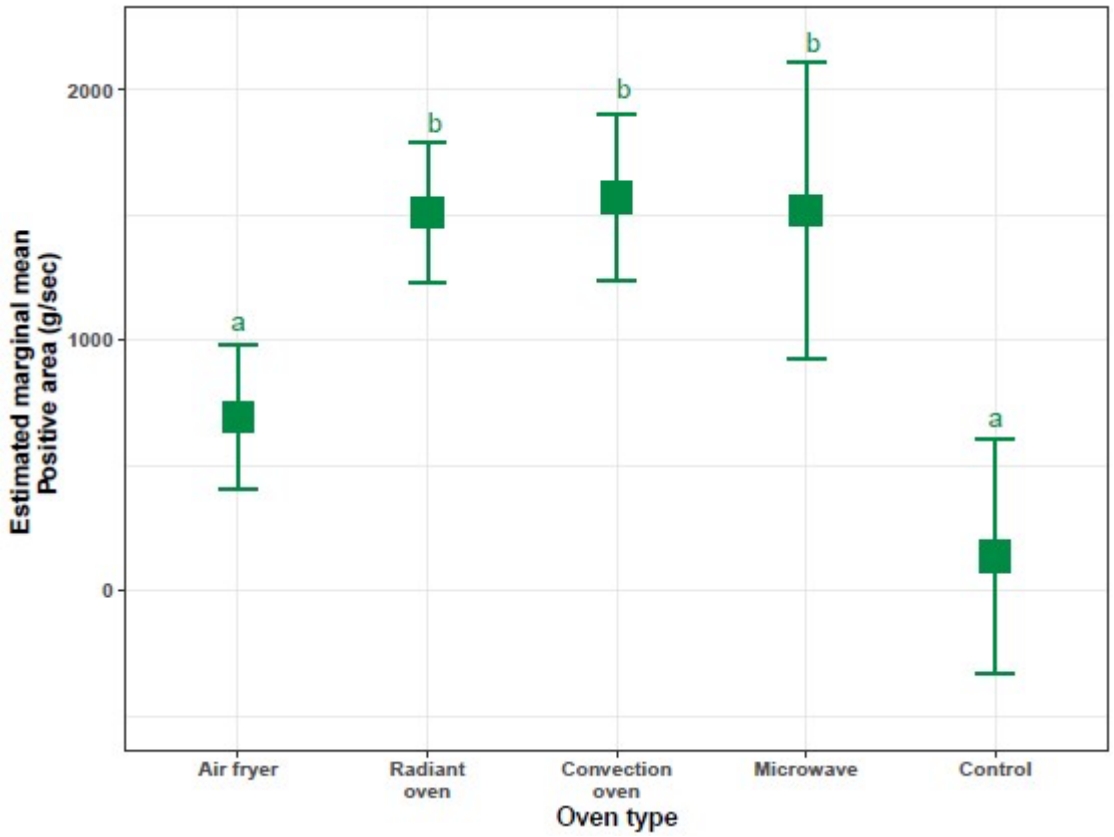

Figure 4.10 One-way ANOVA results for oven type and positive area under the curve. *X-axis shows the oven types and y-axis shows the area under the curve levels.*

Acrylamide Results

Two-way ANOVA for Acrylamide

The results from the two-way ANOVA **(Table 4.17)** revealed that there was a significant difference among time-temperature levels ($F\ (1,26)$ = 7.123, p = 0.013). We observed no significant interaction effect between the oven type and time-temperature ($F\ (2,26)$ =2.956, p=0.07) or main effect of the oven type ($F\ (2,26)$ = 2.14, p = 0.335). Thus, neither the type of the oven nor the interaction between oven type and time-temperature had a significant effect on acrylamide measurements between the air fried and baked samples. Since the interaction between oven type and time-temperature was not significant, we did a post-hoc

analysis only on time-temperature levels. **Figure 4.11** shows the estimated marginal means for each time-temperature level and Tukey-adjusted post-hoc comparisons.

Table 4.17 Two-way ANOVA results for oven and time-temperature interaction effect on acrylamide

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Oven	2	102920	51460	1.140	0.3351
Time_Temperature	1	321380	321380	7.123	0.0129 *
Oven:Time_Temperature	2	266733	133367	2.956	0.0697
Residuals	26	1173142	45121		

