EVALUATION OF TWO PECAN-BASED FOOD PRODUCTS USING SPECIALIZED INGREDIENTS

by

REBECCA JUDITH FORTNER

(Under the Direction of William L. Kerr)

ABSTRACT

Pecan-based foods often suffer from consistency issues due to the oil content of the nuts, and thus product options are somewhat limited in comparison to other nuts. Two potential pecan products were selected and specialized ingredients were applied to address the products' textural shortcomings. Apple and sweet potato flours were included in pecan butter to test their effects on the consistency. The firmness and spreadability increased and visible oil separation was decreases at levels of flour inclusion that did not negatively impact consumer preference. Secondly, a process for producing a pecan-based non-dairy cheese analog was developed. In order to develop a gel network capable of mimicking the textural and thermal behavior of cheese, acid-thinned potato starches were applied at different levels, resulting in the development of a porous gel network, which surrounded both oil droplets and pecan fragments. This allowed for adequate firmness and melting behavior to be achieved.

INDEX WORDS: Pecans, non-dairy cheese, pecan butter, texture analysis, modified starch, apple pomace, dehydrated sweet potato

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REBECCA JUDITH FORTNER

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REBECCA JUDITH FORTNER

Major Professor:	William L. Kerr
Committee:	George A. Cavender
	Ronald B. Pegg

Electronic Version Approved:

Ron Walcott
Interim Dean of the Graduate School
The University of Georgia
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CHAPTER 1

INTRODUCTION

In an era of rapidly evolving food trends and unprecedented options for consumer products, commodity groups are striving to be at the forefront of innovation. Pecans are a highly valuable crop to the United States and specifically to Georgia (USDA, 2016). However, pecan consumption is not growing as quickly as the consumption of other tree nuts and peanuts (Marzolo, 2015). Since pecans contain many healthful nutrients, and consumers are becoming increasingly health conscious, pecan products should be gaining greater popularity in the current market (King, Blumberg, Ingwersen, Jenab, & Tucker, 2008; Venkatachalam, 2004). One potential way to address this shortcoming is the development of more diversified pecan-based products, which could increase the competitiveness of pecans in the nut-based food market sector.

Nut butters such as almond butter are a rapidly growing segment of the market, yet despite the fact that pecan butter has been available to consumers for a considerable amount of time, it holds only a tiny fraction of the market share in its category (Lightspeed/Mintel, 2018). Part of this may be explained by its consistency- due to the presence of high levels of unstabilized oil, the product is prone to rapid separation of oil and solid phases (Wagener & Kerr, 2018). Furthermore, even when processed/ formulated to be homogenous, the product has a texture many consumers find off-putting rather than presenting a spreadable texture like most other nut butters, it flows easily (Dubost, Shewfelt, & Eitenmiller, 2003).

Another new and intriguing product line for the tree nut industry is dairy-free cheese analogs. Since tree nuts have long been being processed into non-dairy milk alternatives, it should come as no surprise that the dairy-free market has recently begun exploring this market segment. These products typically replace the protein/milk fat gel structure with a starch/vegetable fat gel in an attempt to perform similarly to dairy cheese in both texture and thermal behavior (Hanáková, Buňka, Pavlínek, Hudečková, & Janiš, 2013; Kiziloz, Cumhur, & Kilic, 2009). Despite significant developmental work, and the ability of some of the existing products to successfully mimic cheese in their flavor profile, many fall short in texture and/or thermal behavior.

This study attempts to address the textural problems associated with both pecan butter and nut-based cheese alternatives using both formulation and innovative processing. For pecan butter two types of dehydrated plant material were investigated for their ability to stabilize the product and prevent separation of the oil phase. Varying levels of either dehydrated apple pomace or sweet potato flour were each tested to determine the effects of the level and type of plant flour on physical parameters and sensory perception of the product. Secondly, a method for producing a pecan-based cheese analog was developed using two types of modified potato starch as stabilizers/ texturants, and were applied in the cheese-like product at different levels to examine their effects on the texture and thermo-rheological properties of the final product.

CHAPTER 2

REVIEW OF LITERATURE

Pecan Value and Demand

Georgia grown pecans provide high economic value to the state Georgia is the number one pecan producer in the United States, with over $200 million of revenue from pecans reported in 2015 (USDA, 2016). Despite the large-scale production of pecans in the US and Georgia, the US consumption of pecans has remained fairly stagnant. For the last 30 years for which data are available, the US consumption of pecans has remained around 0.4 pounds per capita (Marzolo, 2015). Similar to other tree nuts and peanuts, pecans are popular for use in confections, and snack food applications; however, other current commercial uses of pecans are limited in comparison to other tree nuts and peanuts.

Recently an increasing interest in tree nut consumption as a health food option has been one of the prominent food trends (Lightspeed/Mintelb). This peak in interest is thought to have followed the FDA approval of the use of a health claim for tree nuts and peanuts which allows marketing materials and packaging to state that the regular consumption of nuts as part of a healthy diet may reduce the risk of heart disease (King, Blumberg, Ingwersen, Jenab & Tucker, 2008). Health claims pertaining to heart conditions are of great interest to much of the public since the leading cause of death in developed countries continues to be cardiovascular disease. Cardiovascular disease is predicted to keep growing in prevalence, thus many medical professionals and consumers are seeking diet and lifestyle changes, such as consuming more tree nuts, that may benefit cardiovascular health (Kris-Etherton, Hu, Ros & Sabaté, 2008). Studies suggest that multiple components contribute to the health benefits of tree nuts. The high level of unsaturated fatty acids found in many varieties of tree nuts may help to lower HDL and overall cholesterol and decrease the risk of developing diabetes and coronary heart disease. Pecans in particular are rich in unsaturated fatty acids, with their total lipid content being composed of ~ 60% monounsaturated fatty acids and ~32% polyunsaturated fatty acids depending on cultivar and growing conditions (Venkatachalam, 2004). An array of phytochemicals is abundant in certain tree nuts, including pecans. These compounds are believed to be powerful contributors to the role of pecans in a healthy diet (King, Blumberg, Ingwersen, Jenab, & Tucker, 2008). Pecans are particularly high in gallic acid along with other phenolics that exhibit antioxidant activity and may further contribute to lowering of cholesterol and disease prevention (Venkatachalam, 2004; (King, Blumberg, Ingwersen, Jenab, & Tucker, 2008a; Kris-Etherton, Hu, Ros, & Sabaté, 2008)).

While several new uses for pecans have been suggested, there remain many other potential applications to be explored or further improved. When consumers were asked to identify which nuts they had consumed in the last month, at least 50% indicated that they had consumed peanuts, almonds and cashews whereas only 34% of respondents reported having consumed pecans within the same month. The same survey found that 35% of the respondents who eat pecans only do so a few times a month, with 20% eating pecans once a month or less while peanuts, almonds and cashews were all consumed with greater frequency (Lightspeed/Mintel, 2018a).

While this correlation has not yet been studied, it is proposed that peanuts, almonds and cashews are more popular than pecans in part because they are more commonly used in further processed, snack and health food products. For example, almond “milk” was the most popular milk alternative in 2017 for the 53% of surveyed consumers who had purchased some type of non-dairy milk alternative over three months (Lightspeed/Mintel, 2018b). While nut butters or spreads are less innovative, it is a market in which pecans could gain popularity. Peanut butter continues to be the most popular nut butter holding 43% of the market value, but almond butter and cashew butter are gaining popularity with about 35% and 19% of the market value respectively for 2017. Pecan butter has been introduced to the market, but it only holds less than 4% of the market value (Lightspeed/Mintel, 2018b). It may be possible to increase the popularity of pecan butter and the overall consumption of pecans if pecan butter is improved and more innovative products are developed.

Pecan Butter Background

Traditional pecan spread is made by grinding roasted pecans and adding sugar and salt, but the resulting product has some distinct disadvantages compared with other nut butters. In particular, the high oil content of pecans means that the grinding process releases substantial amounts of oil, creating a paste that separates easily into solid and oil phases during storage and which is very fluid-like even when it is mixed into a continuous phase (Wagener & Kerr, 2018). This is less than ideal, as texture is one of the key factors in determining consumer acceptability, and it has even been proposed as the most important characteristic of some foods (Rohm, 1990). Further, the texture parameter of spreadability has been shown to be of particular importance in nut-based spreads as it correlates with positive consumer opinions, while oiliness has negative implications (Di Monaco, Giancone, Cavella & Masi, 2008).

Waegner and Kerr (2018) previously studied the concept of reducing the oiliness of pecan butter by expelling the oil from the pecan paste and adding it back to the product in lower concentrations than what naturally occurs. The results confirmed that reducing the ratio of oil to solids resulted in a pecan spread with higher acceptability and better textural properties (Wagener & Kerr, 2018). While this research provides useful insight and understanding, it does not address the problem that is created by expelling the oil. If manufacturers must introduce additional processing steps and machinery to expel the oil and recombine only part of the oil, this increases their cost of production and creates a potential waste product. The pecan oil must be either disposed of or further processed before it can be sold. The present research examined the possibility of reducing the oil to solid ratio of the pecan butter by incorporating additional solids in the form of dried plant material, which may also prevent oil separation through oil surface adsorption and absorption into the pant material particles.

Both apple pomace flour and dehydrated sweet potato flour have a brown color and flavor profiles that include sweet fruitiness and roasted/caramelized notes that should compliment pecan butter well. They both provide high levels of insoluble carbohydrates that will increase the solids content of the pecan butter. Additionally, they could potentially improve the perception of the product as a healthful food.

The addition of dehydrated apple pomace is a useful method for redirecting a food waste stream and has the potential to improve the textural and nutritional qualities of pecan butter. Over 360,000 tons of apple pomace are generated yearly as a byproduct of products such as apple sauce, juice and cider. The leftover pomace is of great nutritional interest since most of the antioxidant compounds from the fruit are absorbed and retained in the solids of the pomace after apples have been juiced (van der Sluis, Addie A, Dekker, Skrede, & Jongen, 2002). The pomace can be dehydrated and ground into a fine powder referred to as “apple flour” which has many potential uses and benefits; it is a rich source of dietary fiber and vitamins and an excellent carrier of phenolic compounds with lasting antioxidant activity (Jung, Cavender, & Zhao, 2015;

Lavelli & Kerr, 2012). Apple flour effectively increases the viscosity of some solutions, which could help in reducing the "runny" state of pecan butter (Soukoulis, Lebesi, & Tzia, 2009). Additionally, apple pomace provides radical-scavenging activity within some food matrices (Ibrahim et al., 2011). This could theoretically be beneficial to the product's shelf life since pecan oil is highly susceptible to oxidation. However, the present study will focus on the physical/textural effects of apple flour inclusion in pecan butter.

Dehydrated sweet potato flour is also an attractive option for increasing the solids: oil ratio in pecan butter. Orange-flesh sweet potatoes offer the benefits of high levels of beta-carotene, some minerals (Ca, P, Fe, and K), starchy solids, and a sweet flavor (Van Hal, 2000). The dehydration of sweet potatoes has been studied as a method for preserving the crop since it is highly perishable and cannot be stored or transported easily in developing countries (Ahmed, Akter, & Eun, 2010). Extracted sweet potato starch is used for a wide variety of applications, but dehydrated sweet potato flour (which includes other carbohydrates, fat, protein and micronutrients) is a more novel ingredient. The flour is a better medium for preserving sweet potato's nutrients than the extracted starch, but the application of sweet potato flour in food products has only seen limited success thus far. When used to partially replace wheat flour in baked goods, it had negative effects on savory breads that are expected to have high rise volume, but was more acceptable in sweet baked goods such as cookies (Ahmed et al., 2010). Since the pecan butter is intended to be lightly sweet, the sweetness of the sweep potato flour should compliment the flavor profile well.

Evaluating The Physical Properties Of Pecan Butter

Considering historical evaluation of peanut butter, the texture of nut butters and spreads is of great importance to consumers with high firmness and spreadability being especially good indicators of quality perception. To test these qualities, instrumental firmness and work of shear can be measured using a texture analyzer and a specialized "firmness and spreadability" rig. This method is advantageous in its repeatability, which allows for comparison of results from among different studies. Instrumentally obtained spreadability values (work of shear) have been shown to correlate well with sensory perception of spreadability (Gills & Resurreccion 2000). This could be en effective method of demonstrating the textural differences imparted by the addition of apple and sweet potato flours since previous work showed that including ground peanut skin, a different solid fibrous material, improved textural parameters in peanut butter (Ma et al., 2012). Additionally, an increase in firmness and spreadability of pecan butter through the increase of solid: oil ratio was associated with an increase in sensory acceptability (Wagener & Kerr, 2018). Therefore, an increase in firmness and spreadability will be interpreted as an improvement in the product. However, it is not known if there is a point at which higher firmness and spreadability is no longer desirable. To test the effectiveness of improving the pecan butter from a consumer perception standpoint, consumer sensory analysis is often utilized. Ranked preference testing can be used to evaluate a large number of samples with efficiency. While this method does not provide scaled scores for attributes of each sample, it can be useful for determining the point at which a variable becomes critical to consumers' preference for the product. Since pecan butter is not among the most popular nut butters currently, it will be useful to explore improving its qualities using apple and sweet potato flours.

Potential For A Pecan-Based Cheese Analog: The Market For Non-Dairy Alternatives

One of the more recent and rapidly growing innovations in the tree nut industry is the creation of nut-based alternatives to common dairy products (Lightspeed/Mintel, 2018). A variety of factors are contributing to this demand for non-dairy alternatives to traditionally dairy-based foods, including allergies, lactose intolerance, health concerns, and concerns over environmental impact and animal welfare (Gerber, Vellinga, Opio, & Steinfeld, 2011; Prentice, 2014; Savage, Jessica, MD, MHS, Sicherer, & Wood, 2016). Cow's milk protein allergies are the most common type of food allergy among infants affecting approximately 2.5% of the population if both IgE- and non–IgE-mediated reactions are counted (Schrander et al., 1993). While many children later develop a tolerance to cow's milk protein, it seems that the rate of children sustaining the intolerance into adulthood has increased through recent decades (Savage, Jessica, MD, MHS, Sicherer, & Wood, 2016). If this trend continues, the aging population will continue contributing to a higher demand for dairy alternative products.

Although some meta-data analyses show a neutral or even beneficial effect on human health associated with dairy product consumption, many consumers choose to avoid dairy products in an effort to maintain a healthier lifestyle (Prentice 2014). The avoidance of dairy cheese, in particular, is associated with the effort to reduce consumption of saturated fatty acids since they are associated with a higher risk of coronary heart disease and obesity (Simon et al., 1995, Bachmann 2001). A pecan-based cheese alternative would be of high interest to this group since pecans contain mostly mono and polyunsaturated fatty acids (~60%) with very low levels (6%) saturated fatty acids (US Department of Agriculture, Agricultural Research Service. 2019).

The perception of environmental impacts of dairy farming has also driven a growing number of dairy avoiders. The extent to which the dairy production sector contributes to greenhouse gas emissions continues to be debated. The FAO estimates that the total contribution of the dairy production sector is 4%±26%, which demonstrates the lack of understanding of the true greenhouse gas contribution of the dairy industry (FAO 2010). While modern dairy production practices are decreasing the environmental impacts, it continues to be a concern that contributes to some consumers limiting or eliminating their dairy consumption (Gerber, Vellinga, Opio, & Steinfeld, 2011). Considering the growing market for alternatives to dairy products, there are a number of dairy-free cheese analogs currently produced in the US and globally. The most well-known "vegan cheeses" in the US market are predominantly composed of highly saturated vegetable oils and starch gels.

Nut-Based Non-Dairy Cheese Analogs

With very few pecan-based dairy alternative foods available, this is a market sector with great potential for growth in the pecan industry. In order to appeal to this sector, some small and medium food manufacturers have begun producing "cheese" products from tree nut materials. Consumers can currently find imitation "ricotta" and a semi-solid, cheese-like spread made from almonds and cashews on many grocery store shelves. There is a lack of published scientific research on the properties of these products, but it is evident that they behave much differently than dairy-based cheese, especially in melting behavior. Traditional dairy cheese gains its texture and melting behavior from the protein gel network that is formed when environmental conditions cause the aggregation of specific proteins into a gel network (Hettiarachchy & Ziegler, 1994). The currently available nut-based products do not utilize protein functionality to achieve a true cheese-like texture. Instead, they maintain a semi-solid, pasty texture that is most reminiscent of cheese only in appearance and flavor. While the initial approach to creating a pecan-based "cheese" may be to consider manipulations of the native proteins, previous research indicates that this method may be problematic. Defatted pecan flour has been analyzed for emulsion capacity and foaming capacity. It was found that pecan flour has a high emulsion capacity and high viscosity of the emulsion when a suspension of the flour is adjusted to pH 8.2, but that it had a low viscosity in acidic conditions, which would be reasonable for producing a cheese-like flavor through lactic acid fermentation. Additionally, there were only very low levels of soluble protein found in pecan flour at any pH reasonable for food products (McWatters & Cherry, 1977). In order to mimic the true structure of cheese, the existing protein would need to be capable of aggregating in a gel network that would hold water, lipids and solid particles to maintain an aggregate filled gel. The protein casein is primarily responsible for the aggregated gel network observed in cheese (Hettiarachchy & Ziegler, 1994). This unique behavior is not expected to be easily replicated using only “milk” made from ground pecans, especially with the low levels of soluble protein in pecans. Previous studies have found that the strength of a weak aggregate filled gel can be increased through the mixing of an additional gel-forming polymer to create a reinforced polymeric network (Hettiarachchy & Ziegler, 1994). It is predicted that other network-forming agents such as hydrocolloids may be necessary for achieving a cheese-like texture while utilizing the pecan solids. The feasibility of this concept can be examined by considering other products that have been modified to behave like a natural cheese.

