EFFECTS OF AMOUNTS AND TYPES OF SODIUM BICARBONATE IN WHEAT FLOUR TORTILLAS

A Thesis

by

JESSICA BEATRIZ GARZA CASSO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2003

Major Subject: Food Science and Technology

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ABSTRACT

Effects of Amounts and Types of Sodium Bicarbonate
in Wheat Flour Tortillas. (August 2003)

Jessica B. Garza Casso, B.S., Instituto Tecnológico de Estudios Superiores de Monterrey
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The effects of different types and amounts of sodium bicarbonate (NBC) were evaluated during the processing of flour tortillas. Fat encapsulated NBC, BS199, BS195, BS193, BS180, BS184, HM50 and HM70, and different particle-sized, non-encapsulated NBC, grade 1, grade 2, grade 3 and Tortilla Blend™, were tested at different levels and combinations.

Longer shelf stable tortillas with lower opacity were obtained when the level of NBC decreased. Tortillas with higher opacity, diameter and volume were obtained using the correct types of NBC. Increased tortilla opacity, thickness and shelf stability were obtained using 3 g encapsulated NBC/kg compared to non-encapsulated NBC. Encapsulation of NBC enables a temperature-triggered leavening reaction during baking of tortillas. Combinations of different levels and ratios of fast- and slow-release NBC did not yield significant improvements in tortilla properties.

Tetrasodium pyrophosphate (TSPP, 0.15%) was added to modify protein functionality in tortilla dough containing less NBC. Tortillas with improved opacity, thickness and shelf stability resulted using TSPP with 3 g Grade 1 NBC/kg but similar improvements were not seen with encapsulated NBC. The effects of TSPP with low levels of NBC and slow reacting leavening acids were tested. Slight improvements in opacity were observed with sodium aluminum phosphate (SALP) compared to sodium aluminum sulfate (SAS) using encapsulated and non-encapsulated NBC.

Tortillas produced with these formulations have longer shelf stabilities with similar properties. This benefits the consumers. The manufacturing costs for ingredients are 1.2% less using 0.15% TSPP with 3 g non-encapsulated NBC/kg flour. The manufacturer gains not only by the reduced cost of ingredients but also by the increased ease of attaining target diameter of tortillas. This could also be accomplished by using less dough to form the tortilla.

DEDICATION

This thesis is dedicated to my dad Gerardo Evaristo Garza Villarreal. Papi, esta tesis te la dedico especialmente a ti, por el gran apoyo que has sido para mi en todos estos años. Por tus enseñanzas y por siempre motivarme y darme fuerza para seguir adelante. Muchas Gracias.

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CHAPTER I

INTRODUCTION

Tortilla History

Tortillas are flat breads mainly produced from corn or wheat. The word tortilla comes from the Spanish word "torta" which means "round cake". Tortillas, or "tlaxcallim" were the principal food of the Aztecs, and corn tortillas date back approximately 10,000 years before Christ. When the Spaniards brought wheat to the New World, wheat tortillas where created (TIA 2002a).

In the United States, tortillas were once considered an ethnic food. Now, Americans consume tortillas as substitute for bread from hot dog buns, sandwiches, pizzas to casseroles. Tortillas are not just considered a Mexican food anymore (TIA 2002b).

U.S. Market

The tortilla industry is the fastest growing sector of the U.S. baking industry, according to findings of a market research study conducted in 2002, by Aspex Research Survey. In 2000, the tortilla sales reached the $4.4 billion mark, representing a growth rate of 57% over the past four years. And in 2002, it is expected to reach $5.7 billion in sales. Currently, more than 300 companies in the U.S. produce tortillas. The Tortilla Industry Association (TIA) estimates that Americans consumed approximately 85 billion tortillas in 2000, almost one tortilla a day/American (TIA 2002c).

Tortillas have become so important that a new classification in the segment of baked goods industry has been given. Tortillas are no longer listed as "food preparations not elsewhere classified," instead they have been placed under a category within "Food

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This thesis follows the style and format of Cereal Chemistry.

Manufacturing," where bakeries and tortillerías are assigned together. Now tortilla manufacturing is a subcategory equivalent to that of the manufacturing of bread and bakery products. This classification confirms the significance of the tortilla as a fast growing segment of the U.S. baking industry (TIA 2002b, TIA 2002c).

Tortilla Characteristics

Wheat tortillas in the U.S. are chemically leavened, and are produced under strict quality guidelines to preserve taste and texture, since consumption of the tortilla does not occur immediately after production. The main ingredients in the tortilla consist of flour, water, shortening, and salt. Acidulants, chemical leavening, preservatives, reducing agents, and emulsifiers are also used to increase the storage stability (freshness), and shelf stability (microbial). Tortillas with good quality must be opaque (white in color), flexible, slightly chewy, easy to roll, and resist tearing and cracking (Bello et al 1991; Cepeda et al 2000).

The leavening in tortillas creates a less dense, fluffy/spongy like product with a whiter (opaque) appearance, which are tortilla attributes preferred by the consumers (Waniska 1999). Translucency (lack of whiteness), is considered to be a defect in the tortilla. Opacity is then related to refraction of the light on the surface of the retained air bubbles, which give a white luminous appearance in the baked tortilla; thus the absence of retained bubbles creates translucent tortillas. Therefore the formation and retention of air bubbles in the tortilla is a critical issue in the production of uniform opaque tortillas (Cepeda et al 2000).

Acids are added in the formulations to ensure the activity of the antimicrobials, thus the leavening reaction of tortillas becomes a problem. Flour tortilla dough is normally mixed at 32.2-37.7°C (approximately 7°C more than most chemically leavened bakery products). Leavening acids become soluble and react with sodium bicarbonate, producing gas in earlier stages of the process (Dally and Navarro 1999). These early reactions, at the high processing temperatures of tortilla production, can degas of the dough (LaBell 1999). This can occur during mixing (premature reaction of the leavening system), at the hot-press (excessive pressure at 63-77°C), or by dwell time, resulting in fewer gas bubbles retained in the dough as it enters the oven, thus reducing CO_2 formation during baking, and yielding poor quality tortillas (Dally and Navarro 1999; Waniska 1999). Opacity, diameter, pH, and shelf stability of tortillas are significantly affected by this premature reaction. Therefore improvement of leavening systems for tortillas should be studied, to generate, enlarge, and retain air bubbles that would give fluffy and opaque tortillas with extended shelf life and stability.

Objectives

The objectives of this study are to evaluate the retention of air bubbles in the production of flour tortillas by:

1) Determining the optimum level of sodium bicarbonate required to improve opacity and shelf stability of flour tortillas.
2) Determining the functionality of TSPP (Tetrasodium Pyrophosphate) in bubble retention during chemical leavening of tortillas.

CHAPTER II

LITERATURE REVIEW

Wheat Flour Tortilla Processing

There are three commercially used methods in the manufacture of wheat flour tortillas: hand stretch, die cut, and hot-press. The hand stretch tortillas are sheeted and hand stretched. This method yields tortillas with larger diameter, thinner and stronger than die cut or hot-press methods. However, it requires more labor and production is slower (Dally and Navarro 1999; Waniska 1999). Die cut is an efficient method, yields a low cost product, but results in less soft, pasty tortillas, which loose flexibility faster than hot-press tortillas. The hot-press method is not the most efficient, but is widely used in the industry because it gives the best tortillas (soft texture with more flexibility retained during storage). Improvement in equipment and operating software has increased overall production efficiency and quality of tortillas (Bello et al 1991; Dally and Navarro 1999; Waniska 1999).

Wheat Flour Tortilla Ingredients

There are four major ingredients in wheat flour tortilla formulations: flour, water, shortening and salt. Industrial formulas include leavening agents, antimicrobial agents, emulsifiers, yeast, sugar, and hydrocolloids, which are added to increase shelf life and shelf stability.

Flour is the main ingredient and accounts for 80-95% of the dry matter of tortillas. Tortilla flour should be bleached, enriched, and should contain low levels of malted barley flour. The protein quality and content of the wheat flour affects tortilla properties after baking. High protein quality flour gives longer shelf stability tortillas, compared to low protein quality flour. However, the higher the protein quality in tortillas, they become more difficult to process (Serna-Saldívar et al 1988; Dally and

Navarro 1999; Waniska 1999). Wheat flour for tortilla production must be between 9.5-12.5% protein content, however protein content is not the only factor that determines its suitability for use in flour tortillas (Waniska 1999). When too little amounts of protein are present in the flour, weak sticky dough, with poor handling properties during processing is created (Adams 2001). The type and amount of protein in the wheat flour can have an effect in flour tortilla properties (Suhendro et al 1993). The addition of wheat protein fractions (glutenin and vital wheat gluten) to tortillas improved shelf stability decreased diameter and opacity, in the other hand, addition of gliadin yielded good properties in tortillas (Pascut 2002).

Water is required for the formation and development of the gluten complex. Water temperature is adjusted to provide dough at 30-32°C. In comparison with bread, flour tortillas are processed with less water and more shortening, creating gluten not fully developed as in bread (Serna-Saldívar et al 1988).

Shortening affects dough properties during processing, quality and flavor of the final product. Shortening is incorporated into the gluten network, decreasing its strength by binding to hydrophobic proteins. It also increases machinability of the dough and reduces stickiness. Shortening prevents staling and gives improved rollability of tortillas (Serna-Saldívar et al 1988; Adams 2001)

Salt strengthens the gluten network resulting in less sticky dough. It affects tortilla flavor and increases shelf life while lowering the water activity (Serna-Saldívar et al 1988).

Emulsifiers or dough conditioners interact with many flour components during mixing and baking. Emulsifiers are used to improve dough softness and extensibility in “no-fat” and “low-fat” tortillas (Waniska 1999). Emulsifiers such as Sodium Stearoyl Lactylate (SSL) improve dough mixing hydrophobically with gluten, gliadin and starch, to produce improved dough properties (Friend et al 1995). Also, emulsifiers with good amylose complexing properties, such as distilled monoglycerides, can slow staling and may reduce sticking of tortillas (Serna-Saldívar et al 1988; Waniska 1999; Adams 2001).

Preservatives are used to produce tortillas with longer shelf life. Sodium and calcium propionates, potassium sorbates, sorbic acid, and other acids are added to inhibit molding. However, these additives to react, it required a low pH. Acetic, citric, and phosphoric acids are added to the tortilla to decrease pH (Serna-Saldívar et al 1988). However, fumaric acid is the most common, since it is less soluble in the dough and does not interfere as much with the leavening reaction (Waniska 1999). Encapsulated acids with "high melting point" edible coatings offer delayed release until baking (Dally and Navarro 1999).

Leavening agents are mostly used in the U.S. tortilla production. Leavening agents affect the internal structure of the tortilla allowing the formation of air bubbles during baking. A chemical leavened tortilla has 1.2-2.2 cm^3/g specific volume, spongy texture, white in appearance (Adams 2001). Tortillas produced in Mexico are less leavened translucent flat breads. The main ingredients are wheat flour, shortening, water and salt. Tortillas are consumed mainly the same day of production and can be sold semi-baked or baked. These differences with the U.S. market make the flour tortillas to have unique characteristics depending on the country they are produced.

Reducing agents are utilized to improve dough machinability by increasing extensibility and decreasing elasticity during dough formation and sheeting. L-cysteine, bisulfites, and sodium metabisulfites are used to break the gluten disulfide bonds that are formed during dough mixing (Serna -Saldívar et al 1988).

Leavening

Leavening is the method which aerates a dough or batter during mixing and baking, by introducing bubbles of gas through mechanical forces or due to biochemical or chemical reactions. During the baking process, the bubbles expand, "rise", allowing the final product to become light and porous in texture (Lajoie and Thomas 1991). When there is lack of leavening, products remain flat with a dense crumb, and with inadequate distribution of moisture (Brose and Becker 2001).

Mainly four leavening methods are used to produce baked goods: air incorporation by mechanical forces (mixing), steam or gas creation, carbon dioxide formation due to yeast fermentation or from chemical reactions, and thermal expansion (Lajoie and Thomas 1991, Waniska 1999).

Physical leavening consists of incorporating air by using mechanical forces, such as whipping with or without pressure. Air can be whipped into shortening or egg whites, which are added to other ingredients in the formulation and baked. In the steam creation method, products with several laminated layers of dough and shortening create a water vapor barrier. This vapor evolves during baking and steam promotes expansion. The other two types of leavening depend on the CO_2 release either by yeast fermentation or by bicarbonate reaction with acids, also called chemical leavening (Lajoie and Thomas 1991; Brose and Becker 2001). During fermentation, yeast and sugar react to produce alcohol and carbon dioxide (Equation I). Chemical leavening, release and production of CO_2 can be achieved by reaction of acid with sodium bicarbonate in the presence of moisture and heat (Equation II), or by thermal decomposition (Equation III) (Lajoie and Thomas 1991; Brose and Becker 2001). In all the situations mentioned above, production of gas creates bubbles which expand prior and during baking.

$$Sugar + Yeast \rightarrow Alcohol + CO_2 \qquad \text{Equation I}$$

$$HX + NaHCO_3 \rightarrow NaX + H_2O + CO_2 \qquad \text{Equation II}$$

$$NH_4HCO_3 \xrightarrow{\Delta 60^\circ C} NH_3 + H_2O + CO_2 \qquad \text{Equation III}$$

Chemical Leavening

Chemical leavening makes possible mass production of many baked products. The most frequently used chemical leavening method involves the reaction of sodium bicarbonate (leavening base) with an acid (usually phosphate). In the presence of moisture and heat, produces carbon dioxide at a controlled rate. The gas evolution starts during dough mixing, and continues through proofing and baking (Reiman 1983; Lajoie and Thomas 1991). The carbon dioxide release is associated with the rate the proton from the acid becomes available to react with the bicarbonate. Each leavening acid has its own reaction time. Other factors that affect the reaction rate include the presence of divalent cations such as calcium, sugar concentration, and presence of water binding polymers, such as starches, or gums. In this type of leavening, CO_2 gas is the main source of leavening; however, steam formed by water and the neutral salt formed during the reaction, can have impact on the final product (Heidolph 1996). Leavening agents are selected according to the rate of gas release during processing.