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

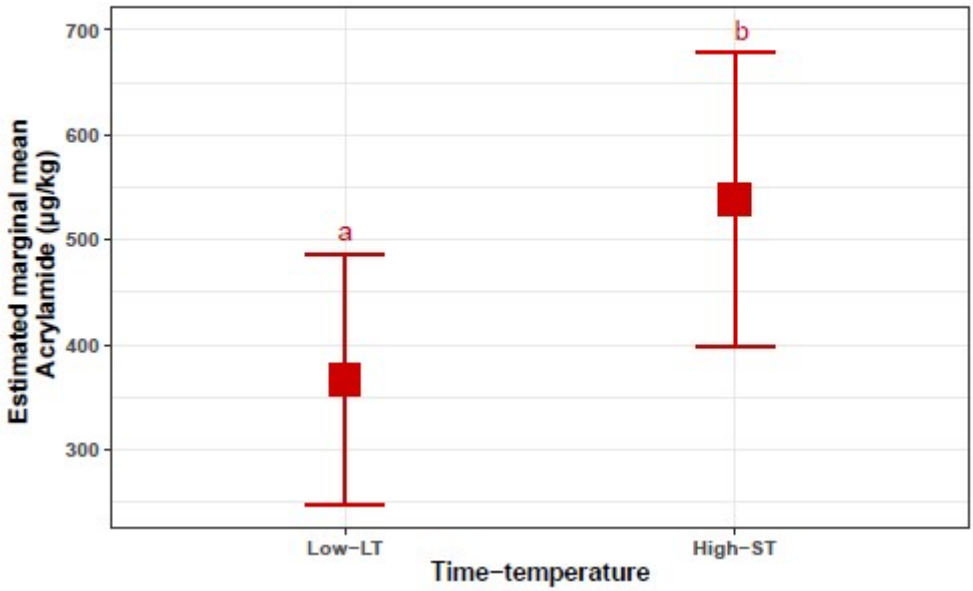

Figure 4.11 Post-hoc analysis for the time-temperature effect on acrylamide. X-axis shows the time-temperature levels and y-axis shows acrylamide levels.

The profile plot of the time-temperature factor, **Figure 4.11,** shows that the estimated marginal means for acrylamide increased as the temperature increase from low temperature-long time (Low-LT) to high temperature-short time (High-ST). The average acrylamide level obtained by the Low-LT time was significantly lower than, the High-ST.

One-way ANOVA for Acrylamide

Based on the results presented in **Table 4.18**, we can conclude that the oven types do not differ significantly concerning the average acrylamide rates, $F\ (4,32) = 0.808$, $p = 0.529$.

Table 4.18 One-way ANOVA results for the acrylamide and oven types

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Oven	4	329336	82334	0.808	0.529
Residuals	32	3259847	1 01870		

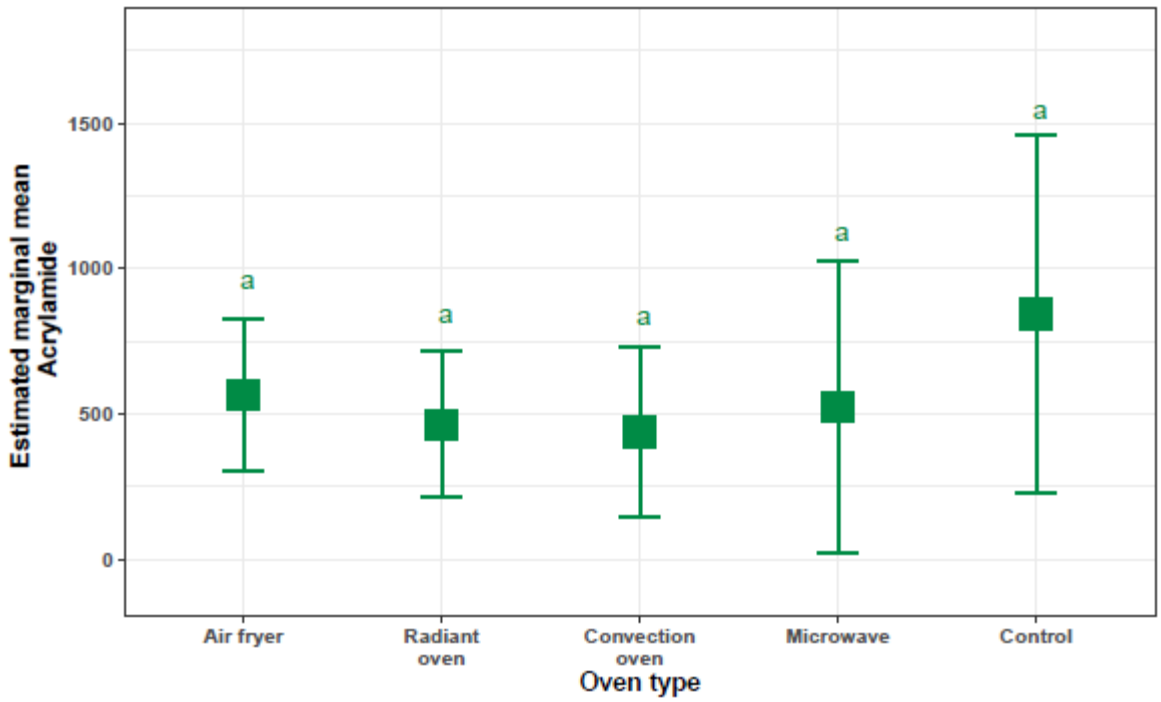

Figure 4.12 One-way ANOVA results for oven type and acrylamide. *X-axis shows the oven types and y-axis shows the acrylamide levels.*