Cheese Analog Background

While nut-based cheeses may be a novel idea, cheese analogs have been studied and well established in the market for decades. The development of cheese analogs was driven by consumers’ desire for a cheese containing lower saturated fat and cholesterol combined with an industrial push for lower cost cheese. This resulted in products that are similar to natural cheese in sensory and thermal properties, but some of the dairy components (such as fat) have been replaced with vegetable components (Bachmann, 2001). One study examined how the replacement of milk fat with vegetable oils in cheese imparted a more open microstructure, but the product still successfully mimicked traditional cheese texture. Since the vegetable oil contained much higher amounts of unsaturated fatty acids than the milk fat, this verified that a cheese-like product could be made with the use of highly unsaturated lipids, especially when paired with an emulsifying agent (Lobato-Calleros et al., 2007). The formulation of imitation cheese has been studied wherein various hydrocolloids are combined with partial constituents of the original dairy milk such as rennet casein or butter fat alone rather than including the total milk mass (Bachmann, 2001). Research has shown that waxy vegetable starches and carrageenan can interact with dairy components to create adequate firmness and meltability (Kiziloz, Cumhur, & Kilic, 2009).

There are several commercially available vegan “cheeses” that already utilize these hydrocolloids and vegetable oils for a meltable, completely dairy-free cheese. However, a recent survey of published scientific literature in the major databases found no published works on the possibility of creating a nut-based “cheese” product that is free of dairy components. The dairy-alternative and nut industries could be revolutionized by the development of a process and formula that incorporates the whole kernel of pecans with functional hydrocolloids to yield a dairy-free cheese analog with appropriate physical and sensorial properties.

The flavor of a non-dairy cheese alternative is obviously of great importance. A traditional dairy cheese acquires its characteristic flavor through a combination of flavor components. Fresh cheeses taste predominantly of the primary ingredients: milk (lactose, fat and proteins), salt, and some degree of astringency thanks to the acidification that develops during a short period of fermentation. Aged cheeses develop complex flavor profiles through the breakdown of lactose, fat and protein into lactic acid, fatty acids, and amino acids through microorganism and enzymatic activity (Kristoffersen, 1973). To develop a pecan-based non-dairy cheese alternative, each of these components must be considered. Natural cheeses have varying levels of “creaminess” depending on the fat content. The high oil content of the pecans may naturally provide a creamy sensory perception when the nuts are ground into a paste. The inherent nutty flavor is also beneficial since nutty flavor notes have been identified among the key attributes of certain aged cheeses (Rétiveau, Chambers, & Esteve, 2005). Vegan cheese manufacturers also use other flavoring ingredients to contribute to a more cheese-like flavor (Kristoffersen, 1973). The selected flavoring ingredients will be further discussed in chapter 4.

It seems that sensory preference based on the texture of cheese is dependent on what the consumer is expecting for a particular kind of cheese (Antoniou, Petridis, Raphaelides, Omar, & Kesteloot, 2000). One of the most obvious deficiencies of the existing nut-based cheese analogs is the lack of a cohesive gel texture and melting behavior that is expected of most dairy cheeses. Firmness has been cited as the primary textural attribute that consumers consider when evaluating the acceptability of a cheese with a polarized preference toward either firm or soft cheese (Lee et al., 1978). The same study found that samples described as having greater elasticity, smoothness, and meltability were favored over those described as having crumbly and grainy textures (Lee et al., 1978). Unfortunately, a ground paste of hydrated pecan kernels is not likely to form a cohesive gel structure similar to a casein network under reasonable conditions due to the lack of functional soluble protein within acceptable pH ranges (McWatters & Cherry, 1977). Therefore, it is not expected to demonstrate any melting behavior. This lack of protein functionality can be observed in the existing nut-based cheese analogs. To overcome this challenge, the incorporation of a thermally reversible gel-forming food ingredient may be beneficial.

Hydrocolloids as Gelling Agents in Foods

A number of hydrocolloid gelling ingredients have been tested in cheese analogs for different purposes. The term “hydrocolloids” encompasses a large family of molecules that all share selected qualities: They are composed of long chain polymers of polysaccharides and sometimes proteins, and they are capable of being dispersed in water to increase viscosity. Some are classified as thickeners as they only partially reduce how freely the substance flows, but it remains a viscous fluid. Others are capable of forming a three dimensional network of cross-linked polymers strong enough to immobilize the water to the extent that it becomes a viscoelastic solid or a gel (Saha & Bhattacharya, 2010). Gel-forming hydrocolloids were of greatest interest for the present research since the objective is to mimic the texture that is created in traditional cheese from a casein gel network. The most commonly used gel-forming hydrocolloids in foods include modified starches, agar, kappa and iota carrageenan, low methoxy pectin, gellan gum, alginate, and methyl and hydroxypropyl methyl cellulose (Saha & Bhattacharya, 2010). They are each used in different varieties of products according to the desired rheological properties of the final product.

In order to be an effective gelling agent in a cheese analog, the selected ingredient should not only be able to form a firm gel, but should also be able to mimic the melting behavior of cheese. Therefore, a thermally reversible gel network is necessary. Blends of k-carrageenan, agar, and modified and native starches have previously been tested as texturizing agents in cheese analogs because they all display some level of gelling and thermally reversible firmness

(Kiziloz et al., 2009). Agar-agar became a popular ingredient for home cooks to use in making vegan "cheeses" because it is easily accessible and relatively simple to use. However, most agar must be heated to high temperatures and held for an extended time to fully solubilize before forming a gel (Medina-Esquivel et al., 2008). In the present research, the extended high heat step was found to be damaging to the pecan constituents causing significant oiling off to be observed. Kappa-carrageenan can form thermally reversible gels under some conditions and shows synergistic improvement of strength and cohesiveness with xanthan gum and locust bean gum. Iota-carrageenan is a common ingredient in many gelled dairy desserts since it forms elastic gels in the presence of calcium ions, which are naturally present in true dairy products. The strength of carrageenan can be compromised by the presence of acid, which is problematic in a directly acidified cheese analog (Blakemore & Harpell, 2010). Finally, these hydrocolloids are generally applied in low dosage levels (0.01-3%). When applied at the levels necessary to achieve a semisolid gel, the resulting product is likely to be brittle and take away from the creamy mouthfeel that is expected of a cheese analog. While carrageenan may be able to improve cheese analog texture when used to only supplement the casein network, it has been found to negatively impact texture and meltability when used to replace the casein gel network at high levels (Kiziloz et al., 2009).

Starches as Gelling Agents In Imitation Cheeses

Starches can be considered the most common type of hydrocolloid in foods (Saha & Bhattacharya, 2010). There are an abundance of varieties with different properties, some of which could be useful for imitating the texture of cheese. All starches are composed of two types of polysaccharide chains: amylose and amylopectin. Amylose is made up of long, unbranched repeating D-glucopyranose molecules connected by α-1,4 glycosidic linkages. Amylopectin is also made up of D-glucopyranose units, but the strands are highly branched at α-1,6 linkages. The length of the chains and the ratio of amylose to amylopectin dictate the functional properties of the starch as an ingredient (Thomas & Atwell, 1999). Native corn and potato starches have long been used to thicken sauces, gravies, and other foods that are heated to thicken. When heated, the starch granules "gelatinize" or lose their crystalline structure and begin swelling and leaching amylose in the presence of water. Newly exposed hydrophilic regions of the starch chains are then free to interact with water and restrict its movement (Burey, Bhandari, Howes, & Gidley, 2008; Thomas & Atwell, 1999). While they are very effective for increasing viscosity, native starches generally do not develop a solid gel network. They cannot be dispersed at high enough concentrations to achieve viscoelastic solid behavior, and they are highly sensitive to shear and extensive heat (Saha & Bhattacharya, 2010). Starches can also be modified through chemical, physical or enzymatic means depending on the goals for the ultimate functionality of the ingredient, and this technology can combat their shortcomings to improve their functional properties as gelling agents non-dairy cheese.

When two types of enzymatically modified maize starch were used in the production of an acid casein based cheese analog, the products were found to have increased elastic properties in acidic pH conditions and good melting properties (Sołowiej et al., 2016). Ingredient labeling of existing vegan cheeses indicates that modified potato starch is an especially popular texturizing ingredient for cheese analogs that are completely exclusive of dairy casein, but little research has been published on this application. Acid-thinned potato starches provide a reasonable solution for developing a cheese-like texture. The term "acid-thinned" indicates that the native starch was combined with an acid in an aqueous environment to cause the hydrolysis of some of the glycosidic linkages. This allows for higher concentrations of the starch to undergo gelatinization and pasting without increasing the viscosity of the solution while it is hot. Therefore, these starches are also referred to as “thin-boiling”. Most importantly for a product that is intended to have a firm gel structure, acid-thinned starches have the ability to form strong gels with high levels of total solids (Thomas & Atwell, 1999).

A US patent that explores the use of other types of modified starches indicates that thin boiling potato starch is the most common starch in the non dairy cheese substitute industry because of its lower gelatinization temperature and ability to form a firm gel without impeding the melting behavior of the product (Bouron, Fonteyn, Klemaszewski, & Lemonnier, 2019). Another patented study focused on cheeses that combined casein and different modified starches in imitation cheese. It claimed to have developed one formulation wherein casein had been totally replaced by modified starch and the product achieved textural properties equivalent to a casein-based mozzarella cheese product. This study pointed out that acid conversion of a high-amylose starch was necessary when applying starches at high levels as this allowed for thin boiling behavior and meltability of the final product (Zallie & Chiu, 1995). The specific functions of the acid thinned potato starch in the product will be further discussed in Chapter 4.

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CHAPTER 3

MOODIFYING THE TEXTURE OF PECAN BUTTER USING DEHYDRATED PLANT MATERIAL[1]

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[1] 1 Fortner, R.F. and W.L. Kerr. To be submitted to *Journal of Texture Studies.*

Abstract

Pecan butter was formulated with the addition of apple and sweet potato flours at 5, 10, and 15% of the product by weight. The effects of the type and amount of flour on the finished pecan butter were evaluated for smooth and crunchy type butters. The addition of apple or sweet potato flour increased the mechanical firmness and spreadability attributes of the product and decreased visible oil separation. For smooth formulations, the highest level of apple flour inclusion increased firmness by 67% whereas the sweet potato flour at the highest inclusion level increased the firmness by 57%. Both flours caused the product to be darker in color and the sweet potato flour imparted more redness. The addition of either type of flour to pecan butter did not have a significant effect on consumer preference between the formulations until it was applied at 15%. At that point, the average preference for the product decreased. The sweet potato flour increased the vitamin A, calcium and potassium content of the pecan butter.

Introduction

While other tree nuts and peanuts have increased in popularity and consumption, the US consumption of pecans has remained around 0.4 pounds per capita for the last 30 years (Lightspeed/Mintel, 2018a; Marzolo, 2015). The current commercial uses of pecans are limited in comparison to other tree nuts and peanuts. The FDA and medical professional associations recommend a diet high in foods, such as tree nuts, containing unsaturated fats that may help prevent coronary heart disease (King et al., 2008; Kris-Etherton, Hu, Ros, & Sabaté, 2008). Pecans are well-suited for these kinds of diets, as they are particularly rich in unsaturated fatty acids, with their total lipid content being composed of ~ 60% monounsaturated fatty acids and

~32% polyunsaturated fatty acids depending on cultivar and growing conditions (Venkatachalam, 2004). Thus, pecan based convenience foods could provide an attractive snacking option for the growing population of individuals experiencing or at risk for cardiovascular disease, yet while there are a number of pecan inclusive snack food options currently available, pecans remain distinctly less popular than other nuts, suggesting that more applications should be explored.

Outside of whole nuts, nut butters are among the most popular products through which nuts are enjoyed in the United States. Peanut butter specifically holds 43% of the market value for nut butters, but almond butter and cashew butter are gaining popularity with 35% and 19% of the market value respectively for 2017 (Lightspeed/Mintel, 2018b). Pecan butter, on the other hand, only holds 4% of the market value (Lightspeed/Mintel, 2018b). Pecan butter is traditionally made by grinding roasted pecans into a paste and combining the paste with sugar and salt for flavor, but this most "natural" form of the product has textural problems. Oil is released from the pecans upon grinding. The pecan butter separates easily into solid and oil phases during storage, and it becomes too fluid when mixed into a continuous phase so the product flows rather than spreads (Wagener & Kerr, 2018). This is a problem as texture is one of the key attributes in determining the consumers' acceptability of a product; the parameter of spreadability has been shown to be of particular importance in nut-based spreads as it correlates with positive consumer opinions, while oiliness has negative implications (Di Monaco et al., 2008; Rohm, 1990). It may be possible to increase the popularity of pecan spread and the overall consumption of pecans if the quality of pecan butter is improved. Reducing the ratio of oil to solids in pecan butter through oil expulsion has been shown to improve the texture and sensory acceptability of the product (Wagener & Kerr, 2018). The present study explores the possibility of reducing the oil to solid ratio of the pecan butter by incorporating additional solids in the form of dried plant material rather than removing the oil.

The plant material selected for this application should provide high levels of insoluble carbohydrates that will increase the solids content of the pecan butter. Both apple pomace flour and dehydrated sweet potato flour were investigated for inclusion in pecan butter as they have color and flavor profiles that may compliment the natural flavor of pecan butter. Additionally, they could potentially improve the perception of the product as a healthful food (Ahmed et al., 2010; Lavelli & Kerr, 2012). Apple flour has already been shown to effectively increase the viscosity of some solutions. This could help in reducing the "runny" state of pecan butter (Soukoulis et al., 2009). It has a variety of catechins and other antioxidants that may be beneficial to health (Laveli & Kerr, 2012). Sweet potato flour could also improve the perception of healthfulness since it contains beta-carotene and minerals (Ca, P, Fe, and K), and the starchy solids necessary for offsetting the separation of oil in pecan butter (Van Hal, 2000).

Most commercially prepared nut butters are stabilized from oil separation by the addition of saturated triglycerides and distilled mono or diglycerides. The mono and diglycerides are amphiphilic and are therefore able to stabilize and emulsify the solid particles within the oil. Also, fully saturated triacylglycerol and mono and diglycerides have straight fatty acid chains that allow for tight, uniform packing and crystal matrix formation. When they are added to ground nut pastes and tempered properly, they act as seeding crystals to trigger the development of a more solid-like fat matrix throughout the product (Metin & Hartel, 2005). This method is effective, but consumers who seek more "natural" foods may perceive the ingredients as unhealthy. In addition, preliminary work with such stabilizers found they were less effective in pecan as compared to peanut butter, presumably as pecans contain considerably more oil than peanuts.

Previous studies have explored the idea of stabilizing oil separation in peanut butter and other nut pastes through the addition of solid powders. A US patent claimed that microparticulate silicone dioxide could be mixed with peanut butter to effectively slow the separation of oil for up to a year. It proposed that the modes of action could include the hydroxyl groups of the SiO_2 helping to reinforce the binding action of the oil to the surface of the peanut particles, and that the SiO_2 particles added so much solid surface area that weak surface interactions prevented the solid particles from settling over time (Perlman, 1999). Studies have also found that the addition of peanut shell flour or ground peanut skins, which are both insoluble fibrous powder, increased the firmness of the product and did not negatively impact the acceptability (Collins & Sanchez, 1979; Ma et al., 2012).

The present research focuses on examining the changes in physical and sensory properties imparted by the addition of sweet potato and apple flour to pecan butter. As mentioned, an increase in firmness and spreadability of pecan butter through the increase of solid: oil ratio was associated with an increase in sensory acceptability (Wagener & Kerr, 2018). Previous studies on the texture of nut-based spreads correlated an increase in firmness with better sensory perception and/or improvement of other product parameters (Gills & Resurreccion, 2000; Ma et al., 2012; Wagener & Kerr, 2018). Instrumentally obtained spreadability values have been shown to correlate well with sensory perception of spreadability (Gills & Resurreccion, 2000).

The purpose of this work was to determine if the addition of non-pecan plant-based dry matter could help improve the quality and desirability of pecan butter. Thus, dry apple pomace flour or sweet potato flour were added at levels up to 15% by weight. Several quality aspects were measured including changes in consistency and spreadability, tendency to separate, and color. To determine optimum formulations, consumer preference testing was conducted. In addition, samples were formulated in both “smooth” and “crunchy” styles to determine if the style of nut butter would influence optimal levels of added dry matter.

Materials and Methods

Pecan Butter Formulation

Fancy Midget Pecan Pieces (*Carya illinoinensis*) of ‘Stuart’ and ‘Desirable’ varieties were provided by the South Georgia Pecan Company (Valdosta, Georgia, USA). Dehydrated apple pomace flour (APL-380) was provided by Marshall Ingredients (Walcott, New York, USA). Organic orange sweet potato dehydrate was provided by Carolina Innovative Food Ingredients, Inc. (Nashville, North Carolina, USA). Florida Crystal Powdered Raw Cane Sugar (10x) and Morton Flour Salt were purchased from US Foods (Rosemont, Illinois, USA).

The pecan pieces were spread into a thin layer on baking sheets and roasted in an impingement oven at 160 °C for 6 min. After the roasted pieces had cooled, they were ground using a Masuko Sangyo Co. Supermasscolloider Small Laboratory Grinder MKCA6-2 fitted with MKE fine grindstones at (Kawaguchi, Saitama, JP). The grindstone gap was positioned as close together as possible without exhibiting friction between the upper and lower stones. A PB-40 Fineness of Grind Gage (Precision Tool & Gage Co. Dayton, Ohio, USA) was used to ensure that the particle size was no more than 0.4 mm. This ground pecan paste was used as the primary component of all pecan butter formulations, with a portion of the roasted pieces left unground as ~2 mm pieces to be added to half of the formulations to create a “crunchy” type of pecan butter.

Table 3.1 shows the constituents of each of the test formulations in percent by weight of the total batch. To produce the pecan butter, the pecan paste was combined with sugar, salt and dehydrated plant material (apple flour or sweet potato flour) in a steam-jacketed kettle. The mixture was continuously stirred and heated until the temperature at the center of the kettle registered 75°C, then the mixture was immediately transferred to 500 mL PET jars with lids. The jars were submerged into an ice bath to prevent deformation of the plastic as the product cooled. The samples were stored at 4°C until the time of further testing.