Bicarbonates

Several carbon dioxide carriers are used in baked goods. The three bicarbonates used as leavening bases are sodium bicarbonate ($NaHCO_3$), potassium bicarbonate ($KHCO_3$), and ammonium bicarbonate (NH_4HCO_3). Potassium and calcium carbonates (K_2CO_3 and $CaCO_3$) are also used (Brose and Becker 2001).

Sodium bicarbonate at 60°C, in the presence of moisture provides low quantities of carbon dioxide in dough and batters. Without leavening acids, sodium carbonate is formed in the dough, increasing the alkalinity and adding a slightly soapy flavor. Sodium bicarbonate solubility characteristics determine the release rate of carbon dioxide.

Potassium bicarbonate is rarely used. The chemical reaction with or without leavening acids is similar to that of sodium bicarbonate. Ammonium bicarbonate, also known as ABC-leavening (Brose and Becker 2001), decomposes to ammonia, CO_2 and water; even in absence of leavening acid. It reacts best at 60°C in the presence of moisture. Potassium carbonate releases carbon dioxide only if leavening acids are present. Calcium carbonate does not release CO_2; however it is used as a bulking agent in baking powders (Brose and Becker 2001).

Bicarbonate type and granulation influences the rate of the chemical leavening reaction: Grade 1 is a fine powder type of sodium bicarbonate that dissolves quickly and has complete availability to react with the leavening acids. Grade 2 is a fine granular particle size that facilitates the rapid distribution and uniform blending. This type of NBC is used in products where minimal leavening during mixing and holding is desired (Arm and Hammer, 1999). Grade 3 is a finer version of grade 1 NBC.

Modifying leavening bases, and evaluating their effect in tortilla properties has been poorly studied. Lajoie and Thomas 1991 studied the type and amount of leavening base in the production of cookies, cakes, and biscuits. Results of their studies showed that varying the level and type of bicarbonate used in the leavening process affects the properties of the cakes, cookies and biscuits. They found that manipulating the leavening base, desirable characteristics could be obtained in baked products. In tortilla formulations, the leavening acids are often modified in order to control CO_2 release; however modifying the leavening base has not been adequately studied.

Acids

There are two important characteristics needed in the selection and evaluation of leavening agents, the neutralization value (NV) and the rate of reaction (ROR). Neutralization is the chemical reaction between sodium bicarbonate and leavening acid that produces a neutral salt, carbon dioxide, and water. All leavening acids are sold according to their minimum NV; this information is used to compare between the available acidity of the different leavening acids, and to use the correct level in a specific formulation. NV is defined as the amount by weight of sodium bicarbonate required to neutralize 100 parts per weight of leavening acid (Heidolph 1996; Brose and Becker 2001).

The rate of reaction (ROR) provides information about the solubility of the acid and the speed of reaction between the leavening acid and the sodium bicarbonate. ROR is the amount of carbon dioxide (%) released within 8 min from the reaction of sodium bicarbonate with a specific leavening acid under standard conditions (Heidolph 1996; Brose and Becker 2001). Leavening acids are grouped into categories based on their ROR: nucleating agents (release during mixing), time released agents (react after a period of time), and heat activated agents (do not react significantly in the bowl, are triggered by heat) this classification then gives how fast or slow an acid will react with the base (Table I).

TABLE I
Leavening Acid Categories

Release Category	**Acids**
Nucleating Agents	Tartaric (cream of tartar), fumaric, citric, adidpic, lactic, and malic acids; Calcium phosphates: Mono calcium phosphate (MCP), Anhydrous monocalcium phosphate (AMCP)
Timed Release Agents	Sodium aluminum pyrophosphate (SAPP) in different grades; Granular fumaric acid; Encapsulated acids
Heat Activated Agents	Sodium aluminum sulfate (SAS), sodium aluminum phosphate (SALP), sodium aluminum phosphate anhydrous (SALPA), dimagnesium phosphate (DMP), dicalcium phosphate dehydrate (DCPD)

Brose and Becker 2001

There are two types of baking powders according to the mechanism of reaction they perform. Single acting baking powders react with the acid (potassium acid tartrate, tartaric acid, calcium pyrophosphate), when are combined with baking soda in the presence of liquid. Thus most of the gas is created before entering the oven.

Double-acting baking powders are designed to have a double reaction. Initial gas is produced when sodium bicarbonate reacts with an acid when liquid is added to the system. In the second reaction, gas is produced as the batter or dough is heated in the oven (Furia, 1975; Fennema, 1996).

In flour tortillas, combinations of fast and slow leavening acids are used to produce double reaction. Acids that hydrate and dissolve rapidly are fast-acting acids such as calcium phosphates and organic acids. About 70% of mono calcium phosphate (MCP) reacts within the first 2 min of mixing at 27°C. Acids that become soluble during the baking process are slow-acting such as sodium aluminum phosphate (SALP), sodium pyrophosphate (SAPP) and sodium aluminum sulfate (SAS). Fast acting acids, like MCP, form a thicker batter or dough compared with slower acting acids (van Wazer 1961). Fast acting acids are used as a leavener themselves (Le Baw 1982).

The chemical reactions of leavening acids that will be used in this study are as follows:

1) Sodium aluminum sulfate (SAS), NaAl $(SO_4)_2$. SAS with sodium bicarbonate produces a very retarded reaction in dough and batters according to the following equation:

$$NaAl(SO_4)_2 + 3NaHCO_3 \rightarrow Al(OH)_3 + 2Na_2SO_4 + 3CO_2$$

Due to the very retarded reaction, SAS is almost always used as a double acting baking powder. The neutralizing value is 95-100 (Brose and Becker. 2001).

2) Sodium aluminum phosphate acidic (SALP). There are two chemically different sodium aluminum phosphates acidic commercially available. The ratio of Na:Al:P is 1:3:8 $NaH_{14}Al_3(PO_4)_8 \cdot 4H_2O$ and 3:2:8 $Na_3H_{15}A_{l2}(PO_4)_8$, the reaction of this acids with sodium bicarbonate are:

SALP 1:3:8

$$NaH_{14}Al_3(PO_4)_8 \cdot 4H_2O + 23NaHCO_3 \rightarrow$$
$$Na_5Al_6(PO_4)_6(OH)_5 \cdot 12H_2O + 10Na_2HPO_4 + 14H_2O + 23CO_2$$

SALP 3:2:8

$$3Na_3H_{15}Al_2(PO_4)_8 + 32NaHCO_3 \rightarrow$$
$$Na_5Al_6(PO_4)_6(OH)_5 \cdot 12H_2O + 18Na_2HPO_4 + 15H_2O + 32CO_2$$

Both products have a neutralizing value about 100. Both leavening acids are bland in flavor. The reaction between SALP 3:2:8 and sodium bicarbonate in dough and batters is slower than SALP 1:3:8 (Brose and Becker 2001)

3) Fumaric Acid, $C_4H_4O_4$

H-C-COOH				*H-C-COONa*	
||	+	*2NaHCO3*	→	||	+ $2CO_2$ + $2H_2O$
H-C-COOH				*H-C-COONa*	

Fumaric acid is sparingly soluble in water. It is available as coarse or fine powder. Compared to coarse, the fine fumaric acid has a faster reaction with sodium bicarbonate in dough and batters (ROR 55-56, or 30-32 respectively). The neutralizing value of fumaric acid is about 145 (Brose and Becker 2001). Fumaric acid is also used to decrease the pH in dough, and is used in refrigerated dough for color stabilization. In tortillas fumaric acid is used to decrease pH and allow antimicrobial agents to react. Coated fumaric acid is commonly used as an acidulant, due to its slow reaction in dough and tortilla production, thus is the best choice in the production of flour tortillas.

Tetrasodium Pyrophosphate (TSPP)

There are four sodium salts of pyrophosphoric acid, however; only two are available to use in food production. One is the acidic sodium acid pyrophosphate (SAPP), $Na_2H_2P_2O_7$, a common acidulant, and in some form can be used as leavening acid. The second salt, called also a "neutral salt" is tetrasodium pyrophosphate (TSPP), $Na_4P_2O_7$, in which all the hydrogens of pyrophosphoric acid have been replaced with sodium. This salt has two characteristics that make it useful in food processing: its high alkalinity and its ability to precipitate alkaline earth and heavy metal ions (Furia 1975).

Tetrasodium pyrophosphate has been used widely in many food products such as meat, cheese, whipping cream, high butter fat dairy products, etc. Uses of TSPP are as dispersant and deflocculating agent for curd, as a gelling agent in buttermilk production, as stabilizer of malted-milk; improving the flavor and creating thin gels (Furia 1975).

Studies done in whipped toppings showed that phosphates serve as buffers and stabilizing agents for protein films, necessary in the formation of stiff stable foams and in the prevention of syneresis. TSPP among other phosphates is very useful in this stabilization. The effects of polyphosphates on improving the whipping properties of egg white have been studied. The addition of polyphosphates to protein compounds has shown improved whipping properties. The mechanism by which polyphosphates stabilize is not yet known, it is speculated that it could be a combination of protein precipitation and the ability to sequester interfering heavy metal ions. After treatment with polyphosphates, the protein form thin walls between the air cells that had sufficient stiffness and storage stability to produce excellent whipped compositions. A protein material in combination with alkyl ester of aliphatic polycarboxylic acids (malonic, succinic, glutaric, tartaric, malic, and citric) and a polyphosphate salt (SAPP, TSPP or STP), provides highly improved whipping compositions with high foam volume and high foam stability (Furia 1975). Due to the properties of TSPP in the stabilization of aerated products and its reaction with proteins in meat and diary systems, TSPP may allow better air retention in dough and tortilla products.

Encapsulation

The encapsulation of sodium bicarbonate can reduce the reaction with the acid or water, provide controlled release, and give uniform performance during baking. Fat and oil coatings are typically used to encapsulate leavening agents for pizza and other dough systems (Pothakamury and Barbosa-Canovas 1995; Gibbs et al 1999). Citric and fumaric acids are also encapsulated to reduce the reaction with the leavening acids and avoid premature formation of CO_2 in bread and tortilla dough.

Experimental Design

1) Compare the leavening reaction rate of the encapsulated and non-encapsulated sodium bicarbonates by determining the time of reaction at different temperatures; titratable acid was recorded.
2) Evaluate tortilla properties with decreased the standard control sodium bicarbonate levels using different solubilization rate sodium bicarbonates.
3) Addition of TSPP in low sodium bicarbonate formulations to increase tortilla quality.
4) Combinations of fast- and slow-release sodium bicarbonates, in combination with TSPP to achieve good tortilla properties.
5) Use of SAS and SALP in combination with various sodium bicarbonate levels with fast- and slow-release sodium bicarbonate in flour tortillas.

Chapter Summary

Tortillas are unique chemically leavened flat breads; require less baking time than typical bread and their volume is much smaller. The chemical leavening system used in tortillas varies within tortilla producers; it mainly consists of sodium bicarbonate, which dissolves and reacts with leavening acids, creating CO_2 gas. The use of specific leavening acids allows different reaction levels and retention of air bubbles in tortillas. Leavening bases have been poorly studied in tortilla production, thus the importance of understanding and optimizing the leavening formulations in the production of wheat flour tortillas.

CHAPTER III

EFFECTS OF SODIUM BICARBONATE TYPES

Introduction

The encapsulation of sodium bicarbonate reduces the solubilization rate of bicarbonate and its reaction with acids, provide a controlled release, and give uniform performance during baking (Pothakamury and Barbosa-Canovas 1995; Gibbs et al 1999). Fat and oil coatings are commonly used as encapsulants in products such as NBC, to increase their ability to flow and reduce caking (Gibbs et al 1999). According to Adams 2001, the rate of bicarbonate reaction should have an effect on leavening of flour tortillas. Therefore, encapsulated and non encapsulated sodium bicarbonates were tested to evaluate the effects of their release and thereby the processing quality attributes of flour tortillas.

Objectives

The objectives of this chapter are:

1) Evaluate the release of CO_2 at different temperatures.
2) Evaluate the effect of encapsulated and non-encapsulated sodium bicarbonate on tortilla properties.

Materials and Methods

Tortilla Formulation

Hot press wheat flour tortillas were prepared as a standard control with the following formulation: 1 kg enriched, unbleached, and malted wheat flour (12.5% protein content, 13.4% moisture content, 0.50% ash, 10.4% protein, falling number 254 sec., 58.6% farinograph absorption, ADM Arkady, Enid, OK), 15 g salt, 5 g sodium 2-stearoyl lactylate (American Ingredients Company, Grandview, MO), 4 g potassium sorbate (ADM Arkady, Olathe, KS), 5 g sodium propionate (ADM Arkady, Olathe, KS), 60 g all purpose shortening (Ventura, Ventura Industry, City of Industry, CA), 6 g sodium bicarbonate grade 1 (Arm and Hammer, Church & Dwight Co., Princeton, NJ), 5.8 g sodium aluminum sulfate (cfb EQUISA Budenheim, N.L. Mexico), Bakesure FT fumaric acid (Balchem Co., Slate Hill, NY), 0.03 g L-cysteine (Sigma Chemical Co., St. Louis, MO), and 530 g distilled water at 35°C.