Carbohydrate Digestion Results

For each sample, glucose levels were measured at minutes 0, 30, 60, 90, and 120 after the initiation of the intestinal digestion step. **Figure 4.13** shows the box-plot graph of the glucose

measurements across oven types. Glucose readings were grouped by time-temperature for each oven type to produce **Figure 4.13.**

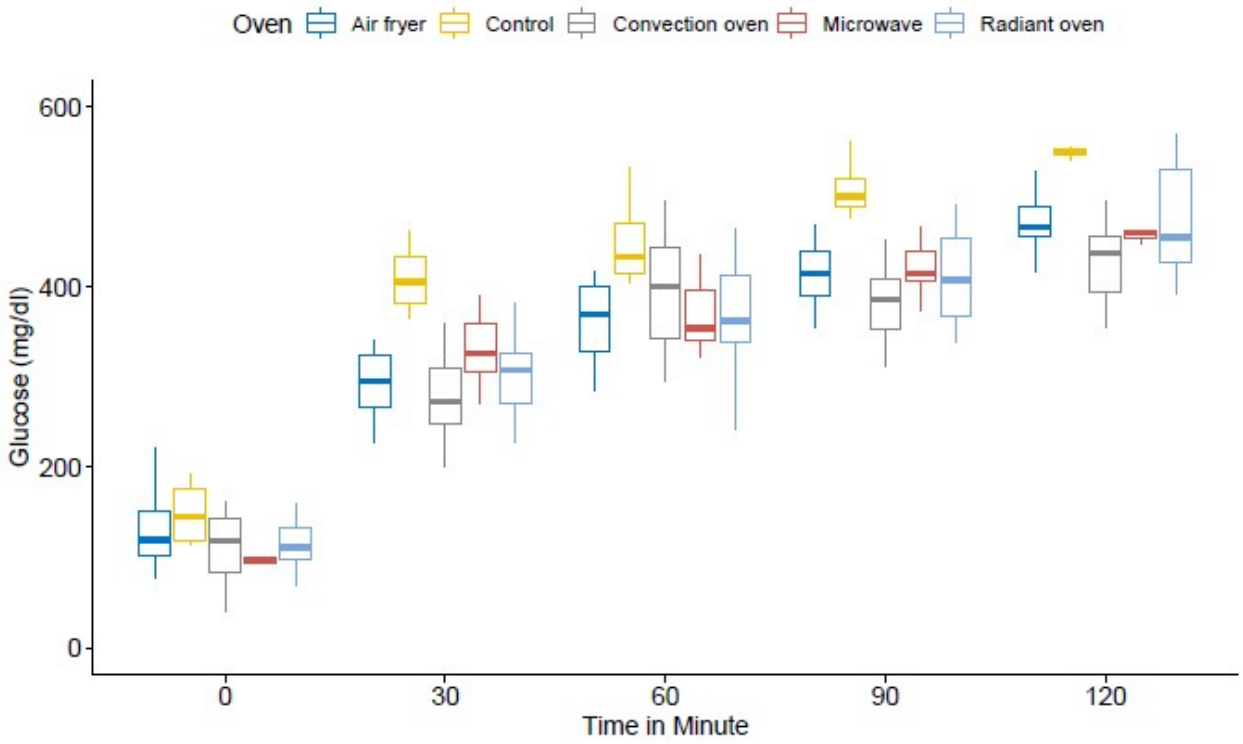

Figure 4.13 Glucose readings during the carbohydrate digestion. X-axis shows digestion period in minutes. Y-axis shows glucose readings. Each bar represents an oven type as labeled above.

Figure 4.13 shows the increase in glucose in digesta over time and the oven types at each time point. At point 0, all oven types had a similar glucose level. After 30 minutes of digestion, glucose for the control chips seems to increase more than the rest of the samples, and this trend continues until minute 120. To assess the significance of these visual differences, we used two-way mixed ANOVA, which evaluates the effect of oven type over the digestion period on glucose readings. **Table 4.19** shows the two-way mixed ANOVA results.

