INCREASING THE UNDERSTANDING OF WHOLE GRAIN USE AND CONSUMPTION, AND IMPROVING WHOLE WHEAT TORTILLA QUALITY

A Dissertation
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

TING LIU

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Dr. Len Marquart

August 2016

© Ting Liu 2016

Acknowledgements

First of all, I would like to sincerely thank Dr. Len Marquart for accepting me into his group as a Ph.D. student. His immense guidance, assistance, support and editing skills have made my Ph.D. journey fulfilling. Dr. Marquart is a very wise professor. He always has great ideas, and is willing to share with me his ideas, knowledge and connections. With his introduction and encouragement, I attended a variety of conferences to gain knowledge and make connections with professional colleagues. I very much appreciate the time we have spent together chatting, which has helped me prepare for new challenges, by improving my English, socio-cultural / relationship and leadership skills.

Second, I want to express my thanks and gratitude to Dr. Gary Hou for providing opportunities and support while I conducted my projects at the Wheat Marketing Center (WMC). I learned and developed my scientific and technical skills through his immense expertise and rich experience in wheat based products. Thanks him for his immense instructions on designing and conducting experiments, analyzing data and writing manuscripts. Without his guidance, I couldn't have finished my projects.

Third, my experience at the WMC was a very precious time for me. I will remember this experience as a fun, productive and rewarding time. I would like to thank the WMC board members, Ms. Janice Cooper, Dr. Gary Hou and Mr. David Shelton for supporting my research. Also many thanks to the staff and visiting scholars at the WMC (Caryn Ong, Kathleen Gehring, Bon Lee, Stuart Conser, Laura Johnson, Jenny Wang, Marie Cardin, Suwei Liu, Naifu Wang, and Wenyin Zheng) for their kind, and helpful suggestions for my research, along with their warm and memorable friendships. And

thanks to Dr. Sharon Book from ICL Food Specialties for sponsoring one of my projects and giving me helpful advice.

Fourth, I would like to thank all my committee members, Dr. Gary Hou, Dr. Joanne Slavin, Dr. Craig Hassel, and Dr. Satya Jonnalagadda. I deeply appreciate their patience, flexibility, encouragement and helpful suggestions throughout this process.

Last but not least, I would like to thank my family and friends for their continuous support and encouragement during my journey at the University of Minnesota. Because of them, my Ph.D. journey became more colorful.

Dedication

This dissertation is dedicated to my father and mother.

Abstract

Although the 2015 U.S. Dietary Guidelines recommend a higher intake of whole grain foods, considerable challenges limit the frequency of use and overall consumption. The objectives of this study were to increase whole grain consumption by gaining a better understanding of whole grain challenges in restaurant settings, along with improving whole-wheat flour (WWF) end-product (tortilla) quality.

Project I: Current use of whole grains and factors that influence future whole grain use in restaurants were examined with 30 Chinese restaurants via face-to-face or phone interviews. Moreover, the acceptability of brown and white rice was compared in a restaurant setting. The main motivator for serving brown rice was to attract health conscious consumers, while low customer request was the major constraint for non-use. Authentic/family-owned restaurants were less likely to serve brown rice than chain restaurants. Brown rice (85%) consumption was significantly higher than white rice (79%) (P=0.02), based on an average serving size of 8.7 oz. These results suggest that future efforts might focus on increasing the availability of brown rice in restaurants, so it becomes an easily accessible and desirable food choice for brown rice eaters.

Incorporating WWF into tortillas is a practical approach to introduce more whole grains into the American diet and potentially increase whole grain consumption. The quality of WWF tortillas was improved by selecting an optimal range of particle size for WWF, choosing an optimal chemical leavening system and processing conditions, and incorporating sprouted WWF.

Project II: As WWFs particle size decreased from 174-176 to 102-106 μm, the CIE L* values decreased but damaged starch, a* and b* values increased. Finer WWF exhibited higher PPO activity than coarser WWF. The Mixolab results showed that development time decreased as the particle size of WWFs reduced, while stability time, starch retrogradation increased. As to the WWF tortilla properties, the rupture distance (extensibility) and breaking force increased with the decrease of particle size from ~175 to ~130 μm; however, the flour particle size did not significantly affect diameter and thickness. The results indicated that reducing the median particle sizes of WWFs from ~175 μm to ~130 μm would significantly improve the WWF tortilla quality.

Project III: Sodium aluminum phosphate (SALP) produced more opaque tortillas than sodium acid pyrophosphate-28 (SAPP-28), followed by sodium aluminum sulfate (SAS). Opacity was improved with increased amount of leavenings (acid and base) while dough temperature and hot press temperature did not significantly affect opacity. In addition, higher hot press temperature produced lighter, thinner but bigger diameter tortillas. Higher amounts of leavenings produced smaller, thicker and brighter color tortillas. SALP produced the largest diameter and lightest weight tortillas. Tortillas made with SAS had the highest breaking force, while tortillas with SALP had the lowest breaking force as determined by TA-XTPlus Texture Analyzer. A leavening system including 2% sodium bicarbonate (and equivalent SALP acid), 177°C hot-press temperature, and 25°C dough temperature would be most suited to produce more opaque WWF tortillas.

Project IV: Sprouted WWF were incorporated into WWF tortillas to examine the effects of sprouted WWF concentrations (0%, 25%, 50%, 75% and 100%) on tortilla properties. Mixolab data showed that water absorption, dough development and stability times decreased with an increase in sprouted WWF content. In terms of tortilla baking performance, tortillas made with higher amounts of sprouted WWF were larger in diameter and specific volume, brighter, and more opaque, and received higher sensory scores in color, flavor, and overall acceptability. For texture parameters, tortillas made with a higher percent of sprouted WWF required less force to break, which indicated that tortillas were less firm. However, tortillas made with higher amounts of sprouted WWF were more shelf-stable after 16 days of storage. The results demonstrated that sprouted WWF would bring benefits to WWF tortilla’s baking performance, i.e. better appearance, higher consumer acceptability, and longer shelf life.

Table of Contents

List of Tables

List of Figures

CHAPTER 1

INTRODUCTION

Observational studies and animal data suggest that whole grains may reduce risk of chronic disease, which may be attributed to the dietary fiber, phytochemicals, vitamins, minerals and fatty acids naturally occurring in grains (Marquart et al., 2007; Vijver et al., 2009; Chanson-Rolle et al., 2015; Mourouti et al., 2015; Aune et al., 2016). The 2015 Dietary Guidelines for Americans recommend that U.S. citizens should consume at least 50% of total grains as whole grains (USDHHS & USDA, 2015). However, National Health and Nutrition Examination Survey (NHANES) data showed nearly 90-95% of the US population does not meet dietary guidance (Reicks et al., 2014). This warrants a concerted public health effort to increase whole grain consumption among U.S. citizens.

Barriers to whole grain consumption include the texture, flavor and appearance, limited knowledge of whole grain foods by consumers, longer preparation time, higher cost and lower availability in foodservice settings, etc. (Adams & Engstrom, 2000; Jetter et al., 2006; Lendway et al., 2014; Schaffer-Lequart et al., 2015). As restaurants play an important role in shaping the way Americans eat, a greater understanding of the challenges and opportunities for whole grain use in restaurant may allow us to identify and design effective steps to increase whole grain consumption among U.S. citizens. In addition, higher quality whole grain products should be developed to meet consumer needs.

Wheat flour tortilla is a thin Mexican flatbread made from wheat flour, with excellent versatility for use in many dishes. The tortilla industry is the fastest growing sector in the U.S. bakery industry. According to the Tortilla Industry Association (TIA), Americans consumed approximately 85 billion tortillas (not including tortilla chips) in

2000 (TIA, 2016). What's more, the sale of tortillas in the U.S. exceeded $11 billion in 2012, representing a growth of 57% over the past six years (Ontiveros-Martínez et al., 2011; Dann, 2014). As whole-wheat bread becomes more acceptable by consumers, other whole-wheat products such as tortillas require additional efforts to maintain and/or improve consumer acceptance and repeat purchase.

The use of whole-wheat flour (WWF) can significantly improve the nutritional profile of tortillas, while potentially delivering more whole grains into the American diet. However, WWF tortillas have encountered more quality, storage and sensory problems compared to refined wheat flour tortillas. The presence of bran and germ produces WWF tortillas with a darker color, less opaque, less extensible and shelf stable, and more off-flavors, which often reduce consumer acceptability (Barro et al., 2010). Flour type, particle size, protein content, gluten, and damaged starch have significant influence on tortilla quality (Suhendro et al., 1993; Mao & Flores, 2000; Pascut et al., 2004). Moreover, ingredients and processing conditions are critical in influencing tortilla quality (Waniska, 1999; Cepeda et al., 2000; Adams & Waniska, 2005; Akdogan et al., 2006). Therefore, through selecting and preparing optimal type and particle size WWF, and modifying formulations and processing conditions, the quality of WWF tortillas will be improved.

Milling is an important step in WWF production. Wheat bran particle size is a critical component in WWF milling, due to its considerable influence on dough properties and quality of finished products, such as bread, noodles, crackers, and pasta (Noort et al., 2010; Chen et al., 2011; Li et al., 2012; Niu et al., 2014a; Cai et al., 2014;

Steglish et al., 2015; Wang et al., 2016). To our knowledge, it is largely unknown how the WWF particle size affects the tortillas quality and the optimal particle size range for tortillas, especially for 100% WWF tortillas.

Translucency, a lack of opacity, is generally considered a quality defect in tortillas because consumers perceive translucency as a characteristic of tortillas that are undercooked or high in fat (Alviola & Awika, 2010). The absence of small air bubbles in the baked tortilla is likely related to translucency since the tortilla appears opaque when light reflects on the surface of small air bubbles (Cepeda et al., 2000). The formation of air bubbles in the dough and retention of air bubbles in the tortilla are closely related to the chemical leavening system and processing conditions (Heidolph, 1996; Cepeda et al., 2000; Adams, 2001; Adams & Waniska, 2002; Casso, 2003; Bejosano & Waniska, 2004). Although considerable research has focused on the chemical leavening system for wheat flour tortillas, there is little research on WWF tortillas.

With the development of controlled grain sprouting techniques, sprouted whole grain foods are an emerging trend in the food market due to their nutritional benefits and consumer's desire for health-promoting foods. Studies have reported that sprouting not only significantly increased antioxidant activity (Hung et al, 2011), vitamin C, E, β-carotene, minerals and folate content (Yang et al, 2001; Plaza et al, 2003; Koehler et al., 2007), but also reduced antinutrients such as phytic acid, which might result in greater bioavailability of nutrients (Azeke et al, 2011). Sprouted wheat has been studied to examine the effects of sprouting on the baking performance of bread, noodles, cookies and cake products (Lorenz & Valvano, 1981; Shneider et al., 2009; Shafqat, 2013; Ricker et al., 2014). However, to the best of our knowledge, the impact of sprouted WWF on tortilla baking performance has not been reported elsewhere.

Significance

Our results will help to identify current challenges and opportunities related to whole grain use in the food system and whole grain consumption by consumers in a restaurant environment. Outcomes will demonstrate to supply chain members new alternatives as they explore tools, approaches and methods to increase whole grain consumption. Furthermore, the tortilla industry will have additional reference points to modify formulation and production conditions to produce higher quality whole-wheat tortilla products. Therefore, with better quality whole grain products and deeper understanding about the food environment, the consumption of whole grains has the potential to increase under joint efforts throughout the food system.

Goals and objectives

Our long-term goals are to increase whole grain consumption by understanding barriers to consumption and improving whole grain product (tortilla) quality.

We plan to accomplish our goals through pursuing the following objectives:

1) Examine the current use of whole grains and factors that influence future whole grain use in Chinese restaurants; Compare the plate waste of brown and white rice in a restaurant setting

2) Examine the effects of WWF particle size on the quality attributes of WWF tortillas; Determine an optimal particle size range for 100% WWF tortillas
3) Modify the chemical leavening systems and processing conditions to improve the opacity and other properties of WWF tortillas
4) Identify the effects of sprouted WWF concentration (0%, 25%, 50%, 75% and 100%) on rheological properties of WWF, and baking performance of WWF tortillas.

CHAPTER 2

LITERATURE REVIEW

Ting Liu wrote this chapter.

2.1 Whole grains and health

Whole grains have served as a primary food staple since the early cultivation of grains about 10,000 to 12,000 years ago (Wilford, 1997). Only recently, during the mid to late 19th century, as societal demand and more advanced milling and refining technology became available, grain foods with a lighter color, softer texture, milder flavor and longer shelf life became accessible to the general population. Modern milling technology removes the bran and germ components to produce refined grains, resulting in a loss of many nutrients, such as dietary fiber, vitamins, and other active compounds (Marquart et al., 2007). Whole grains consist of three components: bran, germ and endosperm. These three components serve different functions. While bran is the outside coat of the seed, the germ is the grain's embryo or seed, and the endosperm is the resource for starch and protein (Whole Grains Council, 2016a). Additionally each component also provides certain macro and micronutrients, such as protein, carbohydrate, fat, vitamins, and minerals, along with known and unknown phytochmicals that may influence health and well-being. In order to consume these nutrients and to eat a healthier diet, whole grains containing the bran, germ and endosperm are strongly recommended by U.S. Department of Agriculture (USDA).

2.1.1 Whole grain definition

The American Association of Cereal Chemist International (AACCI) developed an official ingredient definition for whole grains in 1999. The definition is "Whole grains shall consist of the intact, ground, cracked or flaked caryopsis, whose principal anatomical components—the starchy endosperm, germ and bran—are present in substantially the same relative proportions as they exist in the intact caryopsis." (AACCI, 2016). This official definition is less easily understood by consumers, who lack enough knowledge of these scientific terms. Therefore, the Whole Grains Council provided another definition for whole grains in 2004. "Whole grains or foods made from them contain all the essential parts and naturally-occurring nutrients of the entire grain seed. If the grain has been processed (e.g., cracked, crushed, rolled, extruded, and/or cooked), the food product should deliver approximately the same rich balance of nutrients that are found in the original grain seed."(Whole Grains Council, 2016b). Thus, a whole grain contains all three parts of the seed: bran, germ and endosperm.

2.1.2 Health benefits of whole grains

Whole grains are rich in biologically active compounds such as dietary fiber, oligosaccharides, some vitamins and minerals, antioxidants, unsaturated fatty acids, phytate, and phytoestrogens (Slavin, 2004). These bioactive compounds are known to reduce risk of chronic diseases. Extensive epidemiologic studies have provided evidence for the efficacy of whole grains in reducing risk of type 2 diabetes, cardiovascular disease, certain cancers and obesity (Anderson & Conley, 2007; Slavin, 2007; McIntosh, 2007).

2.1.2.1 Type 2 diabetes (T2D)

Prospective cohort and clinical studies have consistently shown an inverse relationship between whole grain intake and risk for developing type 2 diabetes (T2D) (Montonen et al., 2003; Murtaugh et al., 2003; Anderson & Conley, 2007; Ye et al., 2012; Chanson-Rolle, et al., 2015). Data from the Iowa Women's Health Study first documented an inverse association between whole grain intake and T2D. Women who ate an average of 21 servings of whole grains per week had a 21% lower risk of developing T2D compared to women who consumed only one weekly serving (Meyer et al., 2000). Similar findings were shown in the Finnish Mobile Clinic Health Examination Survey with 2,286 men and 2,030 women, where participants in the highest quintile of whole grain consumption were 35% less likely to develop T2D compared to those in the lowest quintile over a 10-year follow-up period (Montonen et al., 2003). Ye et al. (2012) assessed 6 prospective cohort studies between 1966 to February 2012, and determined that participants who consumed 3-5 servings of whole grains per day had an ~26% lower risk of T2D, compared with those who never / rarely consumed whole grains. A quantitative meta-regression model was developed by Chanson-Rolle et al. (2015), showed that consuming 3 servings of whole grain foods daily would induce a 20% relative reduction in T2D, compared to consuming only a half serving.

2.1.2.2 Cardiovascular disease (CVD)

Epidemiological studies consistently demonstrate an inverse association between whole grain intake and risk for cardiovascular disease (CVD) (Anderson, 2003; Slavin, 2007; Seal & Brownlee, 2010). Mellen et al. (2008) conducted a metal-analysis of seven prospective cohort studies and found a consistent and inverse relationship between whole grains and CVD. After adjusting for CVD risk factors, greater whole grain intake was associated with a lower risk of a CVD event, while there was no association between refined grains and incident CVD events. What's more, a prospective cohort study of

42,850 males aged 40-75 suggested that the hazard ratio of coronary heart disease (CHD) between the highest and lowest quintiles of whole grain intake was 0.82 (95% CI: 0.70-0.96) (Jensen et al., 2004). Similarly, Tang et al. (2015) performed a metal-analysis of studies (up to July 2014) that investigated the relationship between whole grain intake and CHD. Pooled results showed that the lowest versus the highest whole grain intake was associated with reduced risk for CHD (summary relative risk=0.79, 95% CI=0.74-0.83). In addition, Aune et al. (2016) examined 64 publications (until April 2016), and found that 3 servings of whole grains intake had 22% lower risk for CVD (summary relative risk=0.78, 95% CI=0.73-0.85).

2.1.2.3 Certain cancers

A number of retrospective and prospective studies have demonstrated an association between higher whole grain intake and decreased risk for certain cancers (Jacobs et al., 1998, McIntosh, 2007; Mourouti et al., 2015). Chatenoud et al. (1998) reported reduced risk of several neoplasms (oral cavity and pharynx, oesophageal and stomach) with higher intake of whole grain foods. Kasum et al. (2001) analyzed the data from the Iowa Women's Health Study to investigate the relationship between whole grain intake and risk of endometrial cancer. For women who never used hormone replacement therapy, there was an inverse association between the highest quintile of whole grain intake compared to the lowest quintile (RR=0.63, 95% CI=0.39-1.01) and risk of endometrial cancer. In addition, Schatzkin et al. (2007) conducted a study among 291,988 men and 197,623 women, and found that greater whole grain intake was associated with a 21% lower risk of colorectal cancer. This inverse relationship was stronger for men (RR=0.79, 95% CI=0.68-0.91) than for women (RR=0.87, 95% CI=0.70-1.07). A case-control study in women was conducted by Mourouti et al. (2015) to evaluate the relationship between whole grain consumption and breast cancer. The results showed that whole grain consumption of more than 7 times a week had 49% reduced risk of breast cancer.

2.1.2.4 Obesity

Data from the 2011- 2012 National Health and Examination Survey (NHANES) indicates 34.9% of U.S. adults are obese (Body Mass Index (BMI) ≥30 kg m^{-2}) (Cynthia et al., 2013). Epidemiological data show that whole grains are related to lower BMI and reduced risk for obesity (McKeown et al., 2007; Williams et al., 2008). Van de Vijver et al. (2009) conducted a study with 2,078 men and 2,159 women, aged 55-69 years, to examine the association between whole grains and fiber consumption with BMI and risk of being overweight or obese. For each additional gram of whole grains consumed, men or women had a 10% or 4% lower risk of being obese, respectively. Based on NHANES 1999-2000 dietary intake data, women who consumed more than one serving of whole grains per day had significantly lower BMI and waist circumference versus women who consumed no whole grains (Good et al., 2008).

Despite these findings, there are limitations in the scientific data regarding the associations between whole grains and chronic diseases. Data collected in epidemiologic studies are based on participant response to dietary questionnaires, confounding variables, such as physical activity, demographics, and dietary patterns. People who consumed more whole grains tend to have healthier eating habits and participate in more frequent physical exercise, which might contribute to a lower risk of chronic disease.

Although the epidemiological is remarkably consistent, the clinical evidence has been sporadic and linking whole grain to specific disease and points, such as blood glucose, cholesterol, and blood pressure.

Although there is considerable evidence demonstrating reduced risk of chronic disease with higher whole grain intake, the mechanisms by which whole grains reduce the risk are not well understood. However, some hypotheses and insights have been proposed. In terms of obesity, it is hypothesized that whole grains may increase insulin sensitivity and lower insulin demand to support weight management (Pauline & Rimm, 2003). Other potential mechanisms include prolonged gastric emptying by viscous soluble fibers (Leclere et al., 1994; Rigaud et al., 1998) and secretion of gut hormones after consuming high fiber foods, such as cholecystokinin, which leads to a greater feeling of satiety in women (Burton-Freeman et al., 2002). Moreover, the components, which may be attributed to the prevention of CVD in whole grains, are magnesium, vitamin E and phytonutrients (Slavin, 2004). Whole grains are also known to improve carbohydrate metabolism, including slowing digestion and absorption of carbohydrate (Slavin, 2004). Whole grains have the functions of reducing postprandial blood glucose response (Tosh & Chu, 2015), reducing insulin resistance and increasing insulin levels (Pereira et al., 2000). Although more intervention studies could be conducted to confirm observational findings, the current model for examining the efficacy of whole grain foods and risk of chronic disease may not serve as a plausible approach. Innovative approaches are necessary to more clearly define the link of whole grain foods on chronic disease, health and well-being (Welch et al., 2011).

2.2 Whole grain intake

2.2.1 Recommendations

Healthy eating patterns and regular physical activity can reduce risk of chronic disease and promote health and well-being. Since 1980 the U.S. Department of Agriculture (USDA) has worked in collaboration with the U.S. Department of Health and Human Services (USDHHS) to publish the Dietary Guidelines for Americans every 5 years. The 2015 Dietary Guidelines for Americans provides five overarching themes. A healthy eating pattern includes: A variety of vegetables from all of the subgroups-dark green, red and orange, legumes, starchy and other; Fruits, especially whole fruits; Grains, at least half of which are whole grains; Fat-free or low-fat dairy; A variety of protein foods; Oils (USDHHS & USDA, 2015).

For enriched refined grains and whole grains intake, the Dietary Guidelines state that: “The recommended amount of grains in the Healthy U.S.-Style Eating Pattern at the 2,000-calorie level is 6 ounce-equivalents per day. At least half of this amount should be whole grains” (USDHHS & USDA, 2015), which suggests Americans 9+ years of age should consume at least 3 ounce-equivalents of whole grains per day. The guidelines also provide some recommendations on how to make at least half of the grains whole grains, including “Choose 100 percent whole grain foods for at least half of all grains consumed” or “Choose products with at least 50 percent of the total weight as whole grain ingredients. If a food has at least 8 g of whole grains per ounce-equivalent, it is at least half whole grains”(USDHHS & USDA, 2015). These guidelines serve as a reference for

U.S. citizens to use approachable goals in developing and maintaining a healthier eating pattern.

2.2.2 Actual intake of whole grains

Data from the NHANES 2007-2010 indicates that dietary intake of total grains meets recommended levels, yet mean intakes for whole grains are far below recommended levels for all age-sex groups (USDHHS & USDA, 2015). According to NHANES 2009-2010, average daily whole grain intake for all adults was 0.82 ounce-equivalents, and for all children/adolescents it was 0.57 ounce-equivalents. What's more, only 2.9% of children/adolescents (2-18 years) and 7.7% of adults (≥19 years) consumed at least 3 ounce-equivalents of whole grain daily, which are far from satisfactory levels (Reicks et al., 2014). Among the grain-based foods, bread and cereals were the major sources of whole grains in the American diet (Bachman et al., 2008; Reicks et al., 2014). Given most Americans fail to meet whole grain recommendations, additional research is needed to examine factors that influence whole grain intake, along with practical steps to increase consumption.

2.2.3 Barriers regarding low whole grains intake

There are numerous factors that influence whole grain consumption. Cost is a primary barrier to whole grain consumption, as many whole grains cost more than refined grains (Whole Grains Council, 2016c). The second significant barrier is low availability. Jetter et al. (2006) found that 100% whole grain products were less likely to be available in low-income neighborhood grocery stores. Other barriers include: lack of knowledge about the health benefits of whole grains; difficulty in identifying whole grain foods; differences in sensory attributes related to color, flavor and texture of whole grains compared to refined grains; and the less convenience and ease of preparing whole grains (Adams & Engstrom, 2000; Kuznesof et al., 2012; Dammann et al., 2013). Schaffer-Lequart et al. (2015) pointed out that the key barrier to increasing whole grain consumption is to get people to taste whole grain products. Thus, a greater understanding of these barriers can help us to prioritize and focus our efforts while engaging in the most appropriate steps to increase whole grain consumption among U.S. citizens.

2.3 The role of restaurants

2.3.1 Restaurant role in daily life and nutrition

Prepared foods away from home (FAFH) play a significant role in shaping the way Americans eat. FAFH include not only foods eaten in restaurants, fast food and other locations, but also take-out or delivery meals eaten at home (Lin & Guthrie, 2012). About 26% of total food expenditures were spent on FAFH in 1970, whereas this share increased to 50% by 2014 (USDA, 2016a). There are various factors that contributed to the increased food expenditures on FAFH since 1970. On one hand, more women are employed outside the home, which lead to an increased number of two-earner households and higher incomes. As people place more effort on their work lives, they have less time, or they are reluctant to spend significant amounts of time to prepare foods. On the other hand, more diverse restaurants, more affordable and convenient fast food outlets have risen to attract people’s attention, with increased advertisement and promotion (USDA, 2016b).

Restaurants are deeply rooted in the socio-cultural norms and serve as an essential part of daily life in America. According to the 2016 Restaurant Industry Pocket Factbook from the National Restaurant Association (NRA), the restaurant industry is predicted to generate $ 782.7 billion in sales for 2016, which accounts for 47% of the food dollar spent by America (NRA, 2016). In addition, 9 of 10 consumers enjoy going to restaurants, and 50% of consumers treat restaurants as an essential part of their life. Restaurants are favorable to consumers because of the rich flavors and convenience. About 70% of consumers find it is difficult to duplicate the flavors of their favorite restaurant foods at home. Also 80% of consumers consider going to a restaurant with family and friends is a better way to spend their leisure time, rather than cooking and cleaning up at home (NRA, 2016).

Although restaurants provide culturally diverse, tasty and convenient foods for consumers, many of these foods contain excess calories, fat and sodium with limited access to fruits, vegetables and whole grains. Frequent consumption of restaurant foods is associated with poor diet quality in many studies, while poor diets can lead to obesity, cancer, diabetes, stoke and other health problems. Lin & Guthrie (2012) found that FAFH was higher in saturated fat than food prepared at home (FAH). In addition, FAFH contained more sodium (1,820 mg) per 1,000 calories, as compared with 1,369 mg of sodium in FAH. The sodium content was found to be higher in the foods available in restaurants and fast-food outlets, 2,151 mg and 1,864 mg/ 1000 calories, respectively.

Similarly, FAFH contained 144 mg of cholesterol, significantly higher than FAH at 126 mg of cholesterol per 1,000 calories. Dietary fiber content of FAFH was 6.8 grams/1,000 calories, compared with FAH, which contained 7.7 grams/1,000 calories. In addition, Todd et al. (2010) analyzed 2 days of dietary intake data from the NHANES 1994-1996 and 2003-2004 to examine the influence of FAFH on various components of diet quality. According to their findings, an average consumer would gain about two extra pounds per year by eating one meal away from home per week. FAFH had a dramatic adverse impact on the number of servings of fruit, vegetables, whole grains and dairy.

Given the increasing popularity of FAFH, excess consumption poses a considerable threat to health. This has led restaurant owners, operators and patrons to seek healthier foods for use in away from home eating environments. Increasing the use of whole grains in menus can give us a simple and effective approach to improve the nutritional quality of diets. Replacing refined grains with whole grains can be an efficient way to improve diet quality, rather than just trying to remove fat, sodium and sugar from menus. The addition of whole grains not only displaces excessive refined carbohydrates, but also introduces more fiber, antioxidants and phytonutrients. What’s more, whole grain items can be novel, attractive and desirable to health conscious consumers.

According to the Whole Grains Council, over 150 chain restaurants across the U.S. offer whole grain foods to consumers, including oatmeal, whole grain bread, tortilla, brown rice, whole grain pizza, and whole grain spaghetti. (Whole Grains Council, 2016d). The Council has identified 123 fine dining and independent restaurants that offer one or more whole grain options on a daily basis. (Whole Grains Council, 2016e). Given there are over 1 million restaurant locations in the U.S. (NRA, 2016), 150 chain and 123 independent restaurants serving whole grains this is far too few to improve diet quality throughout the U.S. Moreover, for those restaurants with whole grain availability, the ratio of whole grain to refined grain menu options remains relatively small.

In order to help consumers to achieve recommended intakes of whole grains, it is important to make available, attractive and desirable whole grain foods that restaurant clientele want to eat. Despite this need, there is little research in the literature related to understanding and promoting whole grain use in restaurants. Some restaurant operators recognize and follow certain recommendations based on the Dietary Guidelines for Americans, yet this remains an exception rather than a rule.

2.3.2 Chinese restaurants and brown rice

The popularity of Chinese restaurants has steadily grown in the U.S., when railroad construction brought Chinese cuisine to the west coast in the mid nineteenth century (Jang et al., 2009). According to Chinese Restaurant News (2007), there are over 43,000 Chinese restaurants in the U.S., which is more than the number of McDonald's, Burger Kings, Wendy's, Domino's, and Pizza Huts combined (Jang et al., 2011). George (2000) reported that about 90% of Americans have tried Chinese food and 63% consumed Chinese food every month.

More recently, Chinese restaurants have faced intense competition with a growing U.S. food markets and rapidly expanding ethnic cuisine, such as Mexican, Japanese, Indian and Thai (Jang et al., 2009). Additionally Chinese restaurants have been considered to be lower in quality and cleanliness by customers (Jang et al., 2009).

Therefore, with more customers' demanding overall excellence during their dining experience, Chinese restaurants can no longer be successful by simply relying on good taste or low price alone. Aiming for a larger market share of U.S. food sales, Chinese restaurant operators and applied scientists have been studying factors which influence customer preference for food, their eating environment, overall customer service and promotion. Other than improving the food quality and restaurant cleanliness, the addition of healthier whole grain options to menus may attract more health-conscious consumers.

Based on the popularity and large number of Chinese restaurants across the U.S., serving whole grain foods in these establishments can help to increase whole grain consumption among Americans. While from a business perspective, adding whole grain foods to Chinese restaurants' menus could attract more health-conscious consumers.

Rice is a major food staple widely consumed, particularly in Asian regions of the world. Unlike the more popular white rice, brown rice is a whole grain food, with considerable health attributes. Sun et al. (2010) conducted a study among 39,765 men and 157,463 women to assess the relationship between white rice, brown rice and type 2 diabetes. A higher intake of white rice (≥5 servings per week) was associated with higher risk of type 2 diabetes, whereas high brown rice intake (≥2 servings per week) was related to lower risk. Brown rice is known to contain more phenolic compounds located in the bran and germ components than white rice consisting mostly of endosperm (starch). Phenolic compounds have potent antioxidant properties, which might reduce oxidative damage, reduce risk of coronary heart disease and cancer (Tian et al., 2004).

Given that brown rice appears to be more readily accepted by both Chinese restaurant operators and consumers than other types of whole grain foods, increasing brown rice availability and consumption in Chinese restaurants might be beneficial to increase whole grains consumption in the U.S.

2.3.3 Data collection methods

2.3.3.1 Individual interview

The individual interview is a frequently used method in social research. An interview is defined by Wikipedia as "…a conversation between two or more people where questions are asked by the interviewer to elicit facts or statements from the interviewee" (Wikipedia, 2016a). There are three fundamental types of interview methods for research, including structured, semi-structured, and unstructured interviews (Gill et al., 2008). The structured interview, also known as a standardized interview, is a fixed format interview method that all questions are prepared beforehand, and each interview is conducted with exactly the same questions in the same order (Wikipedia, 2016b). However, the semi-structured interview is more flexible than standardized methods as it allows exploration of emergent ideas, rather than relying on set questions defined prior to the interview (Fylan, 2005).

Moreover, this dissertation used both face-to-face or phone interviews depending upon availability of interviewees. As a synchronous communication method, face-to-face interviews allow direct observation of social cues, such as voice, intonation, and body language of interviewees, which could become extra information. Due to the asynchronous communication of place, telephone interviews can expand the reach to interviewees from around the globe. Also telephone interviews can save time, money and energy related to transportation (Opdenakker, 2006).

2.3.3.2 Direct meal observation

Increased attention has been directed toward food intake in the general U.S. population during mealtimes and snacking occasions. Common approaches to assess food intake, include retrospective methods, such as 24-hour recalls, food frequency questionnaires and diet records (Richter et al., 2012); and prospective methods, such as food weighing and direct meal observation (Gittelsohn et al., 1994). The 24-hour recall assists subjects in recollecting what and how much they ate by reviewing their activities during the coarse of a day, however, this method relies on the subjects' ability to remember foods they have previously consumed. Memory loss, memory bias and inaccuracy of subject's information about their eating behavior tend to reduce accuracy of this method (Simons-Morton et al., 1991).

Alternatively, direct meal observation does not depend on an individual's memory and provides less biased information about subjects' actual food intake. Direct meal observation tends to be more feasible when conducted in a defined environment and during a certain period of time, such as a lunch or dinner occasion (Richter et al., 2012). The direct meal observation method allows researchers to observe subjects throughout a defined period of time and take notes on the subjects' eating behaviors in terms of food items, amount consumed, traded and / or spilled (Baglio et al., 2004). Therefore, direct observation can capture details of each subjects' eating behaviors. Due to these advantages, direct meal observation is considered the “gold standard” of food intake data collection methods (Simons-Morton et al., 1991).

Despite the advantages of direct meal observations, there are challenges. This method can be labor intensive, time-consuming and costly due to the amount of time needed to observe large numbers of subjects, along with the necessary observer training to produce accurate and consistent results (Richer et al., 2012; Tritt et al., 2015). However, increased accuracy of the data collected makes it a worthy approach to estimate actual food intake, compared to other methodologies (Richter et al., 2012).

Based on direct meal observation, plate waste can be used to estimate the type and amount of food consumed. Plate waste refers to the amount or percentage of food discarded (Connors et al., 2004), and it can be used to demonstrate the actual amount of food consumed by subjects and the acceptability of the items offered. Plate waste studies can assist foodservice managers in controlling the serving size of food items and avoid waste (Nichols et al., 2002). In addition, accuracy or validity of estimating plate waste has been analyzed by some studies. Gittelsohn et al. (1994) compared visual food-weight estimation and the actual weights of food items plate waste by ten trained Nepalis and found that visual estimation correlated highly ($r=0.96$) with actual weight. The high correlation represents the accuracy of direct meal observation in estimating food intake. Other than weight estimation, the visual estimation of portion size consumed method was a good alternative for estimating food intake by young Indian children. The small differences between estimated mean intake and actual intake, for example, bread (3.8 vs.

3.7 g), puffed rice (1.7 vs. 1.9 g) demonstrated the accuracy of this visual method (Dhingra et al., 2007).

Although direct meal observation has been widely used in school cafeterias, to the best of our knowledge, there are few academic studies using restaurant-based direct meal observation to measure intake by the U.S. population. Tritt et al. (2015) assessed the acceptability of whole grain pizza among children in a restaurant by using direct meal observation. This study demonstrated that this method could also be used in restaurants. Currently 50% of the overall food budget is spent away from home, which necessitate a better understanding of actual food intake and acceptability of foods served in restaurants. Given there are few studies in the literature using direct meal observation in restaurants, it is important to develop advanced direct meal observation methods that are feasible and accurate for use in restaurant settings.