Texture analysis

Instrumental texture analysis of each pecan butter formulation was performed after the method of Ma, et al. (2012) that was adapted from Raju and Pal (2009). A texture analyzer TA-XT2i equipped with a 50 kg load cell and fitted with a conical spreadability rig (TA-425) with Exponent software (Stable Microsystems Ltd., Godalming, Surrey, UK) was used. Samples of pecan butter were removed from the refrigerator at least 18 h prior to testing to allow equilibration to ambient temperature (19°C). The pecan butters were gently stirred to thoroughly distribute any separated oil but avoid air incorporation. For each replicate, a concave cone of the spreadability rig was filled with the pecan butter and leveled using a spatula. The upper cone was positioned at 25 mm above the top of the lower sample cone and lowered at a crosshead speed of 3.00 mm/s to penetrate the sample within 2 mm of the base of the concave sample holder cone. Firmness and “spreadability” (work of shear) were calculated from the force-time plot using Texture Exponent Software. Firmness was recorded as the maximum force (N) during the penetration cycle, and spreadability was recorded as the positive area under the curve (N•mm) (Ma et al., 2012; Raju & Pal, 2009). Analysis of each sample was performed in triplicate.

Color Analysis

Instrumental color analysis was performed using a Konica Minolta CR-400 Chroma Meter (Minolta Sensing Americas, Inc., Ramsey, New Jersey, USA). Triplicate samples of each pecan butter formulation were allowed to equilibrate to ambient temperature (19°C), then thoroughly mixed to incorporate any separated oil. The pecan butter samples were then spread in a thick, even layer onto a smooth plastic surface in a disc with a diameter of 55 mm. A light projection tube was used to separate and protect the light source from the sample surface. The colorimeter was calibrated before each measurement using a white D65 standard tile. Measurements were recorded on the CIE L*a*b* scale in which L* indicates darkness to (0-100), a* represents red versus green where positive values indicate red while negative values indicate green, and b* represents yellow versus blue where positive values indicate yellow while negative values indicate blue (Markovic et al., 2013).

Visual Oil Separation

A qualitative observational test was used to determine how the added plant flours affected the separation of oil over time in the pecan spread products. Each of the pecan butter formulations was thoroughly mixed to uniformly incorporate the oil phase. The jars were left undisturbed at ambient temperature (24°C) for one week to observe any difference in the amount of oil separation.

Microscopic Imaging

In order to assess the particle size and structure of the sweet potato and apple flours, the materials were examined using a Nikon Eclipse E 600 Polarizing Light Microscope (Nikon Instruments, Inc., Melville, New York, USA). Samples of the flour were fixed to slides using clear lacquer. Bright field examination was sufficient for visualizing the shape and size of the particles.

Ranked Preference Consumer Sensory Testing

To evaluate the consumers' preference for varying levels of apple or sweet potato powder, ranked preference testing was performed with all of the pecan butter formulations. Participants over the age of 18 were recruited from the campus of the University of Georgia to participate in the sensory panel. Participants were seated in white, fully lit booths. They received a tray with four coded samples in randomly assigned order. The participants were asked to taste the samples from left to right and give them a rank score of 1-4 with 4 being assigned to the least preferred sample and 1 assigned to the most preferred sample. The ballot is shown in Appendix I. Panelists were instructed to rinse their mouths with water and take a bite of apple to cleanse the palate between each sample (Lawless & Heymann, 2010). All sensory work was overseen by the UGA institutional review board.

The samples were presented as 15 mL portions of the pecan butters placed in 60 mL soufflé cups fitted with lids. The samples had been prepared the day prior to testing to allow for equilibration to ambient temperature. To avoid palette fatigue, only four samples were tested per day. Thus, the formulations were ranked for order of preference in the following groups: four levels of sweet potato powder in smooth pecan butter, four levels of sweet potato powder in crunchy pecan butter, four levels of apple powder in smooth pecan butter, and four levels of apple powder in crunchy pecan butter.

Calculated nutrient content

Proximate analysis of the roasted pecans was performed by the UGA Feed and Environmental Water Laboratory. This was done to ensure the accuracy of the calculated nutrient content of the final formulations. Moisture was analyzed through oven drying at 105°C for 3 h (AOAC method 930.15) and total ash using a muffle furnace at 600°C for 2 h (AOAC method 942.05). Crude protein was analyzed using the Dumas Method (AOAC method 990.03), and the fat content was analyzed using an Ankom extractor with the "Rapid Determination of Oil/Fat Utilizing High Temperature Solvent Extraction" method (PVM 1:2003 and AOCS procedure Am 5-04). Sweet potato and apple flour analyses were provided by their suppliers. The nutrient profiles of the final product formulations were calculated using Genesis R&D Food Analysis Labeling Software (ESHA Research, Salem, Oregon, USA).

Statistical Analysis

Textural analysis was performed triplicate (n=3) and color analysis readings were taken three times per samples in triplicate (n=9). JMP Pro 14 (SAS Institute Inc., Cary, North Carolina, USA) was used to analyze the data. Analysis of variance was performed along with Tukey's test for significant difference at $p<0.05$. For the firmness and spreadability data (Table 3.2) means were compared based on $\log_{10}$ transformed firmness or spreadability measurements to correct for unequal variance between the comparison groups. Consumer ranked preference data were analyzed using Basker tables for determining critical values of difference at $p<0.05$ with the sample size of each test denoted in the figures (Basker 1988).

Results and discussion

Texture analysis

Tables 3.2 (a) and (b) show the results of a concentric-cone firmness and spreadability test for smooth formulations and crunchy formulations respectively. The firmness (N) value indicates the maximum force exerted during compression. The spreadability (N•mm) indicates the work of shear required to lower the convex cone 23 mm into the concave cone. The firmness and spreadability values for the crunchy formulations were at least one degree of magnitude greater than those of the smooth formulations at each plant-flour inclusion level. This is due in part to the probe contacting solid pecan pieces during the compression cycle. Also, as later illustrated in the micrographs of pecan cell structure (Chapter 4), a large amount of oil is stored within the cells of the pecan kernel. When it is trapped within the intact cell, oil is essentially immobile. When the pecan pieces are ground, the cellular matrix is disrupted and oil stores release free oil. Therefore, the finely ground pecan paste expressed much more free oil than the chopped pieces that constituted part of the pecan mass in the crunchy formulations. Though both types of formulations contained the same amount of pecan oil, more of that oil was bound within cells instead of being “free” in the crunchy formulations (Weiss, 1983). It has been shown that when there is less free oil in the pecan butter, firmness and spreadability values increase (Wagener & Kerr, 2018). This reduction of free oil is likely to contribute to the vast difference in firmness and spreadability between smooth and crunchy formulations.

In Table 3.2 (a), the firmness and spreadability of the smooth pecan butters increased with each additional level of either flour. For the smooth apple flour formulations, the firmness of the 15% apple flour formulation was nearly three times greater than that of the control while the firmness of the 15% sweet potato flour formulation was 2.3 times greater than the control in its group. Similar trends were found for the spreadability values. The firmness values for the smooth apple flour formulations were higher than the firmness values of the sweet potato formulations for each set when comparing the same level of flour inclusion. At a level of only 5% apple flour, the firmness of the pecan butter was similar to that with 15% sweet potato flour. The spreadability of the smooth formulations also increased with each level of additional flour. The firmness values ranged from 6.54 to 19.53 N for the apple flour formulations and from 3.89 to 9.02 N for the sweet potato flour formulations. These values were in the expected range when compared with a previous study on the influence of oil content in pecan butter. The pecan butter formulations containing 10-15% of apple flour had firmness and spreadability values similar to literature values of pecan butter containing 50-55% oil. The formulations containing 10%-15% sweet potato flour had firmness and spreadability values more similar to literature values of pecan butter containing 60-65% oil (Wagener & Kerr, 2018).

Though the numerical values of firmness and spreadability for the smooth and crunchy groups were not statistically compared, the trends do show similarities; Table 3.2 (b) shows that the crunchy formulations including apple flour had higher firmness and spreadability values than the sweet potato formulations. With increasing levels of added apple flour, the firmness and spreadability values increased with the exception of the firmness of two highest levels of apple flour inclusion. In the sweet potato groups however, the firmness did not increase compared to the control until the 15% inclusion level, and the spreadability did not increase until the 10%

level. At the 10% sweet potato flour level, the spreadability of the crunchy pecan butter was similar to that of the formulation that used 5% apple flour.

It should be noted that the control samples (0% additive) for the smooth apple formulations had slightly higher firmness and spreadability values than those for the sweet potato formulations. As the apple-based and sweet potato-based samples were made on separation occasions, this difference could be due to slight variation in processing techniques (especially roasting and grinding) and the natural variability of the pecans themselves.

To examine the effects of the additive type alone, Figure 3.1 (a) shows the linear regression of the firmness and spreadability values versus percentage additive for the smooth formulations. The R^2 values indicate that 91-98% of the variability in the firmness and spreadability values can be attributed to effects of the apple or sweet potato additive level depending on the group of products. Figure 3.1 (b) shows the linear regression of the firmness and spreadability values versus percentage additive for the crunchy formulations. The R^2 values indicate that 94%-99% of the variability in the firmness and spreadability values can be attributed to effects of the apple or sweet potato additive level depending on the formulation group. Much of the variability in the data is assumed to arise from the non-homogenous nature of the crunchy type of pecan butter. The slopes of the lines for firmness and spreadability versus percentage additive were higher for the apple formulations than the sweet potato formulations in both smooth and crunchy formulations. For example, for the smooth nut butters the slope for spreadability was 0.87 for the sweet potato and 2.26 N•mm/% for apple-based product. Likewise the slope for hardness was 2.62 for the sweet potato and 6.79 N/% for the apple-based nut butter. This indicates that apple flour has a stronger positive effect on the firmness and spreadability than sweet potato flour at the same dosage levels.

Instrumental Color Analysis

Table 3.3 shows the results of instrumental color analysis of all pecan butter formulations. The average L* values ranged from 42.82 to 37.36 with a trend of decreasing lightness at increasing levels of apple or sweet potato flour inclusion. This was true for both smooth and crunchy formulations, but not all differences were significant. The color values of the products with no sweet potato or apple flour added were in the range of expected color values previously reported for pecan butter (Wagener & Kerr, 2018). The a* values ranged from 4.86 to 7.51. The sweet potato formulations consistently yielded higher a* values than the apple formulations, indicating that the sweet potato flour lends more redness to the product. Increasing levels of apple flour tended to decrease the red saturation and the yellow saturation as indicated by decreasing b* values. The presence of whole pecan pieces in the crunchy formulations did not significantly affect the color of the product.

Visible Oil Separation

Figure 3.2 shows the amount of visible oil separation that occurred over three days of storage at ambient temperature (23°C) for seven days. As expected from the texture analysis, there is much more freely separated oil in the smooth iterations of pecan butter than the crunchy formulations at any level of flour incorporation. The height of the visible oil layer decreases at each increasing level of flour inclusion. However, the plant flour incorporation clearly does not completely retard oil separation under ambient storage conditions except in the 10% and 15% apple flour formulations.

Microscopic Structure of Plant Flours

Figures 3.3 and 3.4 show particles of apple flour and sweet potato flour under 10x magnification. These images contribute to the understanding of each product's stability. The results from the texture analysis indicate that the apple flour is a more effective stabilizing agent in the pecan butter than sweet potato flour. This trend was reinforced by the visible observation of the oil separation over time. In order to understand the difference in effectiveness of the two flours, their microstructural properties should be considered more carefully. Previous work involving the stabilization of oil in nut butter through solids incorporation suggested that the surface area and adsorptive properties of the material may be critical in its ability to prevent oil separation (Perlman, 1999). Fibrous plant materials have been previously used for industrial oil sorption and it has been determined that their capacity for adsorption depends on surface area and pore structure. Initially, oil may be adsorbed onto the irregular surface of the fibrous material through van der Waals interactions. If the material possesses porous structure due to the presence of lignocelluloses, oil may diffuse into the mass through capillary action and be more securely trapped (Thompson, Emmanuel, Adagadzu, & Yusuf, 2010). Apple pomace is composed largely of lignocellulose material having much more fiber than starch in its total carbohydrate content. Because of the adsorptive properties of the fiber particles, apple pomace has been shown to be a very effective adsorbing agent for other substances such as polyphenolics and textile dyes (Robinson, Chandran, & Nigam, 2002; Wu, Melton, Sanguansri, & Augustin, 2014). Conversely, the carbohydrate content of sweet potato flour is mostly accounted for by starch with much lower levels of fiber (Lund & Smoot, 1982). Examination of the microstructure of these two flours confirmed these structural differences. As shown in Figure 3.4, the apple flour contained particles that varied greatly in size and included vascular fragments. These fragments are believed to be composed of cellulose, hemicellulose, and/or lignin and would have the capacity to draw oil in through capillary action. The sweet potato particles are shown at equal magnification in figure 3.5. Sweet potato flour appeared to be composed of larger agglomerations of granular structures rather than the discreet fragments found in the apple flour. The surface of the sweet potato flour particles is clearly irregular and likely participates in surface adsorption through van der Waals forces. However, no vascular structures were detected that would enable the sweet potato material to absorb oil into its inner mass. Finally, the apple flour contained many smaller particles (<50 µm) dispersed through the larger particles, while the sweet potato flour was comprised only of large globular particles (300 µm and greater). Therefore, at equal mass inclusion levels, the apple flour solids would contribute greater surface area and opportunities for surface interaction stabilization of the oil (Perlman, 1999). These differences of microstructural properties are likely to contribute to the observed trend wherein apple flour effectively stabilized more oil against separation than did the sweet potato flour.

Consumer ranked preference testing

Table 3.4 shows the results of four separate rounds of consumer ranked preference testing. In these results, lower rank sum scores indicate that the product was more highly preferred by panelists. The following significant differences were found within the comparison groups: The crunchy type pecan butter with 15% added sweet potato flour was less preferred over the three other formulations in the group. In both smooth and crunchy type pecan butters, the formulations with 15% added apple flour were less preferred than the three other formulations in each group. Consumers did not consistently have a significant difference in preference for the 0, 5, or 10% level formulations, but 15% added flour was enough to cause a decrease in preference (Basker, 1988). For the smooth pecan butter with sweet potato flour and the smooth and crunchy pecan butters with apple flour, the average preference of the formulations including some amount of added flour compared to none at all was higher, but not enough to be significant.

It might be highlighted that the consumer tests did not ascertain consumer attitudes toward shelf stability or product use. That is, the samples were stirred 24 h prior to testing so no visible separation was apparent to consumers. As noted, that is an issue that would become apparent over several days, affecting product appearance and requiring consumers to stir the nut butter before serving. In addition, panelists were not asked to scoop or spread the product, on for example, crackers. Both aspects would be expected to be more desirable in products with the added dry matter.

Calculated nutritional composition

Table 3.5 shows the calculated nutritional composition of all formulations. The caloric content decreased with each increasing level of either apple or sweet potato flour as fat content was displaced with carbohydrate. All formulations were high in unsaturated fats as expected. The greatest differences were among the micronutrients. The sweet potato formulations had increasingly higher levels of Vitamin A than other formulations as expected due to its beta-carotene content. The calcium content increased by a negligible amount in the apple flour formulations, but the 15% sweet potato formulation had 12 mg more calcium than the control. Potassium levels also increased for apple and sweet potato formulations, with greater levels in the sweet potato formulations.

Conclusion

Both apple and sweet potato flour can be used to improve texture and decrease oil separation in pecan butter. Apple flour accomplished these modifications more effectively than the sweet potato flour, possibly due to the presence of capillary cavities in the fibrous apple material. Either type of flour can be included in pecan butter at levels of at least 10% without negatively impacting consumer preference. Pecan butter containing added plant flour could also make the product more attractive to consumers since the addition of these flours decreases the caloric density and adds some micronutrients. While the sweet potato flour had a greater impact on the micronutrient profile, but it may be useful to compare phenolic content of the formulations in future research to fully appreciate the benefits of the apple flour.

Tables

Table 3.1: Pecan butter formulations

Texture Type	Flour [1] %	Pecan Paste %	Pecan Pieces %	Sugar %	Salt %
Smooth	0.0	97.1	0.0	2.5	0.4
	5.0	92.1	0.0	2.5	0.4
	10.0	87.1	0.0	2.5	0.4
	15.0	82.1	0.0	2.5	0.4
Crunchy	0.0	77.7	19.4	2.5	0.4
	5.0	72.7	19.4	2.5	0.4
	10.0	67.7	19.4	2.5	0.4
	15.0	62.7	19.4	2.5	0.4

[1] represents either dehydrated apple pomace flour (Marshall Ingredients, Walcott, New York, USA) or dehydrated sweet potato flour (Carolina Innovative Food Ingredients, Inc. Nashville, North Carolina, USA).

Table 3.2 (a): Firmness and spreadability of smooth pecan butters

Flour type	Flour Level (%)	Firmness (N)[1,2]	Spreadability (N.mm)[1,2]
Apple	0	6.54 ± 0.51 [d]	1.17 ± 0.09 [f]
Apple	5	8.46 ± 0.07 [c]	1.61 ± 0.02 [d]
Apple	10	12.84 ± 1.60 [b]	2.55 ± 0.27 [b]
Apple	15	19.53 ± 0.98 [a]	4.48 ± 0.23 [a]
Sweet Potato	0	3.89 ± 0.04 [f]	0.71 ± 0.02 [g]
Sweet Potato	5	5.36 ± 0.09 [e]	1.01 ± 0.02 [f]
Sweet Potato	10	6.71 ± 0.21 [e]	1.38 ± 0.03 [e]
Sweet Potato	15	9.02 ± 0.13 [c]	2.00 ± 0.05 [c]

[1] Means ± SD followed by the same letter in a column do not significantly differ ($p<0.05$). Means were compared based on $\log_{10}$ transformations of the data shown to correct for unequal variance between formulations.