Two-way mixed ANOVA

Table 4.19 Two-way mixed ANOVA results for oven and digestion time interaction effect on glucose readings

	DFn	DFd	F	p	p<.05
Oven	4	65	3.697	9.00e-03	*
Minute	4	260	721.716	2.01e-139	*
Oven:Minute	16	260	3.329	2.53e-05	*

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

Based on the results, the null hypotheses indicating neither the oven type nor the digestion time has a prominent effect on glucose levels of sweet potato samples can be rejected at $\alpha=0.05$ ($p < 0.001$). This means that the main effects of the factors are significant. Furthermore, we can conclude that there was a statistically significant interaction between the oven type and digestion time, $F(16,260) = 3.329$, $p > 0.001$. In other words, the oven type affected glucose measurements at each digestion time point. Therefore, the glucose levels for oven types depend on the digestion time due to the addition of intestinal digestion enzymes. **Figure 4.14** shows the interaction box-plot with significant differences between different oven types at each digestion time point. The pairwise comparison method was a t-test, and Bonferroni correction was used for the *p*-adjustment for the analysis. There was a significant difference between control and the rest of the oven types at 30 mins. Glucose readings of controls were higher than air-fried, baked, and microwaved samples. Similar results were observed at 90 minutes into digestion as well. At 60 minutes into digestion, control was still higher than all the cooking methods, but the difference was only significant between the air fryer and control. Air frier yielded the lowest glucose measurements despite there being no significant differences.

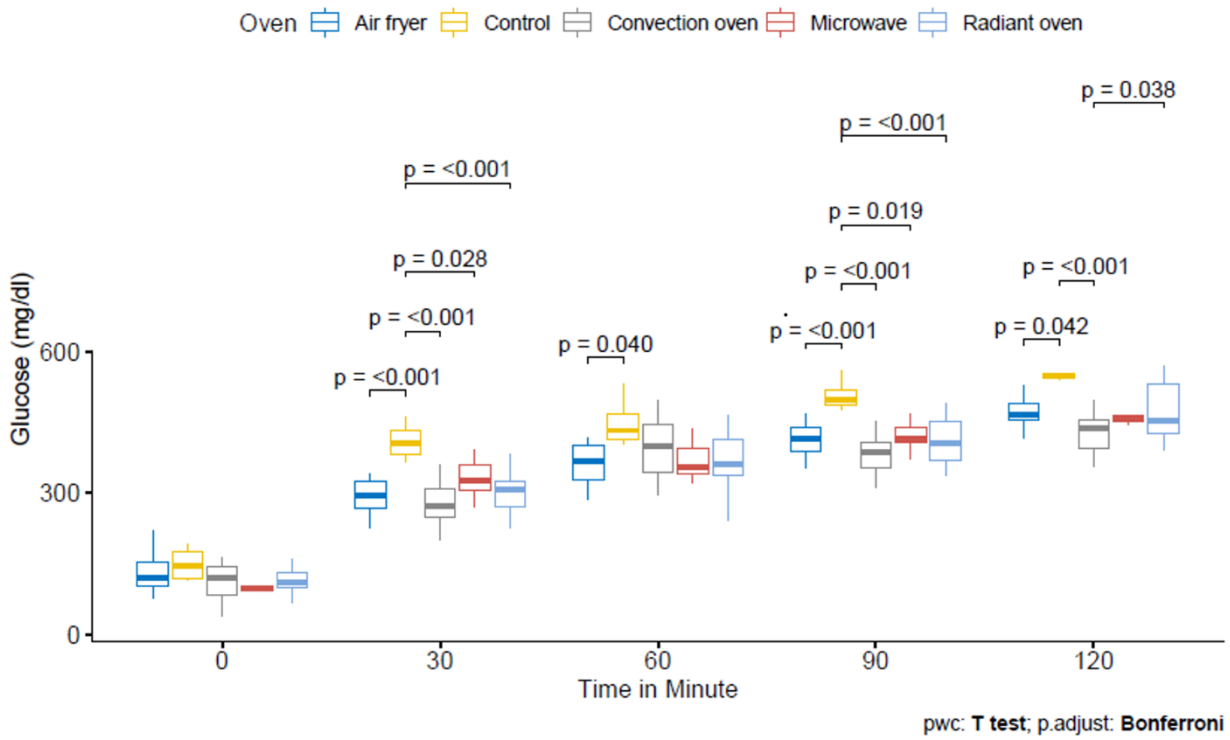

Figure 4.14 Two-way repeated measures ANOVA results. Interaction effect of oven type and digestion time on glucose measurement. *X-axis shows digestion time and y-axis shows the glucose readings. Cooking methods are represented by different colored boxes on the plot.*

Three-way Mixed ANOVA

We used a three-way mixed model to show the interaction between oven type, time-temperature, and the measurement time on glucose readings. **Table 4.20** shows the ANOVA results for the three-way mixed model. We used three-way mixed ANOVA for the only air fryer, convection, and radiant ovens.