Eleven variations of sodium bicarbonate (NBC) were tested. Seven encapsulated sodium bicarbonates Bakesure 180, 184, 193, 199, and 195, 50% and 70% high melting point sodium bicarbonates (Balchem Co., Slate Hill, NY). Three NBCs with different particle sizes, grade 1, grade 2, grade 3, and a Tortilla Blend™ (Arm and Hammer, Church & Dwight Co., Princeton, NJ).

More information on the encapsulation ratios and characteristics of the NBCs tested are shown in Table II. Six grams of NBC per kg of flour were used in each treatment, in combination with sodium aluminum sulfate (SAS) to balance the leavening reaction.

TABLE II
Sodium Bicarbonate Properties

Type of NBC	Abbreviation	% Active $NaHCO_3$	% Coating[a]	Properties[b]
Bakesure 180	BS180	49 Min	51	
Bakesure 184	BS184	85	15	
Bakesure 193	BS193	68-72	28-32	
Bakesure 195	BS195	68-72	28-32	
Bakesure 199	BS199	83-87	13-17	
HighMelt 50%	HM50	50	50	
HighMelt 70%	MH70	70	30	
Grade 1	G1	100	0	Fine (regular)
Grade 2	G2	100	0	Coarse
Grade 3	G3	100	0	Very Fine
Tortilla Blend™	Blend	100	0	Combination

[a] Partially hydrogenated vegetable oil
[b] According to Church & Dwight (Arm and Hammer)

Tortilla Processing

Tortillas were prepared according to the method described by Bello et al (1991). The dough was mixed (Hobart mixer model A-200, Hobart Co., Troy, OH) the dry ingredients with a paddle, at low speed for two minutes, then mix the shortening at low speed for additional six minutes. Warm distilled water with the L-cysteine (32±1°C) was added to develop the dough, by mixing with a hook for 1 min at low speed, followed by 4 min at medium speed. During dough mixing, the dough temperature was controlled using 38°C water in copper tubing coils around the mixing bowl.

Once dough was formed, subjective and objective dough measurements were performed and temperature was recorded. The dough was rested for 5 min in a proof chamber at (69±3%RH, 32±3°C). After proofing in the proofing chamber (model 57638, National Manufacturing Co., Lincoln, NE), the dough was divided and rounded into 36 balls (Bakery Equipment and Service Co., San Antonio, TX). The dough balls were proofed for 10 min. After final proofing, the dough balls were placed in the hot-press (188±2°C, 1100 psi, 1.35 sec) and baked (176±2°C, 30 sec) on a three-tier gas fired oven (model 0P01004-02, Lawrence Equipment, El Monte, CA), and then cooled on a 3-tier belt conveyor (model 3106-INF, Superior Food Machinery Inc., Pico Rivera, CA). The freshly prepared tortillas were further cooled by equilibrating on a table for 1-2 min on each side. The tortillas were packed in 1 mil polyethylene plastic bags and stored at room temperature (25°C).

Acid Titration

Titration of sodium bicarbonate was done with 0.10 N HCl and phenolphthalein as color indicator to attain a pH of 7.2. One gram of sodium bicarbonate was diluted in 25 ml of distilled water, turbidity and personal observations were recorded. Then 5 drops of indicator were used to titrate the NBC with the HCl acid. Titration temperatures ranged from 25 to 85°C, in five degree increments in a cumulative titration, using a hot water bath to increase the temperature. The ml of HCl required to neutralize the NBC at each temperature were recorded. Acid titration was done in triplicates. Titration of non-encapsulated NBC with 1.0 N HCl was also done with Bromothymol Blue (Fisher

Scientific, Fair Lawn, NJ) as color indicator. The NBC's were tested to achieve a pH of approx 6.3 at the different range of temperatures from 25 to 85ºC.

Dough Properties

Dough rheology and handling characteristics were observed by measuring subjectively the dough after mixing. Softness, smoothness, and toughness were rated using a scale of 1 to 5. Softness refers to pressing the dough with the fingers, while determining how hard it is to press (high rating means hard dough). Smoothness of the dough is how the surface of the dough looks after mixing (high rating means rough surface). The dough toughness is measured by pulling a piece of dough and observing how elastic or viscous it is (higher dough viscosity shows lower scores). The press rating was taken before forming the dough balls; the proofed dough was spread out on a round plate prior to dividing and rounding, force applied to press the dough throughout the plate was measured in a scale from 1 to 5. Higher numbers indicate stronger force applied.

Objective dough compression measurements were taken 10 min after proofing the dough balls, using a texture analyzer (model TA.XT2i, Stable Micro Systems, Scarsdale, NY). A dough ball was placed on a flat platform and pressed with a 100 mm diameter cylindrical plate, the peak and equilibrium forces, and gradient were recorded. Dough compression was done in duplicates.

Tortilla Properties

Tortilla moisture, diameter, opacity, height, weight, and pH were evaluated subjectively (Bello et al 1991) one day after the tortilla was processed and stored at 22°C. Rollability and extensibility measurements were done 4, 8, 12, 16, 20, and 24 days after production.

Moisture: A two-stage moisture method consists on drying a tortilla for 24 hr in ambient conditions followed by three-hour moisture. The samples in duplicate were placed in an oven (model 16, Precision Scientific Co. PS, Chicago, IL) and dried for 3 hr at 100°C. Moisture was calculated by loss of weight.

Tortilla pH: Half of a tortilla was grounded with a coffee grinder (Model DCG-20, Cuisinart Coffee Grinder, East Windsor, NJ.) and mixed in 120 ml of distilled water. A Φ 10-pH meter (Beckman Instruments, Fullerton, CA) was used to measure the pH of tortilla in the distilled water solution. An electrode probe (Corning "3 in 1." Corning, Inc., New York, NY) was dipped in the water-tortilla solution and the pH measurement recorded after 25±5 seconds. Tortilla pH was measured 24 hr after processing.

Height: The height of ten tortillas was measured with a 12" electronic digital caliper (Chicago Brand, Chicago, IL) on two opposite points in the tortillas (Fig. C.1).

Diameter: The diameter of ten, randomly selected tortillas was measured using a ruler. Two measurements orthogonal to each other were taken on each tortilla (Fig. C.2).

Opacity: Ten, randomly selected tortillas were observed for opacity vs. translucency with a continuous scale: 100% meaning completely opaque (white), 0% meaning completely translucent (not white). A 100% opaque tortilla means it has uniform, white color with out areas that transmit light through the tortilla (Fig. C.3).

Weight: Ten, randomly selected tortillas were weighed using an analytical scale (Ohaus, Houston, TX).

Specific Volume: Tortilla specific volume (cm^3/g) was determined as follows:

$$SpecificVolume = \frac{(height)x(\pi r^2)}{weight}$$

height = height of 10 tortillas (cm); *weight* = weight of 10 tortillas (g)

r = average radius of 10 tortillas (cm)

Rollability: Subjective rollability measures the cracking and breakage of a tortilla (Fig. C.4) was used to evaluate shelf stability. Rollabilty was determined by wrapping half of a tortilla around a 1.0 cm dowel, rollability score (RS) were given on the scale of 1 to 5, where 5 = perfect rollable tortilla with no cracks; and 1 = a tortilla which breaks immediately, thus cannot be rolled. Tortillas with RS below three (3.0) were considered unacceptable.

Extensibility: Extensibility tests were conducted using the texture analyzer (model TA XT2i, Texture Technologies Co., Scarsdale, NY), using the method by

Suhendro et al (1999). A tortilla strip (70x35 mm) was held between two clamps, which pull the tortilla apart until rupture. The extensibility test was conducted using the return to start option, in the tension mode and trigger force of 0.05 N. Pre and post-test speeds were 10.0 mm/s and test speed of 1.0 mm/s. The modulus of deformation (N/m), force (N) to extend the tortilla strip 1.0 mm, and force (N), distance (mm) and work to rupture (Nm, area under the curve) were recorded.

Quality Index: Quality Index (QI) was calculated for tortillas, according to the method reported for quality index of bread, by the Wheat Technical Board of the Wheat Quality Council (2002) report:

$$QI = Opacity * SpecificVolume * RollabilityScore \quad \text{(After > 12 d storage)}$$

Quality index values above 450 indicate tortillas with good to excellent storage stability, opacity and diameter.

Statistical Analysis

Fisher Least Significant Difference (LSD) was calculated using the General Linear Model procedure at a confidence level of 95% (α=0.05). LSD values were obtained for all dough and tortilla properties evaluations. The statistical software SAS (version 8.0, SAS Institute, Cary NC) was used.

Results

Sodium Bicarbonate Acid Titration

The subjective observations of the solubility behavior on encapsulated NBC are shown in Table III. The NBC's that present non turbid characteristics were more resistant to heat, releasing the NBC at a slower rate than the NBC with the turbid solution. This represents that monoglycerides and triglycerides were used in the encapsulation of NBC; providing different rates of NBC release. According to Balchem Co. (Slate Hill, NY), the NBC composition of the bicarbonate was not modified among the different encapsulants.

TABLE III
Characteristics of Dissolution on the Different Types of Encapsulated NBC

Type of NBC[a]	Characteristics	
BS180	Turbid	Does not dissolve in water contact. NBC granules are suspended on the top of the flask.
BS184	Turbid	Only small particles dissolved.
BS193	Not Turbid	Did not dissolve. Agglomeration of NBC was observed on the bottom and top of the flask.
BS195	Turbid	Partially dissolved. NBC observed on the bottom of the flask.
BS199	Turbid	Small NBC particles did not dissolve. NBC agglomerations sink on the bottom of the flask.
HM50	Not Turbid	NBC flaky granules adhere to the flask wall. Does not dissolve.
HM70	Not Turbid	NBC flaky granules adhere to the flask wall. Does not dissolve.

[a] Types of NBC are defined in Table II

Titration was used to determine the solubility of the different NBC and their release with temperatures increase. The release of components can be controlled either by the capsule wall or by the membrane covering the wall. The permeability through the matrix and the solubility of the component of the capsule influences the rate of diffusion (Gibbs et al 1999). In the case of the tested encapsulated NBC's, the release mechanism through which the lipid membrane or wax can be destroyed is heat. In order to understand the release of sodium bicarbonate, an acid titration with applied heat was used, and a cumulative titration curve was obtained by neutralizing the NBC to a pH of 7.3 (Fig.1; Table A.1). This titration curves reveal three rates of reaction groups; highly soluble (non-encapsulated), medium reaction (BS180, BS184 and BS199), and slow release (HM50, HM70, BS193 and BS195).

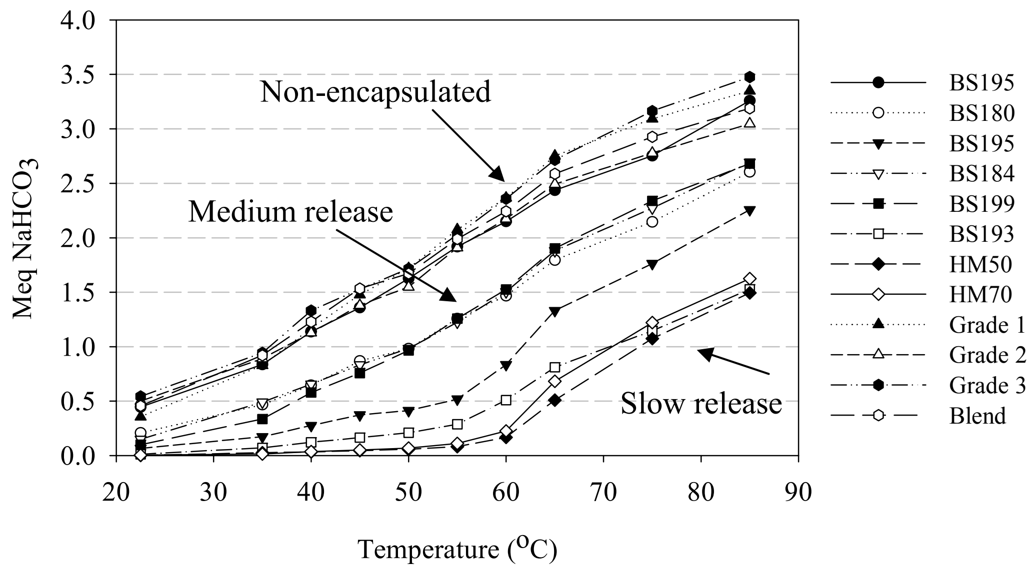

Fig. 1. Titration curves for encapsulated and non-encapsulated NBC at pH 7.2.
Note: LSD = 1.1 at 85°C.

Titration to attain pH 6.3 was performed on the non-encapsulated G1, G2, G3, and control NBC, as a comparison with the titration performed at pH 7.2. According to Adams (2001), the pH of tortilla dough is approximately 6.2. Therefore it is expected that reaction at this pH reaction of NBC with the leavening acids starts. Results of titration to pH 6.3 reveal the same pattern for the non-encapsulated NBC that titration at pH 7.2 (Fig. 2). This figure shows that to obtain a lower pH, more acid is required to neutralize the NBC when titrated to pH 6.3 than to pH 7.2. This was expected since the pKb of bicarbonate is 10.3.