2.3.3.3 Plate waste collection regarding whole grains

Plate waste is defined as the quantity of edible portions of food that people discard after their meals. It can be assessed by many methodologies and be expressed by a variety of terms, such as the proportion of food served that is uneaten, amount of calories or nutrients uneaten (Buzby & Guthrie, 2002). Plate waste has been widely used to examine the consumption of fruits and vegetables, skim milk, and soy (Toma et al., 2009). With increased attention given to whole grain foods, scientists have started to use plate waste methods to determine the acceptability of whole grain foods. Until recently, plate waste studies examining whole grain consumption were primarily conducted with school children. Chan et al. (2008) compared the acceptability of 50:50 blend of white whole wheat and refined wheat flour pizza in school children and observed no difference in consumption. Similarly, the acceptance of 51% and 100% whole grain burritos and cookies was determined via plate waste, with no significant differences in consumption between the refined and whole grain foods (Toma et al., 2009). In addition, Chu et al. (2011) compared the acceptance of whole grain vs. refined pancakes and tortillas in school meals. Based on plate waste, no difference was found in the consumption of whole-wheat pancakes compared to refined wheat pancakes. However, the consumption of whole-wheat tortillas (66% and 100% whole wheat) was lower than refined counterparts, which showed that children, especially elementary students were less likely to consume whole-wheat tortillas than refined products. Tritt et al. (2015) conducted one of the first plate waste studies to examine the acceptance of whole grain pizza crust among children in a restaurant setting. Their results showed that children consumed as much of the whole grain crust as the refined grain crust (p=0.55). Given the success of plate waste methods in examining the acceptance of whole grain products in children, researchers can use this method as a valid and reliable approach to investigate additional whole grain products, such as brown rice and whole grain noodles.

2.4 Wheat flour tortilla

Tortillas are soft, thin, circular, light colored flatbread made from wheat flour or corn, with versatility for use in many dishes. The term “tortilla” comes from the Spanish word “torta” which means “round cake”. The first tortillas, made of native corn with dried kernel, dated back about 10,000 years before Christ (Casso, 2003). As an important part of the diet in Central America and Mexico, tortillas are traditionally grilled on earthenware utensils and often filled or stuffed with meat, vegetables, cheese and salsa (Arora, 2003). Nowadays, tortillas can be steamed, grilled, fried or heated in a microwave or toaster, or baked in the oven (TIA, 2016).

2.4.1 U.S. tortilla market

In the U.S., due to the textural and flavor changes in maize during the nixtamalization process, corn tortillas are less popular than wheat tortillas among Americans, with a ratio of 1:2 (Serna- Saldívar et al., 2004; Dann, 2014). With the growth in the Latino population and widespread popularity of Mexican and Southwestern cuisines, tortillas are becoming more popular than other types of ethnic breads (i.e. bagels, pita bread) in the U.S. (TIA, 2016). Nowadays, tortillas are not only considered as an ethnic food, instead, they often serve as a substitute for sandwich bread, pizzas, hot dog buns, and crackers. Tortillas, tacos and burritos constitute about 8% of major resources of refined grains for Americans (USDA & USDHHS, 2010).

The tortilla industry is the fastest growing sector in the U.S. bakery industry. According to the Tortilla Industry Association, Americans consumed approximately 85 billion tortillas (not including tortilla chips) in 2000 (TIA, 2016). What’s more, the sale of tortillas in the U.S. exceeded $11 billion in 2012, representing a growth of 57% over the past six years (Ontiveros-Martinez et al., 2011; Dann, 2014).

2.4.2 Wheat flour tortilla ingredients

The traditional formulation for wheat tortilla includes four ingredients: wheat flour, water, shortening and salt. These tortillas are usually consumed on the same day and have a short shelf life (2-4 days). However, as consumers demand longer shelf life products that can last for weeks or months, commercial formulas may include leavening agents, emulsifiers, reducing agents, hydrocolloids, sugar, preservatives and acidulants to improve taste, nutritional value and extend shelf life (Friend et al., 1995).

2.4.2.1 Wheat flour

As the main ingredient (80-95% of the dry ingredients) in tortilla formulation, wheat flour has the most impact on tortilla quality. Hard red winter wheat flour with a protein content of 9.5 to 12.5% is commercially available for producing tortillas. The protein content of flour is a primary factor, which influences tortilla quality (Friend et al., 1995, Casso, 2003; Pascut et al., 2004). Tortillas made with lower protein content (<9.5%) have weak and sticky dough, and are easy to crack and spilt apart when folded after one day of storage; whereas, higher protein content flour produce tortillas with a longer shelf life. However, flour with excessively high protein content, are more difficult to process and yield tortillas with a smaller diameter and tougher structure (Serna- Saldívar et al., 1988; Waniska, 1999; Adams, 2001). Aside from protein content, the protein quality and composition also affect tortilla quality properties (Waniska, 1999; Dann, 2014). Wheat protein fractions, such as gliadins and glutenins, have different functionality. And the different compositions of protein fractions have significant influence on protein quality. Pascut et al. (2004) evaluated 10 commercial wheat protein fractions and found that the addition of gliadin and vital wheat gluten could improve shelf stability and yield tortillas with positive attributes.

Flour extraction rate significantly affects flour composition and tortilla texture properties. Flour milled with 74% and 80% extraction rates produced tortillas with the best firmness and rollability, whereas, tortillas prepared with 100% extraction rate flour were acceptable, but were slightly firmer and less rollable (Ramírez Wong et al., 2007). Flour particle size is an important parameter for tortillas as it indicates the degree of total surface exposed (Mao & Flores, 2001). When flours are fractioned into different particle size, the resulting flour fractions vary in chemical and physical properties, and tortillas have various textural properties (extensibility, rollability, etc.) (Wang & Flores, 2000). Reducing flour particle size during milling increases mechanical starch damage, which affects water absorption, dough extensibility and viscosity, and tortilla texture (Mao & Flores, 2001).

2.4.2.2 Water

Water is added to hydrate the wheat proteins and incorporate other ingredients to form and develop into a gluten complex. Excess water in the formula results in sticky dough with poor machinability, which adheres to surfaces and requires more dusting flour. However, with insufficient water, the dough becomes stiff and difficult during handling and pressing (Bello et al., 1991). Thus, an optimal level of water should be added into the tortilla formula. A range of 45-55% water on a flour weight basis is usually used for white flour tortilla dough, based on flour hydration requirements, and other ingredients, such as shortening, and reducing agents (Dann, 2014). Water temperature is generally adjusted to produce dough at 30-32°C, which is an optimum temperature for dough resting (Casso, 2003).

2.4.2.3 Shortening

Shortening is added to the formulation for incorporation into the gluten network and to decrease the strength of gluten bonds via binding to hydrophobic proteins. Shortening affects dough properties during processing along with tortilla flavor and quality. More specifically, shortening helps to reduce dough stickiness, increase tortilla diameter and flexibility, and prevents staling with improved rollability (Serna- Saldívar et al., 1988; Bello et al., 1991; Adams, 2001). The most commonly used shortening in industry is hydrogenated vegetable shortening with levels between 3-15% flour weight basis (Dann, 2014).

2.4.2.4 Salt

Salt plays an important role in tortillas as it enhances flavor, strengthens the gluten network resulting in less sticky dough, and lengthens shelf-stability by lowering water activity (Serna- Saldívar et al., 1988). The tortilla formula generally includes 1.5-3% (flour weight basis) salt (Dann, 2014).

2.4.2.5 Leavening agents

Leavening agents help to form fluffy, thick and opaque tortilla products. Unlike many bread products that use yeast as leavening agents, flour tortillas are produced using a chemical leavening system. Chemical leavening is a neutralization process where bicarbonate is neutralized by an acid yielding carbon dioxide in the presence of moisture and heat (Heidolph, 1996). Incorporation of air into flour during mixing, formation of carbon dioxide by chemical leavening reactions, expansion of air bubbles due to heat, and volatilization of water lead to leavening of flour tortillas (Waniska, 1999; Cepeda, 2000). The evolution of carbon dioxide is initiated during dough mixing, and continues through proofing and baking (Casso, 2003).

The chemical leavening system contains two components: a base (bicarbonate) and an acid (Adam & Waniska, 2002). The most common leavening bases used in baked foods are sodium bicarbonate (SBC, $NaHCO_3$), potassium bicarbonate (KBC, $KHCO_3$) and ammonium bicarbonate (ABC, NH_4HCO_3). The different types, amounts and grades of bicarbonates have been studied relative to tortilla properties (Casso, 2003; Bejosano & Waniska, 2004).

Leavening acids vary in neutralization value (NV) and the rate of reaction (ROR). Based on ROR, leavening acids can be divided into three categories. Acids that release during mixing are nucleating agents, such as calcium phosphates (monocalcium phosphate [MCP]) and organic acids (fumaric, citric, lactic and tartaric). Acids that react after a period of time are called time-released agents, such as sodium aluminum pyrophosphate (SAPP). The third category is heat-activated agent, which reacts when triggered by heat. Sodium aluminum sulfate (SAS), sodium aluminum phosphate (SALP) and dimagnesium phosphate (DMP) are included in this category (Brose et al., 1996; Cepeda, 2000; Casso, 2003). Nucleating agents, as fast-acting acids, are seldom used as a single source of leavening. Instead, the combination of fast and slow leavening acids is used to produce a double reaction (Labaw, 1982, Heidolph, 1996).

2.4.2.6 Emulsifiers

Emulsifiers, also known as dough conditioners, are used to improve dough machinability and tortilla structure. Emulsifiers interact with gluten during mixing to improve dough strength, and form a complex with amylose and amylopectin during baking to slow the starch staling process and reduce tortilla stickiness (Waniska, 1999; Akdogan et al., 2006). Commonly used emulsifiers in the tortilla industry include sodium stearoyl lactylate (SSL), monoglycerides and diglycerides (Serna- Saldívar et al, 1988). Soybean lecithin is also used as a natural emulsifier. Akdogan et al. (2006) examined the effects of emulsifiers on textural properties of whole-wheat tortillas during storage. They found that a lowest usage level (0.125%) for SSL, and a highest usage level (2%) for soybean lecithin were most effective in improving tortilla texture properties.

2.4.2.7 Reducing agents

Reducing agents break down disulfide bonds between proteins and decrease the protein molecular weight by reducing the degree of polymerization. They can help to improve dough machinability by increasing extensibility and decreasing elasticity. Commonly used reducing agents include L-cysteine, bisulfites and glutathione (Serna-Saldívar et al., 1988; Arora, 2003). Although addition of reducing agents (i.e. cysteine) improves dough functionality during mixing, handling, resting, hot pressing, and baking, it requires more stringent processing conditions, such as precise mixing and resting time, and it decreases shelf stability of tortillas (Friend et al., 1995).

2.4.2.8 Hydrocolloids

Hydrocolloids can help to retain moisture and prevent staling; thus, they are generally used to improve tortilla shelf stability (Bello, 1991). Tortillas containing carboxymethyl cellulose (CMC) were more rollable after five freeze-thaw cycles as compared to control tortillas. However, when more gums were added, the dough became stickier and less cohesive. Therefore, there is a level of optimal usage to balance longer shelf stability with effective product processing (Friend et al., 1993).

2.4.2.9 Preservatives and acidulants

Due to a relatively high water activity at 0.88, tortillas are more susceptible to mold growth (Pyler & Gorton, 2009). Thus, preservatives are used to extend shelf life. Sodium and calcium propionate and potassium sorbates, sorbic acid and other acids are commonly used alone or in combinations in the tortilla industry. As propionate and sorbate bring bitter flavors to tortillas, the usage levels should be minimized (Dann, 2014).

In order for preservatives to perform optimally, the dough pH is required to be lower than 6.1, with a target of 5.9-6.1 (Friend et al., 1995). Acidulants, such as acetic acid, citric acid, fumaric acid or phosphoric acid are added to lower the pH (Serna- Saldívar et al., 1988). Among these acids, fumaric acid is most commonly used since it is less soluble in the dough, which prevents its interference with the leavening reactions and reduces the loss of carbon dioxide. To prevent the interaction between acidulants and leavening agents, acidulants are encapsulated in a high melting point edible coating to delay or control their release (Casso, 2003).

2.4.3 Wheat flour tortilla technology

There are three commercial tortilla production methods: hand-stretch, die-cut and hot-press, where hot-press is the most popular and fastest growing method in the U.S. (Waniska, 1999). Each method has its own advantages and disadvantages and yields slightly different quality tortilla products.

The hand-stretch method is the most traditional approach for tortilla production. As indicated by the name, dough balls are sheeted and hand stretched into a thin, circular shape prior to baking (Dann, 2014). This method requires more labor, time, sanitation and maintenance, which lead to higher costs (Serna- Saldívar et al., 1988). Tortillas produced by this method are irregular in shape, larger, thinner and stronger than die-cut or hot-pressed tortillas (Dally & Navarro, 1999; Waniska, 1999), and slightly powdery due to additional dusting flour used in manual stretching (Janson, 1990). These tortillas are generally consumed as table tortillas, burrito or other fried products (i.e. sopaipillas, chimichangas) (Dally & Navarro, 1999; Pyler & Gorton, 2009).

The die-cut method is the most efficient method, which requires the shortest production time and lowest labor (Dann, 2014). In this method, the dough is sheeted to the desired thickness and die-cut into an oblong shape, which will shrink back to circles before baking (Schmidt, 1985). Although the die-cut method is quick and convenient, it produced the most inferior quality tortillas. Die-cut tortillas are less elastic, denser, less soft and pastry like, with a faster loss of flexibility than hot-pressed tortillas (Arora, 2003). These tortillas are mainly used for frozen foods and fried salad bowls (Serna-Saldívar et al., 1988; Pyler & Gorton, 2009)

Although the hot-press method is not the most efficient method, it is the most popular and widely used method because it yields the best quality tortillas (Waniska, 1999). About 95% of commercial tortillas are produced by the hot-press method, while 2% by hand-stretch and 3% by die-cut (Dann, 2014). With the hot-press method, dough is divided and rounded into balls, and the balls are stamped in a heated hydraulic press prior to baking (Dann, 2014). The resulting tortillas are distinctly layered, slightly off-round, elastic, smooth surface, pliable, resistant to tearing, and retain flexibility for longer periods during storage. Hot-press tortillas are preferred for many food items, such as tacos, burritos, wraps and snacks (Bello et al., 1991; Winstone, 2010).

The production of wheat flour tortillas using a commercial hot-press method includes certain major steps: mixing, proofing, dividing and rounding, dough resting, hot pressing, baking, cooling and packaging. Each step is critical in determining final product quality. During the mixing step, dry ingredients are mixed with low speed for 1-2 min before mixing with water and shortening to develop optimum dough. Under-mixed dough will produce tortillas with characteristically small blisters (Bello et al., 1991). Then the dough is proofed for 5 min at 32°C and 70% RH. The large dough is divided and rounded into balls with a divider / extruder. A resting period usually follows the dividing and rounding stage. The dough balls are rested for 20 min in a 32°C, 60-70% RH environment (Bello et al., 1991). The tortilla shape is greatly affected by dough ball resting time and temperature (Serna- Saldívar, 1988).

During the hot pressing stage, the dough surfaces are dehydrated by the hot temperature, and a semi-continuous skin on both external surfaces is formed by the reaction between starch and gluten. This skin formation can prevent the release of carbon dioxide and steam during hot pressing and baking, and maintain tortilla puffiness (McDonough et al., 1996). Hot-press conditions of time, temperature and pressure, directly affect the tortillas (Adams & Waniska, 2005). Typical hot-press operating conditions range from 0.7-3.5 second time, 149-232°C temperature and 300-2000 psi pressure (TIA, 2014). Furthermore, tortillas can be baked by traditional hot griddle, commercial three-tier, gas-fired ovens and infrared radiation. The bake temperature and time for three-tier commercial ovens range from 250-270°C, 18-40 sec, respectively (Waniska, 1999). During baking, the formation of carbon dioxide and hot steam yields puffed tortillas, which deflate shortly after leaving the oven. Tortillas are cooled to room temperature before being packed in low-density polyethylene bags. Insufficient cooling before packaging increases the moisture content within the package, which increases the risk of mold growth and tortilla stickiness (Dann, 2014).

2.4.4 Factors affecting tortilla quality

Good quality tortillas should be light in color, round, symmetrical, puffed, flexible without tearing and cracking when folded, soft without sticking together and with uniform toast spots (Bello et al., 1991; Waniska, 1999). Subjective and objective (rheological) methods have been developed to determine tortilla quality attributes such as moisture content, pH, weight, diameter, thickness, opacity, color, texture, and shelf life.

Flour type, particle size, protein content, gluten, and damaged starch have significant influence on tortilla quality (Suhendro et al., 1993; Mao & Flores, 2000; Pascut et al., 2004). Moreover, ingredients are critical in influencing tortilla quality. The type and amount of leavening agents affect tortilla characteristics, such as diameter, thickness, pH, and opacity (Cepeda et al., 2000; Book et al., 2002). Shortening, reducing agents, water, and emulsifiers can influence tortilla texture and shelf stability (Waniska et al., 2000; Akdogan et al., 2006). Other than ingredients, processing conditions including mixing, hot-press dwell time, pressure and temperature and baking time are influencing tortilla size, texture, color, and shelf stability (Bello et al., 1991; Waniska, 1999; Adams & Waniska, 2005).

2.5 Whole-wheat flour tortillas

2.5.1 Whole-wheat flour

Consumers, especially the health conscious consumer, have demanded more whole grain products due to their known health benefits and recommendations via the Dietary Guidelines. Whole-wheat flour (WWF) production has increased from 2% of total wheat flour production in 2000 to 5% in 2010, and it continues to grow (Doblado-Maldonado et al., 2012). WWF, produced from wheat kernels, includes all three major components of the grain (bran, germ and endosperm). WWF is the main ingredient for producing many whole wheat-based products, such as bread, noodles, cakes, tortillas, etc.

Although milling procedures for refined wheat flour are well established, there is no standard method available for WWF (Dobaldo-Maldonado et al., 2012). The grinding process is the most important step in flour milling. Stone and roller milling are the two predominant techniques used in commercial wheat flourmills. The stone mill is a traditional mill for producing WWF, which uses a combination of compression, shear and abrasion forces to grind kernels between two stones. A disadvantage of the stone mill is that the heat generated by friction may result in considerable damage to starch, protein and fatty acids. Due to its range of selective grinding and ease of operation, the roller mill is the principle grinding technique used in the milling industry. The roller mill includes a separation of the endosperm from the bran and germ, a gradual size reduction, and blending with bran, germ and endosperm. For commercial WWF, different blends of endosperm, bran and germ are prepared based on the baker's specifications (Posner & Hibbs, 2005; Doblado-Maldonado et al., 2012). Aside from stone and roller milling, other milling techniques include plate and hammer milling. Different milling techniques produce WWF with different particle size, chemical compositions, and baking quality (Prabhasankar & Rao, 2001). In addition, reconstituted WWF is produced by regrinding the total wheat bran and germ by a hammer mill, and blending the fine reground materials with straight-grade flour (Posner & Hibbs, 2005).

2.5.2 Opportunities and barriers

Tortillas made from WWF provide opportunities for increasing whole grain consumption. WWF is a good source of dietary fiber, with 12.2 g of fiber/100 g of flour, while refined wheat has 2.7 g fiber per 100 g flour (Akdogan et al., 2006). Friend et al. (1992) observed that 100% whole-wheat tortillas contained 3.0% insoluble and 4.2% soluble fiber, while refined wheat tortillas only contained 0.7% insoluble and 1.1% soluble fiber. What's more, WWF is rich in phenolic compounds, enzymes, vitamins, minerals and phytoestrogens (Li et al., 2012) and it has a lower glycemic index. This of course depends upon how the flour is milled and processed (Prabhasankar & Rao, 2001).

Thus, use of WWF in tortillas can significantly improve the nutritional profile of bakery products.

Considerable challenges exist when incorporating WWF into food products relative to dough properties, processing techniques and product quality. The presence of bran and germ produces WWF products with a darker color, coarser texture, and off-flavors, which often reduce consumer acceptability (Steglich et al., 2015). The higher bran content in WWF generally results in increased dough water absorption due to pentosans present in the bran (Penella et al., 2008). WWF dough requires a longer mixing time for adequate gluten development and a longer resting time to shape the dough. Various mechanisms influence textural changes, including bran dilution, physical disruption, dehydration of the gluten network, and the increase in fiber-gluten interactions (Shiau et al., 2012; Manthey & Schorno, 2002; Li et al., 2012; Noort et al., 2010). Shelf life is another concern for WWF. It is well accepted that the shelf life of WWF is considerably shorter than refined flour, and lipid degradation is the predominant cause. The high oil content in bran and germ makes WWF subject to rancidifaction, which leads to shorter shelf life (Doblado-Maldonado et al., 2012).

WWF has a major impact on the quality attributes of end products. Bread made with WWF has increased water absorption, decreased specific volume, darker crumb color and inferior crumb texture (Seyer & Gélinas, 2009; Zhang & Moore, 1997). Sensory properties, such as taste (bitterness) and texture are barriers to consumption of whole-wheat bread (Bakke & Vickers, 2007). With the addition of WWF, crackers become darker and browner, while stack weight, height, specific volume and breaking strength all decreased (Li et al., 2014). Noodle products made with WWF have a significantly darker, less bright and a less shelf stable color than refined flour noodles. WWF noodles were harder, with lower springiness, cohesiveness and resilience values, compared to noodles made with refined flour (Niu et al., 2014a). Whole-wheat pasta has a darker color, increased cooking losses, decreased firmness, and strong aromas with less appeal for many consumers (West et al., 2013; Steglich et al., 2015).

Although the use of WWF can significantly improve the nutritional profile of tortillas, WWF tortillas have encountered more quality issues compared to their refined counterparts. Whole-wheat tortilla dough requires more water and longer time to be machineable, as it is less soft and extensible than refined flour dough. As compared to refined flour tortillas, whole-wheat tortillas were larger in diameter, thinner, less fluffy (smaller specific volume), darker color, less opaque, weaker, less extensible and shelf-stable (Barros et al., 2010).

Given the emerging tortilla market, incorporating WWF into tortillas is one approach to deliver whole grains into the American diet. Based on the current trends toward healthier food and the popularity of tortillas, manufacturers are striving to provide customers with healthier, more varied, and flavored tortillas. Aside from the numerous consumer challenges facing the successful development, delivery and service of whole grain foods, a focus on three technical areas: flour particle size, chemical leavening system, and use of sprouted white whole-wheat flour may contribute to more desirable whole grain tortillas.

2.5.3 Flour particle size

Wheat bran particle size is a critical component in WWF milling, due to its considerable influence on dough properties and quality of finished products, such as breads, noodles, crackers, and pasta (Noort et al., 2010; Chen et al., 2011; Li et al., 2012; Niu et al., 2014a; Cai et al., 2014; Steglish et al., 2015; Wang et al., 2016). It is believed that reducing wheat bran particle size improves the digestibility of end products and the solubility of nutritional compounds such as ferulic acid and B vitamins for humans (Hemery et al., 2011). However, due to the variation in bran composition and the methods for preparing different particle sizes, the relationship between wheat bran particle size and end product quality is controversial.

Table 2.1 presents studies that have examined flour particle size effects on different end products, i.e. bread, noodles, pasta, crackers and tortillas. Based on this review several general conclusions can be drawn by observing similarities and differences in particle size across studies as it relates to processing, baking and end product. Reducing bran particle size yields products with smoother appearance, improved mouthfeel but a darker color (Zhang & More, 1997; Cai et al., 2014). The darker color may be due to more uniform distribution of finer bran in flour (Niu et al., 2014a). For noodles, finer particle size increased its hardness, cohesiveness and resilience (Chen et al., 2011; Niu et al., 2014a,b). However, the particle size effects on dough strength, bread loaf volume and pasting properties are inconclusive and controversial. For example, some studies (Zhang & More, 1997; Penella et al., 2008; Noort et al., 2010) found that finer particle size had a negative effect on dough strength, while other research (Niu et al., 2014a; Steglich et al., 2015; Wang et al., 2016) showed that decreasing particle size increased dough stability time and yielded products with higher breaking force. Furthermore, each type of product may have its own optimal particle size range for optimal quality (Li et al., 2012; Niu et al., 2014b; Wang et al., 2016).

Several researchers have reported wheat flour particle size effects on refined tortillas or tortillas enriched with barley flour (Table 2.1). Wang & Flores (2000) sieved and separated the refined flour into different particle size fractions and they found that tortillas made from the medium fractions, especially 53-75 µm fractions had longer rupture distance and better foldability. Whereas, Mao & Flores (2001) reground the flour to produce different particle size refined flour and found that finer particle size yielded less stretchable tortillas. However, no research has considered the effects of WWF particle size on whole-wheat tortillas, especially 100% WWF tortillas. Therefore, it is necessary to examine the particle size effect on the quality of WWF tortilla products and to determine an optimal particle size range for WWF tortillas.

Table 2.1: Research studies on flour particle size effects on baking quality

Author(s)	**Sample preparation methods**	**End-product**	**Particle size range**	**Conclusions**
Zhang & More (1997)	Grinding	Bread	Bran mean particle size: 609, 415 & 278 µm	Fine particle size bran decreased dough mixing tolerance and mixing time. Bread baked with fine bran particles had lower loaf volume, darker crumb color, but smoother crust appearance and less gritty mouthfeel.
Penella et al. (2008)	Grinding	Bread	Bran mass median diameter: 795 & 280 µm	Finer bran particle size increased dough water absorption, but decreased development time and stability.

Noort et al., (2010)	Grinding bran by rotor, impact and jet mill	Bread	Bran median particle size: 48-831 µm	Reducing particle size decreased gluten network and showed negative effects on bread quality.
Li et al., (2012)	Grinding	WWF bread	Flour mean particle size: 235.40, 96.99 & 50.21 µm	Whole-wheat bread made with WWF, 96.99 µm had better baking quality than breads made with 50.21 and 235.40 µm.
Cai et al., (2014)	Grinding	WWF bread	Bran median diameter: 332, 233, & 208 µm	Fine grinding of bran may produce a WWF bread of smooth appearance and improved mouthfeel, but reduced shelf life by expediting starch retrogradation during storage.
Chen et al., (2011)	Bran was ground and added to flour at different levels	Noodle	Bran mean size: 210, 530 & 1720 µm	Bran particle size showed no effect on pasting properties, and finer size increased hardness, gumminess and chewiness of cooked noodles. 210 and 530 µm particle size bran flour produced better quality noodle products.
Niu et al., (2014a)	Fine grinding	WWF noodle	Flour median diameter: 178-307 µm (HRS); 185-319 µm (HRW)	Reduction of particle size increased hardness, springiness, cohesiveness and resilience values and improved WWF noodle quality with darker color.
Niu et al., (2014b)	Superfine grinding of bran and germ	WWF noodle	Flour mean particle size: 125, 96, 72 & 43 µm	Reducing particle size increased starch damage and Farinograph water absorption, but reduced the peak and final viscosity. The color, cooking properties, cohesiveness, resilience, and microstructure of WWF noodles were improved as the particle size reduced to 72 µm.
Steglich et al., (2015)	Grinding	WWF pasta	Bran median particle size: 90, 160, 370 & 440 µm	Smaller particle size produced higher breaking strength, smoother surface and higher overall likeness of dried pasta.
Wang et al., (2016)	Grinding	WWF cracker	Flour median diameter: 171.6-89.9 µm (SWW), 170.0-95.6 µm (SRW)	Reduction of WWF particle size increased the maximum resistance to extension and extensibility of cracker dough, and increased the ratio of stack height to dough weight, improving cracker quality.
Wang & Flores (2000)	Sieving	Refined tortilla	Flour particle size fractions:	Flour with 38-75 µm particle size, had a higher protein content for

			<38 µm, 38-53 µm, 53-75 µm & >75 µm	HRW and HW. Tortillas made with medium fractions of HRW and HWW had longer rupture distance and better foldability than the finest or coarsest fractions.
Mao & Flores (2001)	Regrinding flour	Refined tortilla	Flour geometric mean diameter: 63.9-34.2 µm (flour 1); 71.2-37.7 µm (flour 2)	Finer flour particle size increased starch damage, water absorption, tortilla firmness and rollability, but reduced tortilla stretchability and maximum force of Kramer shear.
Prasopsunwattana et al., (2009)	Addition of whole barley flour (WBF)	Tortilla	WBF mean particle size: 237, 131 & 68 µm	With a decrease in WBF particle size, protein, moisture content and mixing stability decreased, while starch content, water absorption and Farinograph peak time increased.

2.5.4 Chemical leavening system

Table 2.2 lists several studies examining chemical leavening system effects on tortillas. In tortilla dough systems, chemical leavening is strongly associated with opacity / translucency, and other quality attributes. Opacity refers to the impenetrability of visible light (Wikipedia, 2016c). Translucency, a lack of opacity, is generally considered a defect in tortillas. Consumers perceive translucency as a tortilla characteristic of being undercooked or high in fat (Alviola & Awika, 2010). A ‘translucent’ tortilla is dark or yellowish in color, while an ‘opaque’ tortilla is bright and white (Dann, 2014). The absence of small air bubbles in the baked tortilla is probably related to translucency, since the tortilla appears opaque when light reflects on the surface of small air bubbles. Thus, formation of air bubbles in the dough and retention of these air bubbles in the tortilla are critical factors in the production of uniformly opaque tortillas (Cepeda et al, 2000; Casso, 2003). The high fiber content in whole-wheat flour weakens the dough gluten network, resulting in a dough less resistant to hot-pressing. Therefore, whole-wheat tortillas have less dough structure and integrity to retain the air bubbles created during baking (Barros et al., 2010), which suggests, opacity is a challenge to achieve in WWF tortillas.

The type, quantity and ratio of leavening agents' effects on opacity have been widely studied on refined flour tortillas (Table 2.2). Generally, encapsulated SBC produced improved tortilla opacity than non-encapsulated (Adams & Waniska, 2002; Casso, 2003). In terms of types of leavening acids, medium-to-slow acids, such as SALP, produced tortillas with better opacity and quality (Cepeda et al., 2000; Book et al., 2002). With a higher amount of leavening base (SBC or ABC), tortillas are more opaque (Cepeda et al., 2000; Adams, 2001; Adams & Waniska, 2002; Bejosano & Waniska, 2004). Low acid-to-base ratio (0.59) was found to increase tortilla opacity by Bejosano & Waniska (2004).

Other than leavening agents, the processing conditions may also affect the opacity of tortillas. With higher dough temperature, the mixing time of flour-water dough reduced, however, more acid solubilizes and reacts with the base in tortilla dough. Thus, the leavening reaction increasingly occurs in warmer dough, which reduces the potential for bubble enlargement during tortilla processing and yields more translucent tortillas (Cepeda, 2000). In addition, hot-press conditions of pressure, time, and temperature directly affect the tortillas. The effects of dwell time and pressure on tortilla quality have been studied by Adams & Waniska (2005). Higher pressure and longer time produced similar opacity, but thinner, larger diameter tortillas. However, hot press temperature has not yet appeared in the literature to determine its influence on flour tortilla quality attributes.

Although the chemical leavening system for refined wheat tortillas are well established, it is necessary to modify the chemical leavening agents and processing conditions in WWF tortillas to improve their opacity and overall quality characteristics given the emerging whole grain market.

Table 2.2: Research studies on the effects of chemical leavening systems on tortilla quality[a]

Author (s)	**Leavening agents**	**Variables**	**Conclusions**
Cepeda et al., (2000)	Acids: SALP, SAS, MCP, SAPP-28, fumaric acid; Base: SBC.	-Type of leavening acids (SALP, SAS, MCP & SAPP-28); - Leavening amount; - Dough temperature (34°C & 38°C)	Tortillas produced with SALP (or SAS) and fumaric acid had higher quality; Increased amounts of acid and base improved opacity and specific volume; Higher dough temperature required more leavening agents for optimum quality.
Adams (2001)	Acid: SALP, Base: SBC	- 4 grades of SBC; - Amount of leavening (optimum, 33% less than optimum, 50% more than optimum); - Hot press pressure; - Hot press dwell time	Higher pressure and longer press time produced thinner and larger diameter tortillas, with a similar volume and opacity; Smaller particle size SBC decreased pH; Increased amounts of SBC increased opacity, but decreased diameter, shelf-life, rollability.
Adams & Waniska (2002)	Acid: MCP, citric acid, SAS, SALP Base: SBC (fine and encapsulated)	- Leavening base type (fine and encap-SBC); - Leavening acid amount (low, medium, high)	Higher amounts of leavening agent by 50% increased opacity, height, but decreased diameter and shelf stability tortillas. Tortillas produced with medium-to-slow acids were thicker, more opaque, but less flexible.
Book et al., (2002)	Acid: SALP, SAPP-28, SAS, MCP, fumaric acid; Base: SBC	- Acid type and combination (SALP, SAPP-28, SAS, MCP, SALP/MCP, SAPP-28/MCP, SAS/MCP); - Type of SBC (grade 1 & a blend)	SALP produced tortillas with the largest diameter, stack height, and less force to break; Tortillas made with SAS had higher weight, smaller diameter, lower stack height and pH, and highest breaking force; MCP produced thinnest tortillas; the combination of other acids with MCP did not affect tortilla size and shape.
Casso (2003)	Acid: SAS & SALP Base: SBC	- Encapsulated & non-encapsulated SBC; - Grades of SBC (grade 1, 2 & 3); - Acid type (SALP & SAS) - Addition of TSPP	Decreased SBC level lead to longer shelf stable, but lower opacity score tortillas; Encapsulated SBC produced improved quality tortillas than non-encapsulated; High opacity tortillas were produced with medium reaction SBC, and slow reaction SBC produced tortillas with unacceptable opacity; SALP and SAS resulted

			in similar quality tortillas; Encapsulated SBC at levels below 3 g/kg with SALP and TSPP improved tortilla quality.
Bejosano & Waniska (2004)	Acid: SAS Base: SBC & ABC	-Different grades of SBC (coarse, regular & fine); - Types of base (SBC, ABC); - Proportion and amount of leaveners	SBC with coarse and regular grades yielded higher quality tortillas; ABC improved tortilla shelf-stability and was acceptable for tortillas; Opacity improved with higher amount of leavening acid and base; the lowest acid-to-base ratio (0.59) produced thicker, higher specific volume, opacity and pH tortillas.
Adams & Waniska (2005)	Acid: SAS Base: SBC	- Hot press time (1.15, 1.35 & 1.55 sec); - Hot press pressure (750, 1150 & 1450 psi)	Thinner tortillas with greater diameter and volume were produced using higher pressure and/or longer press time; tortilla weight, moisture and pH were not affected; less opaque tortillas were produced using 1.15 sec dwell time at 750 and 1450 psi.
Winstone (2010)	Acid: SAPP-28; Base: SBC	- Leavening agent amount (1.0, 1.2 & 1.4%); - Cook temperature (191, 232 & 249°C)	Increased percent of leavening agent produced whiter, smaller, thicker, stronger and tougher tortillas; A higher the cook temperature increased thickness and toughness of tortillas.