Table 4.20 Three-way mixed ANOVA results for Oven, time-temperature and digestion time interaction effect on glucose readings

	DFn	DFd	F	p	p<.05
Oven	2	47	2.682	0.079	
Time_Temperature	1	47	2.025	0.161	
Minute	4	188	1344.301	4.56e-137	*
Oven:Time_Temperature	2	47	12.074	5.87e-05	*
Oven:Minute	8	188	5.004	1.22e-05	*
Time_Temperature:Minute	4	188	2.912	0.023	*
Oven:Time_Temperature:Minute	8	188	1.822	0.075	

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

A three-way repeated measures ANOVA was performed to evaluate the effects of oven type, time-temperature level, and digestion time on glucose levels. As seen in **Table 4.20**, the interaction effect of oven type, time-temperature, and digestion time was not significant, $F(8,188) = 1.822$, $p = 0.075$. The main effect of both oven type and time-temperature were not significant, but the main effect of digestion time was significant. Two way interaction of oven type and time-temperature ($F(2,47) = 12.074$, $p > 0.001$), oven and digestion time ($F(8,188) = 5.004$, $p > 0.001$), and time-temperature and digestion time ($F(4,188) = 2.912$, $p = 0.023$) were significant. **Figure 4.15** shows the visual representation of three-way mixed ANOVA with box-plots.

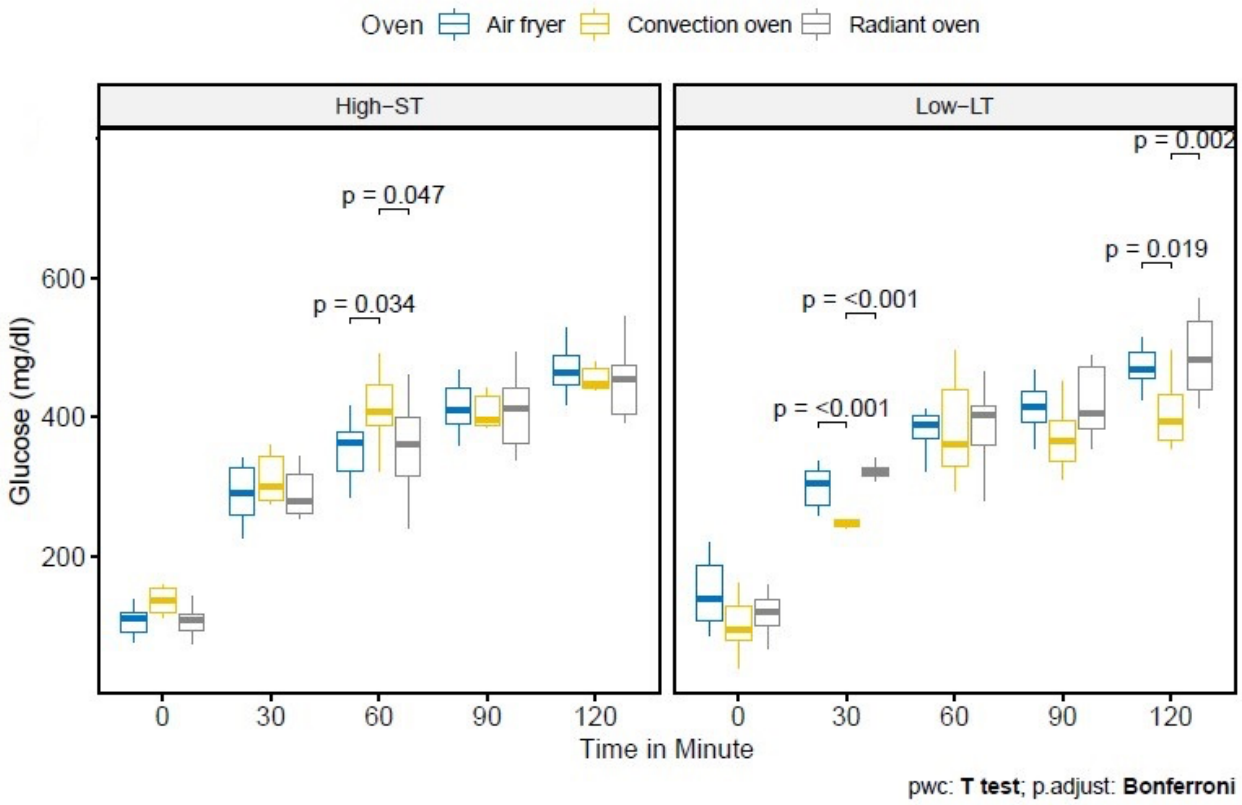

Figure 4.15 Three-way repeated measures ANOVA results. Interaction effect of oven type, time-temperature, and digestion time on glucose measurement. *Each box shows a time-temperature level. X-axis shows digestion time within each box and y-axis shows the glucose readings. Cooking methods are represented by different colored boxes on the plot as labeled above.*

Table 4.21 Correlation table between the variables.