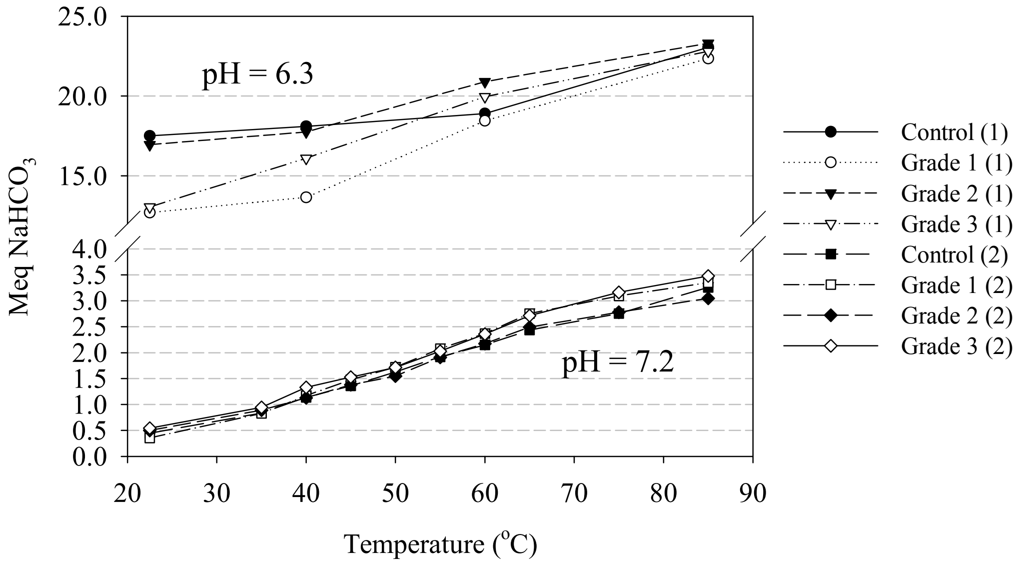

Fig. 2. Titration curves of non-encapsulated NBC at pH 6.3 and 7.2.
Note: Legends with (1) = curve at pH 6.3; legends with (2) represent curves at pH 7.2.
LSD at 80°C= 3.7 for pH 6.3, LSD at 85°C = 0.13 for pH 7.2.

Effects of NBC on Tortilla Properties

Dough objective properties peak force, equilibrium force, and gradient showed no significant differences when NBC was compared at 6 g/kg (Table A.2). Dough subjective measurements: smoothness, softness, toughness and press rating were not significantly affected by any type of encapsulated or non-encapsulated sodium bicarbonate at 6 g/kg flour level (Table IV).

TABLE IV
Effects of NBC Types on Subjective Dough Properties

Type of NBC[a]	Smoothness	Softness	Toughness	Press Rate
Control	1.9	1.9	1.9	1.9
Grade 1	1.9	1.9	1.9	1.9
Grade 2	1.8	2.0	1.8	2.0
Grade 3	1.8	2.2	1.8	2.0
Blend	1.8	2.2	1.9	1.9
BS180	1.9	1.9	1.8	1.9
BS184	1.8	2.0	1.7	1.8
BS193	1.9	1.9	1.6	2.0
BS195	1.9	2.0	1.8	1.8
BS199	1.7	1.8	1.6	1.8
HM50	1.8	2.0	1.8	2.0
HM70	1.8	2.0	1.7	2.0
LSD	0.1	0.3	0.3	0.2

[a] Types of NBC are defined in Table II

Tortilla properties were modified by the use of different particle size and/or encapsulated NBCs. Moisture, pH, and weight of tortillas was not significantly affected by the different NBC tested (Table V).

Tortillas containing HM50, HM70, BS193 and BS195 were significant thinner than control and significantly thinner from tortillas containing other encapsulated NBCs. This could be due to the lack of air bubble creation in the dough before and during baking. The high melting points of the fat encapsulant used in these NBC did not allow the release of sodium bicarbonate at the proper time. Blend and G2 NBC tortillas were significantly thicker than control; this could be do to the different particle size of the bicarbonate tested (Lajoie and Thomas 1991). The Tortilla Blend™ is a unique combination of special sodium bicarbonate granulations, which can produce leavening reactions at different stages of the tortilla production process (Arm and Hammer 2000). Smaller particles of bicarbonate dissolve more quickly and could react faster. G1 is a fine powder, G3 is extracted from the G1 and are the smallest particles of G1, thus a very fast reacting base, and the larger particles correspond to G2 (coarse) NBC (Book et al 2003).

The opacity, specific volume, and diameter of tortillas was affected by the different types and particle sizes of sodium bicarbonate used (Table A.3). High opacity values were obtained with sodium bicarbonates with medium reaction NBC, while the slower reaction encapsulated NBC yield tortillas with unacceptable opacity (scores below 85%). This corresponds to a lack of air bubbles formed and/or retained in the tortillas. Opacity was directly related to the specific volume of the tortillas and the reduced air bubbles.

TABLE V
Effects of NBC Types on Flour Tortilla Properties

Type of NBC[a]	Height (cm)	Weight (g)	Moisture (%)	pH (24 h)
Control	0.26	40.4	34.0	5.3
Grade 1	0.27	40.1	32.6	5.1
Grade 2	0.29	40.6	31.4	5.1
Grade 3	0.27	41.5	31.7	5.1
Blend	0.29	39.4	31.0	5.2
BS180	0.25	40.4	32.5	5.4
BS184	0.26	39.9	32.9	5.3
BS193	0.22	41.8	32.7	5.3
BS195	0.24	40.3	31.2	5.2
BS199	0.26	38.2	32.7	5.2
HM50	0.23	42.7	32.7	5.4
HM70	0.20	40.9	31.8	5.2
LSD	0.03	2.2	4.0	0.3

[a] Types of sodium bicarbonate defined in Table II

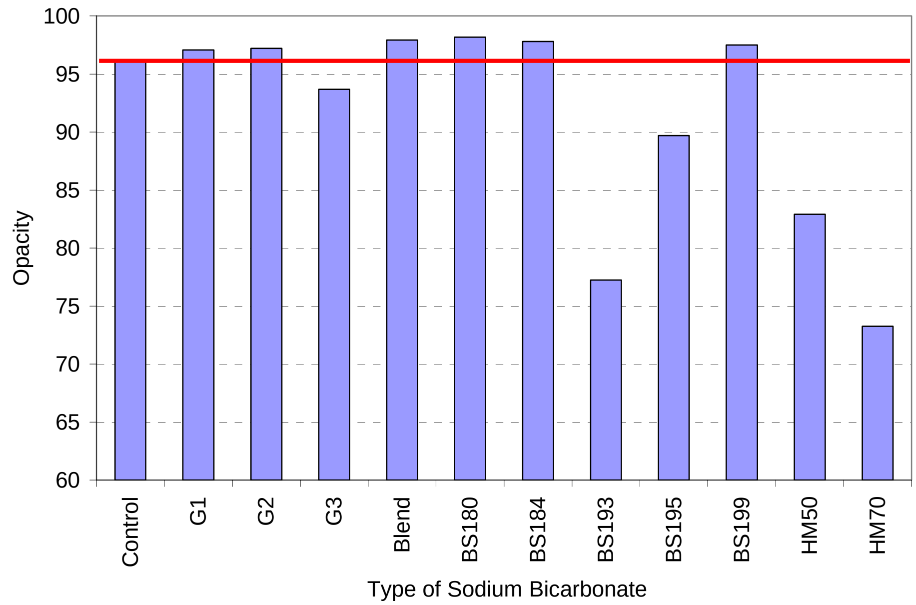

Fig. 3. Effects of NBCs on opacity of flour tortillas.
Note: Solid red line across the figure represents control. Types of NBC are defined in Table II. LSD = 5.97.

Particle size of non-encapsulated NBC did not effect the opacity of tortillas at the 6 g/kg NBC level (Fig. 3). Tortilla opacity significantly decreased when encapsulated HM50, HM70, BS193, and BS195 was used (Table A.3). However, the other encapsulated NBCs tested had slightly improved opacity compared to control tortilla. As shown with the height or thickness of the tortillas, the incomplete solubilization and release of NBC does not allow bubble formation and retention at the proper time during tortilla baking; yielding tortillas with poor properties.

A significant difference was observed in the diameter of the non-encapsulated treatments vs. the tortillas with encapsulated NBC (Fig.4; Table A.3). An increased in tortilla diameter was observed using BS180 and BS184. Many encapsulated NBC caused slightly greater diameters, except BS195. Non-encapsulated NBC treatments tended to have slightly smaller diameter tortillas.

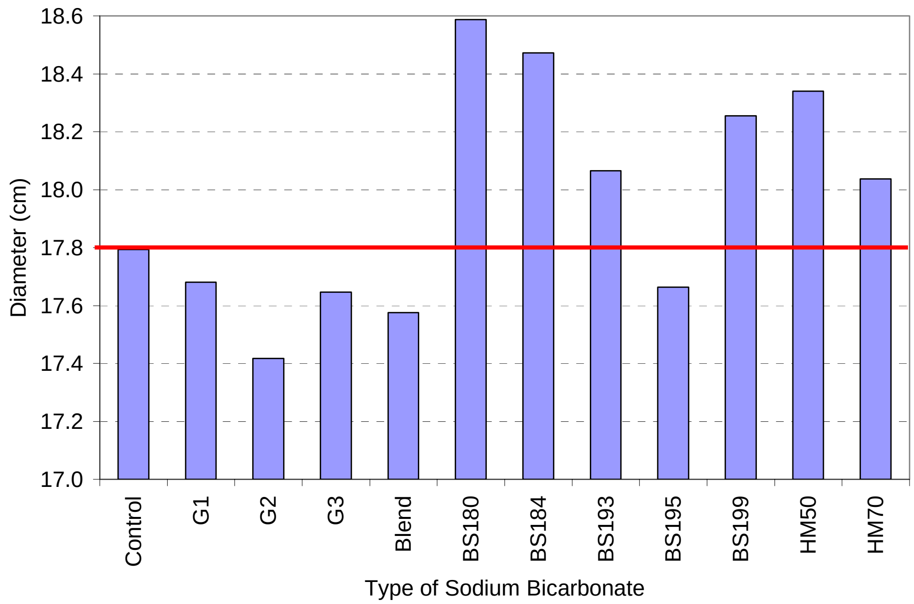

Fig. 4. Effects of NBCs on diameter of flour tortillas.
Note: Solid red line across the figure represents control. Types of sodium bicarbonate are defined in Table II. LSD = 0.66.

The specific volume of the tortillas, a function of the thickness, weight, and diameter, were significantly affected by the type of NBC used (Fig. 5; Table A.3). Tortillas with high opacity also had high values for specific volume (r = 0.95). This is consistent with the hypothesis that more air is present in opaque tortillas.

The relation of opacity and specific volume is illustrated in Fig. 6. Higher opacity values correlate with more air entrapped in the tortilla, as shown by Cepeda et al (2000), when bubbles are created in the tortilla, the refraction of the light creates the opaque appearance. Opacity values above 95% show higher specific volume, than tortillas with lower opacity scores. Thus the air created and retained in the tortillas are important properties of a good quality tortillas.

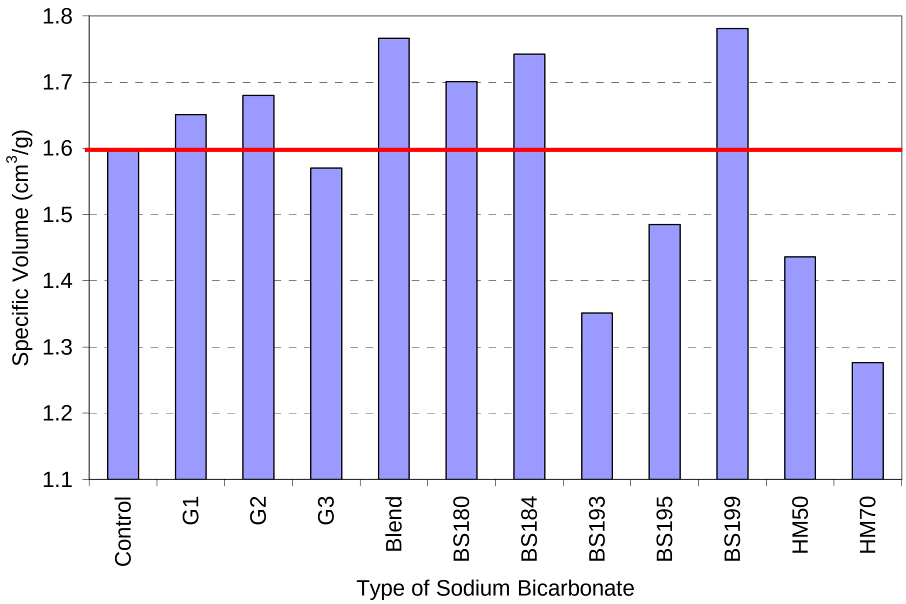

Fig. 5. Effects of NBCs on specific volume of tortillas.
Note: Solid red line across the figure represents control. Types of sodium bicarbonate defined in Table II. LSD=0.20

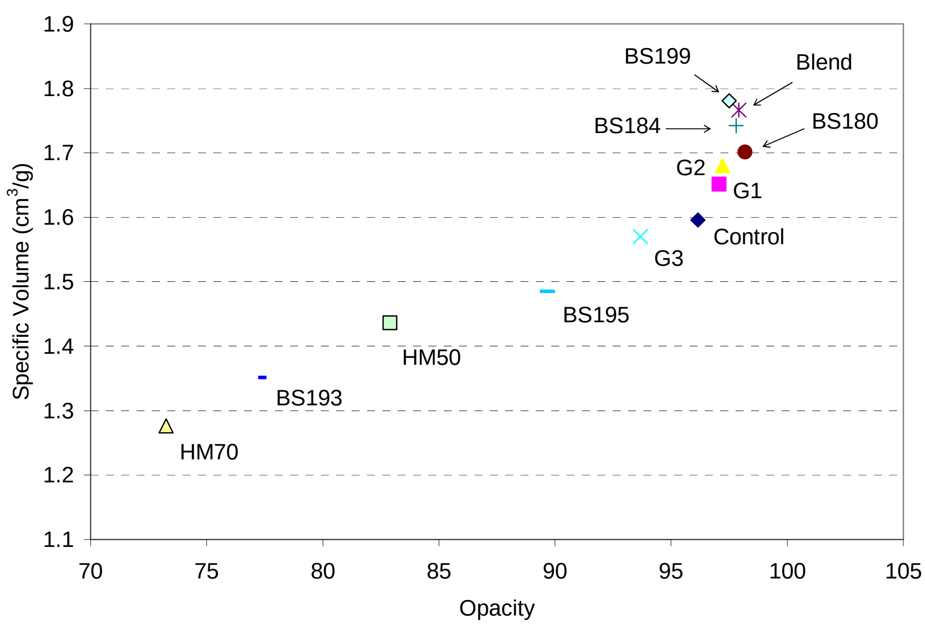

Fig. 6. Scatter plot of specific volume vs. opacity of tortillas with various types of NBC.
Note: types of sodium bicarbonate defined in Table II. LSD = 5.97 for opacity; LSD = 0.20 for specific volume.