[a] Abbreviates: SALP, sodium aluminum phosphate; SAS. Sodium aluminum sulfate; MCP, monocalcium phosphate; SAPP, sodium pyrophosphate; SBC, sodium bicarbonate; ABC: ammonium bicarbonate; TSPP: tetrasodium pyrophosphate.

2.5.5 Sprouted WWF

Although there is no regulated definition of "sprouted grains", according to AACC International, "Malted or sprouted grains containing all of the original bran, germ, and endosperm shall be considered whole grains as long as sprout growth does not exceed kernel length and nutrient values have not diminished. These grains should be labeled as malted or sprouted whole grain." (AACCI, 2016). Historically, Sprouting of wheat was considered as negative due to the increased hydrolytic and proteolytic activity, which degraded carbohydrate and protein into smaller fractions and decreased the functional quality of grain as food. Sprouted grains were under-utilized in baking because of an inferior quality flour processing issues and less than satisfactory end products (Edwards et al., 1989; Sekhon et al., 1995; Shafqat, 2013). Safety issues associated with microbial growth and sprouted seeds might be another reason (Nelson et al., 2013). Accordingly, FDA (1999) developed safety guidelines and recommendations for sprouted seeds.

Sprouting is becoming more popular based on recent scientific evidence linking sprouting with added health benefits (Yang et al., 2001; Plaza et al., 2003; Koehler et al., 2007; Van Hung et al., 2011; Azeke et al., 2011; Dziki et al., 2015). Yang et al. (2001) found that the concentrations of vitamins C and E, β-carotene, ferulic acid and vanillic acid steadily increased with increasing germination time and reached their peaks after 7 days at 550 μg/g for vitamin C, 10.92 μg/g for α-tocopherol, 3.1 μg/g for β-carotene, 932.4 μg/g for ferulic acid and 12.9 μg/g vanillic acid, compared to barely detectable amounts of vitamins C and E, β-carotene in dry wheat grains. Another study showed an increase in vitamins (A, B_1, B_2, B_6, C and E), minerals (Fe, Mg, Ca, Cu, Fe and Zn) and phytoestrogens during sprouting (Plaza et al., 2003). Sprouting has been shown to reduce the content of phytic acid in wheat due to increased phytase activity by 6-fold at day 8 (Azeke et al., 2011). What's more, Hung et al., (2011) concluded that sprouted wheat exhibited better nutritional properties with increased phenolic compounds and antioxidant activity than un-germinated wheat, and they suggested the sprouted wheat could be used to improve the nutritional value in food products. Therefore, incorporating sprouted WWF into grain products meets the desires of health conscious consumers related to more WG options, along with the added nutritional values to food.

Sprouting procedures for producing sprouted WWF include three major steps: steeping, germination and kilning. Carefully selected wheat is steeped in water under precise and controlled conditions of time and temperature, and then the wheat starts to germinate or sprout with circulated humid air to control growth. During the kilning step, the wheat grain is circulated by warm air to dry and develop flavor and color. Finally, the sprouted wheat is milled into WWF (Hübner & Arendt, 2013; Richter et al., 2014). The sprouting / germination conditions, such as temperature, humidity, soaking duration, sprouting time all have effects on chemical composition and quality of flour (Singh et al., 2001; Shafqat, 2013). In terms of the effects of sprouting on product baking performance, Table 2.3 shows several studies in the literature regarding the baking performance of sprouted wheat. Less controlled sprouting, such as pre-harvest sprouting or over sprouting, adversely affected wheat product baking, and yielded bread with sticky dough and inferior texture (Ariyama & Khan, 1990; Every & Ross, 1996). Historically, unintentional wheat sprouted was not seen as a benefit, but rather an unintended consequence of the grain handling and storage process. Based on a review of studies presented in Table 2.3, sprouting resulted in severe product defects, such as darker color noodles (Edwards et al., 1989; Hatcher & Symons, 2000), smaller loaf volume and increased staling of bread (Morad & Rubenthaler, 1983), and decreased volume and appearance scores for cakes and cookies (Lorenz & Valvano, 1981). However, other studies (Shneider et al., 2009; Shafqat, 2013; Richter et al., 2014) found that with suitable and controlled conditions, sprouting would bring benefits to product quality (i.e. higher loaf volume, better texture, and improved sensory scores for bread, higher elasticity and plasticity for pasta).

Sprouted wheat has been studied to produce bread, noodles, cakes and cookie products, whereas, little research has been conducted to examine sprouting effects on tortilla products. Each end product has its own requirements for flour properties, so it is necessary to understand the feasibility of using sprouted wheat to produce sprouted WWF tortillas.

Table 2.3: Research studies on baking performance of sprouted wheat

Author (s)	End-product	Variables	Conclusions
Morad & Rubenthaler (1983)	Bread	Germinated for 20hr, 36hr, vs. control	Germination decreased dough mixing time and water absorption. The 20hr germinated flour produced good quality bread with good loaf volume and soft crumb. Insufficient or excess sprouting (amylase activity) increased crumb firmness and staling.
Edwards et al. (1989)	Cantonese and Korean noodles, pan bread, Arabic flat bread	Simulated rain-damaged wheat vs. control	Sprouting resulted in severe product defects (darker color) in Cantonese and Korean noodles; Lesser but still deleterious effects (smaller size, less symmetrical and smooth, darker in crust color with more blisters) on Arabic flat bread; the quality of pan breads made from sprouted grains was better than control, with increased water absorption, higher loaf volume.
Hatcher & Symons (2000)	Alkaline noodle	Sound vs. sprout damaged patent flour	A higher degree of sprout damage increased the number, size and darkness of discolored spots than control sound flour.
Lorenz & Valvano (1981)	Cake and cookies	Sprouted time: 1, 2, and 4 days	Longer sprouting time showed a detrimental effect on cake volume, external and internal cake characteristics with a coarse grain and a dense and firm texture; Cookies made from longer sprouted flour had higher spread factors, grain scores, darker color, and lower appearance and texture sensory scores.
Shneider et al. (2009)	Pasta	Sprouted whole-wheat vs. whole	Pasta made from sprouted wheat had lower water absorption capacity, lower cooking water

		wheat	free starch, higher plasticity and elasticity.
Shafqat (2013)	Bread	Addition percent of sprouted wheat flour post five days germination: 1%, 5%, 10% & 15%	Bread made with 1% and 5% sprouted wheat flour had increased volume, better texture, and longer shelf life than 10% and 15%; 2.2×10^3 and 11×10^3 unit of α-amylase activity per 100g flour were optimal for developing naturally shelf stable and better quality bread.
Richter et al. (2014)	Bread	Sprouted WWF vs. nonsprouted WWF	100% sprouted WWF resulted in longer farinograph stability, increased mixing tolerance, shorter proof time, increased bread loaf volume (5-9% increase), and improved sensory results (less bitterness) compared to nonsprouted WWF.
Feldpausch et al. (2015)	Bread	Concentrations of sprouted WWF: 0%, 30% & 50%	No significant difference in loaf volume; moderate additions of sprouted WWF (30% or 50%) could lengthen shelf life and increase crumb softness.

CHAPTER 3

FACTORS INFLUENCING THE USE AND CONSUMPTION OF BROWN RICE IN CHINESE RESTAURANTS

This chapter is modified from the published paper:

Liu, T., Wang, X., & Marquart, L. (2016). Factors influencing the use and consumption of brown rice in Chinese restaurants. *Journal of Foodservice Business Research*, *19*(1), 77-88.

Abstract

The objective of this study was to examine factors influencing current use and consumption of brown and white rice in Chinese restaurants. Thirty Chinese restaurants were selected from the Twin Cities metro area to participate in the study. Face-to-face or phone interviews, based on a questionnaire were conducted with a manger/owner of each restaurant. Plate waste observations were used to examine consumption for brown rice consumers (n=200) and white rice consumers (n=153) in a chain-Chinese restaurant. Data were analyzed using a t-test and analysis of variance. Results indicated that in 15 of the total restaurants, both brown and white rice were served. The main motivator for serving brown rice was to attract health conscious consumers, while low customer request was the major constraint for non-use. Authentic/family-owned restaurants were less likely to serve brown rice than chain restaurants. Brown rice (85%) consumption was significantly higher than white rice (79%) (P=0.02), based on an average serving size of 8.7 oz. These results suggest that the availability of brown rice in restaurants increase consumption among brown rice eaters.

3.1 Introduction

Although restaurants provide tasty, convenient and often highly desirable foods, they are frequently associated with excess caloric intake and poor diet quality. This can lead to increased risk for obesity, certain cancers, diabetes, and other health problems (Lin & Guthrie, 2012; Todd et al., 2010). As eating food away from home (FAFH) becomes more popular and poses a threat to the health of Americans, more consumers are seeking more nutritious foods in restaurants. According to a survey by the National Restaurant Association, 72% of consumers reported they are more likely to visit a restaurant if it offers healthful options (NRA, 2014a).

Prepared FAFH play a significant role in shaping the way Americans eat. About 26% of the total food budget was spent on FAFH in 1970, and the percent increased to 43% by 2012 (USDA, 2013). What's more, the restaurant industry is predicting 683.4 billion dollars in sales for 2014, which accounts for 47% of the food dollar spent by Americans (NRA, 2014a). The average monthly restaurant sales from July 2013 to January 2014 was over 45 billion (NRA, 2014b). According to the 2014 Restaurant Industry Pocket Factbook, 9 of 10 consumers enjoy going to restaurants, and 40% believe restaurants are an essential part of their life (NRA, 2014a).

Increasing the use of whole grain foods in restaurants can be a win-win strategy. On one hand, chefs can improve the quality of restaurant menus by introducing tasty whole grain dishes offering greater menu variety with additional health attributes. On the other hand, from a public health perspective, increased availability of whole grain foods may help to achieve recommended intakes of whole grain foods in the U.S. population. There are only about 61 chain restaurants and 44 fine dining and independent restaurants across the United States offering whole grain foods to consumers, including whole grain bread, tortilla, brown rice, and whole grain dough on pizza, whole grain spaghetti and so on (Whole Grains Council, 2014b,c). Given an estimated 616,008 restaurants in the U.S. in 2013 (NPD Group, 2013), few chain and independent restaurants serve whole grains; thus, it is far from sufficient to improve diet quality among Americans. Additionally there is little research in the literature related to understanding and promoting whole grain use in restaurants.

Epidemiologic studies provide evidence that diets high in whole grains are associated with reduced risk of type 2 diabetes (Anderson et al, 2007; Montonen et al., 2003; Murtaugh et al., 2003), cardiovascular disease (Slavin, 2007; Seal & Brownlee, 2010), certain types of cancers (Jacobs et al., 1998, McIntosh, 2007) and obesity (McKeown et al., 2007; Williams et al., 2008; Vijver et al., 2009).

The 2010 Dietary Guidelines for Americans recommend that U.S. citizens consume at least half of their total grains as whole grains, which equates to at least three ounce-equivalents of whole grains per day (USDHHS & USDA, 2010). Despite this recommendation, data from the US Department of Agriculture (USDA) showed that Americans consumed an average of 0.79 servings of whole grains per day in 2009-2010, far below the recommended three ounce-equivalents (USDA, 2012). Moreover, the updated results from 2009-2010 National Health and Nutrition Examination Survey (NHANES) showed that only 2.9% children/adolescents (2-18 years old) and 7.7% adults (older than 18 years old) consumed at least three ounce-equivalents of whole grains (Reicks et al., 2014). Barriers to whole grain consumption include the texture, flavor and appearance, limited knowledge of whole grain foods by consumers, longer preparation time, higher cost and lower availability in foodservice settings (Adams & Engstrom, 2000; Jetter et al., 2006). Additionally, little research has been conducted to directly examine these proposed barriers among adults and children. Therefore, a greater understanding of these barriers should be undertaken to identify steps that might improve whole grain consumption among U.S. citizens.

As one of the “big three” mainstream ethnic cuisines in the American foodservice market, Chinese restaurants are popular, convenient and good value for the price (Liu & Jang, 2009). According to Chinese Restaurant News (2011), there were over 43,139 Chinese restaurants in the U.S., which is more than the number of McDonald’s, Burger Kings, Wendy’s, Domino’s, and Pizza Huts combined (OMGFACTS, 2011). This is further documented as 90% of Americans have tried Chinese food and 63% consumed Chinese food every month (George et al., 2000). Based on the popularity of Chinese cuisine and the large number of Chinese restaurants in the U.S., the availability of whole grain foods in these restaurants may help increase whole grain consumption in the U.S. population.

Compared to other whole grain foods, brown rice is more easily accepted by both Chinese restaurant operators and consumers, since rice is a major staple food and is widely consumed by the world’s population, particularly of Asian descent. However, there is little research regarding brown rice use in restaurants, especially in Chinese restaurants.

Plate waste, a tool to examine food intake, has been used in recent studies to examine the consumption of whole grain foods in school settings. Chan et al. (2008) compared the acceptability of a 50:50 blend white whole wheat and refined wheat flour pizza in children and found that there was no difference in consumption. Tritt et al. (2015) conducted plate waste in a restaurant setting to examine the acceptance of whole grain pizza crust among children. Their results showed that children consumed as much of the whole grain crust as the refined grain crust (p=0.55). Given the success of the plate waste method in examining the acceptance of some whole grain products, this method can be used for other whole grain products, such as brown rice, and whole grain noodles.

The purpose of this study was to: 1) Examine the current situation regarding whole grain use and factors that influence future whole grain use in Chinese restaurants. 2) Compare the acceptability of brown and white rice in a restaurant setting.

3.2 Methods

3.2.1 Subjects

Our convenience sample was selected from the Dex online commercial listing of about 200 Chinese restaurants in the Twin Cities metropolitan area between April and June 2013. A total of 30 Chinese restaurants were selected by Internet and phone calls, based on their location, the availability of whole grains, the type of restaurants (chain/family-owned), and their willingness to be interviewed. Selected restaurants were located in various regions throughout the Twin Cities metropolitan area, among which 15 restaurants had whole grains available on their menu, while 15 did not serve any whole grains.

For the plate waste study, 353 participants ranged in estimated age from 10 to 80 years who visited one of three Panda Express locations (Maplewood Mall, Apple Valley and Southdale Center) between 11am and 7pm from July 2013 to August 2013. In order to decrease the observation error, only consumers who selected two-entrée meals were observed, while consumers with a kid's meal, bowl meal or take-out were excluded. Customers who consumed either fried brown rice (n=200) or fried white rice (n=153) were unaware that they were being observed and no identifying data were collected. This study was approved by the Institutional Review Board at the University of Minnesota.

3.2.2 Procedures

3.2.2.1 Interviews

Face-to-face or phone interviews were conducted with a manager or owner of each restaurant based on availability of interviewees. The interviews were conducted by a two-member team, with one asking questions and the other recording data. Each manager or owner was asked ~10-20 questions regarding whole grain use, primarily including motivations, preparation, serving methods, cost, sales and profits, reasons for non-whole grain use, and the possibility of serving whole grains. All the interview questions were developed for use in a semi-structured format in order to encourage free-flowing discussion. The questionnaire is shown in Table 3.1.

Table 3.1**:** Interview questions

Starting time/motivations	Rice distributors
Cooking techniques	Frequency of cooking
Storage	Serving methods
Prices	Sales and profits
Reasons for no whole grain use	Possibility of using whole grains
Pros and cons of whole grains	Thoughts for new dishes
Market understanding	Future cooperation

3.2.2.2 Plate waste observations

Plate waste observations included practice or pilot sessions conducted at Panda Express restaurants prior to data collection to establish baseline mean serving sizes and accuracy of observation. The lead author was the only observer in this study. About 100 observations were conducted to test the methods and observation forms in the pilot study. The mean serving size of fried rice, including both brown and white rice, was determined using three servers who each weighed 10 rice samples. A total of 30 servings were weighed and averaged.

In addition, the accuracy of observation was also assessed. One server placed a specified amount of rice using a 4*3-inch spoon on the 9-inch plate, which was divided evenly for rice and entrees. The observer monitored the plate and estimated the percentage of rice accounted for, which was the observed percentage of waste. Then the rice waste was weighed. The absolute difference between observed and weighed percentage of rice was the error of observation. The mean error was determined based on 28 assessments.

During restaurant data collection, both fried brown rice and fried white rice were offered to consumers on the serving line. The estimated age, gender and other features of a subject who ordered either fried brown rice or fried white rice were recorded. Once the subject was targeted, the rice type was confirmed, while type of entrees was recorded near the end of the serving line. There were 21 different types of entrées, which were not included as a part of the analysis. The subjects' plates were observed from a safe distance unbeknownst to them, and after choosing their seating location in the dining area. Once the subject finished their meal, the rice and entrees remaining on the plate were observed and estimated for waste percentages.

3.2.3 Data analysis

The absolute number and percentages from interviews were calculated and displayed in graph and tabular form. The plate waste data were analyzed using a t-test and analysis of variance (ANOVA) by RStudio version 3.0.1, at a significance level of 0.05.

3.3 Results and discussion

3.3.1 Interviews

Both chain/franchised and family-owned/authentic Chinese restaurants were selected for participation in this study. Among the 15 Chinese restaurants serving whole grains, nine of them were chain/franchised, and six were family-owned or authentic restaurants. However, 13 Chinese restaurants were family-owned or authentic among the 15 restaurants with non-whole grain use. Additionally 14 Chinese restaurants served brown rice, while only one restaurant served whole grain bread. Since brown rice was the predominant type of whole grain food used in these restaurants, most interview questions were related to brown rice.

Among the 15 restaurants that served whole grains, two started serving whole grains between 1990-1999, and seven of them between 2000-2010. Six Chinese restaurants added whole grains to their menus within the past three years.

Factors influencing the service of whole grains, related to motivators and constraints can be viewed in Figure 3.1. In terms of motivators, among the 15 restaurants that served brown rice, 60% wanted to attract more health conscious consumers, and 40% served it due to customer request. Other motivators include providing more options, Americanizing foods and popularity of brown rice. For 80% of restaurant managers or owners that did not serve whole grains, they believed low customer request was the greatest constraint. They stated that in general over 100 customers per week must request brown rice in order to justify service in Chinese restaurants. The second major constraint in serving whole grains is the cost of brown rice, compared with white rice (Figure 3.2). Of the 14 restaurants that served brown rice, 12 had a higher purchasing price for brown rice, while only two restaurants mentioned that their costs for brown rice were lower than white rice. The price difference of raw brown rice ranged from pennies to 10% per pound higher than white rice, depending on the distributor. The cost of purchasing raw brown rice influenced the selling price of cooked brown rice. Cooked white rice was always included with main entrees, however, the cost of the cooked brown rice option varied by restaurant. Nine of the 14 Chinese restaurants maintained the same selling price for both brown and white rice, while others charged 50¢, 75¢, $1 or $2 more for the brown versus white rice.

Other constraints of concern by these managers and owners included a preference for traditional Chinese foods, complexity of serving whole grains, little interest in changing menus, not enough kitchen and equipment space to cook brown rice, and limited knowledge about whole grains.

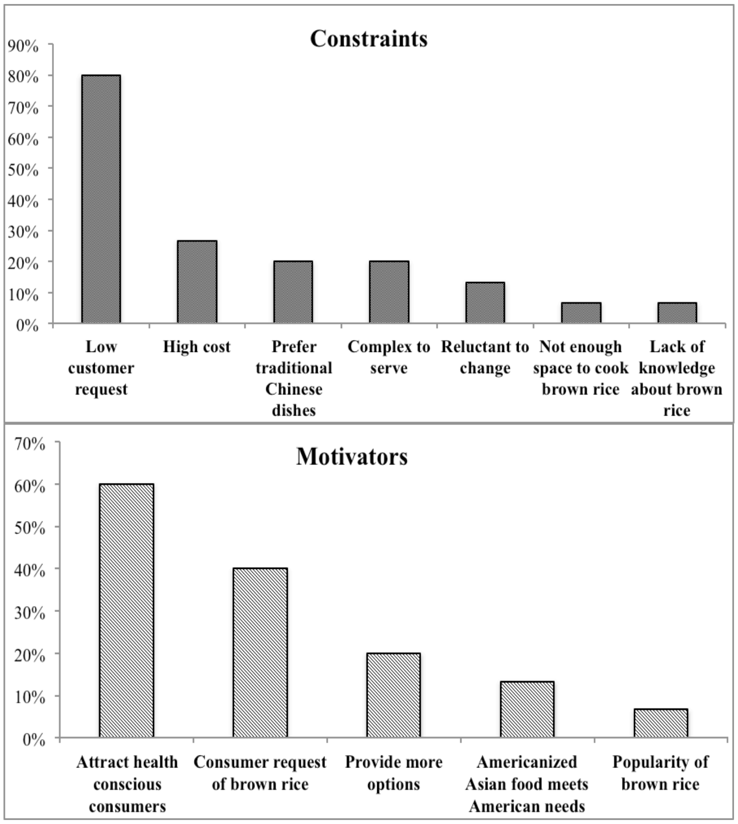


Figure 3.1: Factors influencing the service of whole grains

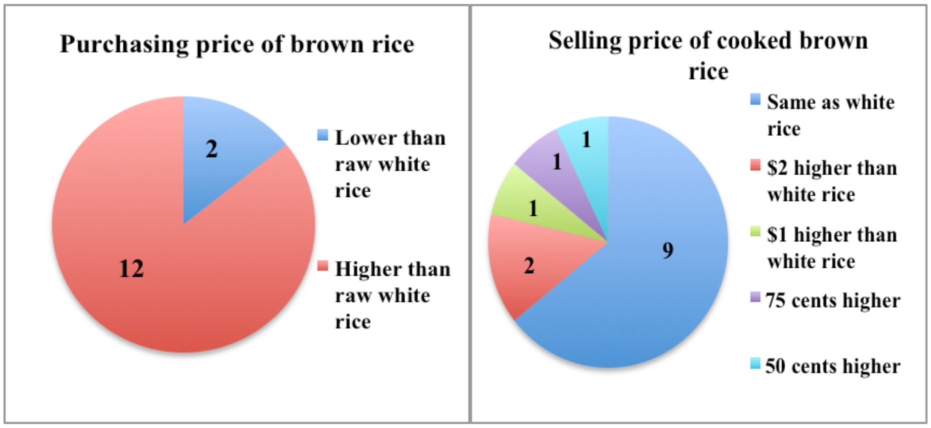


Figure 3.2: Purchasing price of brown rice for restaurants and customers

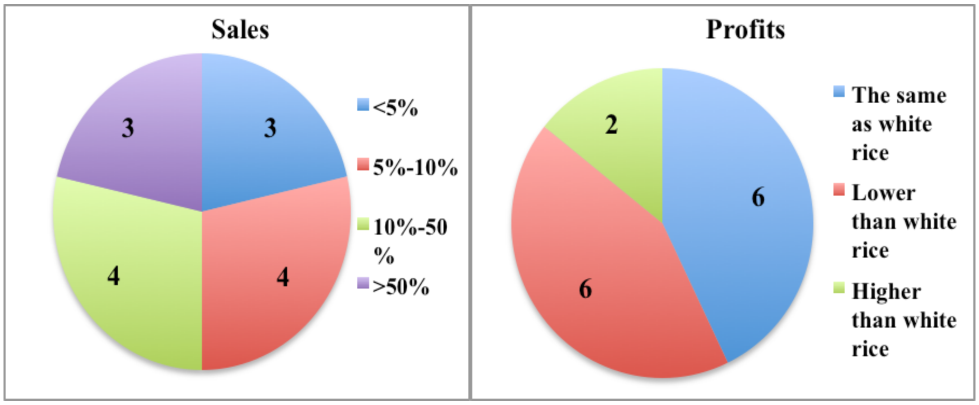


Figure 3.3: Sales and profits of selling brown rice

Sales were measured by the percentage of consumers who ordered brown rice per day, based on manager or owner response (Figure 3.3). Three Chinese restaurants reported higher sales with over 50% of customers ordering brown rice versus white rice per day. Four restaurants had moderate sales ranging from 10-50%, and seven with less than 10% of sales. Potential factors that influenced sales of brown rice included location, number of years serving, brand identity, special dishes, selling price and cultural differences. The Chinese restaurants near the university area had lower sales with the hypothesis that fewer youth and young adults chose whole grain foods, while restaurants located in areas of middle and upper class consumers tended to have higher sales. This might be attributed to higher income and more educated people being more likely to pursue healthier foods. Restaurants that served whole grains for more years were associated with higher sales. The two Chinese restaurants that served brown rice for more than twenty years sold more of this type of rice than other restaurants. Besides years of availability, the type of restaurant (e.g. up scale, white-table cloth, fast or casual) also affected brown rice sales. Some restaurants, such as P F Chang and Panda Express partially base their reputation on selling brown rice. These restaurants are highlighted by the Whole Grain Council as chain restaurants that serve whole grains and are well known establishments by most health conscious consumers (Whole Grains Council, 2014b). Special dishes, such as vegetarian items were usually combined with whole grain foods.

Price had an influence as higher price may have discouraged customers from ordering whole grain foods. In one restaurant, a $2 price difference between brown and white rice was a significant reason for lower sales, based on the manager's response. Moreover, the cultural differences between American and Chinese customers also influenced sales of whole grains. According to the response from the managers and owners, American consumers ordered more brown rice than Asian consumers since Asian consumers are traditionally used to eating white rice.

Restaurant operators considered profit as a major factor in their decision to serve whole grains (Figure 3.3). Based on the managers' or owners' responses, six Chinese restaurants had the same profits for brown rice as for white rice, while six restaurants had lower profits for brown rice. On the other hand, two restaurants pointed out that their profits were higher due to higher brown rice sales; thus, they were willing to continue service. Some chain restaurants chose to serve brown rice in order to offer healthy options to consumers, although their profits for selling brown rice were lower than white rice.

As to managers' or owners' understanding of the disadvantages of serving brown rice, about 27% mentioned that low customer request for brown rice was a definite disadvantage. Other disadvantages included harder texture and flavor, higher price, longer cooking time, difficulty in maintaining freshness, food waste, more complex cooking technique, excess dish (menu) options for consumers and Atkins diet preference for lower carbohydrate meals. Furthermore, the managers and owners understanding of the Chinese food service market was examined. About 63% had no knowledge of which Chinese restaurants served whole grain foods, and about 13% assumed that few Chinese restaurants used whole grains. About one-quarter of managers and owners could point out one or two Chinese restaurants that served whole grains.

Lastly, among the 15 Chinese restaurants with non-whole grain use, their future interest in serving whole grains was examined based on a scale of 1-5, where level 1 equates to low interest and level 5 = high interest. Ten managers/owners showed low interest in future use of whole grains. Four had moderate interest in using whole grains and would base their decision on customer request. And only one showed a comparatively high interest because the owner's personal preference for brown rice influenced his customers, which suggests manager/ owner interest could make a considerable difference. What's more, the managers/ owners indicated that since students and children tended to consume less whole grains, restaurants near school areas have less interest in use.

3.3.2 Plate waste observations

In total, there were 200 brown rice consumers (99 females and 101 males) and 153 white rice consumers (85 females and 68 males) that were observed in this study. Among the 200 brown rice eaters, 22 were estimated to be 10-20 years, while 123 ranged in age from 20-40 years occupying the largest age category. Consumers were diverse in ethnicity ranging from a majority being White, along with some Black and Asian Americans.

The mean serving size for rice was 8.7 oz., excluding the plate weight. The error rate of observation was 5.7%, which was lower than the acceptable error rate (5% -15%)(Tritt et al., 2015). Thus, the observation results for plate waste were relatively accurate. After adjusting for age and gender, the mean percentage for brown rice waste (15.1%) was significantly lower than white rice waste (20.9%), with a p-value of 0.02, which showed that brown rice consumption for brown rice eaters was higher than white rice consumption among white rice eaters (Figure 3.4).

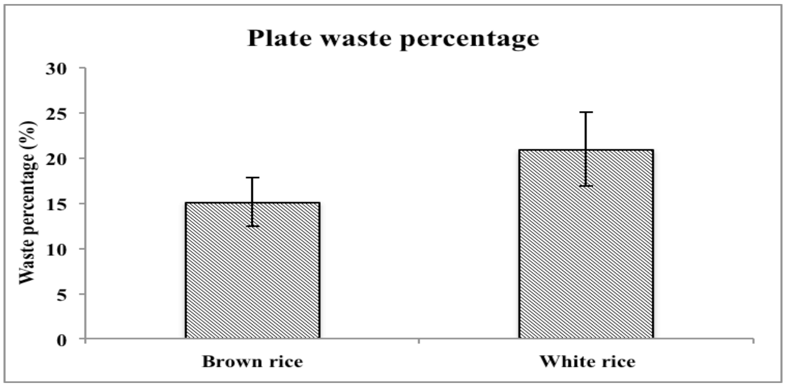


Figure 3.4: Plate waste result

There were some limitations in this study. The 30 restaurants selected in the interviews consisted of a convenient sample instead of a randomized sample, which suggests some bias may exist. Plate waste participants were selected based on their preferred type of rice, which failed to address the situation of feeding brown rice to the general population of rice eaters and subsequently observe their plate waste. The plate waste data were collected on fried rice, while the results may be different when served in the form of steamed rice. What’s more, future studies regarding brown rice consumption should be conducted in more restaurants, either chain or family-owned restaurants, since this study only collected the plate waste data in one chain Chinese restaurant.

3.4 Conclusions

The primary objective of this study was to examine the current use of whole grains and factors that influence future whole grain use in Chinese restaurants. Authentic/family-owned Chinese restaurants were less likely to serve whole grains than chain restaurants. In addition, factors with a potential influence on sales of brown rice included location, years of service, restaurant brand identity, special dishes, selling price and cultural differences. The secondary objective of this study was to compare the plate waste of brown and white rice and examine the consumption of brown rice in a restaurant setting. The results showed that the availability of brown rice in restaurants increased the consumption of brown rice among brown rice eaters. The results suggest that increasing consumers’ awareness to request more whole grains in restaurants might contribute to higher availability and consumption. Furthermore, additional efforts throughout the food system are necessary to develop and deliver more affordable whole grain products to restaurants, such as brown rice and whole grain noodles that are highly acceptable by Chinese restaurant clientele.

3.5 Implications and future prospects

This study has significant strength of novelty and offers some key benefits for future studies. To our knowledge, it is the first study to target restaurants as a potential site to examine the use of brown rice, along with the measurement of brown rice consumption in restaurants. Firstly, the plate waste observation method has been used mainly in school cafeterias, from this study, we know that it can also be used in restaurants, which is necessary to document how much food people consume in restaurants.

Secondly, the results address current challenges and opportunities of introducing whole grain foods into the food system with a focus on the restaurant environment. Restaurants are a strategic point to introduce whole grains, and whole grains such as brown rice, which appear to work well in restaurants, especially among those health conscious consumers. The results demonstrate to supply chain members about a variety of approaches to increase whole grain consumption, not only by improving the taste and quality of whole grain products, but also educating restaurants operators about the knowledge of preparing whole grains and augmenting health as a point of difference as a key marketing strategy. This suggests that we need to learn how to prioritize, focus and strategically apply our efforts around the introduction of whole grain foods and ingredients within the food system and restaurant environment.

Lastly, by prioritizing and carefully focusing on critical gaps in the food system, we can leverage our research efforts to increase whole grain consumption in restaurants. Further research should be conducted to enhance the efficiency and serving capacity for whole grains in restaurants.

CHAPTER 4

EFFECTS OF PARTICLE SIZE ON THE QUALITY ATTRIBUTES OF RECONSTITUTED WHOLE-WHEAT FLOUR AND ITS TORTILLA PRODUCTS

This chapter is modified from the manuscript:

Liu, T., Hou, G. G., Lee, B., Marquart, L., & Dubat, A. (2016). Effects of particle size on the quality attributes of reconstituted whole-wheat flour and its tortilla products. Journal of Cereal Science. *Under review*.

Abstract

The objective of this study was to examine the effects of whole-wheat flour (WWF) particle size on the quality attributes of WWF tortillas. WWF samples of different particle size distributions from commercial U.S. hard white (median diameters: 175.7, 128.6, 120.0, 108.5 and 102.4 µm), hard red winter (median diameters: 173.7, 133.6, 124.3, 110.8 and 104.2 µm) and hard red spring (median diameters: 173.7, 132.1, 124.7, 112.9, 106.3 µm) wheat classes were obtained by fine grinding of bran and shorts and re-combining with the rest of fractions. For all three wheat classes, as WWF median particle size decreased, the L* (lightness) value decreased but the adjusted damaged starch, polyphenol oxidase activity, and a* and b* values increased. Mixolab data showed that development time decreased as WWF particle size was reduced, while stability time and starch retrogradation increased. As for WWF tortilla quality, the breaking force and extensibility increased with decreasing particle size from 174-176 to 129-134 µm, but diameter and thickness were not significantly affected. The results indicated that reducing the median particle sizes of WWFs from ~175 µm to ~130 µm would significantly improve the WWF tortilla quality.

4.1 Introduction

Tortilla is a thin Mexican flatbread made from wheat flour or corn, with excellent versatility for use in many dishes. As the fastest-growing bakery product in the U.S. market, tortillas are more popular than other types of ethnic breads in America (TIA, 2016). Tortillas, burritos, and tacos account for about 8% of refined grain consumption in the diets of U.S. population (USDA & USDHHS, 2010). Given that Americans are recommended to consume at least half of their grains as whole grains (USDHHS & USDA, 2015), incorporating whole-wheat flour (WWF) into tortillas is a practical approach to introduce more whole grains into the American diet and potentially increase whole grain consumption. Although WWF can provide more health benefits (Marquart et al., 2007), the high bran content presents many quality challenges in WWF tortillas, for instance, the larger the flour particle size, the harder and less extensible dough, and less shelf-stable tortillas (Barros et al., 2010). Therefore, strategies designed to improve the quality of WWF tortillas will certainly draw the attention of food manufacturers.

Milling is an important step in WWF production. While the milling procedures for refined wheat flour are well established, there is no standard method available for WWF (Doblado-Maldonado et al., 2012). Different milling techniques (e.g., stone, roller, hammer, and plate milling) result in flour with various particle sizes and functionalities (Prabhasankar & Rao, 2001). More specifically, wheat bran particle size is a critical component in WWF milling, due to its considerable influence on dough properties and quality of finished products, such as breads, noodles, crackers, and pastas (Noort et al., 2010; Chen et al., 2011; Li et al., 2012; Niu et al., 2014a; Cai et al., 2014; Steglish et al., 2015; Wang et al., 2016).