	Bcarotene	PeakPositive	PositiveArea	Acrylamide	L*	a*	b*
Bcarotene	1.000	0.125	0.264	-0.313	0.307	0.437	0.330
		p=0.3	p=0.027*	p=0.056	p=0.065	p=0.007*	p=0.047*
PeakPositive		1.000	0.569	-0.318	0.055	0.198.	0.063
			p<0.001*	p=0.052	p=0.746	p=0.239	p=0.709
PositiveArea			1.000	-0.117	0.218	0.118.	0.086
				p=0.482	p=0.194	p=0.485	p=0.613
Acrylamide				1.000	-0.502	-0.461	-0.519
					p=0.002*	p=0.004*	p=0.001*

The asterisk (*) denotes the significant effect in ANOVA model ($p < 0.05$).

Table 4.21 shows the correlation table between the variables. There is a significant correlation between β-carotene and a* as well as b*. There is also a significant correlation between acrylamide and L*, a*, and b*.

Discussion

In this study, our goals were first to compare the effect of different cooking methods and time-temperature treatments on β-carotene, color, texture, and acrylamide formation, and second to evaluate the effect of cooking method and cooking time-temperature interaction on carbohydrate digestion. We used 7 different ovens (2 air fryers, 2 radiant ovens, 2 convection ovens, and 1 microwave) and two brands of commercially available fries as controls. The average moisture content of the chips was 2.93% with no significant difference due to processing methods **(Table 4.3).**

When we compared all the cooking methods against control, microwaved chips had significantly higher β-carotene content **(Figure 4.3)** which is similar to the results from Tian et.

al. They suggested that steam and microwave retained more bioactive components (Tian et al., 2016) and observed low retention of total carotenoids compared to boiled, steamed, and baked samples. In our study microwave processing yielded more β-carotene than air fryers, radiant, and convection ovens. We observed that low temperature-long time treatment produced chips with less charring **(Figure 4.4)**, and more red and yellow color compared to a high temperature short time treatment **(Figures 4.5 and 4.6)**. We can suggest that low temperature-long time cooking yielded chips that retained the orange color of sweet potato.

Our texture analysis evaluated peak positive force as negatively correlated with, and indicative of crispness (Qiu et al., 2018; Singh et al., 2003). The area under the curve is indicative of toughness. We observed a significant crispness difference between baked chips and air fried chips at low temperature-long time cooking **(Figure 4.7)**. We observed no significant difference in crispness between the samples and the control, but air fried chips were significantly crispier than the baked and microwaved chips **(Figure 4.8)**. The area under the curve, toughness, showed similar results; both baking results were significantly tougher than air fried chips. When compared to the control, air fried chips are similar to control, whereas baked and microwaved chips were significantly tougher than control and air fried chips **(Figure 4.10)**. Our results were parallel with the literature, air fried samples were similar to deep fried chips (McFadden, 2006). Oven baked and microwaved samples were similar to each other in terms of texture but they were different than air fried and deep-fried chips (Sumnu, 2001).

Two-way ANOVA indicated a significant difference between time-temperature treatments for acrylamide. High temperature-short time treatment resulted in more acrylamide formation **(Figure 4.11)**. Even though there is a visual difference, we observed no statistically

significant difference between the cooking methods **(Figure 4.12)**. This statistical result may be due to the lesser number of observations for the control chips.

Carbohydrate data demonstrated that, after the initiation of the intestinal digestion step, glucose readings from the suspension made from the control chips were higher than from all other cooking methods. At point 0, there was no difference between the samples, however, at 30 minutes there was a significant difference between control and each of the other cooking methods and the same is true for minute 90 samples **(Figure 4.14).** Englyst et al., (1992) established an in vitro digestion protocol that is commonly used for starch digestion, classification of starch, and estimating the glycemic index of the food. They suggest the difference in glucose level between minutes 0 and 20 is indicative of rapidly digestible starch. Even though the control chips were not fresh their initial starch breakdown and glucose release were higher than all the other cooking methods. Glucose levels of the control stayed higher through the digestion period but the difference was significant at minutes 30 and 90.

The correlation table revealed a significant correlation between acrylamide and color measurements L*, a*, and b*. There is also a significant correlation between β-carotene and a* and b*. However, the regression plots were was not linear (data not shown). Similar results were shown in potato chips by Gokmen and Senyuva, who observed a correlation between acrylamide levels and a* (Gökmen & Şenyuva, 2006) Pedrechi et. al., showed a correlation between a* and acrylamide levels in fried potato chips (Pedreschi et al., 2005). Lim et. al. showed a strong correlation between acrylamide and b* whereas L* and a* showed no correlation (Lim et al., 2014). These correlations might be useful as a quick method for nutrient retention scanning or prediction of acrylamide levels.