The shelf stability of flour tortillas is determined by the time in days that they will still be rollable. Quality index (QI) is a measurement commonly used in bread quality evaluation. To calculate the quality index of tortilla, opacity, specific volume and rollability scores used. This method is a good approach to evaluate tortillas as a whole (Table VI). No significant differences were observed in the rollability of tortillas with NBC at the same level. Shelf stability properties were not affected by the type of NBC tested. However, the quality index was significantly affected for the HM50, HM70, BS193 and BS195 (Fig. 7), scores below 400 are considered as non-acceptable QI. The decreased values obtained with the slow reacting encapsulated NBC was due to the low opacity and specific volume of these tortillas.

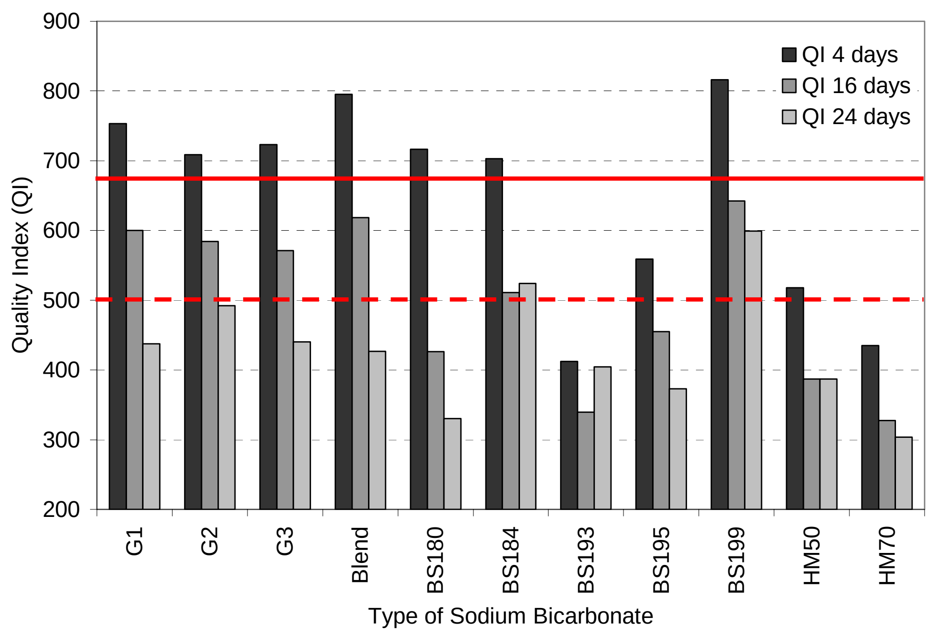

Fig. 7. Effects of types of NBC on quality index (QI) of flour tortillas.
Note: Types of NBC are defined in Table II. Solid line across the bars represents control QI at 4 days. Dotted line across the bars represents control QI at 16 days. LSD at 4 days = 137; LSD at 16 days = 183; LSD at 24 days = 227.

TABLE VI
Effects of NBC Types on Rollability Score (RS) and Quality Index (QI)

Type of NBC[ab]	4 day		8 day		12 day	
	RS	QI	RS	QI	RS	QI
Control	4.4	673	3.8	576	4.1	637
Grade 1	4.7	753	4.0	637	3.8	616
Grade 2	4.5	708	3.7	584	3.4	527
Grade 3	4.8	723	4.2	642	4.1	624
Blend	4.6	795	4.0	696	3.9	673
BS180	4.2	716	3.2	552	2.4	401
BS184	4.1	702	3.4	571	3.8	652
BS193	4.0	412	3.4	349	3.6	378
BS195	4.2	559	3.9	519	3.3	433
BS199	4.7	816	3.3	564	3.8	655
HM50	4.4	517	3.8	446	3.5	417
HM70	4.7	434	4.8	448	3.5	327
LSD	0.6	137	1.1	204	1.0	179

TABLE VI continued

Type of NBC[ab]	16 day		20 day		24 day	
	RS	QI	RS	QI	RS	QI
Control	3.0	455	2.7	417	3.3	509
Grade 1	3.7	600	3.5	561	2.7	437
Grade 2	3.7	584	3.2	502	3.1	492
Grade 3	3.8	571	4.1	619	2.9	440
Blend	3.6	618	3.3	562	2.5	426
BS180	2.5	426	2.1	364	1.9	330
BS184	3.0	511	2.9	494	3.1	524
BS193	3.3	339	3.7	381	3.9	404
BS195	3.4	455	3.1	416	2.8	373
BS199	3.7	643	3.7	634	3.5	599
HM50	3.3	387	3.3	387	3.3	386
HM70	3.5	327	4.3	397	3.3	303
LSD	1.0	183	1.5	239	1.3	227

[a] NBC level 6g/kg
[b] Types of NBC are defined in Table II

Objective tortilla properties over time did not show significant differences in force, distance, gradient, or work (Table A.4). Higher force was required to rupture tortillas as storage time increased. Decreased distance to rupture was observed over time, showing an inverse relationship with force to rupture.

Discussion

The release behavior of encapsulated NBC as determined by titration curves correspond to the findings obtained during tortilla processing. The type of NBC used modifies tortilla opacity, specific volume, and thickness. Non-encapsulated NBC with different particle size produced decreased diameter in all treatments compared to control. Thicker tortillas, with improved specific volumes were obtained with Grade 2 and blend NBCs. Since smaller NBC granules dissolve faster than larger NBC granules, more leavening reactions occur prior to tortilla baking. The gas generated during dough gelatinization contributes to tortilla height and specific volume (Bejosano and Waniska 2003); however opacity in this study was not significantly affected by particle size of NBC.

According to McDonough et al (1996), during hot-pressing of tortillas, starch and gluten form a semi-continuous seal across the tortilla surface. At this stage starch, proteins and leavening agents work together to expand and retain air in the tortilla structure. According to Waniska et al (2002), amylose from starch is involved in the retention of air bubbles in the hot dough system during and immediately after baking tortillas. Amylose in tortillas produces viscous gels which retains air bubbles and thereby impacting tortilla opacity. Starch gelatinization allows air entrapment; however the flipping of tortillas within the oven collapses the not fully gelatinized structure, and the tortilla losses air volume. Further heating generates more gas, expands the bubbles, which are then retained by the increase viscosity of the amylose gel during baking and later during cooling. Flour tortillas attain their fluffy texture through steam and leavening gases entrapped in the starch structure. Flour with mechanically damaged starch negatively effects tortilla opacity and thickness (Mao and Flores 2001).

When encapsulated NBCs are used, the major interaction of leavening with the acids and moisture starts with the dough compression. The fat coated NBC slows solubilization and reaction of the bicarbonate with acids. The use of hot-press equipment increases the dough temperature and reaction rate of chemical leaveners. Solubilization of NBC is slower when fat encapsulated NBC is used because the fat must melt before NBC is released. Starch gelatinization does not occur in the dough before the hot-press (dough temperature below 35°C), but is initiated during hot-pressing and continues during baking (Waniska et al 2001). The reactions of leavening and starch gelatinization occur simultaneously in the early baking process. Using encapsulated NBC, the air is not produced until later in the baking process, thus the starch granules have already swelled and entrapped the air, limiting bubble loss when tortilla flips into the second tier in the oven. Also, at this time, the high oven temperatures (300°C) allows partial or complete melting of the encapsulant and the release of the NBC thus air cells are expanded at the right time to be held by the gelatinized starch. When using encapsulated NBCs, the fat encapsulant protects the release and reaction of the NBC during dough mixing and/or proofing, thus less bicarbonate is lost during the prior steps to baking, and is available to react during the tortilla baking.

Not all encapsulated NBCs allow the same type of reaction, medium reaction NBC yield tortillas with best characteristics vs. slow reacting NBC. The rate at which the NBC is released depends on moisture and temperature that melts the encapsulant and allows dispersion and reaction of the NBC.

As demonstrated by Adams (2001), encapsulated NBC did not disperse evenly, showing speckles through out the tortilla, creating unleavened areas and poor tortilla characteristics. Similar findings were observed when slow release BS193, HM50 and HM70, which yield poor quality tortillas, such as low opacity, height and specific volume. Improved opacity, volume and thickness were achieved with BS180, BS184, and BS199. This implies that NBC was released to the tortilla at the proper time during the process. The type of NBC tested did not affect shelf stability.

Adams (2001) found that tortillas with fine NBC were thicker than tortillas with encapsulated NBC. Tortillas with coated NBC showed speckles due to incomplete dispersion of the NBC. Each sodium bicarbonate tested presented different tortilla properties, depending of encapsulation.

Chapter Summary

Various types of encapsulated sodium bicarbonates yield different tortilla properties. The release of sodium bicarbonate, presented in the titration curve, and the effect of time and temperature release NBC in tortilla properties, resulted in similar behaviors. This means that a good comparison of NBC reaction can be obtained by the titration method. Controlled release of NBC can improve tortilla properties, if the proper encapsulant is used.

Non-encapsulated NBC yield thicker tortillas with decreased diameter. The overall quality of tortillas was decreased in treatments with low opacity (HM50, HM70, BS193, and BS195). Improved tortilla properties of opacity, thickness, diameter, and specific volume were obtained with encapsulated NBC. The best treatment was with encapsulated BS180.

CHAPTER IV

EFFECTS OF SODIUM BICARBONATE TYPES AND AMOUNTS

Introduction

Encapsulation is used to protect and control the release of ingredients into the food system at the appropriate time for their activity. As shown in Chapter III the encapsulation of sodium bicarbonate decreases its solubilization and early reaction with the acid and/or water, providing controlled release. The way sodium bicarbonate solubilizes and reacts during the production of flour tortillas has a great impact on the production of air cells or bubbles in the tortilla protein starch matrix. Tortilla opacity is an important appearance attribute that relates to the consumer acceptability of tortillas, in a previous study by Adams (2001) increasing the amount of NBC created more opaque tortillas, compensating for the early reaction or solubilization of the bicarbonate in the previous stages of the dough and tortilla processing.

When sodium bicarbonate solubilizes at the proper time in the dough, air cells can be created and set, thus the amount of NBC can be reduced if “delivered” to the leavening system at the appropriate time, i.e. using the right encapsulant. Other alternative to aid setting the starch-protein matrix can be the use of salts like tetrasodium pyrophosphate (TSPP). This salt interacts with proteins of the tortilla, and can allow bubble retention, hence the amount of leavening compounds may be reduced.

Objectives

The objectives of this chapter are to determine the effects of:

1) Level of sodium bicarbonate on flour tortilla properties.
2) Addition of tetrasodium pyrophosphate salt using low levels of sodium bicarbonate on properties of flour tortillas.

3) Combinations of sodium bicarbonates with fast and slow release on properties of flour tortillas.

4) Different slow reaction leavening acid on properties of flour tortillas.

Materials and Methods

Tortilla Formulation

Hot press wheat flour tortillas were prepared as a standard control described in Chapter I. The tested sodium bicarbonates used for this experiment were encapsulated Bakesure 180 (Balchem Co., Slate Hill, NY), non-encapsulated grade 1 (G1), and control (Arm and Hammer, Church & Dwight Co., Princeton, NJ). Two encapsulated slow release BS193 and BS195 NBCs (Balchem Co., Slate Hill, NY) were also tested when combinations of NBC were studied.

BS180 and G1 were selected due to their excellent performance shown on Chapter III. The level of bicarbonate varied from 6 to 1.25 g of NBC/kg of flour and was balanced with the corresponding leavening acid. Bakesure FT fumaric acid was used as acidulant levels were adjusted according to NBC amount. Two types of leavening acids were tested for the comparisons of leavening acid section, Sodium Aluminum Sulfate (SAS) and Sodium Aluminum Phosphate (SALP) in a balanced leavening formulation.

Tortilla properties obtained with other types of encapsulated and non-encapsulated NBC, and combinations of several NBCs with 0.1 and 0.2 % TSPP, not shown in this chapter, can be found in Tables B.14 to B.21.

Tortilla Processing

Tortillas were produced and tested with the methods described in Chapter III.

Sensory Analysis

An untrained panel of 35 people evaluated five differently formulated tortillas with and without TSPP (Table VII). A hedonic scale from 1-9 was used to evaluate the tortillas for dislike extremely (1) and like extremely (9) according to Suhendro et al (1995). The tortillas were tested for aroma, appearance, texture, and flavor. Sensory ballot and description to the questions asked in the analysis are shown in Table B.7.