[2] Measurements were performed on three replicates of each sample ($n=3$)

Table 3.2 (b): Firmness and spreadability of crunchy pecan butters

Flour type	Flour Level (%)	Firmness (N)[1,2]	Spreadability (N.mm)[1,2]
Apple	0	77.78 ± 3.48 [c]	25.84 ± 2.59 [f]
Apple	5	116.56 ± 10.43 [b]	38.72 ± 3.46 [c,d]
Apple	10	153.89 ± 27.15 [a]	51.13 ± 9.02 [b]
Apple	15	178.48 ± 17.79 [a]	59.30 ± 5.91 [a]
Sweet Potato	0	70.15 ± 0.90 [c]	23.31 ± 0.30 [f]
Sweet Potato	5	73.72 ± 2.97 [c]	24.49 ± 0.99 [c,f]
Sweet Potato	10	91.50 ± 7.79 [b,c]	30.40 ± 2.59 [d,e]
Sweet Potato	15	107.85 ± 8.52 [b]	35.83 ± 2.83 [c]

[1] Means ± SD followed by the same letter in a column do not significantly differ ($p<0.05$). Means were compared based on $\log_{10}$ transformations of the data shown to correct for unequal variance between formulations.

[2] Measurements were performed on three replicates of each sample ($n=3$)

Table 3.3: Instrumental color analysis of pecan butters

Additive Type	Additive Level (%)	Texture	L*[1,2]	a*[1,2]	b*[1,2]
Apple	0	smooth	42.82 ± 0.09^{a}	5.62 ± 0.03^{c}	10.24 ± 0.09^{a,b}
	5		40.51 ± 0.16^{b}	5.29 ± 0.01^{c,d,e}	9.52 ± 0.03^{b,c}
	10		39.07 ± 0.07^{d,e,f,g}	5.08 ± 0.03^{e,f}	8.80 ± 0.06^{c,d}
	15		37.36 ± 0.26^{i}	4.86 ± 0.13^{f}	8.15 ± 0.25^{d}
Sweet Potato	0		40.23 ± 0.22^{b,c}	6.96 ± 0.06^{b}	10.08 ± 0.11^{a,b}
	5		39.49 ± 0.13^{c,d,e,f}	7.10 ± 0.08^{b}	10.45 ± 0.11^{a}
	10		38.96 ± 0.15^{e,f,g}	7.10 ± 0.11^{b}	10.36 ± 0.19^{a}
	15		38.41 ± 0.07^{g,h}	7.29 ± 0.09^{a,b}	10.52 ± 0.15^{a}
Apple	0	crunchy	42.58 ± 0.29^{a}	5.45 ± 0.10^{c,d}	10.02 ± 0.34^{a,b}
	5		40.04 ± 0.56^{b,c,d}	5.18 ± 0.24^{d,e,f}	9.52 ± 0.43^{b,c}
	10		37.27 ± 0.26^{i}	5.25 ± 0.04^{d,e}	9.06 ± 0.21^{c}
	15		36.09 ± 0.22^{j}	4.96 ± 0.05^{e,f}	8.05 ± 0.12^{d}
Sweet Potato	0		39.87 ± 0.48^{b,c,d,e}	7.00 ± 0.12^{b}	10.40 ± 0.31^{a}
	5		40.05 ± 0.36^{b,c,d}	6.95 ± 0.13^{b}	10.27 ± 0.19^{a,b}
	10		38.84 ± 0.71^{f,g}	7.11 ± 0.13^{b}	10.13 ± 0.33^{a,b}
	15		37.51 ± 0.49^{h,i}	7.51 ± 0.25^{a}	10.44 ± 0.49^{a}

[1] Means ± SD followed by the same letter in a column do not significantly differ ($p<0.05$)

[2] Measurements were performed on three replicates of each sample (n=3)

Table 3.4: Ranked sums of consumer preference testing

Level of Flour (%)	Sum of ranked scores			
	Smooth with apple	Crunchy with apple	Smooth with sweet potato	Crunchy with sweet potato
0	91 [a]	94 [a]	99 [a]	81 [a]
5	86 [a]	88 [a]	96 [a]	84 [a]
10	90 [a]	87 [a]	93 [a]	90 [a]
15	124 [b]	131[b]	80 [a]	124[b]
Number of scorers	n=39	n=40	n=37	n=37

[a] Values (sum of given number of scores) in a column followed by do not significantly differ ($p<0.05$)

Table 3.5: Nutritional composition of pecan butter formulations per 30 g serving[1]

	0% Additive	5% Apple	10% Apple	15% Apple	5% Sweet Potato	10% Sweet Potato	15% Sweet Potato
Calories	200	190	180	170	190	180	170
Total Fat (g)	21	20	19	18	20	19	18
Saturated Fat (g)	2	1.5	1.5	1.5	1.5	1.5	1.5
Unsaturated Fat (g)	18	18.5	17.5	16.5	18.5	17.5	16.5
Cholesterol (mg)	0	0	0	0	0	0	0
Sodium (mg)	50	50	50	50	50	50	50
Carbohydrate (g)	5	6	7	8	6	7	8
Dietary Fiber (g)	3	3	4	5	3	4	4
Total Sugar (g)	2	2	2	3	2	2	3
Protein (g)	3	3	3	3	3	3	3
Vitamin D (μg)	0	0	0	0	0	0	0
Vitamin A (mcg)	0	1	1	1	13	25	37
Calcium (mg)	20	21	21	22	24	28	32
Potassium (mg)	119	121	123	124	143	166	189

[1] Values are calculated based on USDA and supplier-provided data

Figures

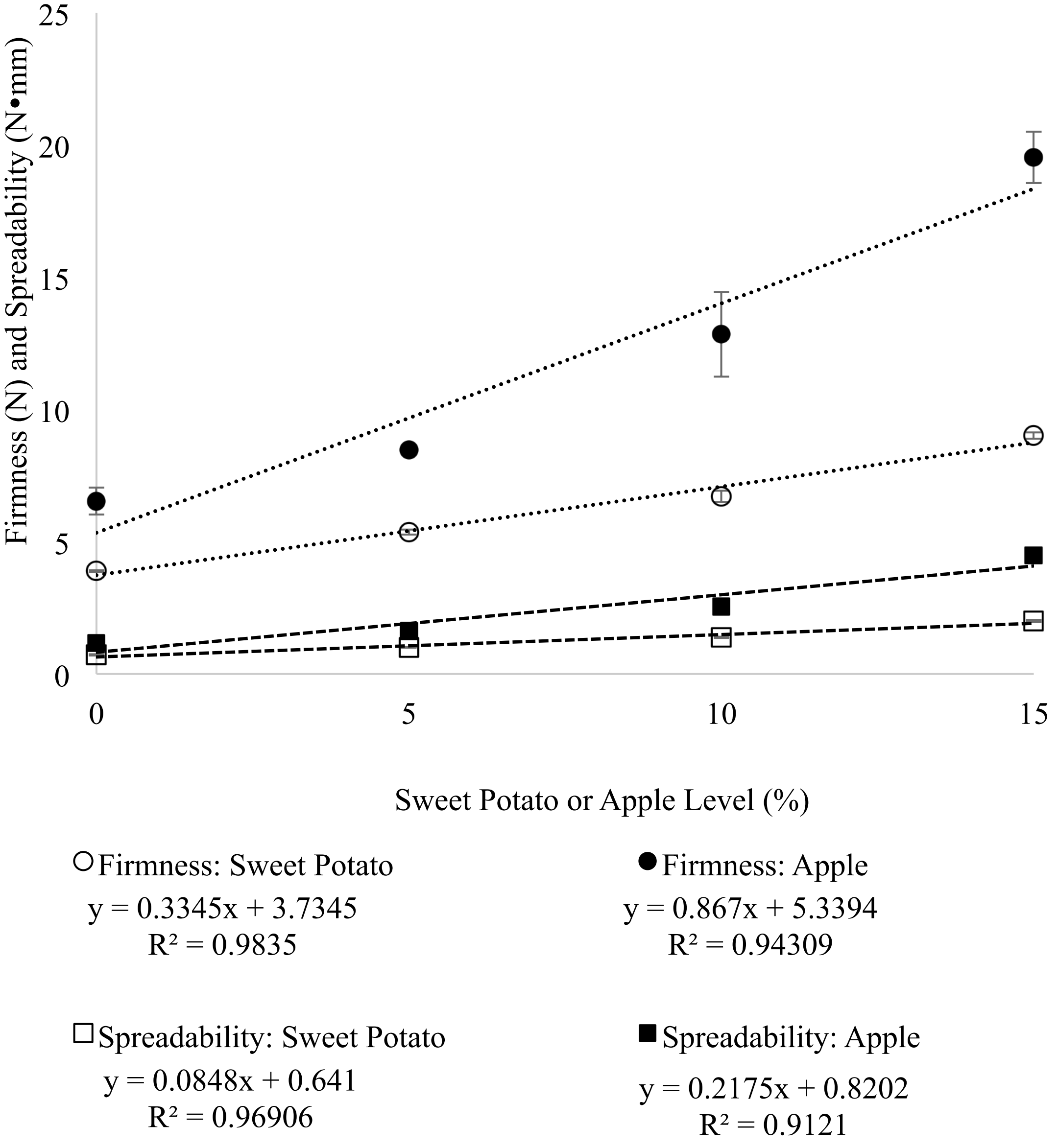

Figure 3.1 (a): Firmness and spreadabiliy versus level of flour for smooth pecan butters
Error bars represent ± 3 standard deviations from the mean

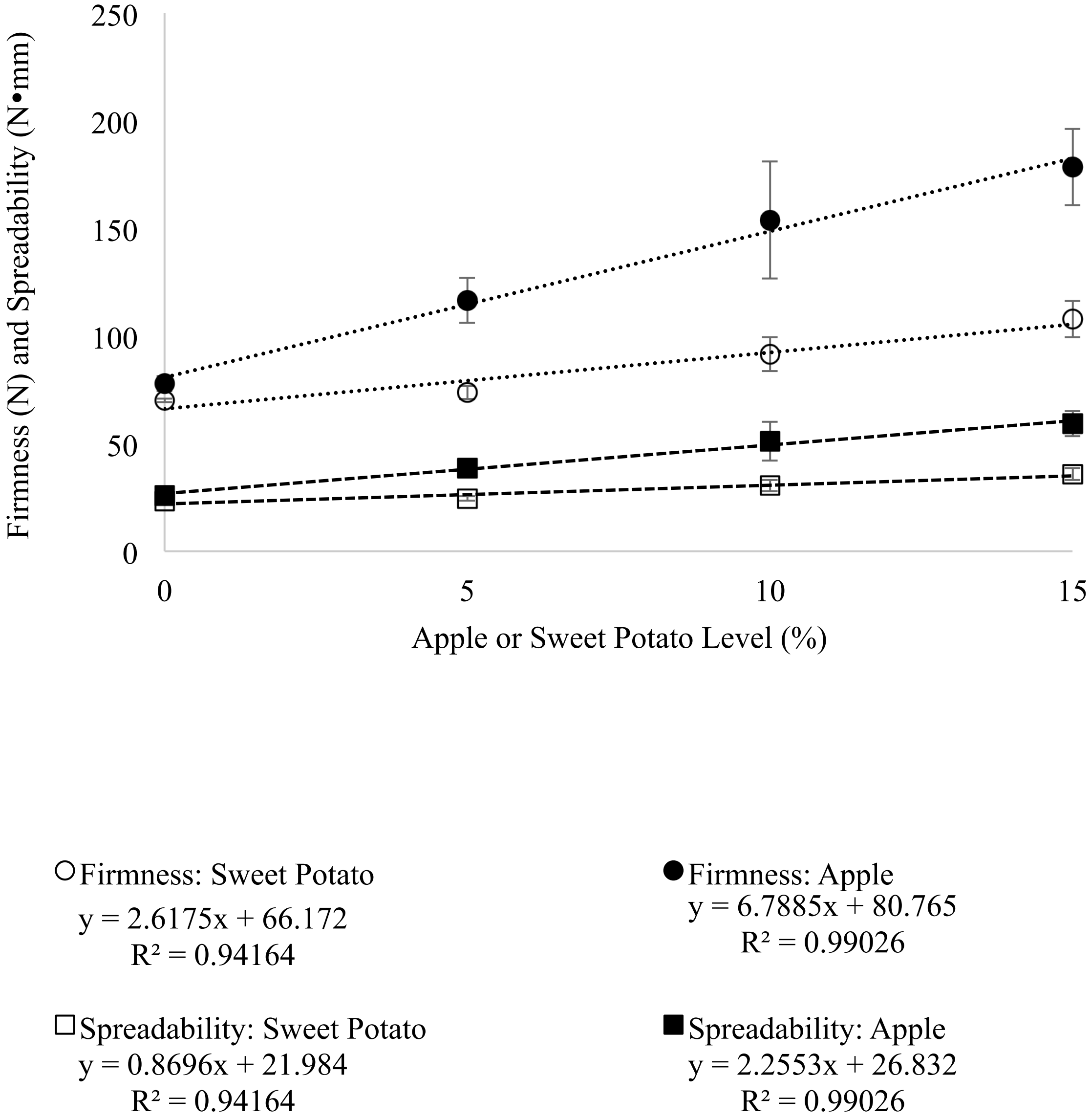

Figure 3.1 (b): Firmness and spreadability versus level of flour for crunchy pecan butters
Error bars represent ± 3 standard deviations from the mean

A) Smooth pecan butter with sweet potato flour

B) Crunchy pecan butter with sweet potato

C) Smooth pecan butter with apple flour

D) Crunchy pecan butter with apple flour

Figure 3.2: Visible separation of oil over 7 days of ambient temperature storage. From left to right, each jar contains 0, 5, 10, or 15% of the noted flour.

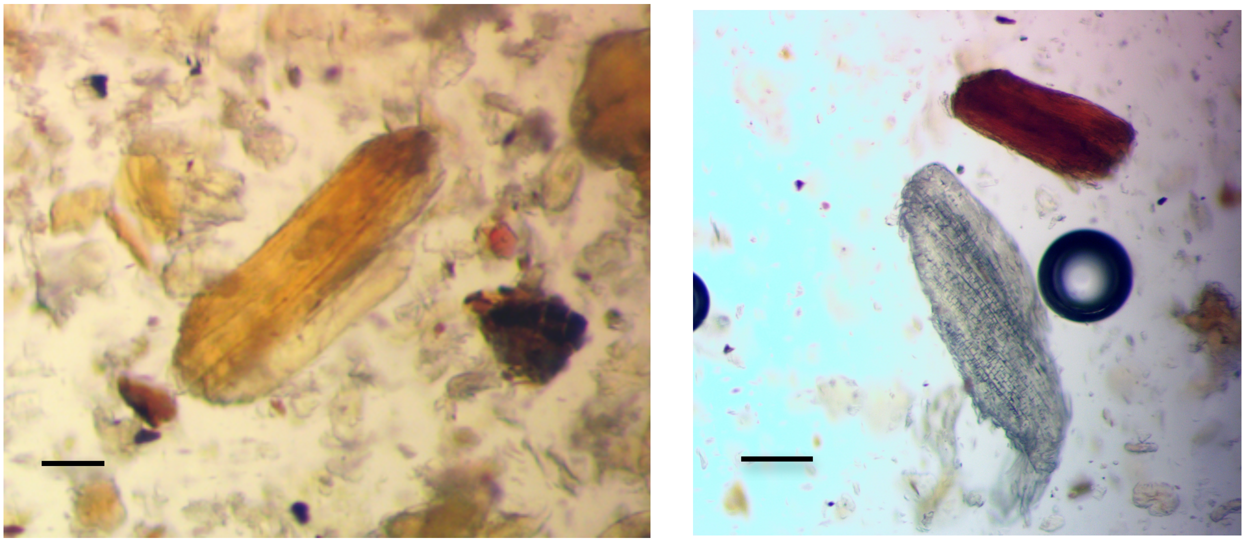

Figure 3.3: 10x magnification of apple flour. Bar represents 50 µm.

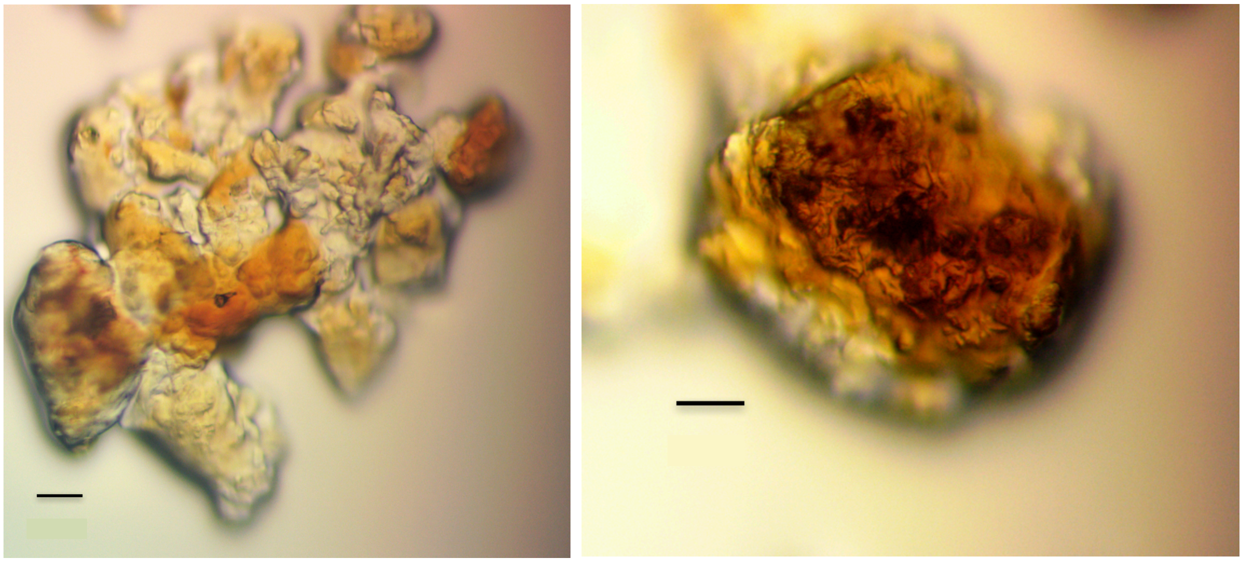

Figure 3.4: 10x magnification of sweet potato flour. Bar represents 50 µm.