To our knowledge, it is largely unknown how the WWF particle size affects the tortillas quality, especially on 100% WWF tortillas. Several researchers have reported the effects of refined wheat flour or barley flour particle size on tortilla. Wang & Flores (2000) sieved and separated refined flours from hard red winter (HRW), hard white winter (HWW), and soft red winter (SRW) into four different particle size fractions (<38, 38-53, 53-75 and >75 µm). They found that tortillas made from the medium fractions (38-75 µm) of HRW and HWW had higher protein content, longer tortilla rupture distance and better foldability than the finest (<38 µm) or coarsest (>75 µm) fractions. However, for SRW flour, protein content increased with the increase in particle size, and tortillas made from <53 µm fractions had longer rupture distance. Mao & Flores (2001) found that as refined flour geometric mean diameter particle size decreased from 63.9 to 34.2 µm (flour 1), and from 71.2 to 37.7 µm (flour 2), the flour tortillas became less stretchable, firmer, but more rollable. Prasopsunwattana et al. (2009) enriched wheat tortillas with whole barley flour (WBF) of three different average particle sizes (237, 131 and 68 µm). With a smaller WBF particle size, protein, moisture content, and mixing stability decreased, while starch content, water absorption, and farinograph peak time increased.

Therefore, it is necessary to examine the particle size effect on the quality of WWF tortilla products given the emerging whole grain market. Results will provide millers and tortilla manufacturers with scientific evidence of a more optimal flour particle size range to improve the quality of WWF tortilla products. The aims of this study were to produce WWFs of different particle sizes, and to examine the particle size effects on flour properties and WWF tortilla baking performance.

4.2 Materials and methods

4.2.1 Materials

Three U.S. wheat classes, hard red spring (HRS), hard red winter (HRW), and hard white (HW) commercial wheat samples were kindly provided by the Federal Grain Inspection Service (FGIS, Portland, OR) and Ardent Mills™ (Denver, CO). Protein contents of HRS, HRW, and HW wheat were 14.4%, 11.6%, and 12.4% (12% mb), respectively. Calcium acid pyrophosphate (Levona Brio®) was offered by ICL Food Specialties (St. Louis, MO). Sodium bicarbonate (powder ACS) was purchased from ChemProducts (Portland, OR). Salt, Crisco vegetable shortening, and sugar were purchased from a local supermarket (Portland, OR). Sodium stearoyl lactylate (SSL) was from Corbion (Kansas City, KS). Potassium sorbate and calcium propionate were obtained from Muhlenchemie GmbH & Co KG (Ahrensburg, Germany).

4.2.2 Reconstituted WWF preparation

The procedures for preparing reconstituted WWFs are shown in Figure 4.1. Three wheat samples were each tempered to 16% moisture level in two steps (15.5% + 0.5%) and milled into straight-grade (SG) flours of 69.93g/100g for HRS, 71.64g/100g for HRW, and 73.58g/100g for HW extraction rates on a pilot-scale Miag Multomat mill (Buhler, Inc., Braunschweig, Germany) at the Wheat Marketing Center (Portland, OR). Bran, shorts, and red dog fractions were collected and weighed. Yield of each fraction was expressed by the percent of its weight in the total recovered product weight.

After milling, the bran and shorts were dusted using a laboratory bran finisher (Model MLU-302, Buhler Inc., Braunschweig, Germany) to remove attached flour from them. Then bran and shorts were each ground 1 to 4 times using a Perten 3100 laboratory mill (Perten Instruments, Hägersten, Sweden). To obtain a finer particle size fraction, 4th grinding bran and shorts were each ground with a blender (Vitamix Corporation, Cleveland, OH) prior to further fine grinding for the 5th time in the Perten 3100 laboratory mill. Since there was very small difference in flour particle size when grinding 3 or 4 times, these two treatments were combined as one sample - 4th grinding. Afterwards, non-ground, 1st, 2nd, 4th, and 5th grinding bran and shorts were combined with bran-dusted flour, shorts-dusted flour, red dog fraction, and SG flour, based on their original yields during milling to obtain reconstituted WWFs (WWF-0, 1, 2, 4 and 5).

Fifty grams of each reconstituted WWF was separated by a Ro-Tap testing sieve shaker (Model R-30050, W.S. Tyler®, Mentor, OH) for 20 min using 45, 75, 106, 150, 212, 300 and 500 µm sieves, and the remaining weight on each sieve was recorded. The mass median particle diameter (µm) of each WWF was calculated by the sum of each sieve average particle size (µm) multiplied by relative particle weight percent (%) (Penella et al., 2008).

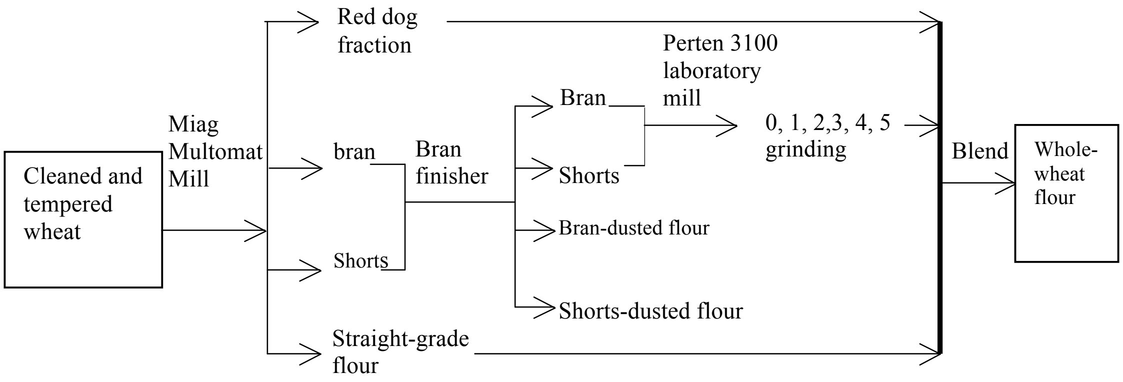


Figure 4.1: Flow chart of preparing reconstituted whole-wheat flour (WWF) of different particle sizes. 0, 1, 2, 3, 4, 5 grinding: bran and shorts were separately ground for 0, 1, 2, 3, 4, and 5 times.

4.2.3 WWF analysis

The damaged starch (AACCI 76-30.02) and total starch (AACCI 76-13.01) contents of WWF and SG flour were determined according to the AACC International Approved Methods. In order to eliminate the influence of bran and germ in WWF, adjusted damaged starch (DS/TS) was expressed as the percent of damaged starch (DS) in the total starch (TS). Flour color was measured using a Minolta Colorimeter (Model CR-410, Konica Minolta Sensing, Inc., Japan) according to the AACCI Method 14-30.01.

The polyphenol oxidase (PPO) activity of WWF and SG flour samples was determined following the methods described by AACCI 22-85.01 and Niu et al. (2014a), with some modifications. A 0.1g WWF sample was placed in a standard 15 mL centrifuge tube containing 10 mL of 10 mmol/L L-DOPA (L-dihydroxyphenylalanine) made up in 50-mmol/L MOPS buffer (pH=6.5). After being stirred on a touch stirrer (Model 232, Thermo Fisher Scientific, Waltham, MA) for 10 s, the slurry was incubated on a rotating shaker (10 r/min) (Labquake Model 415110, Barnstead/Thermolyne, Dubuque, USA) at room temperature for 1 h. Following incubation, the slurry was centrifuged (Model Heraeus megafuge 16 centrifuge, Thermo Fisher Scientific, Waltham, MA) at 5,000 × g for 15 min. A spectrophotometer (Model Spectronic 20D, Milton Roy Company, Warminster, PA) was used to measure the absorbance of the supernatant at 475 nm. The blank sample was analyzed with 10 mL MOPS buffer only. The PPO activity was calculated as the absorbance difference between the WWF sample and the blank sample, and defined as ΔA_{475}/hr•g flour.

In order to measure the rheological behavior of WWFs and SG flour that were subjected to both mixing and heating conditions, the Mixolab analyzer (Chopin Technologies, Villeneuve-La-Garenne, France) was used according to the AACC International Approved Method 54-60.01. The parameters obtained from the Mixolab included the percent of water required for the dough to produce a torque of 1.1 ± 0.05 Nm (water absorption, %), the time to reach maximum torque at 30°C (dough development time, min), the elapsed time that the torque was kept at 1.1 Nm (stability, min), starch gelatinization (C3, Nm), stability of the hot-formed gel (C3-C4, Nm), and starch retrogradation during the cooling phase (C5, Nm) (Huang et al., 2010).

4.2.4 WWF tortilla preparation

The tortillas were produced on pilot-scale tortilla plant equipment. SG flour or WWF (1000 g), salt (15 g), sugar (5 g), shortening (70 g), calcium acid pyrophosphate (18 g), sodium bicarbonate (10 g), SSL (5 g), potassium sorbate (4 g), calcium propionate (5 g), and water were weighed. Different amount of water for each sample was added based on the water absorption data from the Mixolab and dough handling properties. All ingredients were mixed in a spiral mixer (Model SM-25, American Baking Systems, Inc. Cedar Rapids, IA) for 2 min (SG flour) or 4 min (WWFs) at 1st speed and for 5.5-8 min at the 2nd speed until the dough fully developed. 1,400 g of dough was weighed and rested for 15 min at room temperature before being flattened on the Dutchess Divider/Rounder tray (Model JN-3, Dutchess Baker's Machinery Co. Inc. Superior, WI) with uniform thickness. The flattened dough was covered and rested for 5 min before being divided and rounded into dough balls (40 g each). Then the dough balls were put in a covered box for proofing (20 min). Afterwards, the dough balls were hot-pressed by an automatic tortilla press (Model Wedge Press, Bakery Equipment & Service Co., San Antonio, TX) with the temperature at 355°F. Immediately after pressing, tortillas were baked on a griddle (Model TW 2025, ProLuxe™, Perris, CA) on high heat for 30 seconds on each side. Fresh-made tortillas were cooled on a metal rack for 5 min and packed into Ziploc bags, and stored under room temperature.

4.2.5 WWF tortilla evaluation

The weight (using an electronic balance), diameter (using a ruler), and thickness (using a plastic dial caliper) of baked tortillas were determined by averaging the measurements of ten randomly selected tortillas one day after baking. Moisture was measured by using 3 g of the tortilla pieces (cut by scissors) with an infrared moisture analyzer (Model HS 153, Mettler Toledo International, Inc. Columbus, OH). Lightness (L*), redness (a*), and yellowness (b*) values of tortillas were measured with the Minolta Colorimeter (Model: CR-410, Konica Minolta Sensing, Inc. Japan).

Opacity scores on both top and bottom sides were evaluated subjectively on a continuous scale of 0% (completely translucent) to 100% (completely opaque). The breaking force (g) and extensibility (mm) were determined using the TA-XTPlus Texture Analyzer (Texture Technologies Corporation, Scarsdale, NY) with a 7/16-in. (1.11 cm) diameter cylindrical and rounded-end probe (TA-108a). Pre-test, test, and post-test speeds were set to 1.0 mm/sec, 1.0 mm/sec, and 10.0 mm/sec, respectively.

4.2.6 Statistical analysis

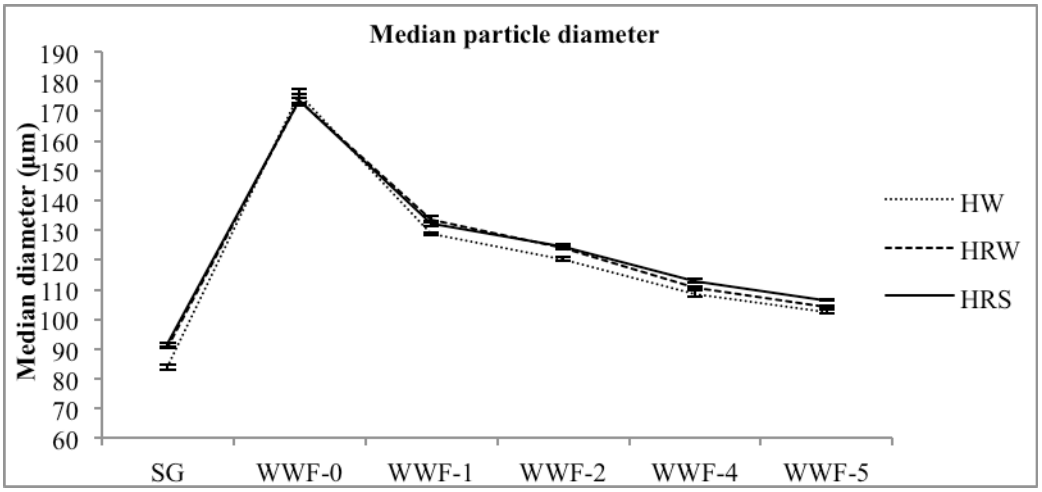
All measurements were performed at least in triplicate. Statistical analyses were carried out with the software SPSS 22 for Mac using one-way analyses of variance (ANOVA). $P<0.05$ are considered to be significant by using the Duncan's test.

4.3. Results and discussion

4.3.1 Particle size distribution and median particle diameter

The particle size distribution and median particle diameter of SG and reconstituted WWFs are displayed in Figure 4.2. For HW, HRW, and HRS, the mass median particle size of WWFs was significantly ($p<0.05$) reduced with an increased number of grinding times (0-5 times). From SG flour, the original (WWF-0) to the 5th grinding (WWF-5), the median particle diameters for HW were 83.8 ± 0.8, 175.7 ± 1.5, 128.6 ± 0.4, 120.0 ± 0.7,108.5 ± 1.1, and 102.4 ± 0.7 μm; for HRW were 90.5 ± 0.2, 173.7 ± 2.0, 133.6 ± 1.0, 124.3 ± 0.7, 110.8 ± 0.1, and 104.2 ± 0.2 μm; and for HRS were 91.5 ± 0.6, 173.7 ± 0.9, 132.1 ± 0.8, 124.7 ± 0.3, 112.9 ± 0.6 and 106.3 ± 0.3 μm, respectively. After fine grinding the bran and shorts 5 times, the particle sizes of WWFs remained significantly ($p<0.05$) larger than their corresponding SG flours. A large portion of unground WWF (WWF-0) remained on top of the 500-µm sieve for HW (15.6%), HRW (14.7%), and HRS (15.0%), but after the 2nd grinding of bran and shorts, all flour fractions passed through the 500-µm sieve. WWF retained on the 300-µm sieve was also significantly ($p<0.05$) reduced after grinding 1 to 5 times. For all wheat classes, the majority of flour particles were retained on the 75-µm sieve.

a.



b.

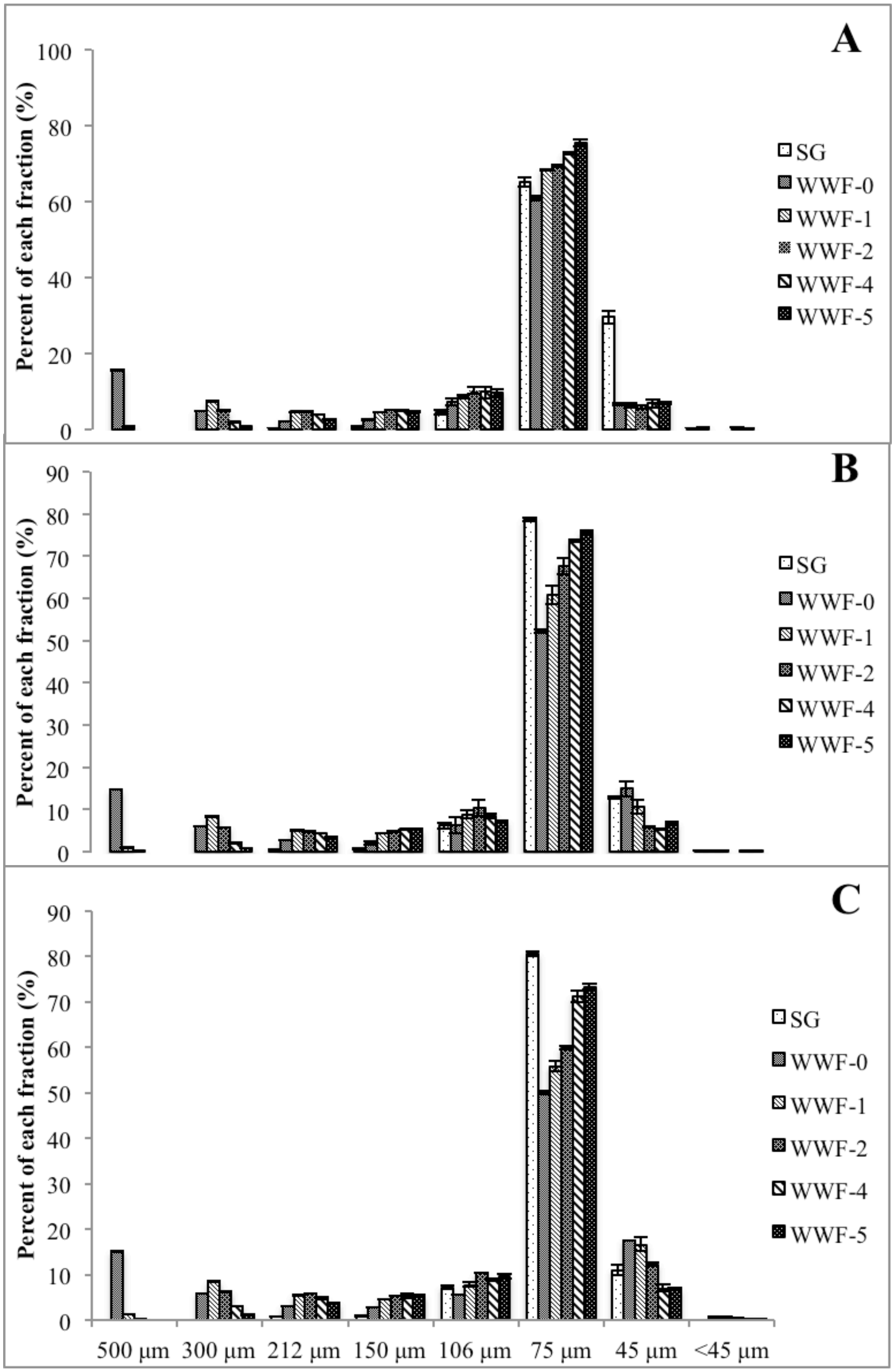


Figure 4.2: Particle size distribution and median diameters of hard white (HW), hard red winter (HRW), and hard red spring (HRS) straight-grade (SG) and whole-wheat flour (WWF) after

fine grinding. WWF-0: WWF containing bran and shorts without any fine grinding; WWF-1, 2, 4, 5: WWF containing bran and shorts that were ground 1, 2, 4 and 5 times, respectively. Results are reported as means ± standard deviation**.** **Figure 3.2a.** Median particle diameter. **Figure 3.2b.** Particle size distribution: **A**, HW; **B**, HRW; **C**, HRS.

4.3.2 Effects of particle size on adjusted damaged starch, color, and PPO activity of WWF

Damaged starch, which is generated from flour milling, is an important flour quality parameter. Previous research (Mao & Flores, 2001) demonstrated that the amount of damaged starch in wheat flour had a negative influence on the machinability and characteristics of baked tortillas. Therefore, too much damaged starch would not be desirable to produce high-quality tortillas. For all three wheat classes, a small but significant ($p<0.05$) increase in adjusted damaged starch (DS/TS) was noted in WWFs with decreased particle size (Table 4.1). Although bran and shorts were dusted to clean out the flour before fine grinding, there was still some flour adherence, which led to increased damaged starch after grinding 1 to 5 times. The differences in adjusted damaged starch between SG and WWFs varied for the three wheat classes, as shown in Table 4.1. For HW and HRS, due to low damaged starch in bran and shorts, WWF-0, WWF-1, and WWF-2 (for HW) had slightly lower DS/TS than their corresponding SG flours; however, after further grinding, WWF-4 and WWF-5 for HRS had slightly higher adjusted damaged starch than SG flours. For HRW flours, DS/TS in SG flour was significantly ($p<0.05$) higher than its corresponding WWFs.

The color and polyphenol oxidase (PPO) activity of the SG flour and WWFs are also shown in Table 4.1. For all three wheat classes, L* (lightness) value decreased, while a* (redness) and b* values (yellowness) increased with WWF particle size reduction. These results indicated that WWF became darker, redder, and yellower with finer particle size. A possible reason for this result was more uniform distribution of finer bran and shorts fractions in WWFs (Niu et al., 2014a).

PPO is well known as a major cause of discoloration. PPO is a tetramer enzyme, which contains four atoms of copper and can catalyze the o-hydroxylation of monophenols to form *o*-diphenols and then catalyze the dehydrogenation of *o*-diphenols to *o*-quinone. Melanins, which cause browning, are produced by the polymerization of *o*-quinone (Fuerst et al., 2010). PPOs and their substrates are primarily located in the bran layer; thus, the darkening problem is more severe in whole-wheat products than in refined flour products. In this study, it was observed that with a decrease in particle size, WWFs had significantly ($p<0.05$) higher PPO activity (Table 4.1). This result confirmed the findings of Niu et al. (2014a) that finer millfeed particle exhibited higher PPO activity for HRW and HRS samples. During the fine grinding, the bran cells were fractured and exposed, which provided more opportunity for PPO to react (Niu et al., 2014a). In addition, PPO activity varied in different wheat classes. Under the same fine grinding treatment, HW flour samples exhibited much lower PPO activity than HRS and HRW flour. In the U.S., HW wheat is generally bred to have a low PPO activity so it can be potentially used for Asian noodle production.

Table 4.1: Adjusted damaged starch, color, and PPO activity of reconstituted whole-wheat flour[1,2]

Sample	**DS/TS[3] (%)**	**L^***	**a^***	**b^***	**PPO[4]**
Hard white					
Straight-grade	10.68 ± 0.04^d	91.27 ± 0.03^f	-2.24 ± 0.01^a	7.99 ± 0.01^a	0.17 ± 0.01^a
WWF-0	9.29 ± 0.04^a	85.81 ± 0.10^e	-0.74 ± 0.04^b	7.98 ± 0.07^a	0.89 ± 0.01^b

WWF-1	10.17±0.08^{b}	84.51±0.09^{d}	-0.27±0.02^{c}	9.71±0.06^{b}	0.94±0.01^{c}
WWF-2	10.33±0.10^{c}	84.25±0.02^{c}	-0.197±0.01^{d}	10.14±0.04^{c}	0.98±0.00^{d}
WWF-4	10.76±0.02^{d}	84.12±0.05^{b}	-0.15±0.01^{e}	10.75±0.05^{d}	1.00±0.00^{e}
WWF-5	10.79±0.06^{d}	83.86±0.04^{a}	-0.12±0.02^{f}	11.24±0.08^{e}	1.02±0.00^{f}
Hard red winter					
Straight-grade	12.57±0.08^{f}	90.94±0.11^{f}	-2.12±0.03^{a}	8.21±0.06^{b}	0.34±0.01^{a}
WWF-0	9.69±0.04^{a}	84.30±0.02^{e}	-0.22±0.04^{b}	7.36±0.07^{a}	3.25±0.01^{b}
WWF-1	10.85±0.03^{b}	82.74±0.01^{d}	0.58±0.06^{c}	9.05±0.08^{c}	3.66±0.03^{c}
WWF-2	11.26±0.05^{c}	82.58±0.07^{c}	0.64±0.01^{c}	9.44±0.04^{d}	3.72±0.03^{cd}
WWF-4	11.47±0.06^{d}	82.12±0.05^{b}	0.85±0.03^{d}	10.14±0.05^{e}	3.77±0.01^{d}
WWF-5	11.98±0.00^{e}	81.53±0.02^{a}	0.99±0.03^{e}	10.65±0.02^{f}	4.13±0.07^{e}
Hard red spring					
Straight-grade	10.77±0.03^{c}	90.66±0.05^{f}	-2.10±0.01^{a}	8.60±0.09^{b}	0.30±0.01^{a}
WWF-0	9.19±0.07^{a}	83.60±0.09^{e}	-0.28±0.05^{b}	7.57±0.02^{a}	3.02±0.11^{b}
WWF-1	10.46±0.08^{b}	82.25±0.04^{d}	0.45±0.01^{c}	8.99±0.04^{c}	3.51±0.01^{c}
WWF-2	10.75±0.13^{c}	81.72±0.10^{c}	0.63±0.04^{d}	9.47±0.07^{d}	3.56±0.03^{cd}
WWF-4	11.43±0.00^{d}	81.48±0.05^{b}	0.74±0.01^{e}	9.85±0.03^{e}	3.61±0.04^{cd}
WWF-5	11.86±0.14^{e}	81.06±0.05^{a}	0.94±0.01^{f}	10.27±0.03^{f}	3.68±0.05^{d}

[1] L*, lightness; a*, redness-greenness; b*, yellowness-blueness; PPO, polyphenol oxidase activity

[2] Results are shown as means ± standard deviations (n=3). Means for the same wheat class in the same column followed by different superscripts are significantly different at P<0.05

[3] Damaged Starch (DS)/Total Starch (TS)

[4] PPO results are defined as ΔA_{475}/hr•g flour

4.3.3 Effect of particle size on Mixolab profiles of WWF

The Mixolab instrument was used to measure the behavior of both wheat protein mixing behavior and starch pasting property when subject to a dual mechanical shear stress and temperature constraint (Huang et al., 2010). A Mixolab profile of good refined flour for hot-press tortillas should have a relatively lower water absorption, shorter dough mixing time, similar gluten strength, higher retrogradation and viscosity values when compared with bread flour (Posner et al., 2014). Table 4.2 shows the effect of particle size on the Mixolab characteristics of WWFs. For all three wheat classes, WWFs had significantly higher water absorption (WA) than their corresponding SG flours due to a higher amount of arabinoxylans present in bran (Penella et al., 2008). Under the condition of C1=1.10 ± 0.05 Nm, WA of WWFs decreased with reducing particle size, but there was no significant difference ($p>0.05$) in WA among WWF-2, WWF-4, and WWF-5 for all three classes. The small difference in median diameters of the WWFs after the 2nd grinding (from around 125 to 106 μm) might contribute to the insignificant ($p>0.05$) differences in WA. The water-binding capacity of fiber reduced with decreasing bran particle size (Noort et al., 2010), which resulted in the decreased WA from WWF-0 to WWF-2. However, our results were contrary to Niu et al. (2014a), who found increased Farinograph water absorption after fine grinding of WWF from 206 to 164 μm. Additionally, Zhang & Moore (1997) reported that coarse wheat bran (609 μm) had better water-holding capacity than fine bran (278 μm), but as wheat brans of different particle sizes were blended into flour, the bran particle size did not show any effect on Farinograph water absorption. It is not clear if the WA values determined by these two methods (Mixolab and Farinograph) are directly correlated with each other, especially for measuring WWF.

Dough development time (C1 time) measures the time between the first addition of water and the time when the dough reaches the optimum elastic and viscous properties (Vizitiu et al., 2011). For all three wheat classes, C1 time of WWFs decreased with a decline in flour particle size from 176 (WWF-0) to 134 μm (WWF-1), which might be attributable to faster absorption of water by finer particle size bran (Penella et al., 2008). Similar results were reported by Zhang & Moore (1997), who found that dough mixing time was reduced from coarse (609 μm) to fine (278 μm) bran particle size. In our study, the number of fine grinding steps (1 to 5 times) did not show significant ($p>0.05$) effect on development time, which was in agreement with the results of Niu et al. (2014b), who reported that the decrease in particle size had little effect on the Farinograph development time with fine (125 μm) to very fine (43 μm) particle size WWFs.

Stability time represents the mixing resistance of dough, with longer time suggesting stronger flour (Niu et al., 2014a). For all three wheat classes, WWF-0 had significantly ($p<0.05$) shorter stability time than its corresponding SG flour. The bran particles in WWF dilute gluten and contribute to weaker dough structure (Barros et al., 2010). Nevertheless, stability time of WWF increased with the reduction of particle size through fine grinding. These results indicated that finer particle size WWFs were more tolerant to mixing and produced stronger dough. These results supported a previous finding that a significant uptrend ($p<0.05$) in stability time was obtained when reducing WWF median particle size from around 206 to 140 μm by Niu et al., (2014a), who explained that finer particles might have less destructive influence on gluten network formation in dough. Noort et al. (2010) added different particle sizes of wheat bran into refined flour and also observed an increase in stability time with reduced bran median particle size from 831 μm to 129 μm.

Torque C3 (Nm) is the maximum torque during the heating stage and represents the degree of starch gelatinization (Huang et al., 2010). For all three wheat classes (Table 4.2), WWFs had lower C3 values than their corresponding SG flours. This was most likely attributed to lower starch content and higher enzyme activities in WWFs. However, there was no significant ($p>0.05$) difference in C3 value among WWFs of different particle sizes. The result was similar to the report of Chen et al. (2011), who found that bran particle size did not show significant impact on pasting properties as measured by the Rapid Visco Analyzer (RVA). The difference between C3 and C4 value (C3-C4, starch gel breakdown value) reflects hot gel stability, with a lower value indicating a lower starch degradation rate and more stable gel (Rosell et al., 2010). As shown in Table 4.2, with a reduction in WWF particle size, a decrease in C3-C4 was in support of finer WWFs having a more stable starch gel than the coarse WWF (WWF-0). Torque C5 measures starch retrogradation in the cooling phase (Teng et al., 2015). With a reduced particle size, C5 value increased, which was an indication of an increased degree of starch retrogradation. This observation was in agreement with Cai et al. (2014), who found that fine bran induced a larger degree of starch retrogradation than unground bran.

Table 4.2: Mixolab parameters of reconstituted whole-wheat flour[1]

Sample	WA[2]	C1 time (min)	Stability (min)	C3 (Nm)	C3-C4 (Nm)	C5 (Nm)
Hard white						
Straight-grade	63.4^{a}	5.35 ± 0.07^{ab}	8.53 ± 0.30^{c}	1.73 ± 0.00^{b}	0.18 ± 0.03^{a}	2.49 ± 0.07^{d}
WWF-0	71.7^{d}	6.15 ± 0.43^{b}	5.69 ± 0.19^{a}	1.66 ± 0.01^{a}	0.56 ± 0.02^{d}	1.91 ± 0.08^{a}
WWF-1	69.2^{c}	4.55 ± 0.53^{a}	7.25 ± 0.11^{b}	1.68 ± 0.01^{a}	0.39 ± 0.05^{c}	2.11 ± 0.01^{b}
WWF-2	68.3^{b}	4.40 ± 0.95^{a}	7.44 ± 0.77^{b}	1.69 ± 0.01^{a}	0.34 ± 0.02^{bc}	2.16 ± 0.06^{bc}
WWF-4	68.8^{b}	4.80 ± 0.54^{a}	7.72 ± 0.23^{bc}	1.69 ± 0.01^{a}	0.27 ± 0.09^{ab}	2.26 ± 0.06^{c}
WWF-5	68.8^{b}	4.67 ± 0.40^{a}	8.41 ± 0.87^{c}	1.70 ± 0.00^{a}	0.27 ± 0.05^{ab}	2.27 ± 0.02^{c}
Hard red winter						
Straight-grade	62.4^{a}	1.2 ± 0.03^{a}	10.04 ± 0.09^{b}	1.77 ± 0.01^{b}	0.14 ± 0.02^{a}	2.44 ± 0.01^{d}
WWF-0	70.5^{c}	7.35 ± 0.42^{c}	9.40 ± 0.25^{a}	1.67 ± 0.01^{a}	0.48 ± 0.01^{d}	1.75 ± 0.01^{a}
WWF-1	69.1^{b}	5.12 ± 0.28^{b}	10.25 ± 0.07^{bc}	1.68 ± 0.02^{a}	0.45 ± 0.02^{c}	1.88 ± 0.05^{b}
WWF-2	69.2^{b}	5.03 ± 0.30^{b}	10.32 ± 0.12^{bc}	1.67 ± 0.01^{a}	0.45 ± 0.01^{c}	1.88 ± 0.01^{b}
WWF-4	69.0^{b}	4.59 ± 0.08^{b}	10.41 ± 0.01^{c}	1.65 ± 0.01^{a}	0.42 ± 0.01^{bc}	1.90 ± 0.01^{b}
WWF-5	69.0^{b}	4.55 ± 0.07^{b}	10.58 ± 0.12^{c}	1.66 ± 0.02^{a}	0.39 ± 0.01^{b}	2.00 ± 0.03^{c}
Hard red spring						
Straight-grade	67.5^{a}	8.47 ± 0.14^{c}	10.25 ± 0.23^{d}	1.48 ± 0.00^{c}	0.21 ± 0.02^{a}	1.99 ± 0.05^{c}
WWF-0	74.3^{d}	7.63 ± 0.47^{b}	7.25 ± 0.41^{a}	1.38 ± 0.02^{a}	0.40 ± 0.06^{c}	1.48 ± 0.12^{a}
WWF-1	73.1^{c}	5.99 ± 0.32^{a}	9.3 ± 0.03^{b}	1.41 ± 0.01^{ab}	0.34 ± 0.02^{b}	1.57 ± 0.13^{ab}
WWF-2	72.0^{b}	5.73 ± 0.27^{a}	9.41 ± 0.14^{bc}	1.43 ± 0.01^{b}	0.33 ± 0.07^{b}	1.65 ± 0.11^{ab}
WWF-4	72.1^{b}	5.57 ± 0.76^{a}	9.73 ± 0.48^{bc}	1.44 ± 0.02^{b}	0.32 ± 0.08^{b}	1.65 ± 0.08^{ab}
WWF-5	72.1^{b}	5.30 ± 0.51^{a}	9.96 ± 0.24^{c}	1.44 ± 0.02^{b}	0.33 ± 0.02^{b}	1.67 ± 0.05^{b}

[1] Results are shown as means ± standard deviations (n=3). Means for the same wheat class in the same column followed by different superscripts are significantly different at $P<0.05$

[2] WA, water absorption

4.3.4 Effect of particle size on tortillas quality

Tortilla baking results are shown in Table 4.3 and Figure 4.3. During tortilla production, a reduced amount of water was added to WWF from WWF-0 to WWF-2, and the same amount of water was used for WWF-2, 4 and 5. However, from WWF-0 to WWF-5, finer particle size resulted in tortillas with higher moisture content and weight. Reduced particle size in WWF increased the water-holding capacity of Arabinoxyans gels, which led to water migration from the gluten network to the Arabinoxyan matrix, resulting in more tightly bound water in the dough and less moisture loss during baking (Li et al., 2012). However, WWF particle size did not show a significant ($p>0.05$) effect on tortilla diameter and thickness. Similarly, Mao & Flores (2001) did not find significant differences in diameter and thickness among the tortillas made from refined flours with different particle sizes, ranging from 63.9 μm to 34.2 μm (flour 1), or 71.2 μm to 37.7 μm (flour 2). They explained that the outcome was probably resulted from the same processing conditions (e.g. resting time, hot-press temperature, baking temperature) for all flour samples.

The whiteness (L* value) of the WWF tortilla decreased with smaller flour particle size, and was positively correlated with WWF L* value. More uniform bran distribution in flour may lead to darker tortillas with reduced bran particle size. Another cause could be an increased browning or Maillard reaction due to more sugars provided by the increased damaged starch (Mao & Flores, 2001). HW produced whiter (higher L*) WWF tortillas, which were generally more favorable by consumers (Doblado-Maldonado et al., 2012), compared to HRW and HRS. Opacity is an important quality trait for tortillas. Tortillas appear opaque when light reflects on the surface of small air bubbles (Cepeda et al., 2000), and more-opaque tortillas are preferred by U.S. consumers (Alviola & Awika, 2010). Tortillas made with WWF-0 had higher opacity scores (especially the bottom scores) than tortillas made with other particle size WWFs. Large visible bran particles were apparent on the surface of WWF-0 tortillas; therefore, when light reflected on these bran particles, tortillas became more opaque. However, there were no significant (p>0.05) differences in opacity scores among tortillas made with WWF-1, 2, 4, and 5. In this study, the same chemical leavening system and processing conditions were used for all tortilla doughs, which might account for no significant (p>0.05) differences in opacity among tortillas with smaller bran particles (WWF-1, 2, 4, and 5).