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Conclusion and Future Work

In this study, we evaluated the production of sweet potato chips with air fryers, radiant ovens, convection ovens, and a microwave and compared them to commercially available deep-fried sweet potato chips. We used different levels of time-temperature combinations to compare the effect of cooking time and temperature as well as the oven effect. We observed that air fryers yielded more consistent chips compared with oven baking and microwaving in terms of moisture content of the chips across the temperature levels. We also observed that air-fried chips were similar to deep-fried chips in terms of texture. Our investigation showed that microwaved chips retained more β-carotene compared to other cooking methods which confirm the literature on microwave treatment and retention of nutrients. Our results showed that acrylamide levels were significantly higher when chips were cooked at a higher temperature for a shorter time. Even though we observed higher acrylamide levels in commercial deep-fried chips compared to microwave, air fryer, and baking this difference was not statistically significant.

This research has implications for both household and industrial use. We compared different cooking methods and showed the advantages and disadvantages of each method. Our results showed that low temperatures even if it was applied for a longer time formed less acrylamide so when baking at home, to lower the acrylamide formation in food one could choose lower temperatures. Cooking at lower temperatures also yielded chips that retained more of the orange color of the sweet potato which could suggest that by assessing the color of the chips we could estimate acrylamide levels of the chips. Cooking at lower temperatures affected the texture results for both radiant and convection ovens and makes chips both tougher and less crunchy but air fryers show desirable texture properties that are similar to deep-fried commercial fries across time-temperature treatments. Microwaves yielded more bright-colored chips and showed

favorable results for nutrient retention indicated by β-carotene levels. Therefore, to make chips at home as an alternative to deep-fried commercial chips people can use air fryers at lower temperatures and obtain a similar product with more nutrients and less acrylamide. Microwaved sweet potato chips can be an alternative snack product with better nutrient retention levels and lower fat.

We used batch production in this study rather than continuous production. Therefore, to use apply these methods to industry, more research is needed to achieve continuous production and confirm the findings of this study by evaluating the properties of the chips obtained. We used a platform to produce chips with a microwave which could create a challenge to apply it in the industry. Air fryers often use a cooking basket with a limited volume which also can be a challenge to apply the method efficiently in the industry.

APPENDICES

Appendix A

Commercially Available Sweet Potato Products and their Acrylamide Levels (FDA, 2015)

Product Name	Acrylamide (ppb)
365 Everyday Value Crinkle Cut Sweet Potato Fries (baked)	<10
Alexia Sweet Potato Fries Sea Salt (fried)	<10
Stahlbush Island Farms Sweet Potato (Fresh Frozen) (baked)	<10
Kiddylicious Sweet Potato Crisps	<10
Alexia Rib Cut BBQ Sweet Potato Fries With Skin On (baked)	10
Wegmans Crinkle Cut Sweet Potato Fries (baked)	10
Wegmans Sweet Potato Fries (baked)	10
Alexia Rib Cut BBQ Sweet Potato Fries With Skin On (baked)	20
Alexia Rib Cut BBQ Sweet Potato Fries With Skin On (fried)	20
Earthbound Farm Roasted Organic Sweet Potato Slices Sea Salt & Olive Oil (panfried)	20
Stahlbush Island Farms Sweet Potato (Fresh Frozen) (baked)	20
Wegmans Chipotle Sweet Potato Fries (fried)	20
Outback Steakhouse Sweet Potato with Honey Butter & Brown Sugar	20
Ore Ida Sweet Potato Straight Fries (fried)	30
Wegmans Sweet Potato Fries (baked)	30
Wegmans Sweet Potato Fries (fried)	30
Long Horn Steakhouse Sweet Potato	30
365 Everyday Value Crinkle Cut Sweet Potato Fries (baked)	40
Stahlbush Island Farms Sweet Potato (Fresh Frozen) (pan fried)	40
Wegmans Crinkle Cut Sweet Potato Fries (baked)	40
Alexia Sweet Potato Puffs (baked)	50
Stahlbush Island Farms Sweet Potato (Fresh Frozen) (pan fried)	50
Wegmans Chipotle Sweet Potato Fries (baked)	53
Alexia Sweet Potato Fries Sea Salt (fried)	60
Alexia Sweet Potato Puffs (fried)	60
Outback Steakhouse Sweet Potato with Honey Butter & Brown Sugar	60
Alexia Sweet Potato Puffs (baked)	70
Earthbound Farm Roasted Organic Sweet Potato Slices Sea Salt & Olive Oil (baked)	70
Long Horn Steakhouse Sweet Potato	70
Alexia Sweet Potato fries (baked)	80
Colton's Steak House Baked Sweet Potato	80
Earthbound Farm Roasted Organic Sweet Potato Slices Sea Salt & Olive Oil (panfried)	90
Colton's Steak House Baked Sweet Potato	90
Wegmans Chipotle Sweet Potato Fries (fried)	103

Appendix A (continued)