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CHAPTER 4

EVALUATION OF THE PHYSICAL AND SENSORIAL PROPERTIES OF A PECAN-BASED CHEESE ANALOG FORMULATED WITH MODIFIED POTATO STARCH[2]

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[2] Fortner, R.F. and W.L. Kerr. To be submitted to *Journal of Texture Studies.*

Abstract

A process was developed for processing pecan kernels into a hydrated paste to then be used as the basis for a non-dairy cheese analog. Two varieties of acid-thinned potato starch were tested at levels of 9, 12, 15, 18 and 21% for their ability to gelatinize and set the pecan paste into a firm gel. The textural and rheological behavior of the formulations of pecan-cheese were compared to that of commercially available cheese products. Mechanical firmness and storage moduli of the products increased with increasing levels of starch and were within ranges comparable to some dairy cheeses. The pecan-based cheese analogs fractured more easily than the dairy cheeses, and exhibited lower internal cohesive forces. The pecan-based cheese analogs softened once heated above 45°C, whereas the true cheeses began softening around 5-10°C. Sensory analysis of the pecan-based products indicated that consumer expectations for non-dairy cheese have not yet been fulfilled by this product.

Introduction

The non-dairy cheese options currently available in most markets can generally be divided into two categories: starch and oil based products with added cheese flavorings, or ground nut pastes that may be naturally fermented to develop cheese flavors. The starch and oil based cheese analogs have existed longer on grocery store shelves and likely borrowed their ingredient technology from the advent of processed cheese analog foods. Those cheese analogs were initially developed with the aim of using some non-dairy elements such as vegetable fats and proteins to replace or supplement the naturally occuring dairy components to create a lower cost, higher yield cheese product (Bachmann, 2001). This product's market sector grew with an increasing demand for cheese as an ingredient in low cost foods, along with increasing interest in products containing less saturated fat and total calories (Bachmann, 2001).

The replacement of fat and protein structure has been the primary focus of creating cheese analogs. As the yield and quality of cheese is highly correlated with the amount of rennet casein present, cheese analogs commonly include sodium caseinate, ultrafiltration retentates of skim milk, or soy protein isolates that mimic the effects of casein (Bachmann, 2001). Researchers have also used pre-gelatinized or modified high-amylose food starches for the partial replacement of casein, but these do not always result in products with appropriate firmness and meltability (Hanáková et al.; 2013; Kiziloz et al., 2009; Mounsey & O'Riordan, 2001; Mounsey & O’Riordan, 2008). Nonetheless, some products in the marketplace have included modified starches to dairy-free vegan cheeses.

The fat content of cheese is also crucial to the product quality. The effects of replacing some or all of the milk fat with hydrogenated vegetable oils and other plant fats has been studied. The plant source, fatty acid ratios and differing degrees of saturation influence the texture, sensory and rheological properties of the final products. The use of oils with higher saturation have generally resulted in cheese products with a creamier mouth-feel along with greater firmness (Lobato-Calleros & Vernon-Carter, 1998; Hanáková et al., 2013). For these reasons, most traditional cheese analogs and vegan starch-based “cheese” products rely on highly saturated lipds to create a semi-solid cheese structure. However, some work has shown promising results from applying polysaccharide gel technology to create a product with semi-firm, cheese-like texture without the inclusion of high levels of saturated fat (Hennelly et al., 2006). Extensive research has been conducted on the replacement or supplementation of various components of cheese with plant-based alternatives, but there is a lack of published research on the development of cheese-like products that are 100% dairy free.

As noted, the second category of non-dairy cheese-like products are those containing ground, hydrated tree nuts. These may be semi-soft, spreadable products that contain higher levels of moisture or firm blocks that have been compressed to develop a sliceable or crumbly cheese texture. These products are made to mimic the flavor of dairy cheese through the use of flavor additives and/or lactic acid fermentation via cheese starter cultures. These cheese analogs are commonly made from cashew nuts, macadamia nuts and almonds as these have a mild, buttery flavor and light color. While their texture is influenced by the nut particle size and level of included water, they do not utilize protein functionality or rely on a protein-gel structure. Even though there are not discreet fat globules dispersed within a protein gel matrix, these nut-based cheese analogs can achieve a "creamy" sensory effect comparable to natural dairy cheeses. This may be because tree nut kernels contain high levels of fat stored naturally within their cellular structure. However, because they contain minimal saturated fat and no thermally reversible gel structure, these products do not exhibit melting or softening behavior typical of cheese.

Pecans are a desirable nut but the market has seen relatively few value-added products containing pecans. For the last 30 years, the US consumption of pecans has remained stagnant (0.4 pounds per capita) with most nuts consumed directly or in seasonal desserts (Marzolo, 2015). There has been increasing interest in tree nut consumption as a healthy food option (Lightspeed/Mintel, 2018c). Part of this demand can be traced to research that indicates pecans and other nuts in the diet may help promote better health, particularly as related to heart disease (King, Blumberg, Ingwersen, Jenab & Tucker, 2008). Thus, there are great opportunities for developing pecan based products such as nut butters, pecan flour, extruded snacks or cheese analogs. However, the production of consumer-accepatble products will depend on incorporating ingredients and technology that provides optimal flavor and texture.

It may be possible to apply classic cheese aging techniques to pecan constituents to achieve cheese-like flavor by inoculating a hydrated pecan paste/milk with cheese cultures and allowing natural fermentation and enzymatic processes to proceed. Preliminary trials of this method did show signs of fermentation, but the progression of fermentation and acidification was much slower than it would be in a dairy substrate (data not shown). Since the process of natural fermentation and aging is highly complex and time intensive in a cheese analog, it is useful to investigate flavor ingredients that provide cheese-like flavor. Indeed, some cheeses such as mozzarella and ricotta are directly acidified. This involves adding organic acids to the milk to lower the pH and to begin proteolysis rather than allowing starter cultures to slowly acidify and coagulate the milk. This method has been beneficial for reducing the production time for some types of cheeses, but can also be applied to mimic cheese flavor in non-dairy products (Micketts & Olson, 1974).

Lactic acid is useful as an acifying agent as it provides flavor notes similar to that produced by lactic acid bacteria. However, the action of lactic acid bacteria leads to the production of many flavor compounds beyond lactic acid in a dairy system. In some cases the incorporation of nutronal yeast may help provide amino acid-based flavors that could not be achieved simply through direct acidification. Nutritional yeast is the dehydrated biomass of *Saccharomyces cerevisiae* that has been cultivated in a carbohydrate source with additional nutrients, often as a byproduct of the brewing industry (Ames & Elmore, 1992; Pancrazio et al., 2016). As the name implies, nutritional yeast is a rich source of nutrients including proteins, nucleic acids, B-complex vitamins, and chromium, so it has been used as an animal feed and human nutritional supplement (Ferreira et al., 2010). In recent years, it has attracted attention for its potential as a food ingredient. Most prominently, nutritional yeast has been tested as a flavor and nutritional enhancer in cured meat products because it has a meaty aroma and umami flavor as a result of the amino acids (Pancrazio et al., 2016). Yeast extracts vary in volatile composition, but include significant levels of sulfur compounds that are associated with meaty and umami flavors and aromas (Ames & Elmore, 1992). Some of these sulfur groups have been identified as key components of flavor development in ripened cheeses such as aged cheddar (Kristoffersen, 1973). Ingredients such as liquid smoke may also be very useful to flavor due to the association of smoke flavor with some cheeses and animal protein products. Sodium content also contributes to the flavor perception of cheese. Salt is added to natural dairy cheeses as a method of controlling microbial growth and enhancing flavor. The salt content of most common dairy cheeses ranges from 0.5 to 2% NaCl, but the perception of saltiness also depends on the ratio of moisture:sodium (Cruz et al., 2011).

Developing desirable textural properties is critical to achieving a consumer accepatble cheese analog. However, the textural properties of cheese are highly variable and dependent on the particular variety. For some cheeses, greater firmness has a positive association with sensory perception, while consumers may prefer a softer texture for other types kind of cheese. The desired texture is dependent on what the consumer expects for that particular kind of cheese (Antoniou et al., 2000). Texture Profile Analysis (TPA) is a common method for analyzing the texture of foods as it correlates with the way that consumers will perceive textural parameters. It has shown especially good sensory correlation with instrumental hardness values and consumer perception of cheese firmness. While TPA was used to quantify tactile perceptual qualities of products, dynamic small oscillatory shear rheometry was used to evaluate the internal structural properties (Gunasekaran & Ak, 2002). Semi-firm, sliceable cheeses have been found to have a storage modulus (G′) higher than the loss modulus (G″) around 20°C, making it a viscoelastic solid.

Cheese texture and structure is dependent on temperature. Traditional dairy cheeses begin to soften around 15-30°C and many fully transition to a viscoelastic fluid ($G' < G''$)at higher temperatures (Nolan et al., 1989, Lu et al., 2007). An important quality parameter for cheeses is the “meltability”, and is particularly critical for particular applications of the product (Gunasekaran & Ak, 2002; Chavan & Jana, 2007). That is, some cheeses (or analogs) may be used in products that are baked or otherwise heated. The manner and temperature at which they undergo a solid-liquid transition, spread on the product, and reset upon cooling are critical to products such as pizza, macaroni and cheese or nachos.

Acid thinned modified potato starches have proven especially effective for developing thermally-reversible firm textures through their gelling ability. The term “acid-thinned” indicates that the native starch was combined with an acid in an aqueous environment to cause the hydrolysis of some of the glycosidic linkages. This allows for higher concentrations of the starch to undergo pasting and gelatinization without increasing the viscosity of the solution while it is hot. Therefore, these starches are also referred to as “thin-boiling”. Most importantly for a product that is intended to have a firm gel structure, acid-thinned starches have the ability to form strong gels at high levels of total solids (Thomas & Atwell, 1999).

The objective of this study was to develop a pecan-based cheese analog with physical properties that mimic dairy cheese, and sensory proeprties that are acceptable to consumers. The products were made using hydrated pecan paste and two modified potato starches, at different levels, to provide a firm meltable structure. Cheese-like flavor was mimicked by acidification with lactic acid and the incorporation of salt, smoke flavor and nutritional yeast. Microscopic analysis was used to determine the structural nature of the analog gel network. Instrumental texture profile analyses was used to examine firmness and related properties, and how these compare to common cheese. In conjunction, samples were analyzed by dynamic rheology to determine viscoelastic properties and how these change with heating and compare to the melting properties of conventional cheeses. Color parameters were also measured to determine how the product appearance was affected by ingredient levels. Finally, consumer sensory panels were used to assess product acceptability.

Materials and Methods

Pecan Paste Manufacturing Process:

Fancy Midget Pecan Pieces (*Carya illinoinensis*) of 'Stuart' and 'Desirable' varieties were provided by the South Georgia Pecan Company (Valdosta, Georgia, USA). The following process for the manufacturing of the pecan cheese analog was developed based on preliminary trials. Equal parts of pecan pieces and deionized water were combined in a steam-jacketed kettle and heated with manual agitation until a minimum temperature of 80°C was achieved at the center of the kettle in order to hydrate and soften the pecan pieces. The water and pecan mixture was run through a MKCA6-2 laboratory stone grinder (Masuko Sangyo Co. Supermasscolloider, Kawaguchi, Saitama, JP) to achieve a smooth, hydrated pecan paste. The paste was allowed to cool, then placed in vacuum-sealed bags. The paste was placed in a freezer to be held at -20°C until further processing, when it was removed and thawed under lukewarm running water.

Pecan Cheese Analog Formulation

Table 4.1 shows the product formulations that were used for manufacturing of the product. In total, ten analog formulations were tested with two types of added starch, which were each applied at five levels (9-21 g/ 100 g product). Two varieties of modified potato starches (Cheesemaker BL320 and Cheesemaker BL130) were provided by KMC ingredients (Brande, Denmark). Simple Truth Organic Nutritional Yeast, Kroger Brand Iodized Salt, and Colgin Natural Hickory Liquid Smoke were purchased from Kroger Marketplace (Athens, Georgia, USA). An 88% food grade lactic acid solution was purchased from the Five Points Bottle Shop (Athens, Georgia, USA).

The dry starch, nutritional yeast, and salt were combined with deionized water in a high shear blender and blended to form a starch slurry. The starch slurry was heated to 75°C and held at this temperature for three min to gelatinize the starch. Next, the heat was reduced and the pecan paste was mixed into the molten starch gel until a homogenous mixture was achieved. Finally, the lactic acid and liquid smoke were thoroughly mixed into the paste and the final mixture was immediately poured into molds. For texture and rheological analysis, the cheese analog was poured into cylindrical silicone molds with a 40 mm diameter. The cheese analog was allowed to set in the molds for at least 48 h before any analyses were performed.

In preliminary trials, two methods of removing excess moisture from the product were tested (data not shown). First, pressure was applied using a Carver Hydraulic Lab Press (Carver, Inc., Wabash, Indiana, USA) to a level of 3 tonnes to mechanically expel moisture. There was no visible separation of an aqueous phase, but rather, the gel structure was compromised with excessive force. Secondly, vacuum drying was tested, but it was found that the product became porous and brittle upon drying. Ultimately, it was determined that high levels of the thin-boiling starch was sufficient for binding the water and achieving a semi-firm cheese texture.

Microscopic Evaluation

To verify that the starch granules had been fully gelatilized, microscope slides containing samples of the starch slurry/gel were prepared before and after cooking and stained with 0.5% Trypan Blue (Thomas Scientific, Swedesboro, New Jersey, USA). Samples of the final product were also prepared for microscopic analysis. The slides were observed under polarized light using a Nikon Eclipse E 600 Polarized Light Microscope (Nikon Instruments, Inc., Melville, New York, USA) to confirm complete cooking of the starch (Flint 1994). In addition, samples of the final product were examined. Small pieces (~5 mm thick) were frozen by Cryostat and thin-sectioned by microtome (CM3050, Leica Biosystems, Ontario). Sections were mounted onto slides and stained with toluidine blue as well as Periodic Acid Schiff-Hematoxylin. The finished product was also prepared in a tissue processor and stained with Oil Red O.

Texture Analysis

Texture profile analysis was performed according to an application study of cheeses provided by Texture Technologies Corporation (Texture Technologies Corporation, 2004). In this modified approach, a cylindrical probe with a diameter smaller than the surface area of the sample was used to compress and penetrate the sample. The test was conducted using a texture analyzer equipped with a 50 kg load cell (TA-XT2i, Stable Microsystems Ltd., Godalming, Surrey, UK) The cheese analog was prepared as a cylinder with a height of approximately 17 mm and a diameter of 40 mm. A TA-11 25 mm cylindrical probe was used to penetrate the sample to 50% of its originally detected height by a 10 g trigger force. This was repeated for a total of two compression cycles at a speed of 2 mm/s. All tests were performed within 5 mof removing samples from a refrigerator, and the temperature of the samples remained in the range of 7-12 °C over the course of the test. Hardness was quantified as the peak force in N at the point of maximum compression. Fracturability was defined as the force in newtons required to fracture the sample, which is denoted by the first major peak on the curve. Cohesiveness describes the sample's resistance to compression during the second compression cycle compared to that to the resistance during the first cycle. This was quantified by dividing the area of work during the second compression by the area of work during the first compression (Texture Technologies Corporation 2004).

Rheological Analysis

A Discovery HR-2 Hybrid rheometer (TA Instruments, New Castle, Delaware, USA) was used to analyze the viscoelastic behavior of the cheese analog samples and other cheese products. Samples of the pecan cheese analog were prepared by using a wire to slice a fixed-width section from the cylindrical molded product to obtain thin discs with a diameter of 40 mm and a height of 1.5 mm. The rheometer was fitted with a 40 mm cross-hatched parallel plate geometry and a Peltier heating plate with a cross hatched base attachment. A thin layer of oil was applied around the border of the sample to prevent loss of moisture during the tests. An oscillation amplitude sweep from 0.01 - 10% strain at a frequency of 1 Hz was initially performed to determine the linear viscoelastic region (LVR) of each sample. Then, an oscillatory frequency sweep from 0.1 - 15 Hz and a temperate ramp from 5 °C to 80°C at 5°C per minute were performed at a stress level within the mid LVR (Gunasekaran & Ak, 2002).

Color Analysis

Instrumental color analysis was performed using a Konica Minolta CR-400 Chroma Meter (Minolta Sensing Americas, Inc., Ramsey, New Jersey, USA). The pecan cheese analog samples were compressed into a solid layer on a clear round dish with a diameter greater than that of the light projection tube. The instrument was programmed to take three continuous readings for each sample. Measurements were recorded on the L* a* b* scale in which L* indicates darkness to lightness (0-100), a* represents red versus green (positive values indicate red while negative values indicate green), and b* represents yellow versus blue (positive values indicate yellow while negative values indicate blue) (Ma et al., 2012).

Sensory Analysis

Consumer acceptability testing was performed according to guidelines from *Sensory Evaluation; A Practical Handbook* (Kemp et al., 2009). The test evaluated two formulations of the "non-dairy pecan cheese analog" and one commercially produced non-dairy cheese analog as a control for a total of three samples. The two formulations to be tested were selected based on their similarity to dairy cheese as evaluated through preliminary informal sensory evaluation. Panelists were recruited from the campus of The University of Georgia and were asked to fill out a demographic questionnaire (Appendix II) before evaluating the samples. Samples were prepared as 28 g cubes in lidded soufflé cups which were marked with randomly assigned codes. Samples were served to the panelists between 2-8°C. The panelists were seated in sensory booths lit with masking lights to diminish the differences in color between the samples. Each panelist received the three samples on a tray along with unsalted crackers and club soda as palate cleansers. The order in which each panelists evaluated the samples was randomized to control for the effects of presentation order. The The samples were evaluated on a 9 point hedonic scale for appearance, flavor/taste, texture, and overall acceptability and on a 5 point scale for purchase likelihood (see ballot, Appendix III). All testing was overseen by the University of Georgia Institutional Review Board.