Table 4.3: Tortilla properties of reconstituted whole-wheat flour[1]

Sample	Moisture (%)	Weight (g)	Diameter (cm)	Thickness (mm)	L*[2]	Opacity (top)	Opacity (bottom)
Hard white							
Straight-grade	32.0±0.0^{a}	34.94±0.65^{b}	18.66±0.34^{b}	2.44±0.04^{b}	85.24±0.52^{c}	86.0±1.0^{b}	52.7±3.8^{a}
WWF-0	31.7±0.3^{a}	33.46±0.30^{a}	17.80±0.65^{a}	2.19±0.01^{a}	69.46±1.12^{b}	82.9±2.3^{ab}	62.0±2.8^{b}
WWF-1	32.5±0.1^{b}	34.43±0.05^{b}	17.73±0.04^{a}	2.16±0.02^{a}	66.49±0.05^{a}	78.8±2.1^{a}	46.7±2.8^{a}
WWF-2	32.9±0.4^{bc}	34.65±0.07^{b}	17.64±0.05^{a}	2.11±0.05^{a}	65.79±0.36^{a}	78.7±2.8^{a}	46.6±3.7^{a}
WWF-4	33.1±0.0^{c}	34.76±0.11^{b}	17.65±0.06^{a}	2.10±0.01^{a}	65.51±0.93^{a}	79.0±1.8^{a}	49.4±1.9^{a}
WWF-5	33.2±0.1^{c}	34.95±0.15^{b}	17.44±0.45^{a}	2.12±0.04^{a}	65.44±0.25^{a}	80.8±2.2^{a}	50.9±3.7^{a}
Hard red winter							
Straight-grade	33.4±0.1^{ab}	36.38±0.51^{b}	16.39±0.42^{a}	2.32±0.07^{a}	84.84±0.12^{e}	85.3±4.4^{b}	74.0±4.7^{c}
WWF-0	33.2±0.2^{a}	35.01±0.55^{a}	16.10±0.70^{a}	2.27±0.10^{a}	63.41±0.42^{d}	76.7±1.8^{a}	61.6±1.5^{b}
WWF-1	33.7±0.2^{b}	35.41±0.48^{ab}	16.30±0.62^{a}	2.30±0.09^{a}	57.40±0.14^{c}	77.8±3.5^{a}	52.0±1.0^{a}
WWF-2	34.0±0.0^{c}	35.50±0.48^{ab}	16.02±0.65^{a}	2.27±0.07^{a}	56.62±0.33^{b}	74.6±3.7^{a}	49.3±1.9^{a}
WWF-4	34.2±0.1^{c}	35.83±0.44^{ab}	16.18±0.26^{a}	2.30±0.05^{a}	56.39±0.12^{b}	76.5±1.6^{a}	45.9±0.1^{a}
WWF-5	34.3±0.0^{c}	36.06±0.05^{ab}	16.14±0.04^{a}	2.21±0.01^{a}	55.72±0.16^{a}	73.4±2.0^{a}	47.5±3.5^{a}
Hard red spring							
Straight-grade	33.7±0.1^{a}	35.46±0.10^{bc}	18.16±0.39^{b}	1.76±0.01^{a}	84.54±0.01^{d}	54.6±0.9^{a}	24.6±1.9^{a}

WWF-0	33.5 ± 0.2^{a}	34.74 ± 0.02^{a}	17.13 ± 0.23^{a}	2.13 ± 0.02^{b}	57.80 ± 0.25^{c}	65.0 ± 2.4^{b}	44.2 ± 2.6^{c}
WWF-1	34.7 ± 0.2^{b}	34.92 ± 0.01^{ab}	17.44 ± 0.08^{a}	2.00 ± 0.11^{b}	55.55 ± 0.38^{b}	62.0 ± 0.9^{b}	35.6 ± 2.3^{b}
WWF-2	35.0 ± 0.0^{bc}	35.27 ± 0.50^{abc}	17.12 ± 0.52^{a}	2.09 ± 0.07^{b}	54.98 ± 0.05^{a}	65.4 ± 1.2^{b}	38.3 ± 3.3^{b}
WWF-4	35.1 ± 0.0^{cd}	35.35 ± 0.04^{bc}	17.33 ± 0.01^{a}	1.99 ± 0.05^{b}	54.85 ± 0.21^{a}	66.1 ± 3.4^{b}	36.3 ± 2.4^{b}
WWF-5	35.4 ± 0.2^{d}	35.66 ± 0.03^{c}	17.11 ± 0.12^{a}	2.02 ± 0.05^{b}	54.70 ± 0.21^{a}	64.9 ± 1.2^{b}	36.4 ± 2.3^{b}

[1] Results are shown as means ± standard deviations (n=3). Means for the same wheat class in the same column followed by different superscripts are significantly different at P<0.05

[2] L*, lightness

The breaking force (g) and extensibility (mm) of tortillas made with different particle size WWF are presented in Figure 4.3. The maximum force required to completely break tortillas relates to tortilla firmness, while the distance until rupture represents tortilla extensibility. Larger breaking force and longer distance indicate a stronger and more stretchable product (Texture Technologies Corporation, 2009). For all three wheat classes, tortillas made with SG flour were stronger and more extensible than WWF tortillas, while tortillas made from fine particle size WWFs (WWF-1 to WWF-5) had a larger breaking force and extensibility than coarse WWF (WWF-0). These results were in line with flour properties as determined by the Mixolab that finer particles interfered less with gluten formation and led to stronger WWF. Zhang & Moore (1997) also reported that finer bran yielded more extensible and resistant dough than coarser bran after a 180-min rest as measured by the Extensograph. Similarly, for the laminated cracker dough made from soft wheat WWF, the dough sheet became stronger and more extensible as WWF particle size was reduced (Wang et al., 2016). However, there were no significant (p>0.05) differences in breaking force and extensibility among tortillas made from WWF-1 to WWF-5. The differences in median particle size from WWF-1 to WWF-5 were much smaller than the differences between WWF-1 and WWF-0, which might account for the insignificant changes in tortilla textural properties.

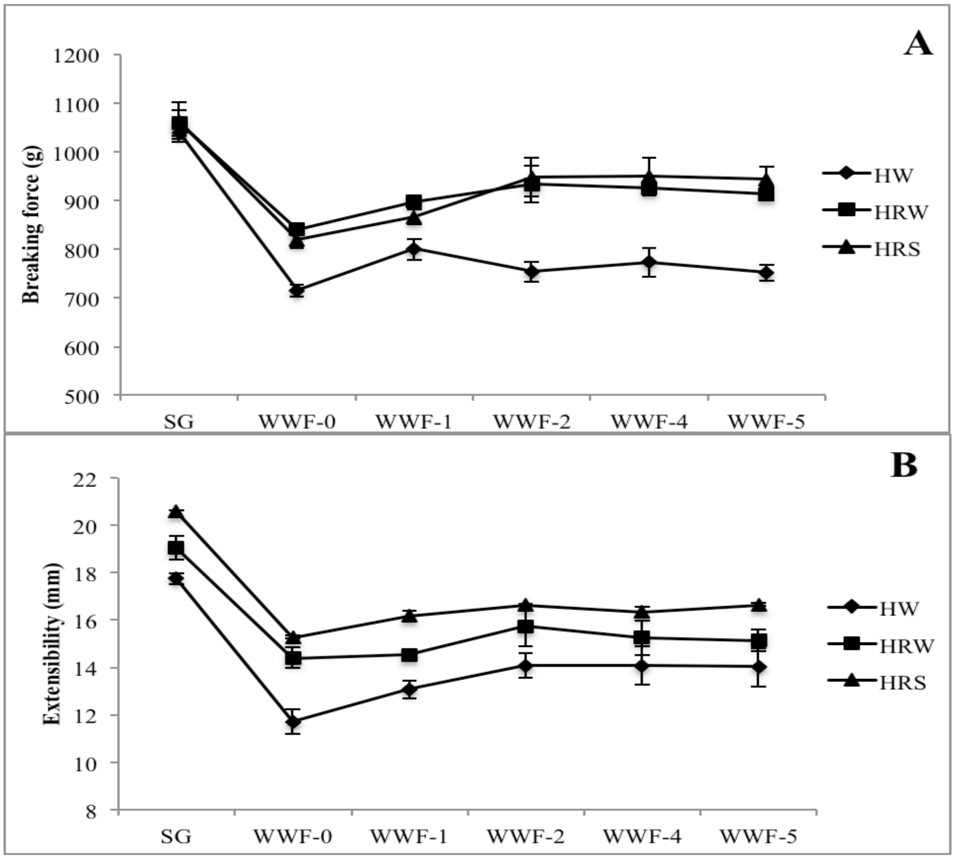


Figure 4.3: Effects of particle size on breaking force and extensibility of whole-wheat flour (WWF) tortillas: **A**, breaking force (g); **B**, extensibility (mm). Results are reported as means ± standard deviation. Abbreviations (SG, WWF-0, 1, 2, 4, 5) are the same as in Figure 4.2.

The tortilla baking results demonstrated that fine grinding of bran and shorts to reduce WWF median particle size from 174-176 µm to 129-134 µm would significantly improve tortilla physical quality, while further reducing WWF particle size to 102-106 µm (median diameter) made little improvement in tortilla texture. Tortillas are generally filled with a variety of food ingredients, which emphasizes tortilla strength and extensibility as essential quality attributes. This study confirmed findings from previous studies (Niu et al., 2014a; Steglich et al., 2015; Wang et al., 2016) that coarse bran and shorts had a destructive effect on the gluten network formation. Thus, WWF of fine particle size was more suitable for tortilla baking. In this study, WWFs of 102-133 µm (median diameter) produced similar quality tortillas for each wheat class. Niu et al. (2014b) prepared WWFs of 125, 96, 72, and 43 µm (mean particle sizes) by superfine grinding technique and found that although excessive damaged starch showed some adverse effect on noodle cooking loss, reducing the flour particle size to 72 µm enhanced the microstructure of whole-wheat noodle products as seen by the improved coverage of starch granules and degree of protein network connectivity. Wang et al. (2016) suggested that reducing particle size of soft wheat WWF to 90-96 µm (median diameter) could significantly improve snack cracker baking performance (similar geometry and texture to refined flour crackers). Li et al. (2012) reported that the whole-wheat bread (WWB) made from WWF with an average particle size of 96.99 µm had better baking quality than breads made from WWF of two other particle sizes, 50.21 and 235.40 µm. The authors confirmed by the Magnetic Resonance Imaging (MRI) technique that the decreased particle size of WWF (50.21 µm) significantly increased the water absorption of Arabinoxylans (AX) gels, which led to water migration from the gluten network to the AX gels and yielded inferior baking quality of WWB. Therefore, there may be an optimal range of WWF particle sizes for each type of product. As the differences in median particle sizes among WWF-1 to WWF-5 in this study were relatively small, further reducing WWF into much finer particles to 70-90 µm (median diameter) would provide additional information to identify a most suitable particle size range for tortillas.

4.4 Conclusions

Reduction of WWF median particle sizes from 174-176 to 102-106 µm led to darker color, higher PPO activity and more adjusted damaged starch. The Mixolab results showed that dough development time and starch gel breakdown value were significantly ($p<0.05$) decreased, but dough stability time and starch retrogradation were significantly ($p<0.05$) increased as WWF particle size became smaller. As for tortilla baking performance, reduced WWF particle size increased tortilla moisture and weight, and decreased surface brightness (L* value), but did not show significant impact ($p>0.05$) on tortilla diameter and thickness. Finer particle size WWF (102-134 µm) produced stronger and more extensible tortillas than coarse WWF (174-176 µm). However, there were no significant ($p>0.05$) differences in texture parameters of WWFs from 102-106 to 129-134 µm median diameter particle sizes. These results indicated that the fine grinding of WWFs to reduce its median particle sizes from ~175 µm to ~130 µm was very effective in improving the quality of WWF tortillas. Future studies to examine the impact of particle size on sensory attributes of WWF tortillas will be beneficial to provide further evidence and confirmation to the flour milling and tortilla industry.

Acknowledgments

The authors acknowledge the Federal Grain Inspection Service (Portland, OR) for providing wheat seeds.

CHAPTER 5

EFFECTS OF CHEMICAL LEAVENING SYSTEM AND PROCESSING CONDITIONS ON THE OPACITY AND OTHER QUALITY CHARACTERISTICS OF WHOLE-WHEAT FLOUR TORTILLAS

This chapter is modified from the published paper:

Liu, T., Hou, G. G., Book, S. L., & Marquart, L. (2016). Effects of chemical leavening system and processing conditions on the opacity and other quality characteristics of whole-wheat flour tortillas. *LWT-Food Science and Technology*, *73*, 123-130.

Abstract

Chemical leavening is a neutralization reaction that can affect not only the opacity but also other physical and chemical properties of tortillas. Whole-wheat flour (WWF) tortilla is often associated with lack of sufficient opacity, generally considered as quality defect in tortillas. The objectives of this research were to evaluate the effects of types and amounts of leavenings (acids and base), hot press and dough temperature on the quality attributes of WWF tortillas. Three leavening acids, three levels of sodium bicarbonate (SBC) (1%, 1.5%, and 2%), hot-press temperatures of 160°C, 177°C, and 193°C, and two dough temperatures (25°C and 35°C) were used. Sodium aluminum phosphate (SALP) produced more opaque tortillas than sodium acid pyrophosphate-28 (SAPP-28), followed by sodium aluminum sulfate (SAS). Increased amount of SBC and lower dough temperature improved opacity. Higher hot-press temperature produced lighter weight, thinner, and bigger diameter tortillas. Higher amount of SBC produced smaller, thicker, and brighter color tortillas. WWF tortillas made with SAS had the largest breaking force, while tortillas with SALP had the smallest breaking force as determined by TA-XTPlus Texture Analyzer. After 45 days of storage at room temperature, all tortillas showed decreased breaking force and extensibility.

5.1 Introduction

Considerable epidemiologic evidence suggests that whole grains are associated with reduced risk for certain chronic diseases (Marquart et al., 2007). The 2010 Dietary Guidelines for Americans (USDA & USDHHS, 2010), via MyPlate, is designed to encourage people to eat at least three whole grain servings per day as part of a healthy meal plan. In step with these recommendations, the food industry has been incorporating whole-wheat flour (WWF) into a variety of grain-based foods to meet consumer taste preferences and provide more whole grains in the U.S. diet (Marquart et al., 2006).

Incorporating WWF into tortillas is one approach to deliver whole grains into the American diet. Tortilla is a thin Mexican flatbread made from wheat flour or corn, with the versatility to be used in many dishes. The Tortilla Industry Association (TIA) reported tortillas were more popular than other types of ethnic breads in the U.S., as approximately 85 billion tortillas were consumed in 2000 (TIA, 2016). Given current trends toward healthier food and the popularity of tortillas, manufacturers are striving to provide customers with healthier, more varied, and flavored tortillas. Although the use of WWF can significantly improve the nutritional profile of tortillas, WWF tortillas have encountered more quality issues compared to refined wheat flour tortillas.

Translucency, a lack of opacity, is generally considered a quality defect in tortillas because consumers perceive translucency as a characteristic of tortillas that are undercooked or high in fat (Alviola & Awika, 2010). A ‘translucent’ tortilla is dark or yellowish in color, while ‘opaque’ tortilla is bright white (Dann, 2014). The absence of small air bubbles in the baked tortilla is likely related to translucency since the tortilla appears opaque when light reflects on the surface of small air bubbles (Cepeda et al., 2000). Thus, the formation of air bubbles in the dough and retention of air bubbles in the tortilla are critical factors for producing uniformly opaque tortillas (Cepeda et al., 2000; Casso, 2003). Leavening agents help to form fluffy, thick, and opaque tortilla products.

Unlike many bread products that use yeast as leavening agents, flour tortillas are produced using a chemical leavening system. Chemical leavening is a neutralization process where bicarbonate is neutralized by an acid or acids yielding carbon dioxide in the presence of moisture and heat (Heidolph, 1996). A chemical leavening system contains two components: a base (bicarbonate) and an acid or acids (Adam & Waniska, 2002). The most commonly used leavening bases in baked foods are sodium bicarbonate (SBC), potassium bicarbonate (KBC), and ammonium bicarbonate (ABC). The different types, amounts, and grades of bicarbonates have been studied relative to tortilla properties (Casso, 2003; Bejosano & Waniska, 2004). Leavening acids vary in the neutralization value (NV) and the rate of reaction (ROR). Based on ROR, leavening acids can be divided into three categories. Nucleating agents release acids during mixing such as calcium phosphates (monocalcium phosphate [MCP]) and organic acids (fumaric, citric, lactic, and tartaric). Time-released agents release acids after a period of time (sodium acid pyrophosphate [SAPP] and calcium acid pyrophosphate [CAPP]). The third category, a heat-activated agent, reacts when triggered by heat. Sodium aluminum sulfate (SAS) and Sodium aluminum phosphate (SALP) are included in this category (Cepeda, 2000; Casso, 2003). Nucleating agents are seldom used as a leavening by themselves. Instead, the combinations of fast and slow leavening acids are used to produce a double reaction (Labaw, 1982; Heidolph, 1996).

In the tortilla dough system, previous research demonstrated that chemical leavening showed effects on end-product opacity. Time-released and heat-activated leavening acids yield more opaque tortillas compared with nucleating agents (Cepeda et al., 2000; Adams

& Waniska, 2002). Slower acids partially dissolve during mixing and nucleate the dough with a sufficient yield of gas bubbles to produce opaque tortillas. During dough resting, dividing, and rounding, some insoluble leavening compounds need to be retained to allow for later chemical neutralization and reactions during the baking process (Adams, 2001). In addition, the tortilla opacity is generally associated with the amount of leavenings used (Adams, 2001; Adams & Waniska, 2002; Bejosane & Waniska, 2004). However, Cepeda et al. (2000) observed small or insignificant improvements in opacity when using more SALP, SAS, and SAPP, while adverse effects were observed when using more MCP. Furthermore, the effects of leavening systems on other tortilla attributes (moisture, pH, diameter, texture, etc.) have been investigated (Cepeda et al., 2000; Adams, 2001; Adams & Waniska, 2002; Book et al., 2002; Bejosano & Waniska, 2004).

With higher dough temperature, less mixing time is required to form dough (Hlynka, 1962). However, more acid solubilizes and reacts faster with the base in tortilla dough; thus, the leavening reaction increasingly occurs in warmer dough, which reduces the potential for bubble enlargement during tortilla processing and yields more translucent tortillas (Cepeda et al., 2000). Cepeda et al. (2000) studied the effect of dough temperature (34°C and 38°C) and determined that at 38°C, more leavening acid and base were needed to compensate for the loss of carbon dioxide incurred during mixing and resting to yield tortillas with comparable opacity.

Other than dough temperature, hot-press conditions of pressure, time, and temperature directly affect the tortillas. Typical hot-press operating conditions range from 300-2000 psi pressure, 0.7-3.5 second time, and 149-232°C temperature (TIA, 2014).

Adams & Waniska (2005) examined the effects of dwell time and pressure on tortilla quality. However, the hot-press temperature has not yet appeared in the literature to determine its influence on flour tortilla characteristics.

Although considerable research has focused on the chemical leavening system for wheat flour tortillas, there is little research on WWF tortillas. Barros et al., (2010) compared the quality of refined and WWF tortillas and found that the WWF tortillas had lower opacity scores than their corresponding refined flour tortillas. The high fiber content in WWF weakens the gluten network and results in dough less resistant to hot pressing (Barros et al., 2010). Therefore, WWF tortillas have weaker dough structure and integrity to retain the air bubbles created during baking. Thus, it is necessary to modify the chemical leavening system and processing conditions in WWF tortilla production to improve opacity and overall quality characteristics.

The objectives of this study were to examine the effects of varying types of leavening acids, amounts of leavening base, hot-press temperature, and dough temperature on the opacity and other quality properties of WWF tortillas.

5.2 Materials and methods

5.2.1 Materials

A 100% hard white WWF with 9.6% moisture content, 13.3% protein (14% mb) and 1.4% ash (14% mb) was kindly provided by Bay State Milling Company (Minneapolis, MN). The leavening acids, SALP, SAS, and SAPP-28 were provided by ICL Food Specialties (St. Louis, MO). Encapsulated fumaric acid was kindly provided by Clabber

Girl Inc. (Terre Haute, IN). SBC (powder ACS) was purchased from ChemProducts (Portland, OR). Sodium stearoyl lactylate (SSL) was obtained from Corbion (Kansas City, KS). Salt, Crisco vegetable shortening and sugar were purchased from a local supermarket (Portland, OR). Potassium sorbate and calcium propionate were obtained from Muhlenchemie GmbH & Co KG (Ahrensburg, Germany).

5.2.2 Preparation of WWF tortilla

The WWF tortilla formula is listed in Table 5.1. The ingredients were weighed and added to a Horbart 5-Quart Mixer (Model A-120, Hobart MFG. Co, Troy, OH) with water jacket and constant temperature circulator (Model 1165, PolyScience, Div. of Preston Industries, Inc. Niles, IL) and mixed for 4 min at the 1st speed and 2-8 min at the 2nd speed until the dough was fully developed. The dough temperature was measured using a thermometer. After resting for 15 min at room temperature, 1,400 g dough was flatted on the Dutchess Divider/Rounder tray (model JN-3, Dutchess Baker's Machinery Co. Inc. Superior, WI) with uniform thickness. The dough was divided and rounded into pieces of dough balls (40g each) after resting for 5 min. The dough balls were then placed in a covered box and proofed for 20 minutes. Finally, each dough ball was hot-pressed by using an automatic Tortilla Press (Model Wedge Press, Bakery Equipment & Service Co. San Antonio, Texas) and baked on a griddle (model TW2025, DoughPro, Perris, CA) for 30 sec on each side. The fresh tortillas were cooled and packed into Ziploc bags and stored at room temperature.

Table 5.1: Whole-wheat flour tortilla formulation

Ingredients	**Dough**	
	%	g
Whole-Wheat Flour	100	1000
Water	58	580
Salt	1.5	15
Sugar	0.5	5
Shortening	7	70
Sodium bicarbonate	1/1.5/2	10/15/20
Leavening acids	Varied per trial	
Encapsulated fumaric acid	0.5	5
Sodium stearoyl lactylate	0.5	5
Potassium sorbate	0.4	4
Calcium propionate	0.5	5

5.2.3 Evaluation of WWF tortilla

Tortillas were analyzed one day after baking and after 45 days of room temperature storage. Tortilla weight and diameter were determined as the average of ten randomly selected tortillas. Thickness was measured with a plastic dial caliper as the average of ten randomly selected tortillas. The moisture content of tortillas was measured using 3 g of tortilla pieces (cut by scissors) via an infrared moisture analyzer (model: HS 153, Mettler-Toledo International Inc.). The pH of the final product was determined by homogenizing 10 g tortilla with 90 ml distilled water in a blender and measuring the pH using a glass electrode (S20 SevenEasy™ pH meter, Mettler-Toledo International Inc.) (Book et al., 2002). A continuous scale of 100% being completely opaque (white) and 0% being completely translucent (not white) was used for opacity analysis.

The color values of the WWF tortillas were determined by a Minolta Colorimeter (Model CR-410, Konica Minolta Sensing, Inc. Japan). Lightness (L*), redness (a*), and yellowness (b*) were recorded. In addition, the breaking force and extensibility of the tortillas were measured with the TA-XTPlus Texture Analyzer (Texture Technologies Corporation, Scarsdale, NY). Force (N) and distance (mm) were determined using a 7/16-

in. (1.11 cm) diameter cylindrical probe with rounded end (TA-108a) with pre-test speed of 1.0 mm/sec, test speed of 1.0mm/sec and post-test speed of 10.0mm/sec.

5.2.4 Experimental design

Three types of leavening acids, including SALP, SAS, and SAPP-28 were initially evaluated for their effects. The second variable was the amount of SBC. Three levels of SBC (1%, 1.5%, and 2% of flour weight) were used, and the amount of each leavening acid was determined based on the level of SBC and its acid NV. The NVs of SALP, SAS and SAPP-28 were 100, 104 and 72, respectively. Encapsulated fumaric acid was added to lower dough pH level (Cepeda et al., 2000). The third variable was the dough temperature (25°C and 35°C) and the last variable was the hot-press temperature (160°C, 177°C, and 193°C). The study was a four factor-Taguchi orthogonal "L" array design, in duplicate, in random order. This design contained 18 runs, with each run duplicated; thus, 36 runs in total. All measurements were performed at least in triplicate.

5.2.5 Statistics analysis

Statistical analyses were carried out with the software SPSS 22 for Mac using one-way analyses of variance (ANOVA). General linear models (GLMs) were created with terms for between-subjects effects of type of leavening acid, amount of SBC, hot-press temperature, dough temperature, and 2-way interactions between the type of leavening acid, amount of SBC, and hot-press temperature. ANOVA were run separately for data on day 1 and day 45 (Table 5.2). Due to differences in sample size and factor level, the interaction between dough temperature and the other three factors are not shown. Coefficient of determination (R^2), which indicates how well data fit the GLMs, is presented in Table 5.2. With R^2 closer to 1, the model was a better fit for the data. In addition, Table 5.2 shows the P value for each factor in the model for each response. $P < 0.05$ suggested that this factor had a significant effect on the response.

5.3 Results and discussion

5.3.1 Effect of type of leavening acid

On day 1, the type of leavening acids was significant ($p<0.05$) for all parameters except for extensibility (Table 5.2). Tortillas made with SALP had lower moisture content (30.17%) than SAS (31.00%) and SAPP-28 (31.95%) (Table 5.3). These findings were different from the results obtained by Adams (2001), which showed little effect of leavening acid on moisture content but were similar to Book et al. (2002). A possible explanation as to why SALP yielded the lowest moisture content tortilla may be the timing of chemical leavening reactions. As a heat-activated leavening acid, most SALP reacted with SBC during baking. Water, as one of the neutralization reaction products, evaporates under high baking temperature. Therefore, more SALP and SBC reactions were attributed to more water evaporation. Due to more water loss, the leavening system with SALP produced the lightest-weight tortillas compared to SAS and SAPP-28. However, SALP resulted in the largest-diameter tortillas, followed by SAPP-28 and SAS (Table 5.3). These results were in agreement with the findings of Book et al. (2002). SAPP-28 produced the thickest tortillas among the three acids. SAPP is a time-released acid, while both SAS and SALP are heat-activated acids. More gas produced by SALP and SAS during baking was quickly released after cooling and yielded thinner tortillas.

Encapsulated fumaric acid was added to lower pH, and it was released gradually over time. On day 1, tortillas made with SAPP-28 had a higher pH (6.57), followed by SALP (6.27), and SAS (5.34) (Table 5.3). Previous studies conducted by Book et al. (2002) and Cepeda et al. (2000) showed the same trend. SAS produced darker tortillas compared to SALP and SAPP-28, while SALP yielded greener and bluer tortillas (Table 5.3). Similar to the trend in brightness, SALP produced more opaque tortillas, followed by SAPP-28 and SAS (Figure 5.1). As a heat-activated agent, SALP would react with SBC when triggered by heat. Thus, more carbon dioxide was produced during baking, which would make the tortilla puffier and appear more opaque. SAS is also a heat-activated agent; however, 35-40% of carbon dioxide formed during mixing and resting stages were not retained as effectively as the gas released by SAPP (Book et al., 2002), which resulted in more translucent tortillas. Unlike SALP and SAS, SAPP-28 is a time-released acid, and it reacts after a period of time. These findings were different from the results obtained by Cepeda et al. (2000), who found that SAPP-28 produced more translucent tortillas than SAS and SALP. The differences may be attributed to the large excess of acid used in their study and different flour dough systems in both studies (WWF tortilla in this study vs. white flour tortilla in their study).

The rupture force (N) and distance (mm) of tortillas were measured by the TA-XTPlus Texture Analyzer at day 1. The maximum force required to completely puncture the tortillas indicates the firmness of tortillas, and the distance until rupture indicates the extensibility of the tortillas. Larger force and distance values indicate a stronger and more stretchable product (Texture Technologies Corporation, 2009). In contrast, a tortilla exhibiting a smaller rupture force tends to break more easily when being filled with meat and vegetables and other ingredients. Tortillas made with SAS (1053.3g) required the greatest force to break compared to SAPP-28 (887.9g) and SALP (832.4g) (Figure 5.2). This was because SAS produced much denser tortillas than other acid types, as reported by Book et al. (2002).

Table 5.2: ANOVA results

		P-Values[1]						
Parameter	**R^2**	**Acid[2]**	**SBC[3]**	**Press Temp.**	**Dough Temp.**	**Acid-SBC**	**Acid-Press Temp.**	**SBC-Press Temp.**
Day 1								
Weight	0.96	0	0.006	0	0.025	0.019	0.183	0.994
Diameter	0.971	0	0	0	0.266	0.32	0.933	0.261
Thickness	0.975	0.003	0	0	0.355	0.206	0.216	0
Moisture	0.8	0.001	0.5	0	0.501	0.225	0.325	0.84
pH	0.992	0	0	0.021	0.028	0	0.015	0.363
Color (L*)	0.979	0	0	0.527	0.032	0.172	0.348	0.507
Color (a*)	0.955	0.001	0	0.003	0.013	0.099	0.756	0.193
Color (b*)	0.973	0	0.003	0.001	0	0	0.013	0.059
Opacity (Top)	0.953	0	0	0.006	0.009	0.061	0.09	0.086
Opacity (Bottom)	0.941	0	0	0.031	0.01	0.003	0.797	0.338
Breaking Force	0.82	0	0.672	0.353	0.912	0.358	0.645	0.409
Extensibility	0.615	0.224	0.141	0.053	0.257	0.603	0.789	0.164
Day 45								
Weight	0.918	0	0.035	0	0.01	0.038	0.374	0.949
Diameter	0.957	0	0	0	0.143	0.128	0.385	0.336
Thickness	0.952	0.004	0	0	0.075	0.082	0.634	0.005
Moisture	0.937	0	0.058	0	0.006	0.08	0.788	0.011
pH	0.998	0	0	0.06	0.733	0	0.332	0.626
Color (L*)	0.971	0	0	0.137	0.005	0.011	0.885	0.134
Color (a*)	0.94	0	0	0.008	0.008	0.02	0.628	0.665
Color (b*)	0.966	0	0.955	0	0.466	0	0.029	0.708
Opacity (Top)	0.944	0	0	0.001	0.009	0.009	0.408	0.306
Opacity (Bottom)	0.953	0	0	0.51	0.098	0.001	0.332	0.019
Breaking Force	0.892	0	0.191	0.307	0.022	0.125	0.294	0.623
Extensibility	0.872	0.001	0	0.012	0.037	0.04	0.302	0.17

[1] $P<0.05$ was considered statistically significant.

[2] Types of leavening acids: Sodium aluminum phosphate, Sodium aluminum sulfate, Sodium acid pyrophosphate-28

[3] Sodium bicarbonate amount

5.3.2 Effect of SBC amount

On day 1, the amount of SBC was significant ($p<0.05$) for weight, diameter, thickness, pH, color, and opacity but not for moisture, breaking force, and extensibility ($p>0.05$) (Table 5.2). Higher amounts of SBC produced smaller diameter but thicker tortillas (Table 5.3), which may be caused by increased dough toughness and gas retention capacity. Similar findings were obtained from Bejosano & Waniska (2004), noting that a decrease in diameter occurred when they increased the amount of leavening from 8.7 to 17.4g/kg with an acid-to-base ratio of 1.90, and from 6.7 to 13.5g/kg with a ratio of 1.24.

Higher amount of SBC contributed to a higher pH (Table 5.3), which suggested that more encapsulated fumaric acid should be used to reduce pH. However, Bejosano & Waniska (2004) found that pH was not affected by the amount of leavening, which might be due to the different acid-to-base ratios used in their study. With a higher amount of SBC, the tortillas were brighter and redder (Table 5.3). Winstone (2010) reported an increase in L* value from 76.2 to 78.4 when leavening agents were increased from 1.0 to 1.4%. In our study, tortillas made with 1.5% of the leavening were slightly bluer than 1% and 2% levels. Similarly, the tortillas were more opaque when produced with more SBC (Figure 5.1). Adams (2001) and Bejosano & Waniska (2004) found similar trends in the refined flour tortillas. Nevertheless, the opacity scores of WWF tortillas were much lower than those of refined flour tortillas, as reported in the literature. The high fiber content in WWF weakens gluten strength, so the dough is less resistant to hot press, which makes it difficult to retain the gas created during baking (Barros et al., 2010). Thus, translucency is more severe in the WWF tortilla system and higher levels of leavenings were necessary. However, the amount of SBC did not show effects on breaking force and extensibility (Figure 5.2).