TABLE VII
Levels and Types of NBC and TSPP Used in Sensory Analysis

Type of NBC[a]	Control	BS180	BS180	Grade 1	Grade 1
Level (g/kg)	6	3	3	3	3
TSPP (g/kg)	0	0	1.5	0	1.5

[a] Types of NBC are defined in Table II

Statistical Analysis

Fisher's least significant difference (LSD) level at $\alpha = 0.05$ was calculated for the subjective and objective tortilla properties.

Results

Effect of Amount of NBC on Tortilla Properties

Subjective and objective dough properties for tortillas prepared with various levels of NBC were not affected. Smoothness, softness, toughness and press rating scores (Table VIII) for control, G1 and BS180 were not significantly affected by the different amounts of NBC tested. Dough objective measurements of force, equilibrium force and gradient showed no significant differences when lower levels of NBC were tested (Table B.1).

TABLE VIII
Effects of Amounts and Types of Leavening on Subjective Dough Properties

Type of NBC[a]	NBC (g/kg)	Smoothness	Softness	Toughness	Press Rate
Control	6.0	1.9	1.9	1.9	1.9
	3.0	1.9	1.9	1.9	2.0
	2.1	2.0	2.1	2.2	2.0
	1.2	1.8	2.2	2.2	2.0
LSD		0.2	0.2	0.2	0.1
Grade 1	6.0	1.9	1.9	2.0	1.9
	4.5	1.8	1.9	1.7	1.9
	3.0	1.9	2.0	1.8	2.1
	2.3	1.8	2.0	1.7	2.0
	1.9	1.9	2.0	1.7	2.0
	1.5	1.8	2.0	1.8	1.9
LSD		0.2	0.3	0.4	0.2
BS180	6.0	1.9	1.9	1.8	1.9
	4.5	1.9	1.8	1.8	1.8
	3.0	1.9	1.9	1.9	1.9
	2.3	1.9	2.0	1.7	1.9
	1.9	1.8	1.9	1.6	1.8
	1.2	1.9	2.0	1.9	1.9
LSD		0.2	0.3	0.2	0.2

[a] Types of NBC are defined in Table II

Tortilla properties were affected by the use of various levels of NBC (Table IX). Moisture, pH, and weight of tortillas were not significantly affected by the decreased amounts of NBC tested.

By lowering the level of NBC to half, the height of tortillas was reduced significantly. Air cells are created in mixing and start their expansion in the first stages of baking, if there is not sufficient NBC available for this reaction, fewer bubbles will expand and the height of tortillas decrease.

TABLE IX
Effects of Amounts and Types of NBC on Flour Tortilla Properties

Type of NBC[a]	NBC (g/kg)	Height (cm)	Weight (g)	Moisture (%)	pH (24 h)
Control	6.0	0.26	40.4	34.0	3.9
	3.0	0.21	40.2	32.9	5.2
	2.1	0.19	39.4	31.3	5.1
	1.2	0.18	41.6	33.2	5.2
LSD		0.02	1.4	2.9	0.2
Grade 1	6.0	0.27	40.1	32.5	5.1
	4.5	0.24	39.3	32.6	5.4
	3.0	0.25	40.6	32.4	5.2
	2.3	0.21	39.5	32.9	5.2
	1.9	0.19	39.8	32.6	5.3
	1.5	0.18	38.8	32.9	5.2
LSD		0.03	1.8	2.08	0.3
BS180	6.0	0.26	39.7	32.6	5.4
	4.5	0.24	39.6	33.4	5.3
	3.0	0.23	40.7	32.5	5.2
	2.3	0.22	41.4	32.4	5.2
	1.9	0.20	38.2	32.7	5.3
	1.2	0.18	40.4	33.0	5.1
LSD		0.3	2.4	3.0	0.3

[a] Types of NBC are defined in Table II

The opacity, specific volume, and diameter of tortillas were also affected by decreased levels of NBC (Table B.2). Diameter of tortillas containing BS180 was larger than control tortillas containing 6 g/kg of NBC. This could be created by the excess of air cells already in the dough at the time of compression in the hot-press. Since the control treatment is a non-encapsulated type of NBC, solvation of the NBC results in a premature reaction of the leavening base. At a level of 3 g/kg NBC, the diameter was not affected by type of NBC. Decreased tortilla diameter occurred at lower levels of BS180 and G1.

Higher opacity values were obtained at 6 g/kg NBC level. A significant decrease in opacity was observed when levels below 3 g/kg were evaluated. At 3 g/kg BS180

NBC tortillas had acceptable opacity. Specific volume decreased in all treatments when lower levels of NBC were used.

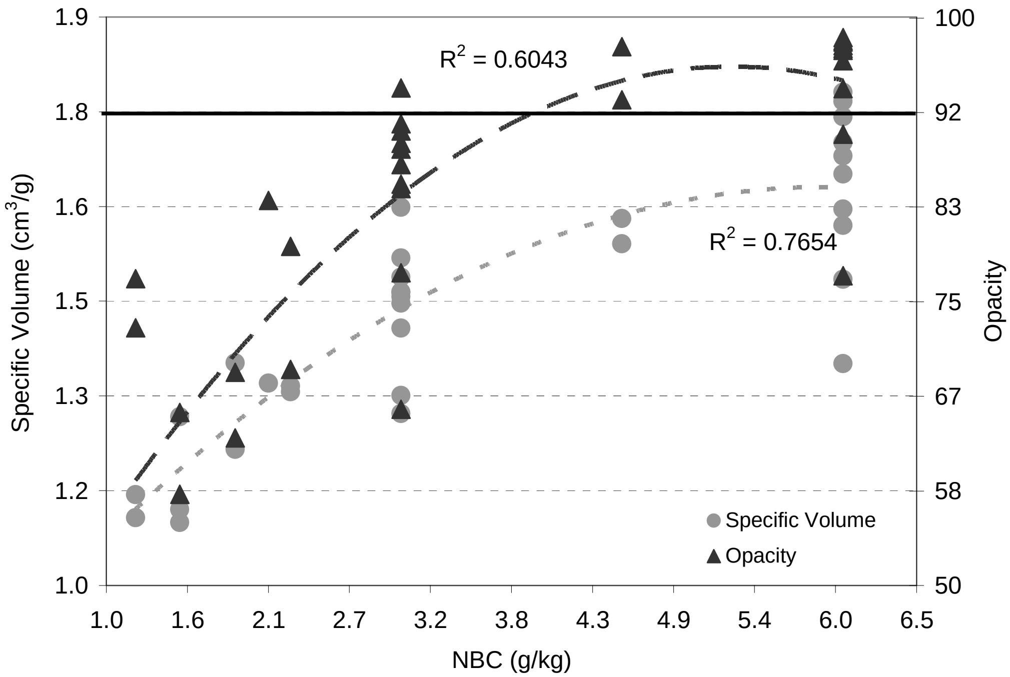

Fig. 8. Effects of amounts and types of NBC in specific volume vs. opacity of flour tortillas.
Note: LSD = 12.53 for opacity, LSD = 0.18 for specific volume.

Opacity and specific volume are directly related. The amount of bubbles created and set in the tortilla is depending upon the amount and type of NBC used. Fig. 8 shows at higher levels of NBC, a higher opacity and specific volume. The figure also represents that different types of NBC can yield good opacity and specific volume results even when low levels of NBC are used.

When comparing encapsulated vs. non-encapsulated NBC in a range of levels, lower opacity scores were obtained with the non-encapsulated NBC (Fig. 9), this confirms the finding shown on Chapter III. At half the level of NBC, opacity scores above 92% can be obtained when using BS180.

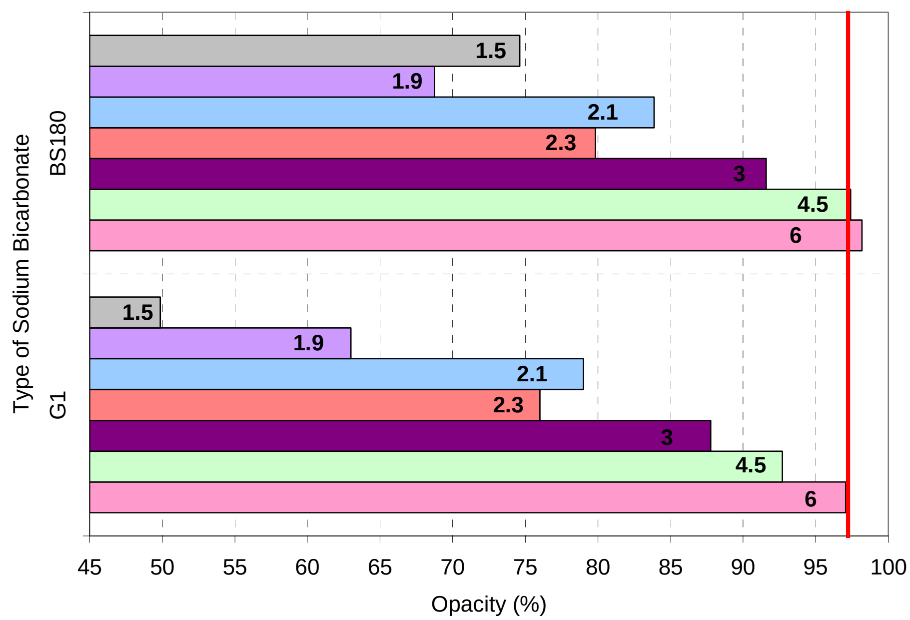

Fig. 9. Effects of amounts and types of NBC on opacity of flour tortillas.
Note: Numbers in the columns reflect g/kg of NBC. Type of sodium bicarbonate is defined in Table II. LSD = 17.60 for Grade 1, LSD = 14.14 for BS180.

The level of NBC modified tortilla diameter. Larger diameter tortillas were obtained with BS180 vs. G1 NBC at any tested level (Fig. 10). This suggests that the controlled release of bicarbonate from the encapsulated treatment does have an effect on dough compression, creating less resistance to compression between plates and allowing more pressure to be applied to the tortilla. In the case of G1 NBC, bubbles are expanded before compression due to an early leavening reaction. Thus the higher amount of air in the tortilla might have reduced the diameter tortillas. The force applied was distributed more efficiently to extend the dough when bubbles were formed after the hot-press.

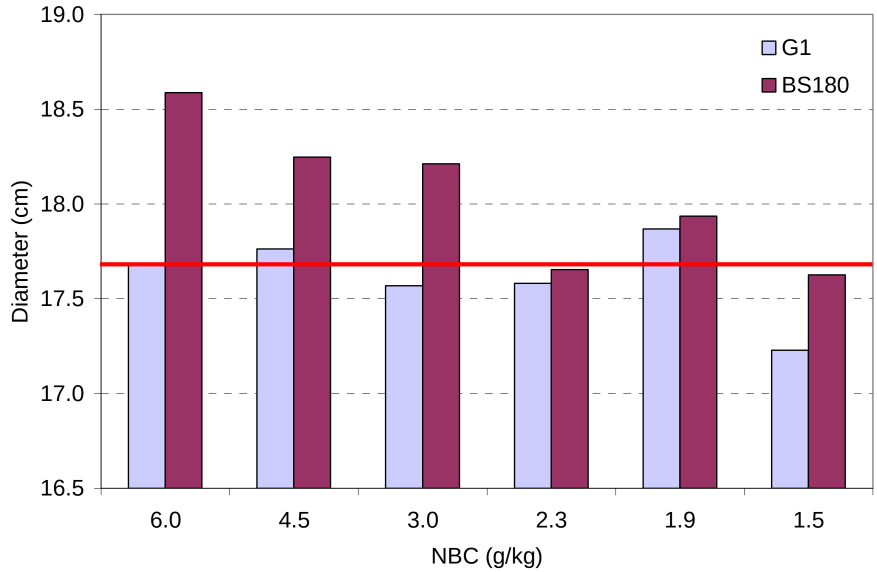

Fig. 10. Effects of amounts and types of NBC on diameter of flour tortillas.
Note: Types of sodium bicarbonate are defined in Table II. LSD = 0.55 for Grade 1, LSD = 0.65 for BS180.

The rollability score and calculated quality index decreased during storage of tortillas (Table X). These values varied less in treatments with decreased levels of NBC. More shelf stable tortillas were with lower levels of NBC (Fig. 11). Adams (2001) found that higher amounts of leavening adversely affected storage stability of tortillas. The lower levels of bicarbonate caused less disruption in the tortilla structure by decreasing the number of air cells. Tortillas with low levels of NBC resist disruption over longer periods of time, i.e., less firming.

Quality Index (QI) at 12 days of storage show unacceptable values for control at levels below 3 g/kg. This lower QI is due to the relation of this attribute to the specific volume and opacity of tortillas. However, higher QI were attained with the BS180 vs. G1 sodium bicarbonates.