Calculated Nutritional Content

Proximate analysis was performed only for the raw pecans and for a sample of the final product to confirm accuracy of calculated values. Analysis was performed by the UGA Feed and Environmental Water Laboratory. Moisture was analyzed through oven drying at 105°C for 3 h (AOAC method 930.15) and total ash using a muffle furnace at 600°C for 2 h (AOAC method 942.05). Crude protein was analyzed using the Dumas Method (AOAC method 990.03), and fat was analyzed using an Ankom extractor with the "Rapid Determination of Oil/Fat Utilizing High Temperature Solvent Extraction" method (PVM 1:2003 and AOCS procedure Am 5-04). The nutrient profiles of the final product formulations were calculated using Genesis R&D Food Analysis Labeling Software (ESHA Research, Salem, Oregon, USA).

Statistical Analysis

JMP Pro 14 (SAS Institute Inc., Cary, North Carolina, USA) was used to analyze the data. Analysis of variance was performed along with Tukey's test for significant difference at $p<0.05$. For the texture profile analysis data, means were compared based on $\log_{10}$ transformed hardness, cohesiveness and fracturability measurements to correct for unequal variance between the comparison groups.

Results and Discussion

Microscopic Evaluation

Figure 4.1 shows the structure of the modified potato starch (a) before and (b) after cooking. Initally, the individual granules are clearly intact as evidenced by the presence of "Maltese cross" patterns under polarized light. After cooking, there were no birefringent granules or evidence of non-gelatinized fragments. This validates that sufficient heat and water were present to allow for full gelatinization of the starch during the cooking process (Flint, 1994).

Figure 4.2 (a) shows the microstructure of the pecan cheese analog treated with toluidine blue, which stained starch fragments within the amorphous gel matrix a light purple and the cell walls of the pecan fragments a dark purple (Guardeño et al., 2013; Dourado et al., 2004). This shows a dispersion of the starch gel with interspersed pecan tissue fragments and occasional pores. There were more instances of intact epidermal tissue. This was expected as the tougher, denser cells in this tissue is harder to disrupt. Figure 4.2 (b) shows samples treated with Periodic Acid Schiff stain with Hematoxylin which stains carbohydrates pink/red and stains proteins blue (Dourado et al., 2004; Srichamnong et al., 2013). Pecan fragments can be identified in two forms. The amorphous globules of pink-outlined cells are from the internal layers of the pecan kernel while the linear chains of pink cells are fragments of the epidermal cells of the pecans. Blue protein bodies can be identified in both forms of the intact cells. The starch complex is seen as the dark pink bodies surrounding the pecan fragments. The starch globules do not appear to be uniform in size or shape, but have formed a porous network surrounding the pecan fragments and pockets of air or water. Figure 4.2 (c) shows the sample stained with Oil Red O. Lipid droplets of nonuniform shape and size are dispersed throughout the gel matrix, but also stored within the intact pecan cells as expected (Dourado et al., 2004).

Texture Analysis

Table 4.2 shows the average hardness, fracturability and cohesiveness respectively for each of the 10 formulations of cheese analog along with measurements for other commercially produced cheese products. The formulations using BL130 starch were consistently harder than the formulations using BL320 starch. The formulation that included 9% BL320 starch had the lowest hardness of 3.2 N followed by the formulation that included 12% BL320 starch, which had a value of 7.0 N. The hardness increased with increasing levels of both types of starch, but the differences were not significant amongst samples with 18-21% BL320. The formulation with 21% BL130 starch was harder than all other pecan cheese formulations at a hardness of 57 N.

Fracturability (fracture force) also increased with starch concentration. However, BL320 formulations had higher fracture force than those with BL130. At 9% starch there was no difference in fracture force (4.2-4.4 N) between the BL320 or BL130 samples. At the highest starch level (21%), the BL320 formulation had an average fracturability of 44.3 N while the BL130 formulation had a fracturability value of 22.3 N.

The cohesiveness values tended to be slightly higher for the formulations using BL320 starch rather than BL130 starch, but most values fell between 0.08 and 0.1 with a lack of significant differences. The 9% BL320 formulation had the greatest cohesiveness and there seems to be a weak association between increasing levels of starch inclusion and decreasing cohesiveness.

When comparing TPA results of the commercially prepared cheeses, the Colby Jack cheese and Daiya (non-dairy) Cheddar Style Block were significantly harder than all of the pecan cheese samples. The samples containing BL130 at 12% and BL320 at 21% were the most similar to Velveeta and goat’s milk cheese for hardness. The samples made with the four highest levels of BL320 and the three lowest levels of BL130 were not significantly different from either the Velveeta cheese product or goat's milk cheese in terms of hardness. The textural differences between the Velveeta and goat's milk cheese versus the pecan cheeses was much more evident in the fracturability results. Velveeta (along with Daiya and Colby Jack) did not fracture under 50% strain. The goat's milk cheese did fracture at a force of 13.8 N, which was similar to the fracture force of 18% BL130 and the 12% BL320. The fact that the commercially prepared samples did not fracture within the applied strain indicates that they will also be more cohesive than the pecan cheeses (Gunasekaran & Ak, 2002). Indeed, the Colby Jack cheese and Velveeta cheese product were more cohesive than any of the pecan-based cheeses. The goat's milk cheese was similar in cohesiveness to the 9% BL320 formulation, which had the lowest hardness and fracture force of all the samples. Some of the other pecan cheese formulations had low cohesiveness values similar to the Daiya cheddar-style product. The commercially produced non-dairy cheese and the pecan-based non-dairy cheeses both shared the behaviour of developing sufficient hardness but lacking the cohesiveness of a traditional dairy cheese. This may indicate that the gel network formed by modified starches is not sufficiently cohesive to mimic the true casein network of cheese. The most apparent difference between the pecan cheeses and the commercially produced cheese products was the fact that the pecan cheeses fractured much more easily than the others (excluding the goat's milk cheese). The starch gel network does seem to be capable of developing sufficiently hard cheese texture, but the internal structure is not strong enough to withstand shearing at the applied levels.

TPA procedures for cheese are empirical and conflicting conclusions have been made from data in various studies (Gunasekaran & Ak, 2002). In work by Chen et al. (1979) mozzarella, provolone and muenster cheeses were found to have hardness values between 1 and

2 kg of force, which would be similar to the three highest levels of BL320 starch formulations and the two lowest levels of BL130 starch formulations. The 15, 18 and 21% BL130 formulations were more similar in hardness to gouda and edam cheese in the previous study (Chen et al., 1979).

As hardness appears to be the parameter most predictably affected by the level and type of starch and the cohesiveness of the product is the most remarkably different from that of natural dairy cheeses, it is useful to examine the relationship between hardness and cohesiveness. Hardness is the force necessary to achieve a given amount of deformation, here when subject to a compressive force. As such, it represents a sum of the intermolecular forces that resist rearrangement of the molecular structure as that structure is coming closer together. Cohesiveness, however, measures how well the sample holds together allowing it to recover from that deformation. As such, it indicates how well the internal bonds can limit the sample from being pulled apart in lateral directions (Gunasekaran & Ak, 2002). Fracturability is a related parameter in that materials with high fracturability present with a relatively large hardness but quickly lose cohesiveness as the sample comes apart along fault lines.

In the present study, the Velveeta cheese product and Colby Jack cheese had greater cohesiveness than the rest of the samples. In agreement with the present work, Chen et al. (1979) reported the processed cheese sample (similar to Velveeta) had the lowest hardness but the highest cohesiveness when compared to other cheeses. The same study reported that 10 of 11 selected commercially prepared products had cohesiveness values higher than 0.2 (Chen et al., 1979). Only one of the pecan cheese formulations had a cohesiveness value over 0.2, and it was the product with the lowest hardness. In addition, the pecan cheese analog with the highest cohesiveness had the lowest hardness. The Vermont Creamery Goat's Milk Cheese had a similarly low level of cohesiveness as the sample that contained 9% BL320, but was more similar to the pecan cheese analogs in terms of hardness. The Daiya Cheddar Style Block had very low cohesiveness in a similar range with samples including BL130 9% and BL320 at 15 and 18%. These combined factors affirm that the starch ingredients were useful for achieving the resistance to deformation that is expected of cheese, but failed to form internal bonds strong enough to recover from compression. Thus the constituents of cows' milk are more effective for creating a cohesive internal network than the starch gel. The goat's milk cheese performed more similarly to the pecan cheeses than any of the other commercially prepared products. The fracture force of the goat's milk cheese was not significantly different from the fracture force for the samples that included BL130 at 18% and Bl320 at 12%. Fresh goats' milk cheese has been described as more crumbly while most cows' milk cheeses are identified as more rubbery (Risch, 1992). It is interesting to note that all of the pecan-based samples had a higher fracture force than the hardness, that is the force measured at the first maxium deformation. The Vermont Creamery Goat Cheese sample did have a fracturability point lower than the hardness, but all other dairy cheeses did not fracture under a strain of 50%.

The potato starch gels are a composite amylose gel matrix that is formed when amylose leaches from starch granules during cooking, and may be reinforced by swollen, rigid starch granules (Gunaratne & Corke, 2007; Ring, 1985). Leloup et al. (1992) suggested that the strength of a starch gel is dependent on the extent of crosslinking within the gel network wherein amylose molecules form double helical associations of glucose units. The amylose network is composed of both crystalline (double helical associations of glucosyl units) and amorphous regions. The amorphous regions contribute to a porous structure in the gel network, and there is greater ability to crosslink and contribute firmness after acid hydrolysis. It is postulated that the porous spaces in the gel allow the network to be filled with the other solid constituents (such as nut pieces). Acid thinning of potato starch increases amylose content and extent of amylose leaching during cooking. This increases the amount of linear polysaccharide chains available for crosslinking after heating thus allowing for a stronger, firmer gel (Gunaratne & Corke, 2007). The rigidity of the amylose network is not thermally reversible, but the remaining amylopectin reinforces the network to develop further firmness. The interspersed amylopectin is thermally reversible, so the gel as a whole can soften upon heating to different extents depending on the extensiveness of the amylopectin network (Miles et al., 1985).

Several starches including maize, waxy-maize, wheat, potato and rice starch, have been studied as partial casein replacements in imitation cheese products (Mounsey & O'Riordan, 2001). For each starch tested, the hardness of the product increased and the cohesiveness decreased with starch inclusion compared to the control. Hardness was increased by wheat, potato or maize starch but not by by waxy-maize or rice starch. In addition, the hardness of the processed cheese that included potato starch was found to be 117.3 N and the cohesiveness was 0.201. These values are higher than those obtained for the present starch-set pecan cheeses. It should be noted, however, that the control in that study was also harder than the control in our work.

Rheological Analysis

Figures 4.3 shows the results of oscillatory amplitude sweeps. Table 4.3 Shows the approximate linear viscoelastic region of stress for each sample along with the storage and loss moduli points recorded within the given LVR. This test determines the limits of the region in which the dynamic shear moduli were independent of the amount of stress applied to the material. The G´ values ranged from 142 to 228 kpa for the pecan products. For reference, previous studies have reported the G′ of part-skim mozzarella cheese at 20°C to be 95 kPa to 105 kPa while that of Parmigiano Reggiano was as high as 2280 kPa after 28 months of aging (Gunasekaran & Ak, 2002; Noël et al., 1996).

The published critical strain limits of traditional dairy cheeses generally fall around 1% strain or less (Gunasekaran & Ak, 2002). All of the pecan cheese analogs had critical strain limits close to 1%, but the three highest levels of BL320 samples were able to withstand even higher strains, up to 1.3%, before the dynamic shear moduli became dependent on the level of stress applied. As starch content increased, the range of the LVR increased as well. The limit of the LVR of the BL130 formulations tended to be higher than the LVR of the BL320 formulations. Higher LVR limits of a material are generally associated with greater internal cohesive forces. This is consistent with the finding that formulations containing BL130 were harder at the given starch:water ratio. The results may seem incongruent with the cohesiveness values presented in Table 4.2, in which increasing starch levels decreased cohesiveness. In the dynamic rheometer, however, relatively small strains are introduced and the material may experience yield or plastic deformation without fracturing. In contrast, the instrumental texture analyses occurs over very large strains (up to 50%), presumably far past the elastic limit of the sample. In addition, althoug not directly measured, the TPA cohesiveness can depend upon adhesiveness between the sample and plates and the rate at which the sample springs back after compression.

Formulas that included 9% starch of either type had the lowest G′ in the LVR. As expected, the G′ and G″ increased with increasing amounts of starch. These results are in agreement with previous studies showing that the storage modulus of potato starch gels is directly dependent on the concentration (Krystyjan et al., 2015). The BL130 formulations exhibited higher average moduli than their BL320 counterparts with equal starch levels, which is comparable to the trend observed for TPA hardness. The formulation containing 21% BL130 had significantly higher G′ and G″ than other formulations. Thus at these levels, the BL130 had provided more solid behavior to the cheese analog than the BL320 starch. At the highest level of BL320 (21%), G′ was no different from the storage modulus of samples containing 12% BL130. It is worth noting that one study on Parmigiano Reggiano reported a 1.7 fold increase in G′ from 12 to 28 months of storage (Noël et al., 1996). This increase in G′ was associated with a loss of elasticity and increase in rigidity of the product. While it may be advantageous to use higher levels of starch to achieve a firm texture in the pecan cheese product, the storage modulus should also be considered as an indicator of the balance between elasticity and rigidity.

Leloup et al. (1992) suggested that the strength of a starch gel is dependent on the extent of crosslinking within the gel network wherein amylose molecules form double helical associations of glucose units. The network is thought to be composed of amylose filaments that associate in local B-crystalline arrays as well as amorphous regions. The balance and extent of association of these regions within the gel accounts for some aspects of the dynamic viscoelastic behaviour (Leloup et al., 1992). Networks with more extensive associations provide greater elastic behavior, while water flows more freely in the amorphous regions and contributes to viscous dissipation of energy. The storage modulus of each sample was greater than the loss modulus for all samples, therefore, these can be classified as viscoelastic solids at 20°C, which is expected for imitation cheese products (Gunasekaran & Ak 2002).

When compared to commercial cheese products, the G′ of most of the pecan cheese samples fell within the same range as the commercially produced samples. The storage modulus of the 21% BL130 formulation (2281 kPa) was not significantly different from that of the Daiya cheddar style block (2248 kPa). Likewise, the G′ of the 9% BL130 (416 kPa) samples was similar to that of goat milk cheese (438 kPa), and the G′ of the 9% BL320 (143 kPa) was close to that of Velveeta (174 kPa). The storage modulus of the Colby Jack (1062 kPa) was closest to that of the 18% BL130 (1451 kPa), but they were significantly different. For all formulations and other cheese products, increasing TPA hardness values followed the same trend with increasing storage modulus values.

Figure 4.4 shows the G′ for each cheese product across a temperature range of 5-80°C. The decrease in storage moduli indicates a loss of elastic properties and softening of the material (Lu et al., 2007). While the pecan cheese analogs did soften with temperature, the particular temeprature ranges and extent of decrease in the moduli differed for products made from the two starches. The pecan cheese analogs maintained a fairly constant G′ for temperatures up to 40-45°C. At higher temepratures the G′ rapidly declined, indicating a loss of elastic properties as more of the energy dissipates as heat. For the BL130 formulations, the slope of the tan(δ) was 0.022 at the 9% level and increased slightly with starch level to a maximum of 0.031 at the 21% BL130. For the BL320 formulations, the slope of tan(δ) was 0.062 at the 9% level and increased to a maximum of 0.072 at the 21% level. Thus, past 50°C, the BL320 formulations were softening more rapidly than the BL130 formulations.

Analysis of temperature scans has been an important tool in polymer science to understand the degree of networking in materials (Ross-Murphy, 1995). Thus some samples, such as hard candies, undergo a large decrease in G′ upon heating as their solid glassy state results from the inability of small molecules to move past each other a relatively low temperatures. In contrast, samples such as egg white polyacrylamide gels experience only minor decreases in G′ as extensive physical or covalent associations persist even at higher temperatures. Thus, from Figure 4.4 it is apparent that the true cheese products experience a 2-3 order of magnitude decrease in G′. Casein gels are particle gels consisting of a transient network of short range reversible interactions that can more easily be disrupted by shear or Brownian motion (related to *k*T), along with some more permanent crosslinks. Thus the structure is more readily disassociated at high temperature. In contrast the starch gel, particularly the acid-thinned starches used here, form gels thorugh association of chains at junction zones that may be considered as crystalline regions held together by hydrogen bonding. Thus, these gels are more resistant to temperature, and some associations may remain intact even at 80°C. It is also apparent that the analogs prepared with BL320 underwent a greater decrease in G′ than those made with BL130. A likely explanation is that BL130-based analogs had greater firmness due to more extensively crosslinking, that persisted to a greater degree at higher temerpatures.

The dairy cheese products (Colby Jack, Velveeta, and Vermont Creamery goat's milk cheese) all began soften within the 5-10°C range and G′ continued to steadily decline. In previous studies, natural and imitation cheeses have been reported to begin softening between 30-40°C while studies of other pasteurized processed cheese products have been shown that softening begins around 15°C (Lu et al., 2007; Nolan et al., 1989). In the present trials, the true dairy cheese products had a much lower G′ at 80°C than the non-dairy cheeses (pecan analogs and Daiya cheddar style). This is indicative of the properties of the starch from which they gain their structure. Miles et al. (1985) concluded that the gel network that forms shortly after the cooking comes from the development of semi-crystalline regions of new associated amylose chains, and that the rigidity imparted is irreversible. However, as the starch gel sets over time, the network gains more solid-like properties as it is reinforced by the reversible crystallization of amylopectin (Miles et al., 1985). In the case of the starch set cheese products, this would imply that the thermal reversibility of the gel that we observed as a softening of the matrix and decline in G′ is due to the disassociation of the network of amylopectin. This would also indicate that the amylopectin network in the analogs remains intact until ~45°C.