Table 5.3: Effects of leavening acid, SBC amount, hot-press temperature and dough temperature on whole-wheat flour tortilla properties at day 1[1]

	Moisture	**pH**	**Weight (g)**	**Diameter (cm)**	**Thickness (cm)**	**Color**		
						L*	**a***	**b***
Leavening acid								
SALP[2]	30.2^{a}	6.27^{b}	35.59^{a}	16.90^{c}	2.78^{a}	74.46^{b}	4.31^{a}	21.87^{a}
SAS[3]	31.0^{b}	5.34^{a}	36.25^{b}	15.60^{a}	2.68^{a}	70.76^{a}	4.73^{b}	24.01^{b}
SAPP-28[4]	31.9^{c}	6.57^{c}	36.33^{b}	16.10^{b}	2.93^{b}	74.16^{b}	4.63^{b}	23.73^{b}
Amount of SBC								
1%	31.0^{a}	5.74^{a}	36.07^{b}	16.55^{b}	2.39^{a}	71.29^{a}	5.21^{c}	23.30^{b}
1.5%	31.3^{a}	6.03^{b}	35.90^{a}	16.36^{b}	2.76^{b}	73.53^{b}	4.39^{b}	22.89^{a}
2%	30.8^{a}	6.40^{c}	36.20^{b}	15.69^{a}	3.25^{c}	74.56^{c}	4.07^{a}	23.42^{b}
Hot-press temperature								
160°C	32.0^{b}	6.09^{b}	36.58^{c}	15.31^{a}	3.26^{c}	73.14^{a}	4.48^{a}	23.54^{b}
177°C	31.4^{b}	6.13^{b}	36.24^{b}	16.05^{b}	2.87^{b}	73.35^{a}	4.30^{a}	22.79^{a}
193°C	29.7^{a}	5.96^{a}	35.34^{a}	17.24^{c}	2.26^{a}	72.90^{a}	4.90^{b}	23.28^{b}
Dough temperature								
25°C	31.3^{a}	6.15^{b}	36.27^{b}	16.06^{a}	2.86^{a}	73.68^{b}	4.29^{a}	22.41^{a}
35°C	30.8^{a}	5.97^{a}	35.84^{a}	16.35^{a}	2.74^{a}	72.57^{a}	4.83^{b}	24.00^{b}

[1] Values under each factor section and in the same column followed by the same letter are not significantly different ($P>0.05$)

[2] Sodium aluminum phosphate

[3] Sodium aluminum sulfate

[4] Sodium acid pyrophosphate-28

Table 5.4: Effects of leavening acid, SBC amount, hot-press temperature and dough temperature on whole-wheat flour tortilla properties at day 45[1]

	Moisture	pH	Weight (g)	Diameter (cm)	Thickness (cm)	Color		
						L*	a*	b*
Leavening acid								
SALP[2]	30.0^a	5.91^b	35.20^a	16.82^c	2.67^a	71.70^b	4.45^a	21.48^a
SAS[3]	31.0^b	5.18^a	35.99^b	15.50^a	2.61^a	66.81^a	4.67^b	22.45^b
SAPP-28[4]	31.0^b	6.17^c	35.93^b	15.93^b	2.80^b	71.20^b	5.00^c	23.69^c
Amount of SBC								
1%	30.6^a	5.39^a	35.69^{ab}	16.57^c	2.28^a	68.06^a	5.32^c	22.57^a
1.5%	30.5^a	5.80^b	35.59^a	16.20^b	2.66^b	70.28^b	4.57^b	22.53^a
2%	31.0^a	6.07^c	35.85^b	15.47^a	3.15^c	71.37^c	4.23^a	23.54^a
Hot-press temperature								
160°C	31.5^b	5.73^a	36.14^b	15.29^a	3.13^c	69.87^{ab}	4.60^a	22.90^b
177°C	31.3^b	5.75^a	36.03^b	15.74^b	2.79^b	70.47^b	4.52^a	22.87^b
193°C	29.3^a	5.77^a	34.96^a	17.22^c	2.16^a	69.37^a	5.00^b	21.86^a
Dough temperature								
25°C	31.3^b	5.76^a	36.05^b	15.69^a	2.85^a	70.94^b	4.41^a	22.66^a
35°C	30.1^a	5.75^a	35.36^a	16.47^a	2.53^a	68.87^a	5.00^b	22.43^a

[1] Values under each factor section and in the same column followed by the same letter are not significantly different (P>0.05)

[2] Sodium aluminum phosphate

[3] Sodium aluminum sulfate

[4] Sodium acid pyrophosphate-28

5.3.3 Effect of hot-press temperature

Hot-press temperature significantly ($p<0.05$) affected most parameters one day after baking (day 1) except for color (L*), breaking force, and extensibility ($p>0.05$) (Table 5.2). At a higher press temperature, tortillas tended to lose more water during pressing; as a result, the higher press temperature (193°C) yielded lower moisture and lower-weight tortillas (Table 5.3). A higher hot-press temperature made the dough less viscous and more extensible; thus, larger-diameter and thinner tortillas were produced with higher hot-press temperature. In addition, tortillas made at 193°C hot-press temperature had a significantly ($p<0.05$) lower pH than those at 160°C or 177°C on day 1 (Table 5.3). The reason for this could be that encapsulated fumaric acid pre-released faster at 193°C hot-press temperature during baking and yielded lower pH. After 45 days, with the release of encapsulated fumaric acid, tortillas made with 160°C, 177°C, and 193°C hot-press temperatures did not have significant differences in pH ($p>0.05$). Hot-press temperature did not show much influence ($p>0.05$) on tortilla color and opacity. However, tortillas made with 193°C hot-press temperature had much lower opacity scores, indicating that 193°C press temperature was considered too high for WWF tortillas to have an acceptable opacity score. Similarly, Adams (2001) examined the effects of hot-press dwell time and pressure on wheat flour tortillas and found that opacities of tortillas were similar except when using extreme low or high dwell times and pressures. More starch gelatinization occurred under extreme high press temperature might be the cause that air bubbles were poorly retained and tortillas became more translucent. Moreover, tortilla breaking force and extensibility were not significantly ($p>0.05$) influenced by hot-press temperature.

5.3.4 Effect of dough temperature

On day 1, higher dough temperature produced lower weight tortillas due to greater moisture evaporation, while diameter and thickness was not significantly ($p>0.05$) affected by dough temperature (Table 5.3). Tortillas made with higher dough temperature (35°C) had a lower pH on day 1 than those with a lower dough temperature (25°C), which may be attributed to more encapsulated fumaric acid being dissolved under a higher mixing temperature. Additionally, we noticed a higher dough temperature reduced the amount of time to mix the dough to optimum development.

Higher dough temperature yielded darker, redder, and yellower tortillas (Table 5.3). With a higher dough temperature, the tortillas were more translucent (Figure 5.1). About 20-30% of total carbon dioxide is generated from SALP, SAPP within the first 2 min of mixing at 27°C (Molins, 1990). Even without leavening acids, due to the acidity of flour and other ingredients, there is reaction of SBC that will generate gas (Stauffer, 1990). The solubility of leavening base and acids, even the slow-acting acids, increase during mixing and resting under a higher dough temperature (Heidoph 1996; Cepeda et al. 2000). This will lead to less gas formation during baking and produce less opaque tortillas. Cepeda et al. (2000) found that higher amount of leavenings were required at 38°C dough than at 34°C to achieve a desired opacity. Previous studies (Hlynka, 1962; Waniska, 1999) reported that higher dough mixing temperature decreased mixing time and dough-resting time, which may explain why the industry would use a higher dough temperature even though a lower dough temperature produced more opaque products.

5.3.5 Effect of storage time

After 45 days of storage (day 45), some changes were found in tortilla parameters. Due to moisture loss, the moisture content and weight of tortillas were slightly reduced from day 1. The pH values of tortillas decreased after 45 days of storage as a result of a gradual release of encapsulated fumaric acid over time (Table 5.3 & 5.4). Due to the full solubility and reaction of leavening acids and base, hot-press temperature and dough temperature did not affect the pH values of tortillas on day 45, but the type of leavening acids and the amount of SBC significantly ($p<0.05$) influenced the tortilla pH. A pH< 6.1 was required to obtain extended shelf life for tortillas (Friend et al., 1995). Although some tortillas had initial pH values higher than 6.1, after 45 days of storage all pH values were decreased to 6.1 or below, and no mold growth was noticed on any tortilla.

Tortillas of all leavening systems became darker and redder, and most tortillas tended to be slightly bluer after 45 days (Table 5.3 & 5.4). Polyphenol oxidase (PPO) activity might contribute to the discoloration of tortillas during storage. Niu et al. (2014a) found that the whole-wheat noodles became darker, redder and bluer after 24 h storage at room temperature, which was attributed to the production of colored substances by PPO activity. However, slight changes were found in opacity scores in all tortilla leavening systems (Figure 5.1).

For all leavening systems, the breaking force and extensibility decreased after 45 days of storage. A similar decreasing trend has been found in previous research (Book et al., 2002; Winstone, 2010; Alviola & Awika, 2010). During storage, the amorphous starch transformed gradually to a partially crystalline, retrograded state and dispersed (Bejosano et al. 2005). Changes in starch functionality were mainly responsible for staling of tortillas (Alviola & Waniska, 2008), which resulted in a weaker and less flexible texture. The differences in breaking force among the three acids were greater on day 45 compared to day 1 (Figure 5.2). SALP required a significantly ($p<0.05$) smaller force to break compared to SAPP-28 and SAS. Similar to day 1, tortillas made with SAS had the biggest breaking force on day 45. The leavening amount and hot-press temperature did not show significant ($p>0.05$) effects on breaking force, but dough temperature had a significant ($p<0.05$) influence. Tortillas made with a higher dough temperature required less force to break, which may be attributed to more moisture loss.

Although the tortilla extensibility was not significantly ($p>0.05$) affected by any of the four factors on day 1, significant ($p<0.05$) differences were observed on day 45, partly because the tortillas became more uniform in structure after storage and test variations of extensibility were much smaller (Figure 5.2). On day 45, tortillas made with SAS (11.1 mm) had a shorter distance compared to those made with SALP (12.2 mm) and SAPP-28 (12.6 mm). The dense and firm tortilla dough with SAS contributed to the shorter extensibility. The amount of leavening significantly ($p<0.05$) increased the extensibility of tortillas as thicker tortillas were produced with a higher amount of leavening. There was no difference in tortilla extensibility between 160°C and 177°C press temperatures ($p>0.05$), but tortillas made at 193°C press had a significantly ($p<0.05$) shorter extensibility than others because they were the thinnest and required less time to rupture. Dough temperature significantly ($p<0.05$) decreased the extensibility as higher moisture loss caused the tortillas to break more easily.

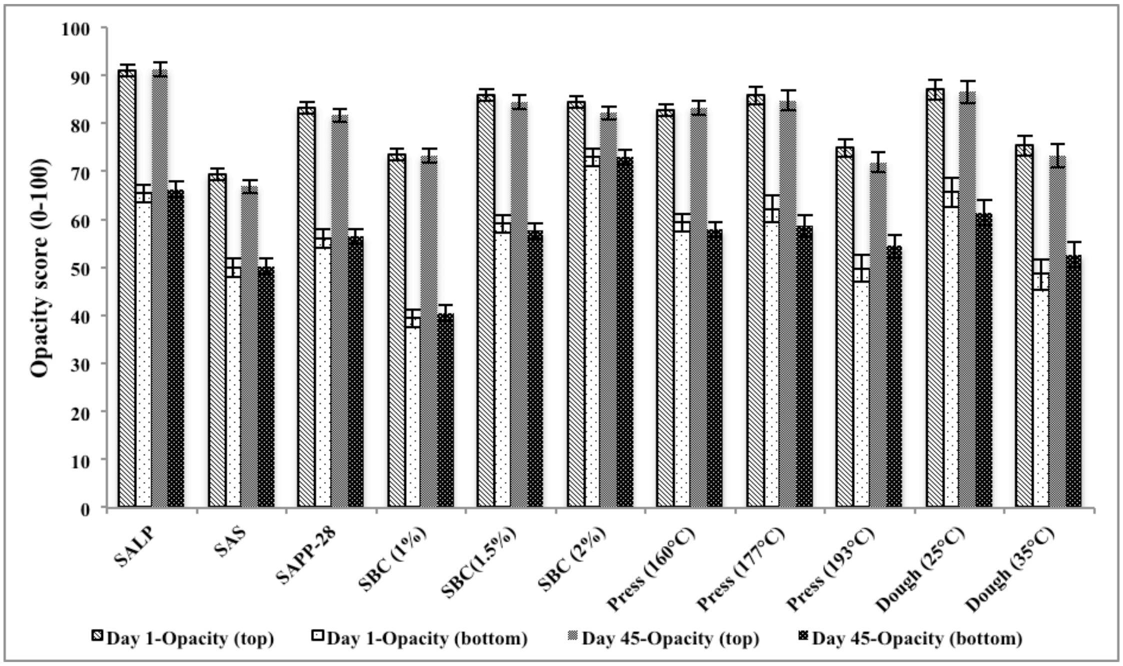
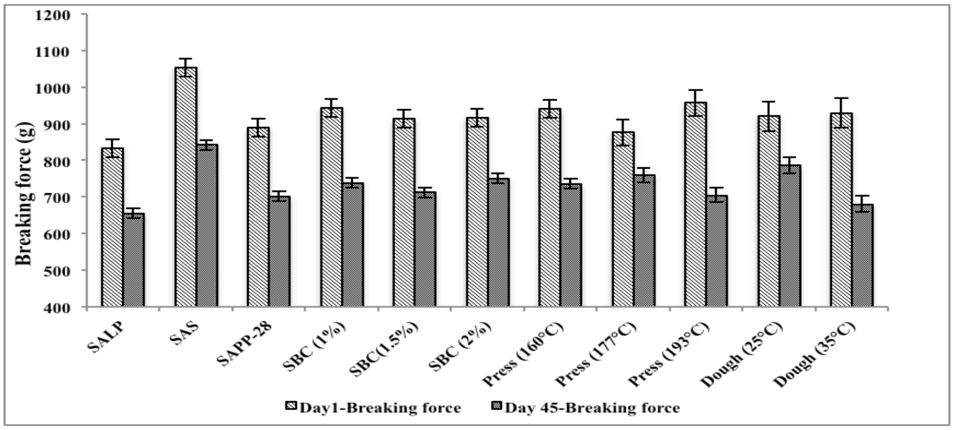


Figure 5.1: Effect of leavening acid, SBC, hot-press temperature and dough temperature on the opacity of whole-wheat flour tortillas on day 1 and 45. Data shown are means ± standard deviations (3 replicates). SALP: Sodium aluminum phosphate; SAS: Sodium aluminum sulfate; SAPP-28: Sodium acid pyrophosphate-28; SBC: Sodium bicarbonate

a.



b.

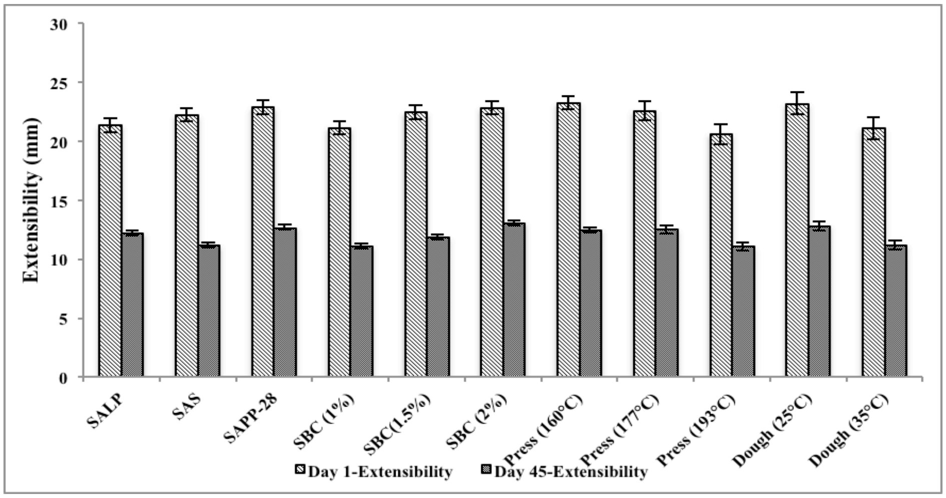


Figure 5.2: Effect of leavening acid, SBC, hot-press temperature and dough temperature on the (a) breaking force and (b) extensibility of whole-wheat flour tortillas on day 1 and 45. Data shown are means ± standard deviations (3 replicates). SALP: Sodium aluminum phosphate, SAS: Sodium aluminum sulfate, SAPP-28: Sodium acid pyrophosphate-28, SBC: Sodium bicarbonate

5.4 Conclusions

The type of leavening acid, SBC amount and dough temperature were the major factors influencing the opacity of WWF tortillas. A leavening system including 2% SBC (and equivalent SALP acid), 177°C hot-press temperature, and 25°C dough temperature would be most suited to produce more opaque WWF tortillas. Since each variable showed a different effect on each quality parameter, the tortilla industry should choose an ideal leavening system for their products based on their specific quality objectives. Future research to examine the differences in leavening acids (composition, mineral effects, gas production, etc.) will be beneficial to further understand the differences in their effects on WWF tortilla properties.

Acknowledgments

The authors would like to thank ICL Food Specialties (St. Louis, MO) for sponsoring this study.

CHAPTER 6

EFFECTS OF SPROUTED WHOLE-WHEAT FLOUR CONCENTRATION ON QUALITY PROPERTIES OF WHOLE-WHEAT FLOUR TORTILLAS

This manuscript authored by Ting Liu, Gary G Hou, Marie Cardin, and Len Marquart is to be submitted.

Ting Liu performed the experiments and wrote this chapter.

Abstract

With the development of controlled grain-sprouting techniques, sprouted whole-grain foods are an emerging trend in the food market due to consumers' desire for health-promoting foods. The objectives of this study were to examine the effects of sprouted whole-wheat flour (WWF) concentration (0%, 25%, 50%, 75% and 100%) on the rheological properties of WWF and its tortilla products. Flour samples were analyzed for gluten index, color, solvent retention capacity, and Mixolab parameters, while tortillas were analyzed for weight, diameter, thickness, color, opacity, texture, rollability, and sensory attributes. Mixolab data showed that water absorption, dough development, and stability times decreased with an increase of sprouted WWF content. In terms of tortilla baking performance, tortillas made with higher amounts of sprouted WWF were larger in diameter and specific volume, brighter, and more opaque, and received higher sensory scores in color, flavor, and overall acceptability. For texture parameters, tortillas made with a higher percent of sprouted WWF required less force to break, which indicated that tortillas were less firm. After 16 days of storage, tortillas made with higher amounts of sprouted WWF were more rollable and shelf-stable. The results demonstrated that sprouted WWF would bring benefits to WWF tortilla's baking performance, i.e. better appearance, higher consumer acceptability, and longer shelf life.

6.1 Introduction

Whole grains (WG) are nutritionally superior to refined grains, as the bran and germ components are abundant in nutrients and potential bioactive compounds such as dietary fiber, vitamins, sterols, phytins, and other phenolic compounds (Miller et al., 2000; McKeown et al., 2007). These protective components in WG may work individually or synergistically to reduce risk of type-2 diabetes, cardiovascular disease, certain types of cancer, and obesity (Marquart et al., 2007). Based on these health benefits, it is recommended that Americans consume at least half of their grains as whole grains (USDHHS & USDA, 2015). Consumers, especially health-conscious consumers, are looking for more whole-grain choices in the market. One innovative choice is sprouted grains, which are becoming more mainstream.

According to AACC International, "Malted or sprouted grains containing all of the original bran, germ, and endosperm shall be considered whole grains as long as sprout growth does not exceed kernel length and nutrient values have not diminished. These grains should be labeled as malted or sprouted whole grain" (AACCI, 2016). The production of sprouted whole-wheat flour (WWF) consists of three major steps: steeping, germination, and kilning (Hübner & Arendt, 2013; Richer et al., 2014). Carefully selected wheat is soaked in water under precise and controlled conditions of time and temperature. The wheat germinates, or sprouts, via circulating humid air to control growth. In the kilning step, warm air is circulated through the wheat grain to dry and develop flavor and color. The sprouted wheat can be milled into WWF. Controlled sprouting is a less expensive but more efficient method to improve nutrient profiles of grains. Studies have reported that sprouting not only significantly increased antioxidant activity (Hung et al., 2011), vitamin C, E, β-carotene, minerals (i.e. Cu, Fe, K, and Zn), and folate content (Yang et al., 2001; Plaza et al., 2003; Koehler et al., 2007) but also reduced antinutrients, such as phytic acid, which might result in greater bioavailability of nutrients (Azeke et al., 2011). In addition, sprouted grains are more easily digested by humans than non-sprouted grains (Dziki et al., 2015). Therefore, incorporating sprouted WWF into grain products meets the desires of health conscious consumers for more WG options, along with the added nutritional values.

As to baking performance, several studies have shown that less controlled sprouting, such as pre-harvest sprouting or over sprouting, adversely affected wheat product baking and yielded bread with sticky dough and inferior texture (Ariyama & Khan, 1990; Every & Ross, 1996). However, a recent study demonstrated that 100% whole-wheat bread made from controlled sprouted WWF had an increased loaf volume, decreased proof time, and less bitterness compared to bread made with non-sprouted control flour (Richter et al., 2014). In the case of producing WWF pasta, sprouting lowered water absorption capacity and cooking water free starch but increased plasticity and elasticity of cooked pasta (Shneider et al., 2009).

Tortillas are more popular than other types of ethnic breads in the US, and this segment of the market continues to grow (Perez-Carrillo et al., 2015). As whole-wheat bread becomes more acceptable to consumers, other whole-wheat products, such as tortillas, require additional efforts to maintain and/or improve consumer acceptance and repeat purchase. To the best of our knowledge, the impact of sprouted WWF on tortilla baking performance has not been reported elsewhere. The objectives of this study were to examine the effects of sprouted WWF concentration (0%, 25%, 50%, 75%, and 100%) on the rheological properties of WWF and baking performance of WWF tortillas.

6.2 Materials and methods

6.2.1 Materials

Commercial sprouted hard white spring WWF and regular hard white spring WWF were kindly provided by a flour milling company. The median particle sizes of the original sprouted WWF and regular WWF were 136.56 and 98.94 μm, respectively. In order to minimize the particle size effects, the original sprouted WWF was sifted to pass through a 95-μm screen. The fractions above the 95-μm screen were further ground 2 times using a Perten 3100 laboratory mill (Perten Instruments, Hägersten, Sweden) equipped with a 0.6-mm metal mesh screen and blended with other fractions to obtain a similar median particle size as regular WWF. Sodium bicarbonate (powder ACS) was purchased from ChemProducts (Portland, OR), and sodium aluminum phosphate (SALP) was provided by ICL Food Specialties (St. Louis, MO). Salt, Crisco vegetable shortening, and sugar were purchased from a local supermarket (Portland, OR). Sodium stearoyl lactylate (SSL) was available through Corbion (Kansas City, KS). Potassium sorbate and calcium propionate were obtained from Muhlenchemie GmbH & Co KG (Ahrensburg, Germany).

6.2.2 Flour analysis

The ratios of sprouted WWF to regular WWF were 0:100 (control), 25:75, 50:50, 75:25, and 100:0, respectively. Protein (AACCI 46-30.01), moisture (AACCI 44-15.02), ash (AACCI 08-01.01), damaged starch (AACCI 76-30.02), wet gluten and gluten index (AACCI 38-12.02), falling number (AACCI 56-81.03), and color (AACCI 14-30.01) of five different WWF blends were determined according to the AACC International Approved Methods, and results are shown in Table 6.1. The thermomechanical characteristics of each flour blend were measured using the Mixolab analyzer (Chopin Technologies, Villeneuve-La-Garenne, France) (AACCI 54-60.01). The parameters obtained from the Mixolab included the percent of water required for the dough to produce a torque of 1.1±0.05Nm (water absorption, %), the time to reach the maximum torque at 30°C (dough development time, min), the elapsed time that the torque was maintained at 1.1Nm (stability, min), protein weakening (C2, Nm), starch gelatinization (C3, Nm), stability of the hot-formed gel (C3-C4, Nm), and starch retrogradation during the cooling phase (C5, Nm) (Huang et al., 2010). In addition, the solvent retention capacity (SRC) values of flour blends were determined according to the AACCI Method 56-11.02, with four solvents as lactic acid SRC (LA-SRC), sodium carbonate SRC (SC-SRC), sucrose SRC (Suc-SRC), and water SRC (W-SRC). Gluten performance index (GPI), which was defined as GPI=LA-SRC/(SC-SRC+Suc-SRC), was also calculated (Kweon et al., 2011).

Table 6.1: Flour analysis of whole-wheat flour (WWF) blends substituted by sprouted WWF[1,2]

Flour Properties	**Sprouted Whole-Wheat Flour Concentration (%)**				
	0% (control)	**25%**	**50%**	**75%**	**100%**
Moisture (%)	8.70±0.01^{a}	9.02±0.04^{b}	9.48±0.05^{c}	9.76±0.06^{d}	10.12±0.03^{e}
Protein (14%mb)	12.23±0.13^{a}	12.29±0.06^{a}	12.55±0.05^{b}	12.71±0.11b^{c}	12.91±0.02^{c}
Ash (14%mb)	1.55±0.00^{c}	1.53±0.01^{bc}	1.53±0.00^{b}	1.52±0.01^{b}	1.50±0.01^{a}
Falling Number (s)	416.0±2.8^{e}	406.0±5.7^{d}	349.5±2.1^{c}	300.0±2.8^{b}	266.0±5.7^{a}
Wet Gluten (14%mb)	22.65±0.33^{a}	23.82±0.27^{b}	28.41±0.54^{c}	29.11±0.07^{d}	30.67±0.07^{e}
Gluten Index (%)	93.7±2.0^{d}	90.0±0.2^{c}	87.9±0.1^{b}	85.9±0.2^{b}	80.9±1.0^{a}
Damaged Starch (14%mb)	4.52±0.02^{e}	4.28±0.01^{d}	3.95±0.04^{c}	3.64±0.01^{b}	3.32±0.02^{a}
Particle Size (μm)	98.94±0.64^{d}	96.92±0.24^{c}	94.99±1.12^{b}	94.65±0.48^{b}	93.03±0.05^{a}

Color (L*)	83.63±0.10^{a}	83.94±0.04^{b}	84.50±0.20^{c}	84.97±0.04^{d}	85.39±0.02^{e}
Color (a*)	-0.18±0.01^{d}	-0.20±0.00^{bc}	-0.21±0.01^{b}	-0.24±0.01^{a}	-0.25±0.01^{a}
Color (b*)	11.99±0.09^{e}	11.55±0.02^{d}	10.87±0.10^{c}	10.3±0.02^{b}	9.67±0.06^{a}

[1] L*, lightness; a*, redness-greenness; b*, yellowness-blueness.

[2] Results are shown as means ± standard deviations (n=3). Means in the same row followed by different superscripts are significantly different at P<0.05.

6.2.3 Tortilla preparation

6.2.3.1 Formulation

Ingredients included flour (100%), salt (1.5%), sugar (0.5%), shortening (7%), SALP 1%), sodium bicarbonate (1%), SSL (0.5%), potassium sorbate (0.4%), calcium propionate (0.5%), and water. All ingredients were scaled on the basis of 1000-g flour weight. Different amounts of water for each flour blend was added based on the water absorption data from the Mixolab and dough handling properties.

6.2.3.2 Process

The tortillas were produced on pilot-scale tortilla plant equipment at the Wheat Marketing Center (Portland, OR). The ingredients were weighed and added to a Hobart Mixer (Model A-120, Hobart MFG. Co, Troy, OH) equipped with a spiral mixing head to mix for 4 min at the 1st speed and 2-4 min at the 2nd speed until the dough fully developed. Ice water was used to obtain a desired dough temperature of 29-30°C. Tortillas were processed according to the procedures described by Liu et al. (2016). Freshly baked tortillas were cooled on a metal rack for 5 min, packed into Ziploc bags, and stored at room temperature.

6.2.4 Tortilla properties evaluation

The moisture content and pH of tortillas were measured with an infrared moisture analyzer (Model HS 153, Mettler-Toledo International, Inc., Columbus, OH) and a glass electrode (Model S20, SevenEasy™ pH meter, Mettler-Toledo International, Inc., Columbus, OH), respectively, as described by Liu et al. (2016). Tortilla weight (scale), diameter (ruler), and thickness (plastic dial caliper) were measured, using their respective devices, as the average of ten randomly selected tortillas. Specific volume (cm^3/g) was calculated: $= \pi*(Diameter/2)^2*thickness*1000/weight$. In addition, Tortilla color values were read with a Minolta Colorimeter (Model CR-410, Konica Minolta Sensing, Inc., Osaka, Japan), including lightness (L*), redness (a*), and yellowness (b*) values. Furthermore, tortilla opacity scores on both top and bottom sides were measured using a continuous scale of 0-100%, with 0% being completely translucent (not white) and 100% being completely opaque (white).

The breaking force (g) and extensibility (mm) of tortillas were measured using a TA-XTPlus Texture Analyzer (Texture Technologies Corporation, Scarsdale, NY, USA) with a rounded nose probe (TA-108a, 7/16'' or 1.11 cm diameter cylinder with a rounded edge). In addition, the rollability of tortillas was evaluated on 1, 4, 8, 12, and 16 days of storage by wrapping a tortilla around a dowel (1.0 cm diameter). The cracking and breakage of the tortilla were rated using a continuous scale of 1-5 (5= no cracking, 4= signs of cracking but no breaking, 3= cracking and breaking beginning on the surface, 2= cracking and breaking imminent on both sides, 1= unrollable, breaks easily) (Cepeda et al., 2000).

Sensory evaluation was conducted by 30 untrained adults. Each person received a tray containing five tortilla samples labeled with random three-digit codes. Subjects were instructed to evaluate the samples and rate their likings on product color, texture, flavor, and overall acceptability on a 5-point categorical scale, where 1 meant “dislike very much” and 5 referred to “like very much.”

6.2.5 Statistical analysis

Statistical analyses were conducted with SPSS 22 software for Mac using one-way analyses of variance (ANOVA) with the Duncan’s test. $P<0.05$ was considered to be significant. In addition, single correlation coefficients (Pearson’s correlation) were determined to investigate the relationships between flour properties and tortilla quality attributes. All measurements were performed at least in triplicate, and the data were presented as mean ± standard deviation.

6.3 Results and discussion

6.3.1 Effect of sprouted WWF on Mixolab properties of WWF blends

The Mixolab system has the ability to measure both flour protein and starch behavior when subjected to a dual temperature and mechanical-stress constraint (Ozturk et al., 2008). The effect of sprouted WWF concentration (from 0% to 100%) on Mixolab parameters of WWF blends is shown in Table 6.2. Under condition of $C1 = 1.1\pm0.05$ Nm, water absorption (WA) decreased significantly ($p<0.05$) with the increased amount of sprouted WWF. This might be attributed to lower damaged starch content (Table 6.1) in flour blends with higher amounts of sprouted WWF. The reduction of WA in this study was similar to the report of Shafqat (2013), who found that by adding 15% sprouted flour into commercial refined hard wheat flour, flour Farinograph absorption decreased from 59.7% to 54.5%. Table 6.2 shows that addition of sprouted WWF significantly ($p<0.05$) shortened the time (dough development time, C1 time) required for the dough to reach optimum elastic and viscous properties. This might be caused by the increased protease activity in sprouted WWF, which softened the gluten and thus reduced mixing time (Edwards et al., 1989; Shafqat, 2013). Similarly, Morad & Rubenthaler (1983) also noted a decrease in dough mixing time and water absorption by Mixograph after 20 hours germination of soft white wheat flour.

Dough stability time is mainly determined by flour gluten strength and its resistance to kneading forces (Dabčević et al., 2009), with longer time suggesting stronger gluten (Niu et al., 2014a). Stability time decreased significantly ($p<0.05$) from 11.47 min to 8.66 min with addition of sprouted WWF from 0% to 100% (Table 6.2). Thus, dough containing a higher amount of sprouted WWF was weaker, which was in agreement with the decreased gluten index, as shown in Table 6.1. Gluten index is defined as the percent of wet gluten remaining on the sieve after centrifugation, and a higher gluten index indicates stronger gluten (Barros et al., 2010). Although addition of sprouted WWF increased the protein content of the flour blends (Table 6.1), it produced weaker dough. Due to limited information on wheat varieties used in our study, it was uncertain whether the weakening of gluten in sprouted WWF was due to specific wheat varieties or the sprouting process. Additional research is needed to further clarify these results.

Nevertheless, these observations might be explained from two perspectives related to the sprouting process. On the one hand, some studies reported that sprouting would increase flour protein content (Lemar & Swanson, 1976; Morad & Rubenthaler, 1983). However, Lemar & Swanson (1976) suggested that the apparent increase in protein content after germination might reflect either a loss in carbohydrate material or the alternation of nitrogenous substances rather than an actual increase in absolute protein. Therefore, the actual protein content of sprouted WWF might be lower than the regular WWF (control) in our study. On the other hand, during sprouting, the increased proteolytic enzyme activity hydrolyzed the gluten and broke high molecular weight proteins into smaller subfractions. These reactions would ultimately decrease dough strength (Sekhon et al., 1992; Singh et al., 2001; Barbeau et al., 2006). As shown in Table 6.2, with higher amounts of sprouted WWF, ranging from 0% to 100%, torque C2 value (Nm) decreased, suggesting weaker gluten strength (Koksel et al., 2009).

The latter stages of Mixolab curve describe starch-pasting properties. Torque C3 (Nm) represents the degree of starch gelatinization and peak viscosity (Dabčević et al., 2009). Addition of sprouted WWF decreased the dough peak viscosity, as shown in Table 6.2. The decline was mainly due to the higher amount of degraded starch in sprouted WWF. During sprouting, native starch granules were degraded into smaller molecular-size starch chains or dextrins by increased enzyme activities (i.e., α-amylases, β-amylases) and exhibited lower pasting viscosity than that of native starch (Chung et al., 2012). Torque C3-C4 (hot gel stability, Nm) reflects the amylolytic activity, where a bigger difference in C3 and C4 indicates higher amylolytic activity (Koksel et al., 2009).

The C3-C4 value increased with higher amounts of sprouted WWF (Table 6.2), which was in line with lower falling number (Table 6.1). Torque C5 (Nm) measured starch retrogradation in the cooling phase (Teng et al., 2015). Table 6.2 showed that C5 value decreased significantly ($p<0.05$) with increasing sprouted WWF content, ranging from 0% to 100%. The degraded amylose structure in sprouted WWF contributed to a smaller recrystallization of gelatinized starch molecules (Chung et al., 2012). This reduced starch retrogradation is responsible for slowing the staling of bakery products during storage (Cai et al., 2014).

Table 6.2: Mixolab profile of whole-wheat flour (WWF) blends substituted by sprouted WWF[1]

Sample	**WA[2]**	**C1 Time (min)**	**Stability (min)**	**C2 (Nm)**	**C3 (Nm)**	**C3-C4 (Nm)**	**C5 (Nm)**
0% (control)	69.0^{e}	9.06 ± 0.72^{c}	11.47 ± 0.40^{c}	0.51 ± 0.01^{d}	1.74 ± 0.01^{c}	0.28 ± 0.00^{a}	2.30 ± 0.07^{e}
25%	68.1^{d}	8.88 ± 0.09^{bc}	10.94 ± 0.64^{bc}	0.49 ± 0.00^{c}	1.73 ± 0.01^{c}	0.42 ± 0.01^{b}	1.98 ± 0.03^{d}
50%	67.1^{c}	8.18 ± 0.44^{b}	10.53 ± 0.52^{bc}	0.46 ± 0.01^{b}	1.68 ± 0.01^{b}	0.52 ± 0.01^{c}	1.72 ± 0.02^{c}
75%	66.3^{b}	7.12 ± 0.37^{a}	9.92 ± 0.62^{b}	0.44 ± 0.02^{b}	1.66 ± 0.01^{b}	0.59 ± 0.01^{d}	1.58 ± 0.02^{b}
100%	65.8^{a}	6.85 ± 0.47^{a}	8.66 ± 0.46^{a}	0.40 ± 0.01^{a}	1.59 ± 0.02^{a}	0.65 ± 0.01^{e}	1.35 ± 0.03^{a}

[1] Results are shown as means ± standard deviations (n=3). Means in the same column followed by different superscripts are significantly different at $P<0.05$.