Alexia Sweet Potato Puffs (fried)	120
Logan's Roadhouse Baked Sweet Potato	130
Alexia Sweet Potato fries (baked)	160
Smokin' Joes Sweet Potato Fries	190
Tuttle's Sweet Potato Fries	190
Texas Land & Cattle Steakhouse Baked Sweet Potato	230
Colton's Steak House Sweet Potato Fries	240
Logan's Roadhouse Baked Sweet Potato	250
Terra Sweet Potato Chips No Salt	260
J&J's Scoreboard Bar & Grill Sweet Potato Tots	280
Texas Land & Cattle Steakhouse Baked Sweet Potato	293
Tuttle's Sweet Potato Fries	370
Ore Ida Sweet Potato Straight Fries (baked)	380
Woody's Grille Sweet Potato Fries	500
Red Robin Sweet Potato Fries	560
Woody's Grille Sweet Potato Fries	610
Applebee's Sweet Potato Fries	620
Colton's Steak House Sweet Potato Fries	640
Red Robin Sweet Potato Fries	640
J&J's Scoreboard Bar & Grill Sweet Potato Tots	700
Smashburger Sweet Potato Fries	700
Big Al's Gourmet Butter-Made Burgers Sweet Potato Fries	760
Grub Burger Bar Sweet Potato Fries	760
Smashburger Sweet Potato Fries	860
Applebee's Sweet Potato Fries	880
Big Al's Gourmet Butter-Made Burgers Sweet Potato Fries	940
Grub Burger Bar Sweet Potato Fries	1020
Red Robin Sweet Potato Fries	1030
Sweet Potato Chips with Sea Salt Crinkle Cut	8440

Reference

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https://www.fda.gov/media/130927

Appendix B

MICROBAC®

CERTIFICATE OF ANALYSIS

Nc State University
Jonathan Allen
400 Dan Allen Dr., 204 Schaub Hall
Raleigh, NC 27695-7624

REPORT # W1J0521
RECEIVED 10/15/2021
REPORTED 10/22/2021

PROJECT Food Chemistry Testing

SAMPLE DESCRIPTION: **101 Microwaved Sweet Potato Chip** — LAB ID: **W1J0521-01**

2 tubes, 50 gr

ANALYSIS	RESULT	UNITS	NOTE	ANALYZED	METHOD
Calculation					
Calories*	464	cal/100g		10/21/2021	Atwater Calculation Factors
Carbohydrate, Total*	69.6	g/100g		10/21/2021	Calculation
Food Chemistry					
Ash*	2.83	%		10/19/2021	AOAC 923.03
Fat*	19.1	%		10/20/2021	AOAC 922.06 Modified
Moisture*	4.95	%		10/16/2021	AOAC 925.09
Protein*	3.51	%		10/19/2021	AOAC 992.15 (Dumas)

SAMPLE DESCRIPTION: **102 Air Fried Sweet Potato Chip** — LAB ID: **W1J0521-02**

2 tubes, 50 gr

ANALYSIS	RESULT	UNITS	NOTE	ANALYZED	METHOD
Calculation					
Calories*	507	cal/100g		10/21/2021	Atwater Calculation Factors
Carbohydrate, Total*	63.9	g/100g		10/21/2021	Calculation
Food Chemistry					
Ash*	2.83	%		10/19/2021	AOAC 923.03
Fat*	26.4	%		10/20/2021	AOAC 922.06 Modified
Moisture*	3.45	%		10/16/2021	AOAC 925.09
Protein*	3.46	%		10/19/2021	AOAC 992.15 (Dumas)

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CERTIFICATE OF ANALYSIS

SAMPLE DESCRIPTION

103 Baked Sweet Potato Chip

2 tubes, 50 gr

LAB ID

W1J0521-03

ANALYSIS	RESULT	UNITS	NOTE	ANALYZED	METHOD
Calculation					
Calories*	513	cal/100g		10/21/2021	Atwater Calculation Factors
Carbohydrate, Total*	65.1	g/100g		10/21/2021	Calculation
Food Chemistry					
Ash*	2.67	%		10/19/2021	AOAC 923.03
Fat*	26.7	%		10/20/2021	AOAC 922.06 Modified
Moisture*	2.38	%		10/16/2021	AOAC 925.09
Protein*	3.14	%		10/19/2021	AOAC 992.15 (Dumas)

Notes

Methods used outside of their intended scope are verified/validated to the extent agreed upon with the customer

%: Percent

Cal/100g: Calories per 100 Milliliters

g/100g: Grams per 100 Grams

Subcontracting

Laboratory	Method
*Microbac Laboratories Inc., Pittsburgh Division	Atwater Calculation Factors
	Calculation
	AOAC 922.06 Modified
	AOAC 923.03
	AOAC 925.09
	AOAC 992.15 (Dumas)

REVIEWED BY

Abhishek Patel/Supervisor Food & Nutrition

Microbac Laboratories, Inc.

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