Additionally, the non-dairy Daiya Cheddar Style Block (which is also starch-set) began to soften around 15°C, remained stable from 35-45°C, then continued to soften past 45°C in the same manner as the pecan-based cheeses. This two-phase melting is indicative of a composite network of starch and another hydrocolloid, in that case xanthan. Such ingredient combinations have been shown to provide an increase in gel strength, and may help limit retrogradation (BeMiller, 2011). In order to build a firmer initial product and allow the product to begin softening at lower temperatures similar to dairy cheese, a starch-hydrocolloid combination may be an avenue for the improvement of nut-based cheeses.

Color Analysis

Table 4.4 shows the results of instrumental color analysis of each product. The L* values ranged from 54.98 to 56.64 with weak association between increased starch and decreased lightness. The a* values ranged from 6.35 to 7.20 with no particular trend. The b* values ranged from 13.48 to 14.60 with no particular trend. Overall, values were typical of a light brown product. The L* and a* values were similar to those found in previous work which evaluated ground, unroasted pecans (Maciel et al., 2020). The b* values, however, were lower indicating that the hydration and other ingredients may have skewed the color away a more saturated yellow chroma and more towards the neutral center of the color space. The starch to pecan paste ratio does not appear to have a strong effect on the color of the product. The L* values were in the mid range of light to dark in the color space. Thus, it would be difficult to apply colorants that successfully mask the brown color or be able to produce a lighter more orange-yellow color typical of dairy cheese.

Calculated Nutritional Composition

Table 4.5 shows the calculated nutritional content for a 28 g serving of each of the pecan cheese formulations along with USDA data for a 1 ounce serving of “American Cheese”. The products are all roughly similar in energy and total fat content. As the starch content increases, the caloric values decrease as a result of fat content (from the pecans) being replaced with carbohydrates from the starch. The pecan cheese formulations have a maximum of 0.5 g of saturated fat per serving as opposed to almost 4 g of saturated fat in the American Cheese. The pecan cheese formulations contain mostly monounsaturated and some polyunsaturated fatty acids. Additionally, the pecan-based samples contain no cholesterol while the American cheese would contain about 22 mg per serving. These properties make the product more attractive over dairy cheese for customers who are concerned about saturated fat and cholesterol consumption for health reasons (Micha &Mozaffarian, 2010). The pecan cheese also shows nutritional advantages in containing less sodium and more dietary fiber than the dairy cheese example, but it falls short in terms of protein and micronutrients in comparison to dairy cheese. The dairy cheese example contains more vitamin D, calcium and potassium than the pecan cheese formulations. The pecan cheeses also contain more carbohydrates than the dairy cheese, which may make it less desirable to certain demographics of consumers depending on their nutritional goals.

Sensory Analysis

Table 4.6 shows the demographic data for the 100 participants of the consumer panel. Table 4.7 shows the acceptability of appearance, flavor, texture, and overall acceptability on a 9-point hedonic scale, while purchase likelihood is shown on a 5-point scale. The commercially produced dairy-free cheese consistently scored higher than the pecan cheese samples with each acceptability attribute receiving an average score between 6 and 7 where 6 represents “like slightly” and 7 represents “like moderately”. For appearance, flavor, and overall acceptability, the pecan cheese samples average scores fell between the “dislike slightly” and “neither like nor dislike” markers with no difference between the two formulations. However, the 21% BL130 sample did score higher than the 15% BL320 sample for texture and purchase likelihood. Still, all of the samples, including the control did not receive purchase likelihood scores higher than the “may or may not buy” marker.

Acceptability of flavor and texture were significant predictors of overall acceptability ($p<0.001$) while appearance was not a strong predictor. The acceptability of flavor scores had a bimodal distribution at 4 and 7 for the pecan cheese samples indicating that the flavor of the cheese is acceptable to a large number of people, but also unacceptable to a second population of consumers. Just as previous studies showed that some people prefer soft cheese to hard cheese and vice versa, differences in consumer expectation and preference is likely to have skewed the acceptability of this product (Foegeding et al., 2003).

The demographic data showed some correlation between consumption habits and acceptability. Respondents who reported sometimes following a vegan/dairy-free diet scored the texture of Daiya 7.4±1.1 which was higher than those who do or do not follow a vegan/dairy-free diet. Respondents who reported following a vegan/dairy-free diet gave the 15% BL320 sample an average score of 6±1 for the texture acceptability, which was higher than the non or sometimes vegan/dairy-free respondents. Respondents who reported following a veg/df diet always or sometimes gave the 21% BL130 sample an average score of 5.6±1.8 for the flavor acceptability, which was higher than the non veg/df respondents. They also reported higher purchase likelihood for 21% BL130 than the non vegan/dairy-free respondents.

Conclusion

Pecan-based cheese analogs were formed with the inclusion of acid-thinned potato starch. At the levels used (9-21%) the starches were able to provide a gel structure with a firmness reminicent of cheese spread or soft cheese. However, the pecan analogs were slightly less cohesive than dairy cheese. At small levles of deformation, the pecan-based cheese analogs appeared to have viscoelastic behavior very similar to dairy cheeses, but analyses at greater deformation reveled that the internal network of the pecan-based product was considerably weaker than that of normal dairy cheeses. Future studies may determine if firmenss can be further increased by the addition of more starch, or using combinations of starch and hydrocolloids. Although not identical to dairy cheese, the pecan cheese analogs could be caused to “melt” at temperatures above 50°C. Microscopy and rheological analyses indicated that the pecan anlogues gained their structure and texture from small pecan pieces immeshed in a starch gel, in which the oil resides both inside and outsied of cells. The gels gain their firmness from crosslinked zones and these seem to be more extensive in the BL130 versus the BL320 systems. Due to the nature of pecans, the color was browner than most conventional cheeses, but there were no attempts to mask this in this study. In terms of nutrition, the cheese anlogues contain more fiber and polyunsatruated fatty acids than dairy cheese, but have lower levels of calcium and vitamin D. The pecan analogs were liked less than a commercial product with respect to texture, flavor, appearance and overall assessment. Part of this may be due to the difficulty of exactly matching consumer expectations for dairy cheese, and in general scores were higher amongst consumers who follow vegan or dairy-free diets. There is reason to believe that a firmer texture could be attained by including greater strarch levels or combinations with other polysaccharides. In addition, there is reason to believe the flavor could be improved by a more extensive investigation of the many flavor ingredients available, or use of advanced fermentation.

Tables

Table 4.1: Pecan cheese analog formulations

Starch (%)[a]	Water (%)	Pecan Paste (%)	Nutritional Yeast (%)	Iodized Salt (%)	Lactic Acid Solution (%)	Smoke Flavor (%)
9	23.7	61.9	1.58	1.05	0.79	0.16
12	23.7	58.9	1.58	1.05	0.79	0.16
15	23.7	55.9	1.58	1.05	0.79	0.16
18	23.7	52.9	1.58	1.05	0.79	0.16
21	23.7	49.9	1.58	1.05	0.79	0.16

[a] Starches included either BL120 or BL320 potato starch (KMC Ingredients, Denmark)

Table 4.2: Texture profile analyses of pecan cheese analogs and other cheese products

Starch/Cheese Type	Starch Level	Hardness (N)[1,2]	Fracturability (N)[1,2]	Cohesiveness[1,2]
BL320	9%	3.2 ± 0.1^{k}	4.4 ± 0.1^{g}	0.22 ± 0.050^{b}
BL320	12%	7.0 ± 0.4^{j}	13.6 ± 0.4^{d}	0.13 ± 0.007^{c}
BL320	15%	9.6 ± 0.5^{i}	21.9 ± 0.4^{c}	$0.12 \pm 0.011^{c,d}$
BL320	18%	12.9 ± 0.5^{h}	34.6 ± 0.3^{b}	$0.10 \pm 0.008^{c,d,e,f}$
BL320	21%	$14.8 \pm 1.6^{g,h}$	44.3 ± 0.8^{a}	$0.09 \pm 0.015^{e,f,}$
BL130	9%	$8.3 \pm 0.1^{i,j}$	4.2 ± 0.1^{g}	$0.12 \pm 0.005^{c,d,e}$
BL130	12%	18.4 ± 1.4^{f}	6.2 ± 0.3^{f}	0.08 ± 0.012^{f}
BL130	15%	26.5 ± 0.2^{e}	8.6 ± 0.0^{e}	0.07 ± 0.003^{f}
BL130	18%	34.5 ± 0.5^{d}	15.8 ± 1.9^{d}	$0.09 \pm 0.016^{d,e,f}$
BL130	21%	57.0 ± 0.4^{c}	22.3 ± 3.1^{c}	0.08 ± 0.006^{f}
Colby Jack		102.0 ± 3.2^{b}	N/A	0.664 ± 0.006^{a}
Daiya		129.6 ± 16.1^{a}	N/A	0.138 ± 0.006^{c}
Velveeta		$16.6 \pm 1.2^{f,g}$	N/A	0.547 ± 0.016^{a}
Goat's Milk		13.8 ± 0.1^{h}	13.8 ± 0.5^{d}	0.20 ± 0.021^{b}

[1] Means ± SD followed by the same letter in a column do not significantly differ ($p<0.05$). Means were compared based on $\log_{10}$ transformations of the data shown to correct for unequal variance between formulations.

[2] Measurements were performed on three replicates of each sample ($n=3$)

Table 4.3 Average storage (G′) and loss (G″) moduli of pecan cheese analogs and other cheese products in the linear viscoelastic region

Starch/Cheese Type	Starch Level	Stress limit (kPa)	Average G′[1] (kPa)	Average G″[1] (kPa)
BL320[2]	9%	0.6	143 ± 6.8^{j}	25 ± 0.4^{k}
BL320[3]	12%	1.5	256 ± 12^{i}	$37 \pm 1.0^{j,k}$
BL320[4]	15%	4.0	348 ± 16^{h}	$40 \pm 1.5^{i,j}$
BL320[4]	18%	7.7	680 ± 29^{f}	67 ± 4.2^{h}
BL320[4]	21%	10.0	860 ± 35^{e}	81 ± 6.8^{g}
BL130[5]	9%	3.0	416 ± 22^{g}	66 ± 1.3^{h}
BL130[5]	12%	7.0	849 ± 41^{e}	107 ± 3.8^{f}
BL130[6]	15%	7.0	1226 ± 43^{c}	146 ± 5.2^{e}
BL130[7]	18%	20.0	1459 ± 140^{b}	170 ± 13^{d}
BL130[3]	21%	12.8	2281 ± 126^{a}	253 ± 35^{b}
Colby Jack[2]		6.0	1062 ± 37^{d}	318 ± 3.3^{a}
Daiya Cheddar[8]		8.0	2248 ± 31^{a}	183 ± 9.4^{c}
Velveeta[5]		3.0	174 ± 2.8^{j}	50 ± 0.2^{i}
Goat[9]		1.5	438 ± 2.1^{g}	111 ± 1.6^{f}

[1] Means ± SD followed by the same letter in a column do not significantly differ ($p<0.05$).
[2] Means are based on 17 data points from within the LVR of the curve (n=17).
[3] Means are based on 19 data points from within the LVR of the curve (n=19).
[4] Means are based on 22 data points from within the LVR of the curve (n=22).
[5] Means are based on 20 data points from within the LVR of the curve (n=20).
[6] Means are based on 18 data points from within the LVR of the curve (n=18).
[7] Means are based on 24 data points from within the LVR of the curve (n=24).
[8] Means are based on 15 data points from within the LVR of the curve (n=15).
[9] Means are based on 16 data points from within the LVR of the curve (n=16).

Table 4.4 CIEL*a*b* color values for pecan cheese analogs

Starch Type	Starch Level	L*	a*	b*
BL320	9%	$56.14 \pm 0.05^{a,b}$	7.17 ± 0.05^{a}	14.60 ± 0.16^{a}
BL320	12%	$56.17 \pm 0.24^{a,b}$	$6.73 \pm 0.06^{c,d}$	13.49 ± 0.17^{c}
BL320	15%	56.64 ± 0.22^{a}	$6.61 \pm 0.18^{c,d,e}$	$13.75 \pm 0.40^{b,c}$
BL320	18%	$55.56 \pm 0.15^{b,c}$	7.20 ± 0.06^{a}	14.59 ± 0.14^{a}
BL320	21%	$55.49 \pm 0.66^{b,c}$	$6.80 \pm 0.08^{b,c}$	$14.36 \pm 0.41^{a,b}$
BL130	9%	$56.28 \pm 0.05^{a,b}$	$7.03 \pm 0.01^{a,b}$	$14.34 \pm 0.06^{a,b}$
BL130	12%	$55.97 \pm 0.16^{a,b,c}$	$6.51 \pm 0.05^{d,e,f}$	$13.90 \pm 0.24^{b,c}$
BL130	15%	54.98 ± 0.50^{c}	$6.39 \pm 0.02^{e,f}$	$14.11 \pm 0.13^{a,b,c}$
BL130	18%	$55.81 \pm 0.57^{a,b,c}$	6.35 ± 0.10^{f}	$14.21 \pm 0.15^{a,b}$
BL130	21%	$55.46 \pm 0.23^{b,c}$	$6.42 \pm 0.05^{e,f}$	$14.17 \pm 0.15^{a,b}$

[1] Means ± SD followed by the same letter in a column do not significantly differ ($p<0.05$).

[2] Measurements were performed in triplicate on three replicates of each sample ($n=9$).

Table 4.5: Nutritional composition of pecan cheese analog formulations per 28 g serving

	9% Starch	12% Starch	15% Starch	18% Starch	21% Starch	American Cheese
Calories	92	87	82	80	77	89
Total Fat (g)	8	7	6	6	5	6.6
Saturated Fat (g)	0.5	0.5	0.5	0.5	0	3.8
Polyunsaturated Fat (g)	2.5	2	2	2	1.5	1.8
Monounsaturated Fat (g)	4.5	4	3.5	3.5	3	0.3
Cholesterol (mg)	0	0	0	0	0	22
Sodium (mg)	140	140	140	140	140	371
Total Carbohydrate (g)	4	5	6	6	7	2.5
Dietary Fiber (g)	1	1	1	1	1	0
Total Sugar (g)	0	0	0	0	0	2
Protein (g)	1	1	1	1	1	4.9
Vitamin D (μ g)	0	0	0	0	0	1.84
Calcium (mg)	8	8	7	7	7	386
Potassium (mg)	53	49	46	43	40	80.2

[1] Values are calculated based on USDA and supplier-provided data

Table 4.6: Consumer sensory panel demographic data

Gender		
	Male	52
	Female	48
Age Group		
	18-24	74
	25-34	10
	35-44	6
	45-54	5
	55 or older	5
Frequency of consuming dairy-free cheese	Never	79
	1-3 times per month	14
	1-3 times per week	2
	Daily	5
Frequency of consuming pecans or pecan products	Never	17
	1-3 times per month	65
	1-3 times per week	16
	Daily	2
Follow a vegan and/or dairy-free diet?	Yes	4
	No	81
	Sometimes	45

Table 4.7: Sensory acceptability of two pecan cheeses and one commercially produced vegan cheese

	Daiya Cheddar[1,2]	BL320, 15%[1,2]	BL130, 21%[1,2]
Appearance[3]	6.9 ± 1.1 [a]	4 ± 1.6 [b]	4.5 ± 1.9[b]
Flavor[3]	6.3 ± 1.7 [a]	4.4 ± 1.9 [b]	4.7 ± 2.1[b]
Texture[3]	6.8 ± 1.5 [a]	4.3 ± 2 [c]	5.3 ± 2.0[b]
Overall[3]	6.4 ± 1.6 [a]	4.3 ± 1.8 [b]	4.8 ± 2.0[b]
Purchase likelihood[4]	3.1 ± 1.1 [a]	2.0 ± 0.9 [c]	2.3 ± 1.1[b]

[1] Means ± SD followed by the same letter in a column do not significantly differ ($p<0.05$).
[2] Samples were evaluated by 100 panelists ($n=100$).
[3] Based on a 9-point scale.
[4] Based on a 5-point scale

Figures

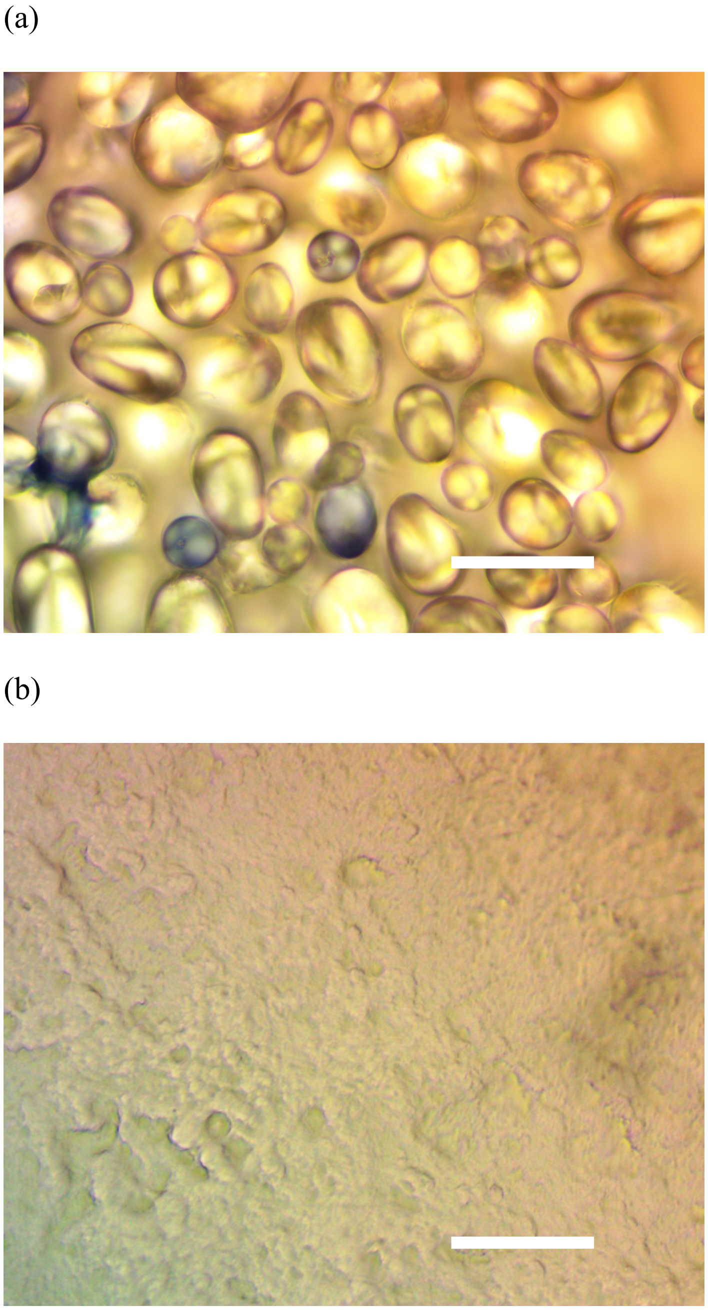

Figure 4.1: Micrograph (10x, polarized light) of 10% modified potato starch (BL130) (a) prior to cooking and (b) after heating to 80°C. Bar: 50 µm.