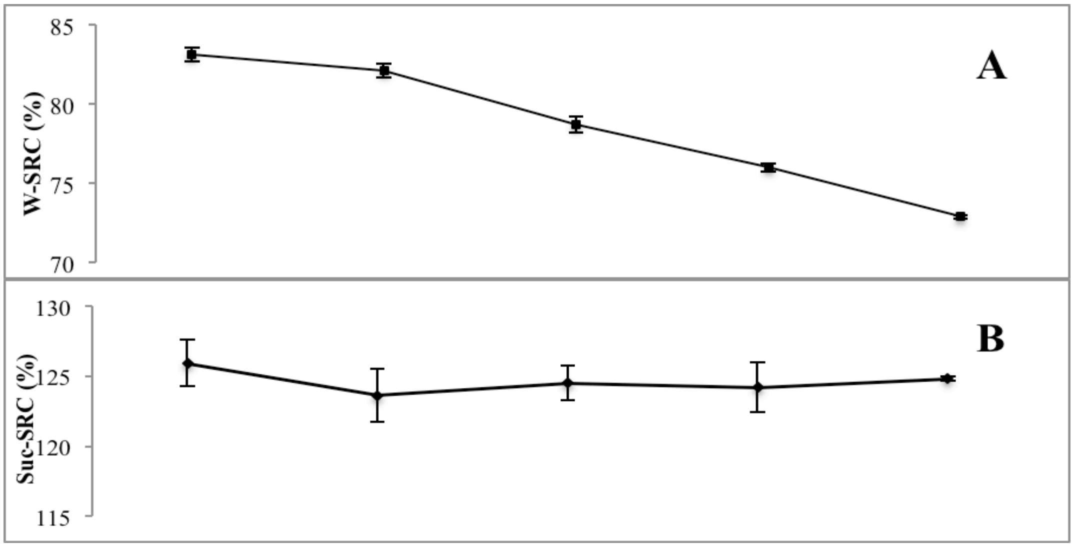
[2] WA, water absorption.

6.3.2 Effect of sprouted WWF on SRC profiles of WWF blends

The solvent retention capacity (SRC) method was initially developed to evaluate soft wheat flour functionality in cookie and cracker products, yet it also has the potential to evaluate hard wheat flour (Kweon et al., 2011). The SRC profiles and GPI values of WWF blends are shown in Figure 6.1. Suc-SRC is associated with arabinoxylans (pentosan) properties, LA-SRC indicates glutenin functionality, SC-SRC reflects the level of damaged starch, while W-SRC is influenced by all three functional components

(AACCI Approved Methods 56-11.02). However, GPI was reported to be a better indicator of overall performance capability of glutenin than the LA-SRC alone in cracker flour (Kweon et al., 2011; Li et al., 2014).

As shown in Figure 6.1, addition of sprouted WWF resulted in a significant ($p<0.05$) decrease in W-SRC, SC-SRC, LA-SRC and GPI values, but it did not affect the Suc-SRC value. With a higher damaged starch content, which absorbs more water than native wheat starch, the control flour had a higher W-SRC value of 83.1%, compared with 72.9% for 100% sprouted WWF. The decrease in W-SRC values was in agreement with the reduction of Mixolab water absorption (Table 6.2). However, the addition of sprouted WWF did not show a significant ($p>0.05$) effect on arabinoxylan contents (Suc-SRC) among WWF blends. The reduced SC-SRC value was attributed to lower damaged starch content (Table 6.1) in WWF blends with a higher percent of sprouted WWF. The lower LA-SRC and GPI values referred to weaker gluten strength. These results were confirmed by a downtrend in the gluten index values and Mixolab stability times.



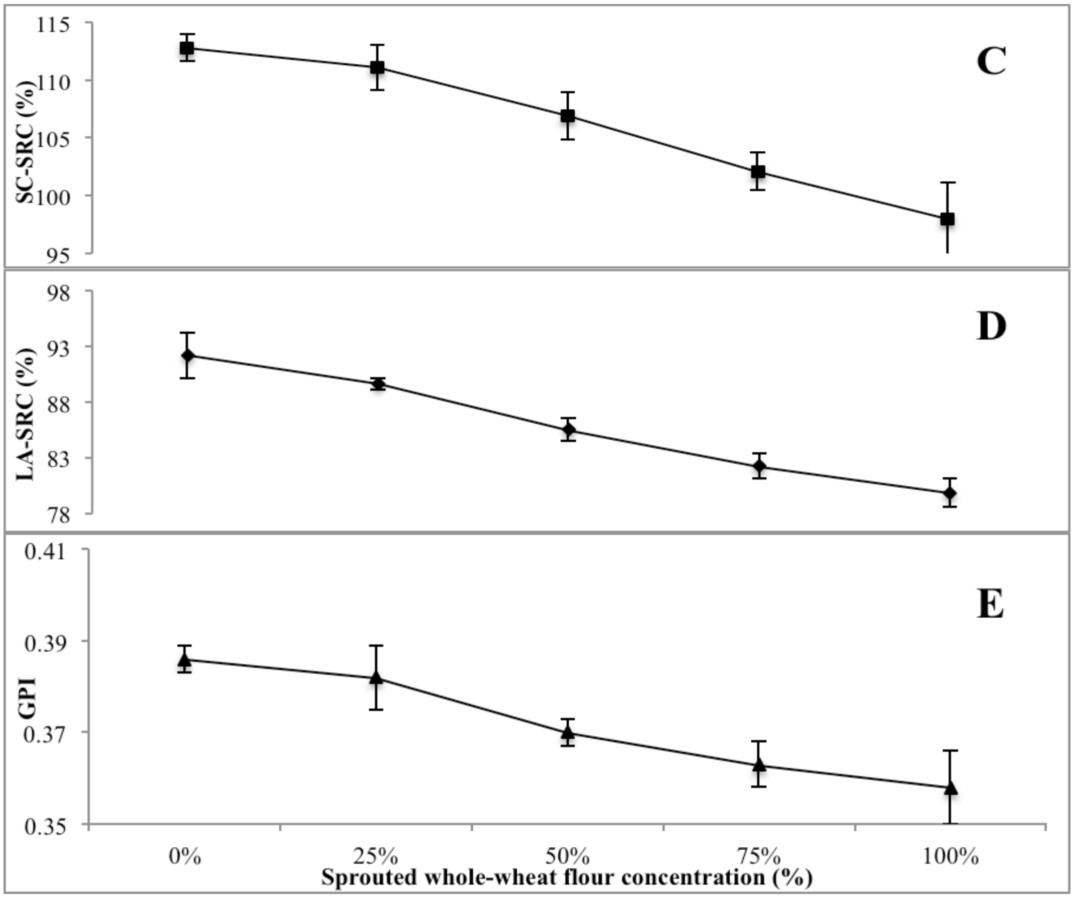


Figure 6.1: Effects of sprouted whole-wheat flour (WWF) concentration on the solvent retention capacity (SRC) of WWF blends. SRC: solvent retention capacity; W-SRC: water SRC; Suc-SRC: sucrose SRC; SC-SRC: sodium carbonate SRC; LA-SRC: lactic acid SRC; GPI: gluten performance index; GPI= LA-SRC/(SC-SRC+Suc-SRC). Results are reported as means ± standard deviation. **A**, W-SRC (%); **B**, Suc-SRC (%); **C**, SC-SRC (%); **D**, LA-SRC (%); **E**, GPI.

6.3.3 Effect of sprouted WWF on tortilla properties

The effect of sprouted WWF on tortilla quality attributes are shown in Table 6.3. Addition of sprouted WWF from 0% to 100% did not significantly ($p>0.05$) affect moisture content, pH, and weight, but it did produce significantly ($p<0.05$) larger-diameter tortillas. Strong gluten dough tends to shrink back more during hot pressing and results in smaller-diameter tortillas (Barros et al., 2010). As mentioned earlier when discussing the Mixolab and SRC results, WWF blends with higher amounts of sprouted WWF had weaker dough strength, so they produced larger-diameter tortillas. Specific volume, which corresponds to the fluffiness of tortillas, is calculated based on weight, diameter, and thickness. Good quality tortillas should be puffy since consumers prefer puffed tortillas to dense tortillas (Waniska, 1999). In this study, no significant ($p>0.05$) difference in thickness was found, while slightly higher specific volume (from 1.26 to 1.38 cm^3/g) was observed with an increased amount of sprouted WWF from 0% to 100%.

As shown in Table 6.3, with higher amounts of sprouted WWF from 0% to 100%, tortilla L* value increased from 64.98 to 71.23, while a* and b* values decreased from 6.53, 25.96 to 5.01, 24.04, respectively. These results indicated that tortillas became whiter, greener, and bluer, which corresponded to flour color changes (Table 6.1). Opacity is an important quality trait for tortilla and more-opaque tortillas are favored by consumers (Alvoia & Awika, 2010). Addition of sprouted WWF significantly ($p<0.05$) increased the opacity scores on both the top and bottom sides of tortillas from 67.65% to 85.05% (top), and from 46.41% to 67.35% (bottom) (Table 6.3). It was proposed that a higher degree of starch gelatinization could make WWF tortillas more translucent (Liu et al., 2016); as such, tortillas with a lower starch gelatinization and retrogradation rate as shown by the Mixolab would appear more opaque.

Table 6.3: Tortilla properties of whole-wheat flour (WWF) blends substituted by sprouted WWF[1,2]

Tortilla Properties	**Sprouted Whole-Wheat Flour Concentration (%)**				
	0% (control)	**25%**	**50%**	**75%**	**100%**
Moisture (%)	33.63 ± 0.06^a	33.54 ± 0.31^a	33.48 ± 0.25^a	33.29 ± 0.16^a	32.93 ± 0.62^a

pH	5.68±0.03^{a}	5.67±0.07^{a}	5.67±0.11^{a}	5.65±0.06^{a}	5.57±0.05^{a}
Weight (g)	35.65±0.09^{a}	35.83±0.04^{a}	35.75±0.07^{a}	35.71±0.12^{a}	35.98±0.23^{a}
Diameter (cm)	16.10±0.11^{a}	16.12±0.15^{a}	16.43±0.08^{ab}	16.44±0.35^{ab}	16.62±0.04^{b}
Thickness (mm)	2.20±0.01^{a}	2.24±0.08^{a}	2.23±0.08^{a}	2.28±0.04^{a}	2.29±0.06^{a}
Specific Volume (cm^3/g)	1.26±0.03^{a}	1.27±0.04^{a}	1.32±0.04^{ab}	1.35±0.04^{ab}	1.38±0.04^{b}
Color (L*)	64.98±0.45^{a}	66.28±0.93^{b}	67.74±0.21^{c}	69.83±0.18^{d}	71.23±0.28^{e}
Color (a*)	6.53±0.18^{c}	6.20±0.28^{bc}	5.85±0.13^{b}	5.31±0.08^{a}	5.01±0.14^{a}
Color (b*)	25.96±0.18^{d}	25.71±0.08^{cd}	25.33±0.34^{c}	24.75±0.01^{b}	24.04±0.18^{a}
Opacity (top) (%)	67.65±1.66^{a}	70.86±1.79^{a}	73.83±0.42^{ab}	79.71±2.91^{bc}	85.05±2.30^{c}
Opacity (bottom) (%)	46.41±3.41^{a}	45.00±0.41^{a}	56.80±1.13^{b}	63.34±0.42^{c}	67.35±2.90^{c}

[1] L*, lightness; a*, redness-greenness; b*, yellowness-blueness.

[2] Results are shown as means ± standard deviations (n=3). Means in the same row followed by different superscripts are significantly different at $P<0.05$.

The maximum force needed to completely puncture the tortillas indicates tortillas' firmness, while the distance until rupture refers to tortillas' extensibility. Larger force and longer distance indicate a stronger and more stretchable product (Texture Technologies Corporation, 2009). One day after baking, tortillas made with higher amounts of sprouted WWF had much lower breaking force and were weaker than those made with control flour (Figure 6.2). This result agreed with previous data from the gluten index and Mixolab stability time that addition of sprouted WWF weakened the dough. In addition, there was no significant ($p>0.05$) difference in extensibility (day 1) among tortillas made with different flour blends; however, the extensibility measured on day 4 increased with additional sprouted WWF.

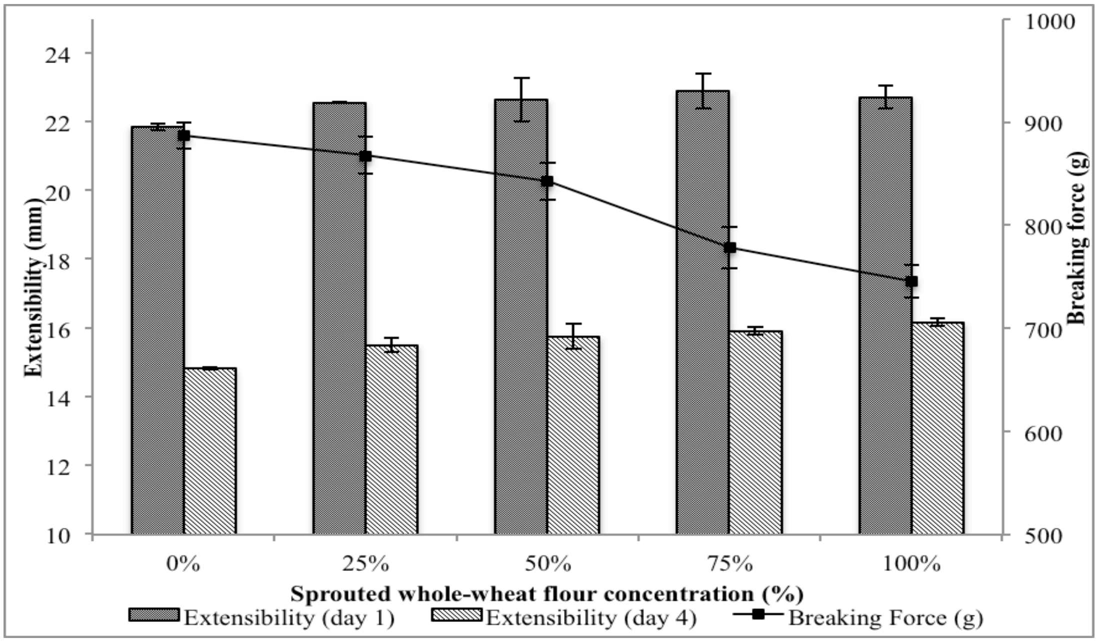


Figure 6.2: Effects of sprouted whole-wheat flour (WWF) concentration on breaking force (g) and extensibility (mm) (day 1 & day 4) of WWF tortillas. Results are reported as means ± standard deviation.

Shelf stability is another important parameter for tortillas, and it can be determined by a subjective rollability test. When tortilla stales, the texture becomes less flexible and rollable to fold without cracking or breaking (Bejosano et al., 2005). Figure 6.3 showed that the tortilla rollability scores reduced with a longer storage time (from day 1 to day 16). Tortillas made with higher amounts of sprouted WWF have a higher rollability score on day 16, which suggested that those tortillas were more shelf-stable. Seetharaman et al. (2002) pointed out that a main cause for tortilla staling was a gradual transformation of amorphous starch to a partially crystalline and retrograded state after baking. As shown by the Mixolab C5 values, lower recrystallization of gelatinized starch molecules in WWF blends with higher amounts of sprouted WWF might contribute to slower staling in tortillas. Since the rollability test is subjective and time-consuming, which takes a period of at least two weeks, it would be prudent to look for an objective texture parameter (measured within 4 days) that can be more efficient in predicting shelf stability (Alviola & Awika, 2010). In our study, we observed a positive correlation ($R^2 = 0.77$, $p<0.01$) between the rollability score on day 16 and extensibility (mm) on day 4, confirming the finding of a previous study that rupture distance (day 4) could be a good predictor of day 16 rollability with an R^2 of 0.59 (Alviola & Awika, 2010).

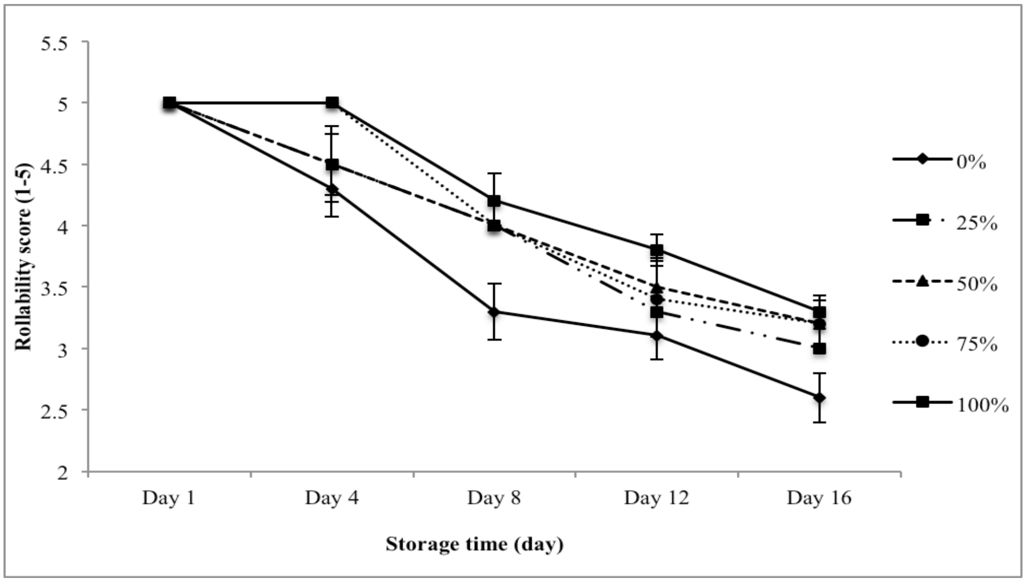


Figure 6.3: Effects of sprouted whole-wheat flour (WWF) concentration on rollability scores of WWF tortillas on 1, 4, 8, 12, and 16 days of storage. Results are reported as means ± standard deviation.

Sensory evaluation results are summarized in Table 6.4. Color, texture, flavor, and overall acceptability scores of control tortilla samples were between 2 and 3, where "2 = dislike moderately", and "3 = neither like nor dislike," whereas tortillas made with 100% sprouted WWF had color, texture, flavor, and overall acceptability scores between 3 and

4 (“3 = neither like nor dislike,” and “4=like moderately”). With the addition of sprouted WWF, tortillas were whiter (higher L* value) and received a higher color likeness score from 2.77 to 4.03. Subjects preferred the texture of tortillas with 75% and 100% sprouted WWF ($p<0.05$) to the control tortillas. Addition of sprouted WWF contributed to a moderate increase in flavor score from 2.57 (0%) to 3.70 (100%). Slightly less grainy texture and bitterness were reported by the subjects. Similarly, previous research demonstrated that bread made with sprouted wheat flour had less bitterness and received improved sensory results compared with non-sprouted WWF (Richter et al., 2014). Tortillas made with higher amounts of sprouted WWF received higher overall acceptability scores, indicating that addition of sprouted WWF would increase consumers’ acceptability and liking of whole-wheat tortillas.

Table 6.4: Sensory evaluations of whole-wheat Flour (WWF) tortillas substituted by sprouted WWF[1]

Sample	Color	Texture	Flavor	Overall
0% (control)	2.77^{a}	2.93^{a}	2.57^{a}	2.80^{a}
25%	3.23^{b}	3.30^{ab}	3.30^{b}	3.38^{b}
50%	3.53^{bc}	3.43^{ab}	3.33^{b}	3.50^{b}
75%	3.80^{cd}	3.60^{b}	3.63^{b}	3.92^{c}
100%	4.03^{d}	3.60^{b}	3.70^{b}	4.02^{c}

[1] Means in the same column followed by different superscripts are significantly different at $P<0.05$.

6.3.4 Correlation analysis

The correlations among the end-product quality parameters, flour properties, Mixolab, and SRC values are shown in Table 6.5. Tortilla diameter and specific volume correlated negatively ($p<0.01$) with gluten index, damaged starch, Mixolab C1 time, and stability, W-SRC, LA-SRC, SC-SRC, and GPI, and correlated positively ($p<0.05$) with protein content. Since there were no significant differences in tortilla weight and thickness among different flour blends, tortilla specific volume was highly correlated with tortilla diameter. Barros et al. (2010) also reported that tortilla diameter and specific volume had negative correlations ($p<0.01$) with gluten index and Farinograph dough development time and stability. Generally speaking, higher protein content of refined wheat flour led to smaller-diameter tortillas as strong dough would shrink back during hot-pressing (Barros et al., 2010). However, in our study, while the addition of sprouted WWF increased protein content, gluten strength was weakened. Therefore, the correlation between protein content and diameter was contrary to previous reports by Waniska et al. (2004) and Barros et al. (2010). Tortilla breaking force was positively ($p<0.01$) correlated, while extensibility was negatively ($p<0.05$) associated with all these flour and dough parameters, except for protein content and Suc-SRC. Protein content correlated negatively ($p<0.01$) with breaking force with an R^2 of 0.96, but it correlated positively ($p<0.05$) with extensibility with an R^2 of 0.59 (day 1) and 0.79 (day 4). Finally, tortilla L* and opacity (top and bottom) correlated positively ($p<0.01$) with flour (L*) value. The correlation data showed that gluten index, damaged starch, Mixolab, and SRC could be useful in predicting the performance of whole-wheat tortilla containing sprouted WWF.

Table 6.5: Correlations among quality parameters of tortillas, Mixolab profiles, SRC parameters, protein content, gluten index and damaged starch of whole-wheat flour (WWF) blends substituted by sprouted WWF[a]

Flour Parameters	Diameter	Specific Volume	Breaking Force	Extensibility (Day 1)	Extensibility (Day 4)	Color (L)	Opacity (top)	Opacity (bottom)
Protein	0.87^{**}	0.92^{**}	-0.96^{**}	0.59^{*}	0.79^{**}			
Gluten	-0.87^{**}	-0.89^{**}	0.96^{**}	-0.55^{*}	-0.86^{**}			

index								
Damaged Starch	-0.86**	-0.91**	0.98**	-0.57*	-0.87**			
C1 time	-0.81**	-0.84**	0.93**	-0.54*	-0.74**			
Stability	-0.78**	-0.92**	0.88**	-0.62*	-0.64*			
W-SRC	-0.86**	-0.92**	0.98**	-0.54*	-0.82**			
Suc-SRC	-0.03	-0.04	0.08	-0.30	-0.25			
LA-SRC	-0.82**	-0.87**	0.96**	-0.53*	-0.87**			
SC-SRC	-0.83**	-0.89**	0.94**	-0.53*	-0.83**			
GPI	-0.71**	-0.76**	0.87**	-0.40	-0.76**			
Color (L)						0.98**	0.94**	0.96**

[**] Correlation is significant at the 0.01 level (p<0.01)

[*] Correlation is significant at the 0.05 level (p<0.05)

[a] Abbreviations of SRC parameters as in Figure 6.1

6.5 Conclusions

Substitution of regular WWF with sprouted WWF affected the rheological behaviors of flour blends and tortilla properties. Tortillas made with higher levels of sprouted WWF were slightly bigger in diameter and specific volume, whiter and more opaque, and weaker but more shelf-stable. Sensory evaluation indicated that addition of sprouted WWF in tortillas would increase the consumer likeness in color, texture, flavor, and overall quality. Therefore, sprouted WWF would bring benefits to regular WWF tortillas in nutrition values, appearance, consumer acceptability, and shelf life. Nevertheless, WWF blends with higher amounts of sprouted WWF had weaker gluten strength, which is a concern for tortilla manufacturers. It is suggested that sprouted WWF be incorporated at an optimal level (i.e. 50%) in WWF tortillas. In addition, protein content did not appear to be a reliable indicator for WWF and tortilla quality when substituted with sprouted WWF. Instead, gluten index, Mixolab parameters, and SRC results all appeared to be good quality indicators of WWF tortillas containing sprouted WWF. Future studies to examine the effects of controlled sprouting conditions and wheat class and varietal differences on the baking performance of WWF tortilla or other whole-wheat products will be valuable.

CHAPTER 7

CONCLUSIONS AND FUTURE WORK

Based on the first project, which examined the current use of whole grains in Chinese restaurants, factors with a potential influence on sales of whole grains include location, type of restaurants (chain or authentic), number of years serving whole grains, brand identity, special dishes, selling price and cultural differences. The main motivator for serving brown rice is to attract health conscious consumers, while low customer request is the major constraint for non-whole grain use. A foundational first step is to better understand whole grain use in restaurants by owners / manager, chefs, food service personnel and consumers.

After adjusting for gender and age, the mean percentage of brown rice waste among brown rice eaters was significantly lower than white rice waste among white rice eaters, which suggests that the availability of brown rice in restaurants can potentially increase consumption in restaurants. It is important to improve the quality of whole grain products, and to educate restaurant operators about the knowledge of preparing and selling whole grains.

The results suggest the plate waste method can be successfully used in restaurant settings to monitor food consumption among consumers. However, there are some limitations in this project. Subjects participating in in plate waste data collection were selected based on their preferred type of rice, which did not address feeding brown rice to the general population and observing the waste. Secondly, only Chinese restaurants were examined, as Chinese restaurants are only one part of the overall food system and the results from Chinese restaurants might not be transferrable to other types of (independent, family, fusion) restaurants.

When it comes to whole-wheat flour (WWF) tortillas, quality will be significantly improved with an optimal particle size range, modification of formula and processing conditions, and with the addition of sprouted WWF. Fine grinding of WWF to reduce its median particle sizes from ~175 μm to ~130 μm improved the texture profile of WWF tortillas. A leavening system including 2% SBC, 2% SALP, 177°C hot-press temperature, and 25°C dough temperature is most suited to produce more opaque WWF tortillas. Furthermore, substitution of regular WWF with sprouted WWF at an optimal level (i.e. 50%) can produce tortillas with improved appearance, consumer acceptability, shelf life and nutrition profile.

The impact of particle size on WWF and its tortillas is significant. When reducing WWF median particle size from 174-176 to 102-106 μm, WWF has a darker color, higher PPO activity, more adjusted damaged starch, decreased dough development time and starch gel breakdown value, but increased dough stability time and starch retrogradation. As to WWF tortilla baking performance, finer particle size produces lower surface brightness (L* value) tortillas, which may not be a drawback, as consumers generally relate darker color of baked products as better for you. Tortillas are generally filled with a variety of food ingredients, which emphasizes tortilla strength and extensibility as essential quality attributes. Tortillas become stronger and more extensible as WWF particle size is reduced from 174-176 to 129-134 μm, while further reducing particle size to 102-106 μm results in little improvement in tortilla breaking force and extensibility.

The type of leavening acid, SBC amount, dough temperature and hot press temperature are important factors influencing the opacity and other quality attributes of WWF tortillas. SALP yields the lightest weight, largest diameter, required the least force to break and most opaque tortillas. Increasing the amount of SBC from 1% to 2% increases opacity, thickness and extensibility of WWF tortillas, which suggests that tortilla manufacturers can consider using more leavening acid and base to improve the opacity of WWF tortillas. As the hot press temperature increases from 160°C to 193°C, tortillas become lighter in weight, larger diameter, and thinner. A hot press temperature of 193°C is too high to produce opaque tortillas. Therefore, 177°C will be most suitable for WWF tortillas. In addition, higher dough temperature (35°C) produces tortillas with a lower opacity score, L* value and lighter weight, compared to 25°C dough temperature. Since each variable shows a different effect on each quality parameter, the tortilla industry should choose an ideal leavening system for their products based on their specific quality objectives.

The substitution of regular WWF with sprouted WWF also affects the tortilla baking performance. Although the incorporation of sprouted WWF reduces gluten strength, it produces bigger specific volume, brighter, more opaque and more shelf stable tortillas. As sprouted WWF has higher nutritional values than regular WWF due to the sprouting process, it can be incorporated into regular WWF at an optimal level (50%) to produce WWF tortillas with a better nutritional profile, more attractive appearance, higher consumer acceptability, and longer shelf life, without sacrificing tortilla strength.

Future work should be conducted to deeply understand each factor that influences the quality and sensory attributes of WWF tortillas, but also to further examine the availability, acceptability and consumption of whole grain products in foodservice settings. To achieve quality improvement in WWF tortillas, the differences in reducing median flour particle size from ~130 to ~104 μm was relatively small in this project; however, by further reducing WWF into a finer particle size of 70-90 μm will provide additional data to identify a more optimal particle size range for WWF tortillas. The sprouted WWF used in this study were commercial products with limited knowledge about wheat class, variety and sprouting conditions. Therefore, it will be important to examine the effects of sprouting conditions, wheat class and varieties on the baking performance of tortillas. Furthermore, the impact of particle size, chemical leavening system and sprouted WWF on sensory attributes and plate waste of WWF tortillas will be examined to provide additional evidence and confirmation of consumer preference to the flour milling and tortilla industry. As confirmed by the first project that plate waste method can be used in restaurant settings, the plate waste of whole grain foods (i.e. brown rice, WWF tortillas) among general population in different types of restaurants should be studied. Other future work includes prioritizing and focusing on critical gaps in the food system, and enhancing the efficiency and serving capacity for whole grains in restaurants. In order to help consumers achieve recommended intake of whole grains, it is important to continue to make available, attractive and desirable whole grain foods that restaurant clientele want to eat.

Bibliography

AACC International. (2010). Approved Methods of Analysis, 11th Ed. AACC International: St. Paul, MN.

AACC International. (2016). Whole Grains. Retrieved July 2016, from http://www.aaccnet.org/initiatives/definitions/Pages/WholeGrain.aspx.

Adams, J. F., & Engstrom, A. (2000). Helping consumers achieve recommended intakes of whole grain foods. *Journal of the American College of Nutrition*, *19*(sup3), 339S-344S.

Adams, J. L. (2001). *Effects of the timing and amounts of leavening during processing of wheat flour tortillas* (Doctoral dissertation, Texas A & M University).

Adams, J. L., & Waniska, R.D. (2002). Effects of amount and solubility of leavening compounds on flour tortilla characteristics. *Cereal Foods World*, *47(2)*, 60-65.

Adams, J. L., & Waniska, R.D. (2005). Flour tortilla attributes affected by hot-press conditions. *Cereal Foods World, 50*, 72-75.

Akdogan, H., Tilley, M., & Chung, O. K. (2006). Effect of emulsifiers on textural properties of whole wheat tortillas during storage. *Cereal Chemistry*, *83*(6), 632-635.

Alviola, J. N., & Waniska, R. D. (2008). Determining the role of starch in flour tortilla staling using α-amylase. *Cereal Chemistry*, *85*(3), 391-396.

Alviola, J. N., & Awika, J. M. (2010). Relationship between objective and subjective wheat flour tortilla quality evaluation methods. *Cereal Chemistry, 87(5)*, 481-485.

Anderson, J. W. (2003). Whole grains protect against atherosclerotic cardiovascular disease. *Proceedings of the Nutrition Society*, *62*(01), 135-142.

Anderson, J. W., & Conley, S. B. (2007). Whole grains and diabetes. In Marquart L., Jacobs, D. J., McIntosh, G. H., Reicks, M. (Eds.), *Whole grains and health* (pp. 29-46). Ames, IA: Blackwell Publishing Professional.

Arora, S. (2003). *The effect of enzymes and starch damage on wheat flour tortilla quality* (Doctoral dissertation, Texas A&M University).

Ariyama, T., & Khan, K. (1990). Effect of laboratory sprouting and storage on physiochemical and breadmaking properties of hard red spring wheat. *Cereal Chemistry, 67,* 53-58.

Aune, D., Keum, N., Giovannucci, E., Fadnes, L. T., Boffetta, P., Greenwood, D. C., ... & Norat, T. (2016). Whole grain consumption and the risk of cardiovascular disease, cancer, and all-cause and cause-specific mortality–a systematic review and dose-response meta-analysis of prospective studies. *BMJ*, 353, i2716.

Azeke, M. A., Egielewa, S. J., Eigbogbo, M. U., & Ihimire, I. G. (2011). Effect of germination on the phytase activity, phytate and total phosphorus contents of rice (Oryza sativa), maize (Zea mays), millet (Panicum miliaceum), sorghum (Sorghum bicolor) and wheat (Triticum aestivum). *Journal of Food Science and Technology*, *48*(6), 724-729.

Bachman, J. L., Reedy, J., Subar, A. F., & Krebs-Smith, S. M. (2008). Sources of food group intakes among the US population, 2001-2002. *Journal of the American Dietetic Association*, *108*(5), 804-814.

Baglio, M. L., Baxter, S. D., Guinn, C. H., Thompson, W. O., Shaffer, N. M., & Frye, F. H. (2004). Assessment of interobserver reliability in nutrition studies that use direct observation of school meals. *Journal of the American Dietetic Association*, *104*(9), 1385-1392.

Bakke, A., & Vickers, Z. (2007). Consumer liking of refined and whole wheat breads. *Journal of Food Science*, *72*(7), S473-S480.

Barbeau, W. E., Griffey, C. A., & Yan, Z. H. (2006). Evidence that minor sprout damage can lead to significant reductions in gluten strength of winter wheats. *Cereal Chemistry, 83,* 306-310.

Barros, F., Alviola, J. N., & Rooney, L. W. (2010). Comparison of quality of refined and whole wheat tortillas. *Journal of Cereal Science*, *51*(1), 50-56.

Bejosano, F. P., & Waniska, R. D. (2004). Functionality of bicarbonate leaveners in wheat flour tortillas. *Cereal Chemistry, 81(1)*, 77-79.

Bejosano, F. P., Joseph, S., Lopez, R. M., Kelekci, N. N., & Waniska, R. D. (2005). Rheological and sensory evaluation of wheat flour tortillas during storage. *Cereal Chemistry*, *82*(3), 256-263.

Bello, A. B., SO, S. S., Waniska, R. D., & Rooney, L. W. (1991). Methods to prepare and evaluate wheat tortillas. *Cereal Foods World*.

Book, S. L., Brill, R. V., & Heidolph, B. B. (2002). Effects of leavening acids on characteristics of fresh and 30-day-old tortillas. *Cereal Foods World, 47(8)*, 390-393.

Brose, E., Becker, G., & Bouchain, W. (1996). *Chemical Leavening Agents*. Chemische Fabrik Budenheim.

Burton-Freeman, B., Davis, P. A., & Schneeman, B. O. (2002). Plasma cholecystokinin is associated with subjective measures of satiety in women. *The American Journal of Clinical Nutrition*, *76*(3), 659-667.

Buzby, J. C., & Guthrie, J. F. (2002). Plate waste in school nutrition programs. In *Report to Congress, 21*, 2003.

Casso, J. B. G. (2003). *Effects of amounts and types of sodium bicarbonate in wheat flour tortillas*. Doctoral dissertation, Texas A&M University.

Cai, L., Choi, I., Hyun, J. N., Jeong, Y. K., & Baik, B. K. (2014). Influence of bran particle size on bread-baking quality of whole grain wheat flour and starch retrogradation. *Cereal Chemistry*, *91*(1), 65-71.

Cepeda, M., Waniska, R. D., Rooney, L. W., & Bejosano, F. P. (2000). Effects of leavening acids and dough temperature in wheat flour tortillas. *Cereal Chemistry, 77(4),* 489-494.

Chan, H. W., Burgess-Champoux, T. L., Vickers, Z., Reicks, M., & Marquart, L. (2008). White whole grain flour can be substituted for red in pizza crust for school children. *Journal of Child Nutrition Management*, *32*(1).