TABLE X
Effects of Amounts and Types of NBC on Rollability (RS) and Quality Index (QI)

Type of NBC[a]	NBC (g/kg)	4 day		8 day		12 day	
		RS	QI	RS	QI	RS	QI
Control	6.0	4.4	674	3.8	577	3.4	514
	3.0	4.7	517	4.3	470	4.3	472
	2.1	4.8	477	4.5	447	4.0	395
	1.2	4.9	418	4.5	383	3.9	332
LSD		0.4	109	0.5	107	0.7	126
Grade 1	6.0	4.7	753	4.0	637	3.8	615
	4.5	4.6	661	4.3	611	3.4	482
	3.0	4.8	612	4.5	572	4.3	552
	2.3	4.9	490	4.8	478	4.3	422
	1.9	4.9	371	4.9	375	4.6	350
	1.5	5.0	276	4.8	270	4.6	255
LSD		0.3	159	0.9	182	1.2	196
BS180	6.0	4.2	716	3.2	552	2.4	400
	4.5	4.9	754	3.7	566	3.8	577
	3.0	4.8	640	4.4	584	4.0	540
	2.3	4.9	513	4.7	492	4.3	448
	1.9	4.9	456	4.9	451	4.4	411
	1.2	4.3	357	4.2	348	4.1	337
LSD		0.5	139	0.6	145	0.9	199

TABLE X continued

Type of NBC[a]	NBC (g/kg)	16 day		20 day		24 day	
		RS	QI	RS	QI	RS	QI
Control	6.0	3.0	455	2.7	417	3.3	509
	3.0	4.1	449	4.0	431	3.6	388
	2.1	4.1	403	3.9	385	3.9	383
	1.2	3.8	320	3.7	311	3.2	272
LSD		0.7	122	0.9	134	1.1	189
Grade 1	6.0	3.7	600	3.5	561	2.7	438
	4.5	4.0	571	2.3	321	2.5	357
	3.0	4.2	535	3.7	479	4.0	507
	2.3	4.1	409	3.9	386	4.0	397
	1.9	4.5	344	4.2	317	4.3	325
	1.5	4.6	255	4.5	249	4.0	224
LSD		1.0	161	0.7	164	1.0	198
BS180	6.0	2.5	426	2.1	364	1.9	330
	4.5	3.4	519	3.8	577	3.1	481
	3.0	3.6	489	3.5	465	3.5	465
	2.3	4.3	455	3.1	324	4.0	420
	1.9	4.5	421	4.3	402	4.4	404
	1.2	3.7	304	3.7	307	3.6	301
LSD		0.9	170	1.1	212	0.8	167

[a] Types of NBC are defined in Table II

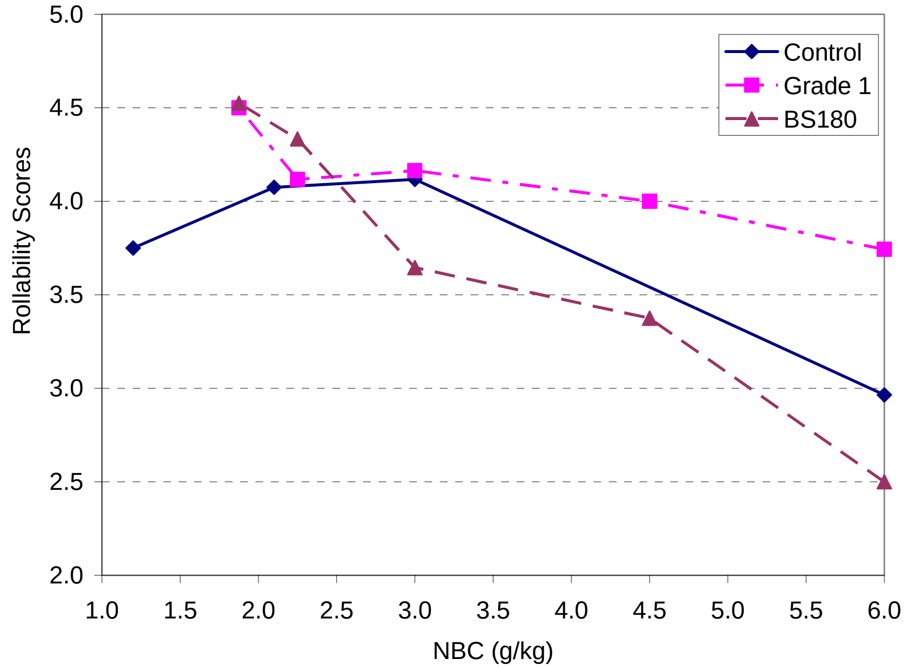

Fig. 11. Effects of NBC amount and types on rollability scores.
Note: Measurement taken at 16 days of storage at 22°C. LSD = 8.0.

Objective tortilla properties of force, distance, work, and gradient (Table B.3), show a significant increase in force to rupture tortillas as the level of NBC decrease on the same day of storage, this finding supports that less disruption in the tortilla structure is present when fewer air bubbles are expanded. Force to rupture increased as time of storage increased; this is consistent with the findings of Kelekci (2001). Distance to rupture decreased over storage time, and was also significantly affected by the decrease in NBC within treatments. Work and gradient were inversely related to the amount of NBC tested.

Effect of Tetrasodium Pyrophosphate on Tortilla Properties

Subjective and objective dough properties were affected with addition of TSPP at the various levels of NBC tested. At 1.5 g/kg TSPP in the G1 treatment a significant effect on smoothness, softness, and toughness of the dough were observed, however press rating was not effected (Table XI; Table B.4). Use of TSPP decreased compression force, equilibrium force, and gradient in non-encapsulated NBC treatments. Encapsulated BS180 force in compression was significantly lower than G1.

TABLE XI
Effects of Amounts and Types of NBC and TSPP on Subjective Dough Properties

Type of NBC[a]	NBC (g/kg)	TSPP (%)	Smoothness	Softness	Toughness	Press Rate
Grade 1	6.0	0	1.9	1.9	2.0	1.9
	4.5	0	1.8	1.9	1.7	1.9
	3.0	0	1.9	2.0	1.8	2.1
	2.3	0	1.8	2.0	1.7	2.0
	1.9	0	1.9	2.0	1.7	2.0
	1.5	0	1.8	2.0	1.8	1.9
	6.0	0.15	1.9	2.1	1.6	1.9
	4.5	0.15	2.0	1.8	1.7	1.9
	3.0	0.15	1.8	2.0	1.8	2.0
	2.3	0.15	1.9	2.2	1.6	2.1
	1.9	0.15	2.0	2.2	1.6	2.2
	1.5	0.15	2.0	2.2	1.5	2.0
LSD			0.7	0.1	0.1	0.1
BS180	6.0	0	1.9	1.9	1.8	1.9
	4.5	0	1.9	1.8	1.8	1.8
	3.0	0	1.9	1.9	1.9	1.9
	2.3	0	1.9	2.0	1.7	1.9
	2.1	0	2.1	2.1	2.0	2.1
	1.9	0	1.8	1.9	1.6	1.8
	1.5	0	1.9	2.0	1.6	2.0
	1.2	0	1.9	2.0	1.9	1.9
	6.0	0.15	1.8	2.0	1.6	1.8
	4.5	0.15	1.9	1.9	1.9	1.9
	3.0	0.15	1.9	1.9	1.9	1.9
	2.3	0.15	1.9	1.9	1.9	2.0
	1.9	0.15	2.0	1.9	1.6	2.0
	1.5	0.15	1.8	1.9	1.6	2.0
LSD			0.1	0.1	0.1	0.1

[a] Types of NBC are defined in Table II

Tortilla properties of weight and pH did not change significantly throughout the treatments with or without TSPP at the same level of NBC. With lower levels of G1, and with addition of TSPP, a slight increase in tortilla height was observed when compared with the treatments without TSPP (Table XII). When BS180 was tested, TSPP did not cause a significant increase in thickness at low levels of NBC. This suggests that an optimum leavening reaction and setting of the starch structure in the tortilla during baking must have occur, regardless of the use of TSPP. The creation of the bubbles in the leavening system including BS180 appears to take place at the right time, i.e., the reaction of the NBC is not too early, yielding bubbles just before the setting of the structure of the tortilla.

Opacity, diameter and specific volume (Table B.5) significantly changed when 0.15 g/kg TSPP was added in combination with different levels of non-encapsulated NBC. Higher opacities were obtained for tortillas containing TSPP (Fig. 12). At a level of 3 g/kg NBC, G1 with TSPP treatment reached the same level of opacity as BS180 without TSPP, increasing opacity above 90%, this suggest that TSPP interacts with the proteins in the starch-protein matrix of the tortilla, allowing the air cells already created to become more stable. In the non-encapsulated NBC, bubbles are not created in earlier stages of the process, thus the TSPP aid is not required (Fig. 13). However, significantly higher opacity values were achieved at levels below 3.0 g/kg NBC when TSPP was used in the BS180 vs. the G1 treatments. Overall higher opacity values were obtained with encapsulated NBC. At high levels of NBC smaller differences in opacity were noticed.

TABLE XII
Effects of Amounts and Types of NBC and TSPP on Flour Tortilla Properties

Type of NBC[a]	NBC (g/kg)	TSPP (%)	Height (cm)	Weight (g)	Moisture (%)	pH (24h)
Grade 1	6.0	0	0.27	40.1	32.5	5.1
	4.5	0	0.24	39.3	32.6	5.4
	3.0	0	0.25	40.6	32.4	5.2
	2.3	0	0.21	39.5	32.9	5.2
	1.9	0	0.19	39.8	32.6	5.3
	1.5	0	0.18	38.8	32.9	5.2
	6.0	0.15	0.24	39.3	33.4	5.3
	4.5	0.15	0.24	39.6	33.5	5.3
	3.0	0.15	0.23	40.8	33.6	5.2
	2.3	0.15	0.21	38.8	33.4	5.5
	1.9	0.15	0.21	41.2	33.2	5.3
	1.5	0.15	0.20	40.6	32.5	5.4
LSD			0.02	0.8	1.5	0.1
BS180	6.0	0	0.26	39.7	32.6	5.4
	4.5	0	0.24	39.6	33.4	5.3
	3.0	0	0.23	40.7	32.5	5.2
	2.3	0	0.22	41.4	32.4	5.2
	1.9	0	0.20	38.2	32.7	5.3
	1.5	0	0.21	39.6	32.4	5.3
	6.0	0.15	0.26	39.5	32.4	5.4
	4.5	0.15	0.26	41.0	34.0	5.3
	3.0	0.15	0.22	39.9	32.6	5.3
	2.3	0.15	0.22	40.3	32.7	5.3
	1.9	0.15	0.20	38.7	32.8	5.4
	1.5	0.15	0.21	41.7	32.8	4.4
LSD			0.02	1.0	1.0	0.1

[a] Types of NBC are defined in Table II

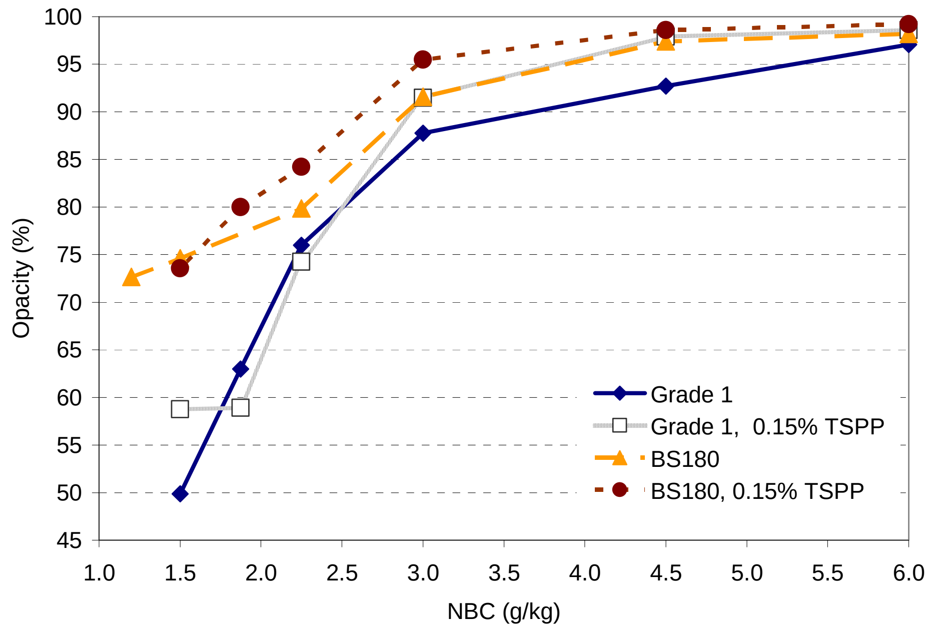

Fig. 12. Effects of amounts and types of NBC and TSPP on opacity of flour tortillas. Note: Tortillas were stored for 24 h. LSD = 6.3.

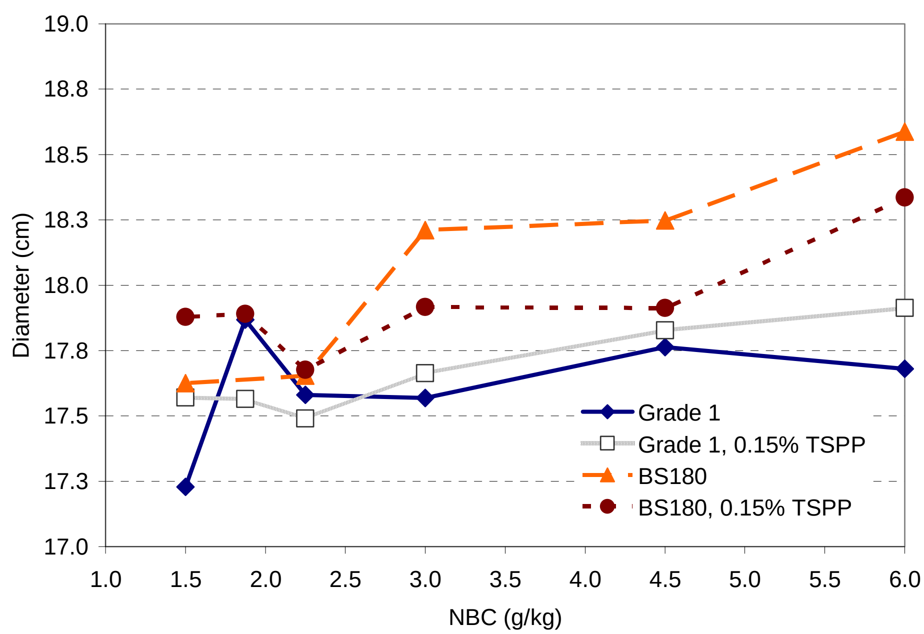

Fig. 13. Effects of amounts and types of NBC and TSPP on diameter of flour tortillas. Note: LSD = 0.16.