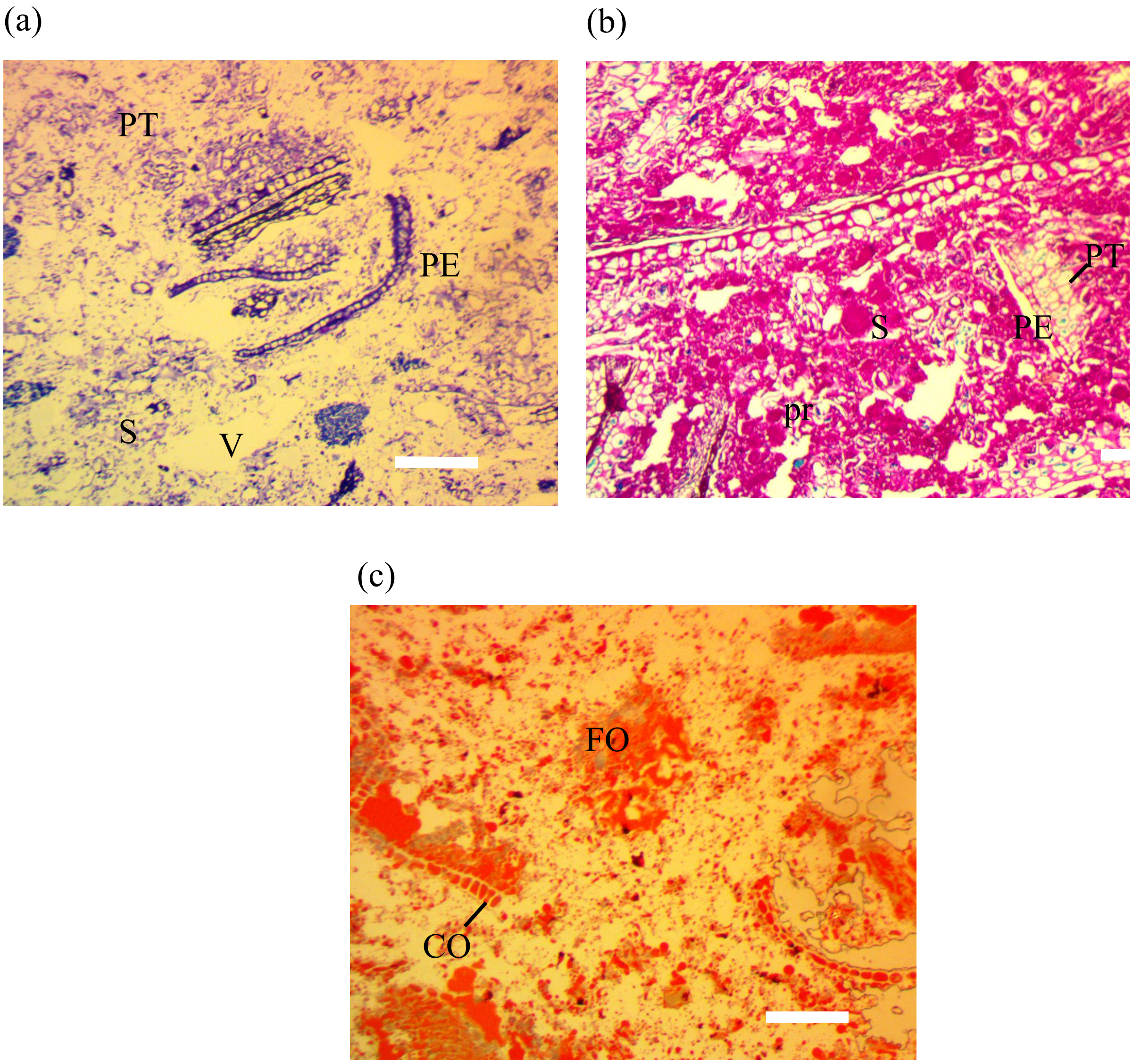

Figure 4.2: Micrographs (10x) of pecan cheese cheese analogs stained with (a) Toluidine blue, (b) Periodic Acid-Shiff with hematoxylin and (c) Oil Red O. S- starch gel, PE- pecan epidermal tissue, PT- pecan endosperm, V- pores, FO- free oil, CO- cell oil, Pr- protein bodies. Bar: 50 µm.

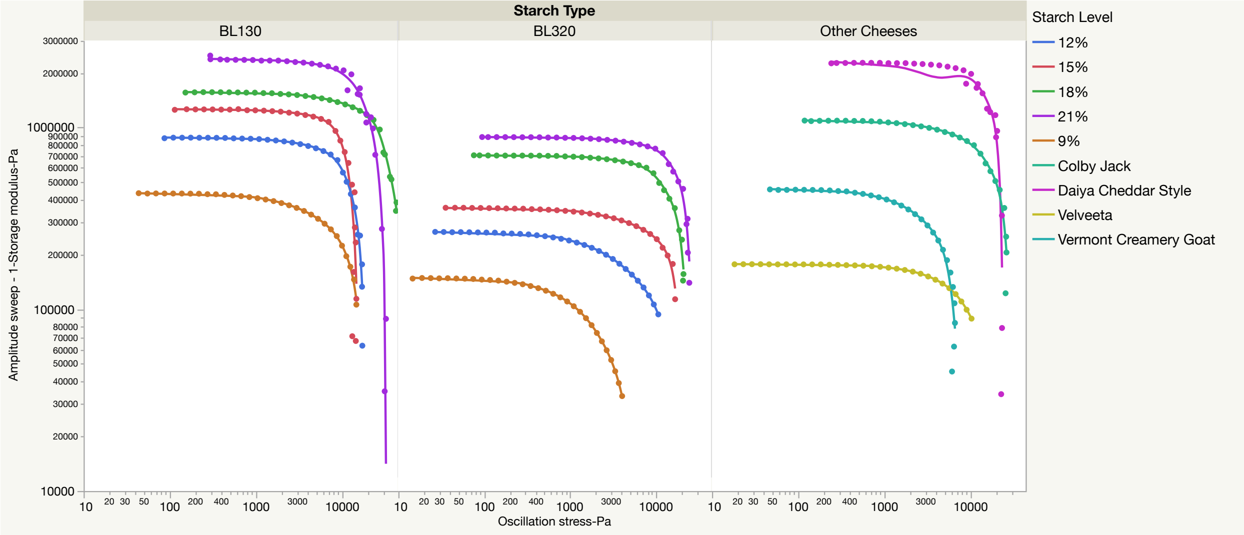

Figure 4.3: Storage moduli as a function of oscillatory stress at 1 Hz, showing the linear viscoleastic region (LVR) for pecan cheese analogs and cheese products

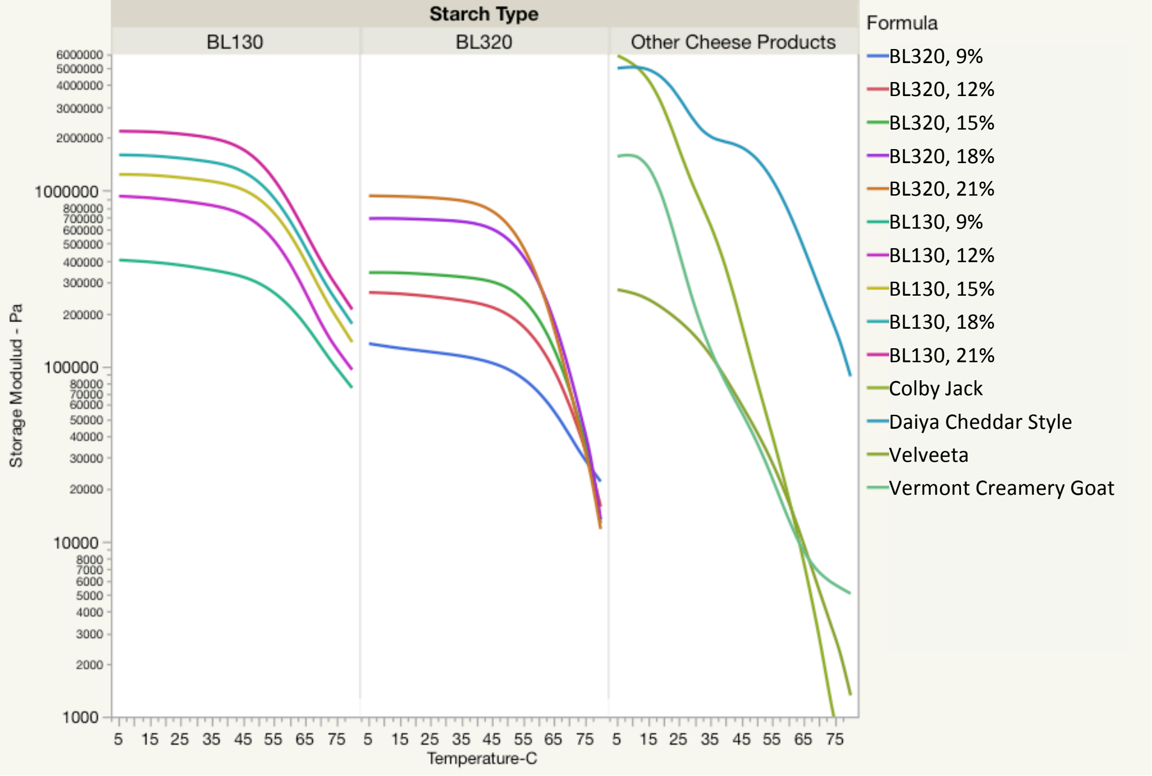

Figure 4.4: Storage moduli during temperature scans from 5°C to 80°C for pecan cheese analogs and cheese products.

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CHAPTER 5

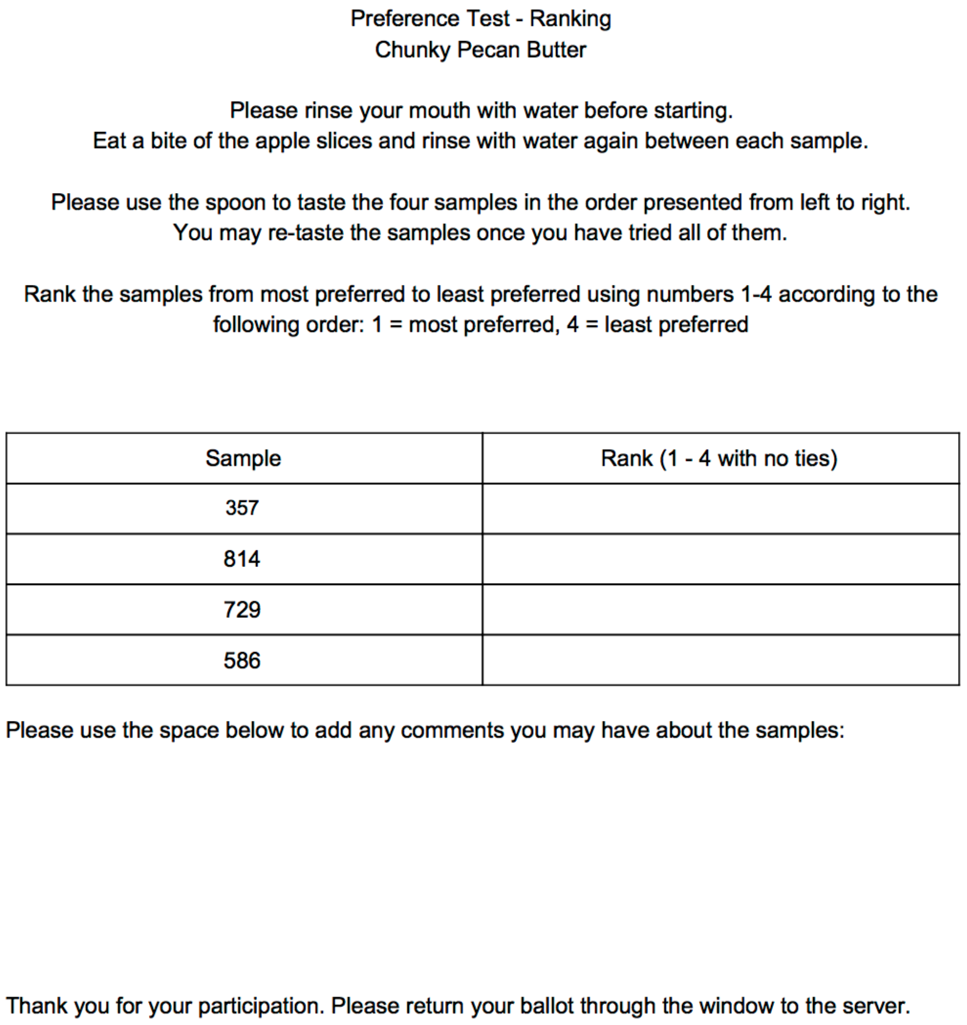
CONCLUSIONS

The first focus of this study was to test the effectiveness of two varieties of dehydrated plant materials for stabilizing the consistency of pecan butter. While both were effective, apple flour was a more effective agent for stabilizing the consistency of pecan butter when compared to sweet potato flour. When either apple flour or sweet potato flour was added to the pecan butter product, the degree to which the oil separated from the solid phase of the pecan butter during storage did decrease, but the effect was stronger with the apple flour. The mechanical values of firmness and work of shear increased with increasing levels of either type of flour. Vascular microstructure was observed in the apple flour, which could contribute to its greater effect on oil stabilization. Either flour could be used to improve the texture of pecan butter up to 10% by weight without influencing the consumer preference for the product In future studies, it would be useful to evaluate the antioxidant activity over time and test for multi attribute consumer acceptability of these pecan butter formulations.

Secondly, this study aimed to test the feasibility of a non-dairy pecan-based cheese analog that used acid thinned potato starch to develop a gel network capable of mimicking cheese. The combination of hydrated pecan paste and potato starch did form a firm gel capable of mimicking some aspects of the texture and rheological behavior of dairy cheese. Firmness values similar to American processed cheese or a fresh goat's milk cheese were achieved in some formulations, but the pecan based cheese analogs did not develop the extent of internal crosslinking necessary to achieve high levels of cohesiveness. Rheological analysis showed that the pecan cheese analogs had similar viscoelastic behavior to some dairy cheeses at low stress levels, and they softened well upon heating above 50°C. In further research it would be useful to increase the starch to moisture ratio even more to achieve a stronger gel network. Additionally, specially formulated non-dairy cheese flavors could be helpful in meeting consumers' expectations for the product.

APPENDICES

Appendix I: Consumer Ranked Preference Ballot



Preference Test - Ranking
Chunky Pecan Butter

Please rinse your mouth with water before starting.
Eat a bite of the apple slices and rinse with water again between each sample.

Please use the spoon to taste the four samples in the order presented from left to right.
You may re-taste the samples once you have tried all of them.

Rank the samples from most preferred to least preferred using numbers 1-4 according to the following order: 1 = most preferred, 4 = least preferred

Sample	Rank (1 - 4 with no ties)
357	
814	
729	
586	

Please use the space below to add any comments you may have about the samples:

Thank you for your participation. Please return your ballot through the window to the server.

Appendix II: Consumer Demographic Questionnaire

Demographic Questionnaire

Date:____________

Ballot Number:________________

Please provide the following information about yourself. All answers will remain confidential.

1. Age group
   - ☐ 18-24 years
   - ☐ 25-34 years
   - ☐ 35-44 years
   - ☐ 45-54 years
   - ☐ 55 years or older

2. Gender
   - ☐ Male
   - ☐ Female

3. How often do you consume dairy-free cheese alternatives?
   - ☐ Never
   - ☐ 1-3 times per month
   - ☐ 1-3 times per week
   - ☐ Almost daily

4. How often do you consume pecans and pecan products?
   - ☐ Never
   - ☐ 1-3 times per month
   - ☐ 1-3 times per week
   - ☐ Almost daily

5. Do you follow a dairy-free and/or vegan diet?
   - ☐ Yes
   - ☐ No
   - ☐ Sometimes

Appendix III: Consumer Acceptability Ballot

Sample ____________ **Ballot Number** ______________

Pecan Product Acceptability

Please cleanse your palate with crackers and rinse your mouth with water before starting. You can rinse at any time during the test if you need to. Thank you!

Please <u>look</u> at this sample, and then answer the following questions:

1. Mark the box that best describes your liking of the appearance for this sample.

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

Please <u>taste</u> this sample and answer the following questions:

2. Mark the box that best describes your liking of the overall flavor and taste for this sample.

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

3. Mark the box that best describes your liking of the texture for this sample.

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

5. Mark the box that best describes your OVERALL liking for this sample.

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

6. Mark the box that best describes your likelihood to purchase this product.

☐	☐	☐	☐	☐
Definitely would not buy	Probably would not buy	May or may not buy	Probably would buy	Definitely would buy