Chanson-Rolle, A., Meynier, A., Aubin, F., Lappi, J., Poutanen, K., Vinoy, S., & Braesco, V. (2015). Systematic review and meta-analysis of human studies to support a quantitative recommendation for whole grain intake in relation to type 2 diabetes. *PloS one*, *10*(6), e0131377.

Chatenoud, L., Tavani, A., La Vecchia, C., Jacobs, D. R., Negri, E., Levi, F., & Franceschi, S. (1998). Whole grain food intake and cancer risk. *International Journal of Cancer*, *77*(1), 24-28.

Chen, J. S., Fei, M. J., Shi, C. L., Tian, J. C., Sun, C. L., Zhang, H., ... & Dong, H. X. (2011). Effect of particle size and addition level of wheat bran on quality of dry white Chinese noodles. *Journal of Cereal Science*, *53*(2), 217-224.

Chinese Restaurant News. (2007). 2006 Top 100 award. Retrieved July 2016, from http://www.c-r-n.net/Jin_e/ContentDetail.aspx?id=301324514.

Chu, Y. L., Warren, C. A., Sceets, C. E., Murano, P., Marquart, L., & Reicks, M. (2011). Acceptance of two US Department of Agriculture commodity whole-grain products:

a school-based study in Texas and Minnesota. *Journal of the American Dietetic Association*, *111*(9), 1380-1384.

Chung, H. J., Cho, D. W., Park, J. D., Kweon, D. K., & Lim, S. T. (2012). In vitro starch digestibility and pasting properties of germinated brown rice after hydrothermal treatments. *Journal of Cereal Science, 56(2),* 451-456.

Connors, P. L., & Rozell, S. B. (2004). Using a visual plate waste study to monitor menu performance. *Journal of the American Dietetic Association*, *104*(1), 94-96.

Cynthia, L. O., Margaret, D. C., Brian, K. K., & Katherine, M. F. (2013). Prevalence of obesity among adults: United States, 2011–2012. *NCHS Data Brief*, *131*, 1-8.

Dabčević, T., Hadnađev, M., & Pojić, M. (2009). Evaluation of the possibility to replace conventional rheological wheat flour quality control instruments with the new measurement tool–Mixolab. *Agriculturae Conspectus Scientificus (ACS)*, *74*(3), 169-174.

Dally, V., & Navarro, L. (1999). Flour tortillas: a growing sector of the US food industry. *Cereal foods world*.

Dammann, K. W., Hauge, D., Rosen, R. A., Schroeder, N., Marquart, L., Delcour, J. A., & Poutanen, K. (2013). Consumption and consumer challenges of wholegrain foods. In Delcour, J. (Ed.). *Fibre-rich and wholegrain foods: improving quality* (pp. 120-149). Woodhead Publishing.

Dann, O. E. (2014). *Selecting wheat varieties for tortilla production* (Doctoral dissertation, Kansas State University).

Dhingra, P., Sazawal, S., Menon, V. P., Dhingra, U., & Black, R. E. (2007). Validation of visual estimation of portion size consumed as a method for estimating food intake by young Indian children. *Journal of Health, Population, and Nutrition*, *25*(1), 112.

Doblado-Maldonado, A. F., Pike, O. A., Sweley, J. C., & Rose, D. J. (2012). Key issues and challenges in whole wheat flour milling and storage. *Journal of Cereal Science*, *56*(2), 119-126.

Dziki, D., Gawlik-Dziki, U., Różyło, R., & Miś, A. (2015). Drying and Grinding Characteristics of Four-Day-Germinated and Crushed Wheat: A Novel Approach for Producing Sprouted Flour. *Cereal Chemistry*, *92*(3), 312-319.

Edwards, R. A., Ross, A. S., Mares, D. J., Ellison, F. W., & Tomlinson, J. D. (1989). Enzymes from rain-damaged and laboratory-germinated wheat. I. Effects on product quality. *Journal of Cereal Science, 10,* 157-167.

Every, D., & Ross, M. (1996). The role of dextrins in the stickiness of bread crumb made from pre-harvest sprouted wheat or flour containing exogenous alpha-amylase. *Journal of Cereal Science, 23,* 247-256.

FDA (U.S. Food and Drug Administration). (1999). Microbiological safety evaluations and recommendations on sprouted seed. Retrieved July 2016, from http://www.fda.gov/food/guidanceregulation/guidancedocumentsregulatoryinformation/produceplantproducts/ucm078789.htm.

Feldpausch, M., Cropper, S., Faubion, J., & Krishock, D. (2015). The effect of sprouted grain flour concentration on physical and textural properties of whole wheat pan bread. *Cereal Food World.* 3-P. Retrieved July 2016, from http://www.aaccnet.org/meetings/Documents/2015Abstracts/aacci2015abs182.htm.

Friend, C. P., Serna- Saldívar, S. O., Waniska, R. D., & Rooney, L. W. (1992). Increasing the fiber content of wheat tortillas. *Cereal Foods World, 37,* 325-328.

Friend, C. P., Waniska, R. D., & Rooney, L. W. (1993). Effects of hydrocolloids on processing and qualities of wheat tortillas. *Cereal Chemistry*, *70*, 252-252.

Friend, C. P., Ross, R. G., Waniska, R. D., & Rooney, L. W. (1995). Effects of additives in wheat flour tortillas. *Cereal Foods World*, *40*(7), 494-497.

Fuerst, E. P., Anderson, J. V., Morris, C. F., & Hou, G. G. (2010). Effects of polyphenol oxidase on noodle color: mechanisms, measurement, and improvement. *Asian Noodles: Science, Technology, and Processing*, 285-312.

Fylan, F. (2005). Semi structured interviewing. In Miles, J., Gilbert, P (Eds.). *A handbook of research methods for clinical and health psychology* (pp. 65-78). Oxford University Press.

George, R. T. (2000). Dining Chinese: A consumer subgroup comparison. *Journal of Restaurant & Foodservice Marketing*, *4*(2), 67-86.

Gill, P., Stewart, K., Treasure, E., & Chadwick, B. (2008). Methods of data collection in qualitative research: interviews and focus groups. *British Dental Journal*, *204*(6), 291-295.

Gittelsohn, J., Shankar, A. V., Pokhrel, R. P., & West, K. P. (1994). Accuracy of estimating food intake by observation. *Journal of the American Dietetic Association*, *94*(11), 1273-1277.

Good, C. K., Holschuh, N., Albertson, A. M., & Eldridge, A. L. (2008). Whole grain consumption and body mass index in adult women: an analysis of NHANES 1999-2000 and the USDA pyramid servings database. *Journal of the American College of Nutrition*, *27*(1), 80-87.

Hatcher, D. W., & Symons, S. J. (2000). Influence of sprouted damage on oriental noodle appearance as assessed by image analysis. *Cereal Chemistry, 77(3),* 380-387.

Heidolph, B. B. (1996). Designing chemical leavening systems. *Cereal Foods World*, *41*(3), 118-126.

Hemery, Y., Chaurand, M., Holopainen, U., Lampi, A. M., Lehtinen, P., Piironen, V., ... & Rouau, X. (2011). Potential of dry fractionation of wheat bran for the development of food ingredients, part I: Influence of ultra-fine grinding. *Journal of Cereal Science*, *53*(1), 1-8.

Hübner, F., & Arendt, E. K. (2013). Germination of cereal grains as a way to improve the nutritional value: a review. *Critical Reviews in Food Science and Nutrition*, *53*(8), 853-861.

Huang, W., Li, L., Wang, F., Wan, J., Tilley, M., Ren, C., & Wu, S. (2010). Effects of transglutaminase on the rheological and Mixolab thermomechanical characteristics of oat dough. *Food Chemistry, 121(4),* 934-939.

Jacobs Jr, D. R., Marquart, L., Slavin, J., & Kushi, L. H. (1998). Whole-grain intake and cancer: An expanded review and meta-analysis. *Nutrition and Cancer*, *30*(2), 85-96.

Jang, S. S., Ha, A., & Silkes, C. A. (2009). Perceived attributes of Asian foods: From the perspective of the American customers. *International Journal of Hospitality Management*, *28*(1), 63-70.

Jang, S., Liu, Y., & Namkung, Y. (2011). Effects of authentic atmospherics in ethnic restaurants: investigating Chinese restaurants. *International Journal of Contemporary Hospitality Management*, *23*(5), 662-680.

Janson, J. J. (1990). Tortilla manufacturing. In *Proceedings annual meeting of the American Society of Bakery Engineers*.

Jensen, M. K., Koh-Banerjee, P., Hu, F. B., Franz, M., Sampson, L., Grønbæk, M., & Rimm, E. B. (2004). Intakes of whole grains, bran, and germ and the risk of coronary heart disease in men. *The American Journal of Clinical Nutrition*, *80*(6), 1492-1499.

Jetter, K. M., & Cassady, D. L. (2006). The availability and cost of healthier food alternatives. *American Journal of Preventive Medicine*, *30*(1), 38-44.

Kasum, C. M., Nicodemus, K., Harnack, L. J., Jacobs, D. R., & Folsom, A. R. (2001). Whole grain intake and incident endometrial cancer: the Iowa Women's Health Study. *Nutrition and Cancer*, *39*(2), 180-186.

Koehler, P., Hartmann, G., Wieser, H., & Rychlik, M. (2007). Changes of folates, dietary fiber, and proteins in wheat as affected by germination. *Journal of Agricultural and Food Chemistry*, *55*(12), 4678-4683.

Koksel, H., Kahraman, K., Sanal, T., Ozay, D. S., & Dubat, A. (2009). Potential utilization of Mixolab for quality evaluation of bread wheat genotypes. *Cereal Chemistry, 86(5),* 522-526.

Kuznesof, S., Brownlee, I.A., Moore, C., Richardson, D.P., Jebb, S.A., & Seal, C.J. (2012). Whole heart study participant acceptance of wholegrain foods. *Appetite*, *59*, 187-93.

Kweon, M., Slade, L., & Levine, H. (2011). Solvent retention capacity (SRC) testing of wheat flour: principles and value in predicting flour functionality in different wheat-based food processes and in wheat breeding-A review. *Cereal Chemistry. 88(6),* 537-552.

Lemar, L. E., & Swanson, B. G. (1976). Nutritive value of sprouted wheat flour. *Journal of Food Science*, *41*(3), 719-720.

Labaw, G. D. (1982). Chemical leavening agents and their use in bakery products. *Bakers Digest*, *56*(1), 16.

Leclere, C. J., Champ, M., Boillot, J., Guille, G., Lecannu, G., Molis, C., ... & Galmiche, J. P. (1994). Role of viscous guar gums in lowering the glycemic response after a solid meal. *The American Journal of Clinical Nutrition*, *59*(4), 914-921.

Lin, B. H., & Guthrie, J. F. (2012). *Nutritional quality of food prepared at home and away from home, 1977-2008* (No. 142361). United States Department of Agriculture, Economic Research Service.

Li, J., Kang, J., Wang, L., Li, Z., Wang, R., Chen, Z. X., & Hou, G. G. (2012). Effect of water migration between arabinoxylans and gluten on baking quality of whole wheat bread detected by magnetic resonance imaging (MRI). *Journal of Agricultural and Food Chemistry*, *60*(26), 6507-6514.

Li, J., Hou, G. G., Chen, Z., Chung, A. L., & Gehring, K. (2014). Studying the effects of whole-wheat flour on the rheological properties and the quality attributes of whole-wheat saltine cracker using SRC, alveograph, rheometer, and NMR technique. *LWT-Food Science and Technology*, *55*(1), 43-50.

Liu, T., Hou, G. G., Book, S.L., & Marquart, L. (2016). Effects of chemical leavening system and processing conditions on the opacity and other quality characteristics of whole-wheat flour tortillas. *LWT - Food Science and Technology. 73,* 123-130.

Liu, Y., & Jang, S. S. (2009). Perceptions of Chinese restaurants in the US: what affects customer satisfaction and behavioral intentions? *International Journal of Hospitality Management*, *28*(3), 338-348.

Lorenz, K., & Valvano, R. (1981). Functional characteristics of sprout-damaged soft white wheat flours. *Journal of Food Science*, *46*(4), 1018-1020.

Mao, Y., & Flores, R. A. (2001). Mechanical starch damage effects on wheat flour tortilla texture. *Cereal Chemistry*, *78*(3), 286-293.

Manthey, F. A., & Schorno, A. L. (2002). Physical and cooking quality of spaghetti made from whole wheat durum. *Cereal Chemistry, 79,* 504-510.

Marquart, L., Chan, H. W., Orsted, M., Schmitz, K. A., Arndt, E. A., & Jacobs Jr, D. R. (2006). Gradual incorporation of whole-grain flour into grain-based products. *Cereal Foods World, 51* (3), 114-117.

Marquart, L., Jones, J. M., Cohen, E. A., & Poutanen, K. (2007). The future of whole grains. In Marquart L., Jacobs, D. J., McIntosh, G. H., Reicks, M. (Eds.), *Whole grains and health* (pp. 3-16). Ames, IA: Blackwell Publishing Professional.

McDonough, C. M., Seetharaman, K., Waniska, R. D., & Rooney, L. W. (1996). Microstructure changes in wheat flour tortillas during baking. *Journal of Food Science*, *61*(5), 995-999.

McKeown, N., Serdula, M., & Liu, S. (2007). Whole Grains and Related Dietary Patterns in Relation to Weight Gain. In Marquart L., Jacobs, D. J., McIntosh, G. H., Reicks, M. (Eds.), *Whole grains and health* (pp. 47-58). Ames, IA: Blackwell Publishing Professional.

McIntosh, G. H. (2007). Whole grains and cancer prevention. In Marquart L., Jacobs, D. J., McIntosh, G. H., Reicks, M. (Eds.), *Whole grains and health* (pp. 69-74). Ames, IA: Blackwell Publishing Professional.

Mellen, P. B., Walsh, T. F., & Herrington, D. M. (2008). Whole grain intake and cardiovascular disease: a meta-analysis. *Nutrition, Metabolism and Cardiovascular Diseases*, *18*(4), 283-290.

Meyer, K. A., Kushi, L. H., Jacobs, D. R., Slavin, J., Sellers, T. A., & Folsom, A. R. (2000). Carbohydrates, dietary fiber, and incident type 2 diabetes in older women. *The American Journal of Clinical Nutrition*, *71*(4), 921-930.

Miller, H. E., Rigelhof, F., Marquart, L., Prakash, A., & Kanter, M. (2000). Antioxidant content of whole grain breakfast cereals, fruits and vegetables. *Journal of the American College of Nutrition*, *19*(sup3), 312S-319S.

Mourouti, N., Kontogianni, M. D., Papavagelis, C., Psaltopoulou, T., Kapetanstrataki, M. G., Plytzanopoulou, P., ... & Panagiotakos, D. B. (2015). Whole Grain Consumption and Breast Cancer: A Case-Control Study in Women. *Journal of the American College of Nutrition*, 1-7.

Montonen, J., Knekt, P., Järvinen, R., Aromaa, A., & Reunanen, A. (2003). Whole-grain and fiber intake and the incidence of type 2 diabetes. *The American Journal of Clinical Nutrition*, *77*(3), 622-629.

Morad, M. M., & Rubenthaler, G. L. (1983). Germination of soft white wheat and its effect on flour fractions, breadbaking, and crumb firmness. *Cereal Chemistry, 60(6):* 413-417.

Molins, R. A. (1990). Phosphates in food. CRC Press (Chapter 6).

Murtaugh, M. A., Jacobs, D. R., Jacob, B., Steffen, L. M., & Marquart, L. (2003). Epidemiological support for the protection of whole grains against diabetes. *Proceedings of the Nutrition Society*, *62*(01), 143-149.

National Restaurant Association (NRA). (2014a). 2014 Restaurant Industry Pocket Factbook.[online]. Retrieved July 2016, from http://www.restaurant.org/News-Research/Research/Forecast-2014.

National Restaurant Association (NRA). (2014b). Economist's Notebook: Restaurant sales cooled in January amid extreme weather conditions. [online]. Retrieved July 2016, from http://www.restaurant.org/News-Research/News/Economist-s-Notebook-Restaurant-sales-cooled-in-Ja

National Restaurant Association (NRA). (2016). 2016 Restaurant Industry Pocket Factbook. Retrieved July 2016, from https://www.restaurant.org/Downloads/PDFs/News-Research/research/Factbook2015_LetterSize-FINAL.pdf

Nelson, K., Stojanovska, L., Vasiljevic, T., & Mathai, M. (2013). Germinated grains: a superior whole grain functional food?. *Canadian Journal of Physiology and Pharmacology*, *91*(6), 429-441.

Nichols, P. J., Porter, C., Hammond, L., & Arjmandi, B. H. (2002). Food intake may be determined by plate waste in a retirement living center. *Journal of the American Dietetic Association*, *102*(8), 1142-1144.

Niu, M., Hou, G., Lee, B., & Chen. Z. (2014a). Effects of fine grinding of millfeeds on the quality attributes of reconstituted whole wheat flour and its raw noodle products. *LWT-Food Science and Technology, 57,* 58-64.

Niu, M., Hou, G. G., Wang, L., & Chen, Z. (2014b). Effects of superfine grinding on the quality characteristics of whole-wheat flour and its raw noodle product. *Journal of Cereal Science*, *60*(2), 382-388.

Noort, M. W. J., van Haaster, D., Hemery, Y. M., Schols, H. A., & Hamer, R. J. (2010). The effect of particle size of wheat bran fractions on bread quality—Evidence for fibre-protein interactions. *Journal of Cereal Science, 52,* 59-64.

NPD Group. (2013). U.S. Total Restaurant Count Increases by 4,442 Units over Last Year Reports NPD. [online]. Retrieved July 2016, from https://www.npd.com/wps/portal/npd/us/news/press-releases/us-total-restaurant-count-increases-by-4442-units-over-last-year-reports-npd/.

Opdenakker, R. (2006). Advantages and disadvantages of four interview techniques in qualitative research. In *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*, *7*(4).

OMGFACTS. (2011). There are more Chinese restaurants in the United States than the number of McDonald's, Burger Kings, Wendy's, Domino's, and Pizza Huts combined. [online]. Retrieved July 2016, from http://www.omg-facts.com/Science/There-are-more-Chinese-restaurants-in-th/39008.

Ontiveros-Martínez, M., Ochoa-Martínez, L. A., González-Herrera, S. M., Delgado-Licon, E., Bello-Pérez, L. A., & Morales-Castro, J. (2011). Effect of sourdough on quality and acceptability of wheat flour tortillas. *Journal of Food Science*, *76*(9), C1278-C1283.

Ozturk, S., Kahraman, K., Tiftik, B., & Koksel, H. (2008). Predicting the cookie quality of flours by using Mixolab®. *European Food Research and Technology*, *227*(5), 1549-1554.

Pascut, S., Kelekci, N., & Waniska, R. D. (2004). Effects of wheat protein fractions on flour tortilla quality. *Cereal Chemistry*, *81*(1), 38-43.

Pauline, K. B., & Rimm, E. B. (2003). Whole grain consumption and weight gain: a review of the epidemiological evidence, potential mechanisms and opportunities for future research. *Proceedings of the Nutrition Society*, *62*(01), 25-29.

Penella, J. S., Collar, C., & Haros, M. (2008). Effect of wheat bran and enzyme addition on dough functional performance and phytic acid levels in bread. *Journal of Cereal Science*, *48*(3), 715-721.

Perez-Carrillo, E., Chew-Guevara, A. A., Heredia-Olea, E., Chuck-Hernández, C., & Serna- Saldívar, S. O. (2015). Evaluation of the functionality of five different soybean proteins in hot-press wheat flour tortillas. *Cereal Chemistry*, *92*(1), 98-104.

Pereira, M. A., Jacobs, D. R., Pins, J. J., Raatz, S. K., Gross, M. D., Slavin, J., & Seaquist, E. (2000). The effect of whole grains on inflammation and fibrinolysis. In *Circulation*, *101*(6), 711-711.

Plaza, L., de Ancos, B., & Cano, P. M. (2003). Nutritional and health-related compounds in sprouts and seeds of soybean (Glycine max), wheat (Triticum aestivum. L) and alfalfa (Medicago sativa) treated by a new drying method. *European Food Research and Technology*, *216*(2), 138-144.

Posner, E. S., & Hibbs, A. N. (2005). *Wheat flour milling* (No. Ed. 2). American Association of Cereal Chemists, Inc.

Posner, E. S., Chew-Guevara, A. A., Mitre-Dieste, M., Perez-Carrillo, E., Heredia-Olea, E., Wilson, J. D., & Serna- Saldívar, S. O. (2014). Generation of a Mixolab profile after the evaluation of the functionality of different commercial wheat flours for hot-press tortilla production. *Cereal Chemistry, 91(2),* 139-145.

Prasopsunwattana, N., Omary, M. B., Arndt, E. A., Cooke, P. H., Flores, R. A., Yokoyama, W., ... & Lee, S. P. (2009). Particle size effects on the quality of flour tortillas enriched with whole grain waxy barley. *Cereal Chemistry, 86 (4),* 439-451.

Prabhasankar, P., & Rao, P. H. (2001). Effect of different milling methods on chemical composition of whole wheat flour. *European Food Research and Technology*, *213*(6), 465-469.

Pyler, E. J., & Gorton, L. A. (2009). Flatbreads. In *Baking Science & Technology* (pp. 225-234). Kansas City, MO: Sosland Publishing Co.

Ramírez-Wong, B., Walker, C. E., Ledesma-Osuna, A. I., Torres, P. I., Medina-Rodríguez, C. L., López-Ahumada, G. A., ... & Flores, R. A. (2007). Effect of flour extraction rate on white and red winter wheat flour compositions and tortilla texture. *Cereal Chemistry*, *84*(3), 207-213.

Reicks, M., Jonnalagadda, S., Albertson, A. M., & Joshi, N. (2014). Total dietary fiber intakes in the US population are related to whole grain consumption: results from the National Health and Nutrition Examination Survey 2009 to 2010. *Nutrition Research*, *34*(3), 226-234.

Richter, S. L., Vandervet, L. M., Macaskill, L. A., Salvadori, M. I., Seabrook, J. A., & Dworatzek, P. D. (2012). Accuracy and reliability of direct observations of home-packed lunches in elementary schools by trained nutrition students. *Journal of the Academy of Nutrition and Dietetics*, *112*(10), 1603-1607.

Richter, K., Christiansen, K., & Guo, G. (2014). Wheat sprouting enhances bread baking performance. *Cereal Foods World*, *59*(5), 231-233.

Rigaud, D., Paycha, F., Meulemans, A., Merrouche, M., & Mignon, M. (1998). Effect of psyllium on gastric emptying, hunger feeling and food intake in normal volunteers: a double blind study. *European Journal of Clinical Nutrition*, *52*(4), 239-245.

Rosell, C. M., Santos, E., & Collar, C. (2010). Physical characterization of fiber-enriched bread doughs by dual mixing and temperature constraint using the Mixolab®. *European Food Research and Technology*, *231*(4), 535-544.

Schatzkin, A., Mouw, T., Park, Y., Subar, A. F., Kipnis, V., Hollenbeck, A., ... & Thompson, F. E. (2007). Dietary fiber and whole-grain consumption in relation to colorectal cancer in the NIH-AARP Diet and Health Study. *The American Journal of Clinical Nutrition*, *85*(5), 1353-1360.

Schaffer-Lequart, C., Lehmann, U., Ross, A. B., Roger, O., Eldridge, A. L., Ananta, E., ... & Wavreille, A. S. (2015). Whole grain in manufactured foods: current use, challenges and the way forward. *Critical Reviews in Food Science and Nutrition*, *55*.

Schmidt, C. O. (1985). Tortilla production. In *Proc. American Society Bakery Engineers* (pp. 120-126). USA: The American Society of Bakery Engineers.

Seal, C. J., & Brownlee, I. A. (2010). Whole grains and health, evidence from observational and intervention studies. *Cereal Chemistry*, *87*(2), 167-174.

Seetharaman, K., Chinnapa, N., Waniska, R. D. & White, P. (2002). Changes in textural and thermal properties of two baked products during storage: Buns and wheat tortillas. *Journal of Cereal Science, 35,* 215-223.

Sekhon, K. S., Singh, N., & Nagi, H. P. S. (1992). Effect of pearling and blending on bread making properties of sprout-damaged wheat. *Cereal Food World, 37,* 715-724.

Sekhon, K. S., Singh, N., Kaur, H., & Nagi, H. P. S. (1995). Improving the functional and bread making properties of sprouted Indian wheat. *Journal of Food Processing and Preservation*, *19*, 147-160.

Serna-Saldívar, S., Rooney, L. W., & Waniska, R. D. (1988). Wheat-flour tortilla production. *Cereal Foods World*, *33*(10), 855.

Serna- Saldívar, S. O., Guajardo-Flores, S., & Viesca-Rios, R. (2004). Potential of triticale as a substitute for wheat in flour tortilla production. *Cereal Chemistry*, *81*(2), 220-225.

Seyer, M. È., & Gélinas, P. (2009). Bran characteristics and wheat performance in whole wheat bread. *International Journal of Food Science & Technology*, *44*(4), 688-693.

Shafqat, S. (2013). *Effect of Different Sprouting Conditions on Alpha Amylase Activity, Functional Properties of Wheat Flour and on Shelf-Life of Bread Supplemented with Sprouted Wheat* (Doctoral dissertation).

Shneider, D., Moiseeva, A., & Moiseev, I. (2009). Whole and sprouted wheat dough properties and pasta quality. *Cereal Food World, 54,* A66. Retrieved July 2016, from http://www.aaccnet.org/meetings/Documents/2009Abstracts/p09ma181.htm.

Shiau, S. Y., Wu, T. T., & Liu, Y. L. (2012). Effect of the amount and particle size of wheat fiber on textural and rheological properties of raw, dried and cooked noodles. *Journal of Food Quality*, *35*(3), 207-216.

Simons-Morton, B. G., & Baranowski, T. (1991). Observation in assessment of children's dietary practices. *Journal of School Health*, *61*(5), 204-207.

Singh, H., Singh, N., Kaur, L., & Saxena, S. K. (2001). Effect of sprouting conditions on functional and dynamic rheological properties of wheat. *Journal of Food Engineering*, *47*(1), 23-29.

Slavin, J. (2004). Whole grains and human health. *Nutrition Research Reviews*, *17*(01), 99-110.

Slavin, J. (2007). Whole grains and cardiovascular disease. In Marquart L., Jacobs, D. J., McIntosh, G. H., Reicks, M. (Eds.), *Whole grains and health* (pp. 59-68). Ames, IA: Blackwell Publishing Professional.

Stauffer, C. E. (1990). Functional additives for bakery foods. Springer Science & Business Media (Chapter 22).

Steglich, T., Bernin, D., Moldin, A., Topgaard, D., & Langton, M. (2015). Bran Particle Size Influence on Pasta Microstructure, Water Distribution, and Sensory Properties. *Cereal Chemistry*, *92*(6), 617-623.

Sun, Q., Spiegelman, D., van Dam, R. M., Holmes, M. D., Malik, V. S., Willett, W. C., & Hu, F. B. (2010). White rice, brown rice, and risk of type 2 diabetes in US men and women. *Archives of Internal Medicine*, *170*(11), 961-969.

Suhendro, E. L., Waniska, R. D., & Rooney, L. W. (1993). Effects of added proteins in wheat tortillas. *Cereal Chemistry*, *70*, 412-412.

Tang, G., Wang, D., Long, J., Yang, F., & Si, L. (2015). Meta-analysis of the association between whole grain intake and coronary heart disease risk. *The American Journal of Cardiology*, *115*(5), 625-629.

Teng, Y., Liu, C., Bai, J., & Liang, J. (2015). Mixing, tensile and pasting properties of wheat flour mixed with raw and enzyme treated rice bran. *Journal of Food Science and Technology*, *52*(5), 3014-3021.

Texture Technologies Corporation. (2009). Texture Exponent 32 V3.0 5.0. Scarsdale, New York.

Tian, S., Nakamura, K., & Kayahara, H. (2004). Analysis of phenolic compounds in white rice, brown rice, and germinated brown rice. *Journal of Agricultural and Food Chemistry*, *52*(15), 4808-4813.

Todd, J. E., Mancino, L., & Lin, B. H. (2010). The impact of food away from home on adult diet quality. *USDA-ERS Economic Research Report Paper*, 90.

Toma, A., Omary, M. B., Marquart, L. F., Arndt, E. A., Rosentrater, K. A., Burns-Whitmore, B., ... & Sung, A. (2009). Children's acceptance, nutritional, and instrumental evaluations of whole grain and soluble fiber enriched foods. *Journal of Food Science*, *74*(5), H139-H146.

Tortilla Industry Association (TIA). (2014). On-site technical report. Retrieved July 2016, from http://www.tortilla-info.com.

Tortilla Industry Association (TIA). (2016). Tortilla talk. Retrieved July 2016, from http://www.tortilla-info.com/default.asp?contentID=6#tortillahistory.

Tosh, S. M., & Chu, Y. (2015). Systematic review of the effect of processing of whole-grain oat cereals on glycaemic response. *British Journal of Nutrition*, *114*(08), 1256-1262.

Tritt, A., Reicks, M., & Marquart, L. (2015). Reformulation of pizza crust in restaurants may increase whole-grain intake among children. *Public Health Nutrition*, *18*(08), 1407-1411.

U.S. Department of Agriculture. (2016a). Food prices and spending. Retrieved July 2016, from http://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/food-prices-and-spending.aspx.

U.S. Department of Agriculture. (2016b). Food-away-from-home. Retrieved July 2016, from http://www.ers.usda.gov/topics/food-choices-health/food-consumption-demand/food-away-from-home.aspx.

U.S. Department of Agriculture, Agricultural Research Service. (2012). Nutrient Intakes from Food: Mean Amounts Consumed per Individual, by Gender and Age, What We Eat in America, NHANES 2009-2010. [online]. Retrieved July 2016, from www.ars.usda.gov/ba/bhnrc/fsrg.

U.S. Department of Agriculture, Economic Research Service. (2013). *Food away from home: Total expenditures*. [online]. Retrieved July 2016, from http://www.ers.usda.gov/data-products/food-expenditures.aspx.

U.S. Department of Agriculture & U.S. Department of Health and Human Services. (2010). *Dietary Guidelines for Americans, 2010.* 7th Edition. Washington, DC: U.S. Government Printing Office.

U.S. Department of Health and Human Services & U.S. Department of Agriculture. (2015). *2015 – 2020 Dietary Guidelines for Americans*. 8th Edition. Retrieved July 2016, from http://health.gov/dietaryguidelines/2015/guidelines/.

Van de Vijver, L. P. L., Van den Bosch, L. M. C., Van den Brandt, P. A., & Goldbohm, R. A. (2009). Whole-grain consumption, dietary fibre intake and body mass index in the Netherlands cohort study. *European Journal of Clinical Nutrition*, *63*(1), 31-38.

Van Hung, P., Hatcher, D. W., & Barker, W. (2011). Phenolic acid composition of sprouted wheats by ultra-performance liquid chromatography (UPLC) and their antioxidant activities. *Food Chemistry*, *126*(4), 1896-1901.

Vizitiu, D. A. N. I. E. L., & Danciu, I. O. A. N. (2011). Evaluation of farinograph and mixolab for prediction of mixing properties of industrial wheat flour. *Acta Universitatis Cibiniensis Series E: Food Technology*, *15*, 31-38.

Waniska, R. D. (1999). Perspectives on flour tortillas. *Cereal Foods World*, *44*(7), 471-473.

Waniska, R. D., Rooney, L. W., & Srinivasan, M. (2000). Effects of ingredients and processing on dough rheology of wheat flour tortillas. *Food Science and Technology International, 6*(4), 331-338.

Waniska, R. D., Cepeda, M., King, B. S., Adams, J. L., Rodney, L. W., Torres, P. I., & Bechtel, D. B. (2004). Effects of flour properties on tortilla qualities. *Cereal Food World, 49(4):* 237-244.

Wang, L., & Flores, R. A. (2000). Effects of flour particle size on the textural properties of flour tortillas. *Journal of Cereal Science*, *31*(3), 263-272.

Wang, N., Hou, G. G., Kweon, M., & Lee, B. (2016). Effects of particle size on the properties of whole-grain soft wheat flour and its cracker baking performance. *Journal of Cereal Science*, *69*, 187-193.

West, R., Seetharaman, K., & Duizer, L. M. (2013). Effect of drying profile and whole grain content on flavour and texture of pasta. *Journal of Cereal Science*, *58*(1), 82-88.

Welch, R. W., Antoine, J. M., Berta, J. L., Bub, A., de Vries, J., Guarner, F., ... & Patterson, C. C. (2011). Guidelines for the design, conduct and reporting of human intervention studies to evaluate the health benefits of foods. *British Journal of Nutrition*, *106*(S2), S3-S15.

Whole grains council. (2016a). What is a whole grain? Retrieved July 2016, from http://wholegrainscouncil.org/whole-grains-101/what-is-a-whole-grain.

Whole Grains Council. (2016b). Definition of Whole Grains. Retrieved July 2016, from http://wholegrainscouncil.org/whole-grains-101/definition-of-whole-grains.

Whole Grains Council. (2016c). Survey: Two-thirds of Americans make half their grains whole. Retrieved July 2016, from http://wholegrainscouncil.org/newsroom/blog/2015/08/survey-two-thirds-of-americans-make-half-their-grains-whole.

Whole Grains Council. (2016d). Chain restaurants. Retrieved July 2016, from http://wholegrainscouncil.org/find-whole-grains/chain-restaurants.

Whole Grains Council. (2016e). Fine dining and independent restaurants. Retrieved July 2016, from http://wholegrainscouncil.org/find-whole-grains/fine-dining-and-independent-restaurants.

Wikipedia. (2016a). Interview. Retrieved July 2016, from http://en.wikipedia.org/wiki/Interview.

Wikipedia. (2016b). Structured interview. Retrieved July 2016, from https://en.wikipedia.org/wiki/Structured_interview.

Wikipedia. (2016c). Opacity (optics). Retrieved July 2016, from https://en.wikipedia.org/wiki/Opacity_(optics).

Wilford, J. N. (1997). New clues show where people made the great leap to agriculture. *New York Times*, F1.

Williams, P. G., Grafenauer, S. J., & O'Shea, J. E. (2008). Cereal grains, legumes, and weight management: a comprehensive review of the scientific evidence. *Nutrition Reviews*, *66*(4), 171-182.

Winstone, L. M. (2010). *Leavening and temperature effects on the physical and rheological properties of wheat flour tortillas* (Doctoral dissertation, Oklahoma State University).

Yang, TK Basu, B. & Ooraikul, F. (2001). Studies on germination conditions and antioxidant contents of wheat grain. *International Journal of Food Sciences and Nutrition*, *52*(4), 319-330.

Ye, E. Q., Chacko, S. A., Chou, E. L., Kugizaki, M., & Liu, S. (2012). Greater whole-grain intake is associated with lower risk of type 2 diabetes, cardiovascular disease, and weight gain. *The Journal of Nutrition*, *142*(7), 1304-1313.

Zhang, D., & Moore, W. R. (1997). Effect of wheat bran particle size on dough rheological properties. *Journal of the Science of Food and Agriculture*, *74*(4), 490-496.