The use of TSPP in combination with lower levels of NBC (Fig. 13; Table B.5) did not have significant effects on tortilla diameter. This finding suggests that the phosphate salt does not interfere with the dough relaxation or bubble formation at earlier stages of the tortilla processing. When bubbles are formed before hot-pressing, smaller diameter tortillas are obtained.

Specific volume increased with higher levels of NBC with or without TSPP (Fig.14; Table B.5). Significant differences in specific volumes of tortillas were not observed between types of NBC with or without TSPP. This behavior was not expected, since tortillas containing TSPP had higher opacity (more bubbles). Apparently, tortillas that are more opaque not necessarily need to be thicker. Small bubbles refract the light, creating the opaque appearance in the tortilla. Small size of the air cells in the baked tortilla might not interfere with the thickness achieved after hot-pressing the dough.

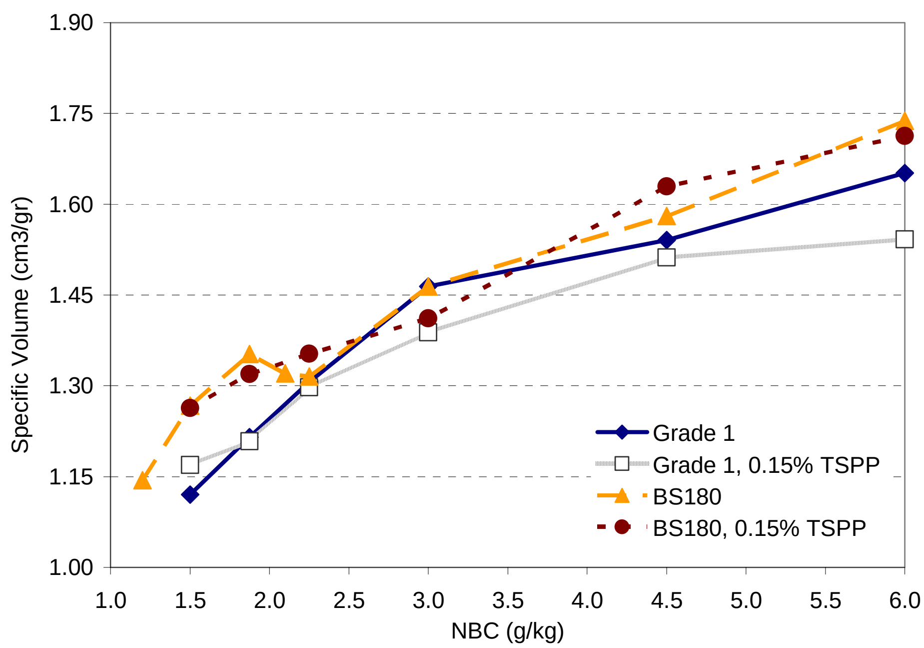

Fig. 14. Effects of amounts and types of NBC and TSPP on specific volume of flour tortillas.
Note: LSD = 0.076.

Rollability scores where higher in treatments with low levels of NBC (Table XIII). Non-acceptable quality index (QI) values were found for tortillas with G1 at levels below 2.3 g/kg with and without TSPP. However, improved QI values were shown when encapsulated NBC was tested, even at levels below 2.3 g/kg. Best tortillas were retained with BS180 throughout storage.

TABLE XIII
Effects Amounts and Types of NBC and TSPP on Rollability Score (RS) and Quality Index (QI)

Type of NBC[a]	NBC (g/kg)	TSPP	4 day		8 day		12 day	
			RS	QI	RS	QI	RS	QI
Grade 1	6.0	0	4.70	753	3.98	637	3.84	616
	4.5	0	4.63	660	4.28	610	3.38	482
	3.0	0	4.77	612	4.45	572	4.30	552
	2.3	0	4.93	490	4.82	478	4.25	422
	1.9	0	4.85	371	4.90	375	4.58	350
	1.5	0	4.95	276	4.84	270	4.57	255
	6.0	0.15	4.68	711	2.75	418	3.60	547
	4.5	0.15	4.90	725	4.65	688	2.85	422
	3.0	0.15	4.83	613	4.83	613	4.40	559
	2.3	0.15	5.00	481	4.93	474	4.90	472
	1.9	0.15	4.95	352	4.73	336	4.35	309
	1.5	0.15	4.91	337	4.73	324	4.52	310
LSD			0.1	117	0.4	100	0.5	109
BS180	6.0	0	4.20	716	3.24	552	2.35	401
	4.5	0	4.90	754	3.68	566	3.75	577
	3.0	0	4.78	640	4.36	584	4.03	540
	2.3	0	4.88	513	4.68	492	4.27	448
	1.9	0	4.90	456	4.85	451	4.43	411
	1.5	0	4.98	478	4.69	443	4.59	434
	6.0	0.15	4.83	820	4.35	739	3.25	552
	4.5	0.15	4.08	655	3.38	542	3.75	602
	3.0	0.15	4.90	660	4.73	637	4.48	603
	2.3	0.15	4.94	562	4.90	558	4.43	504
	1.9	0.15	4.95	523	4.90	517	4.45	470
	1.5	0.15	4.92	457	4.71	438	4.39	408
LSD			0.2	81	0.3	66	0.5	71

TABLE XIII continued

Type of NBC[a]	NBC (g/kg)	TSPP	16 day		20 day		24 day	
			RS	QI	RS	QI	RS	QI
Grade 1	6.0	0	3.74	600	3.50	561	2.73	437
	4.5	0	4.00	571	2.25	321	2.50	357
	3.0	0	4.16	535	3.73	479	3.95	507
	2.3	0	4.12	409	3.88	386	4.00	397
	1.9	0	4.50	344	4.15	318	4.25	325
	1.5	0	4.56	255	4.46	249	4.01	224
	6.0	0.15	3.13	475	2.63	399	3.08	467
	4.5	0.15	3.50	518	3.83	566	3.83	566
	3.0	0.15	3.99	506	3.90	495	3.75	476
	2.3	0.15	3.95	380	3.13	301	4.50	433
	1.9	0.15	4.33	308	4.20	299	3.75	267
	1.5	0.15	4.55	312	4.69	322	4.35	299
LSD			0.4	89	0.5	82	0.5	90
BS180	6.0	0	2.50	426	2.13	364	1.94	330
	4.5	0	3.38	520	3.75	577	3.13	481
	3.0	0	3.65	489	3.47	465	3.47	465
	2.3	0	4.33	455	3.08	324	4.00	420
	1.9	0	4.53	421	4.33	402	4.35	404
	1.5	0	4.47	423	4.07	385	3.95	373
	6.0	0.15	2.83	480	2.50	425	2.38	403
	4.5	0.15	3.20	514	2.38	381	2.13	341
	3.0	0.15	4.04	544	3.38	455	4.00	539
	2.3	0.15	4.26	486	3.55	404	4.00	456
	1.9	0.15	4.20	443	3.65	385	3.45	364
	1.5	0.15	4.46	414	4.23	393	3.70	344
LSD			0.4	61	0.5	66	0.5	62

[a] Types of NBC are defined in Table II

Objective tortilla properties (Table B.6) showed that force to rupture decreased when TSPP salt was added for both types of NBC tested. Force to rupture also increased over storage time in all tortilla treatments. Slight increases in distance to rupture were observed when TSPP was added, however a clear trend was not observed. Rupture distance decreased with storage time. Work and gradient were significantly modified in both NBC treatments with and without TSPP.

Sensory Analysis of Flour Tortillas

Sensory testing of tortillas with 3 g/kg vs. control tortillas with 6 g/kg was tested with and without 0.15% TSPP (Table XIV). The flavor, aroma, appearance, and texture changes due to TSPP were evaluated. No significant differences where observed for aroma, appearance, or texture. Flavor was similar within all treatments, however a significant flavor improvement was observed in G1 treatment with TSPP vs. G1 without TSPP. A slight flavor of TSPP was perceived by the panelist. The preferred combinations were BS180 and G1 treatments with 1.5 g/kg of TSPP.

TABLE XIV
Sensory Results on Tortilla Attributes[d]

NBC Type	Control[a]	BS180[b]	BS180 + TSPP[c]	Grade 1[b]	Grade 1 + TSPP
Aroma	6.2	6.2	6.2	5.7	6.1
Appearance	7.0	6.3	6.5	6.4	6.4
Texture	6.0	6.0	6.4	5.8	6.0
Flavor	5.6[ab]	6.0[ab]	6.3[a]	5.3[b]	6.3[a]

[a] Control NBC level 6g/kg
[b] BS180 NBC level 3g/kg
[c] TSPP level at 0.15 g/kg
[d] Note: Test performed with 35 untrained panelists. Tortillas were tested 24 h after production. Values with different letters are significantly different

Effect of the Combinations of Fast- and Slow- Release Sodium Bicarbonates on Tortilla Properties

Fast- and slow-release NBCs were tested in different levels and combinations to evaluate dough and tortilla properties. Dough smoothness, softness, and toughness were not affected by the combination of NBCs (Table XV). However, press rating was significantly affected when lower levels of NBC were used. Objective dough properties: compression force, equilibrium force, and gradient were not significantly modified by any combination of fast- or slow-release NBC tested (Table B.8).

TABLE XV
Effects of Amounts and Types of NBC Combinations on Subjective Dough Properties

NBC[a] (g/kg)	NBC_1	NBC_2	NBC Ratio	Smoothness	Softness	Toughness	Press Rate
3	Grade 1	BS184	(1:1)	2.0	1.8	1.8	1.8
3	Grade 1	BS199	(1:1)	2.0	1.8	2.4	1.6
3	BS180	BS193	(1:1)	2.0	1.8	1.8	1.8
3	BS180	BS199	(1:1)	1.8	2.1	2.2	1.8
3	BS184	BS193	(1:1)	2.0	1.8	1.8	1.6
3	BS184	BS199	(1:1)	2.1	1.8	2.0	1.6
3	Grade 1	BS193	(1:1)	1.9	2.0	1.7	2.1
1.5	Grade 1	BS193	(1:2)	1.9	2.1	1.6	2.1
1.5	Grade 1	BS193	(2:1)	1.9	2.0	1.7	2.0
3	Grade 1	BS180	(1:1)	1.9	1.9	1.7	1.9
1.5	Grade 1	BS180	(1:2)	1.9	1.9	1.7	1.8
1.5	Grade 1	BS180	(2:1)	2.0	2.1	1.5	1.9
1.5	BS180	BS193	(1:1)	2.0	2.0	1.8	1.9
1.5	BS180	BS193	(2:1)	1.9	2.0	1.7	2.1
1.5	BS180	BS193	(1:2)	1.9	1.8	1.7	1.8
1.5[b]	BS180	BS193	(1:1)	1.9	1.8	1.7	2.0
LSD				0.2	0.3	0.4	0.3

[a] Types of NBC are defined in Table II
[b] Treatment with TSPP at 0.15 g/kg.

Tortilla height, weight, moisture, and pH are presented in Table XVI. No significant differences were observed in moisture or pH of tortillas. Tortilla height decreased in all treatments using slow-release encapsulated NBC; all combinations that contained BS193 yielded significantly thinner tortillas. Tortillas thickness was slightly improved when higher ratios of G1 were used with BS193. No height improvement was observed in different ratio combinations of G1 and BS180 NBCs. Treatments with fast-release NBC such as BS199 and BS184 gave thicker tortillas. All combinations of sodium bicarbonates at levels below 3 g/kg produced poor quality tortillas.

TABLE XVI
Effects of Amounts and Types of NBC Combinations on Flour Tortilla Properties

NBC[a] (g/kg)	NBC_1	NBC_2	NBC Ratio	Height (cm)	Weight (g)	Moisture (%)	pH (24h)
3	Grade 1	BS184	(1:1)	0.23	39.5	32.1	5.1
3	Grade 1	BS199	(1:1)	-	40.2	32.7	5.1
3	BS180	BS193	(1:1)	0.22	39.9	31.4	5.1
3	BS180	BS199	(1:1)	0.24	41.2	32.8	5.1
3	BS184	BS193	(1:1)	0.22	39.9	34.2	5.1
3	BS184	BS199	(1:1)	0.25	41.6	32.4	5.1
3	Grade 1	BS193	(1:1)	0.19	38.8	34.6	5.1
1.5	Grade 1	BS193	(1:2)	0.19	40.8	37.8	5.1
1.5	Grade 1	BS193	(2:1)	0.20	39.1	35.1	5.2
3	Grade 1	BS180	(1:1)	0.23	40.2	35.1	5.1
1.5	Grade 1	BS180	(1:2)	0.20	40.6	32.6	5.1
1.5	Grade 1	BS180	(2:1)	0.20	39.4	35.0	5.1
1.5	BS180	BS193	(1:1)	0.19	39.6	36.6	5.0
1.5	BS180	BS193	(2:1)	0.19	38.8	34.6	5.2
1.5	BS180	BS193	(1:2)	0.19	41.2	35.2	5.1
1.5[b]	BS180	BS193	(1:1)	0.20	39.5	35.0	5.2
LSD				0.03	3.3	8.8	0.2

[a] Types of NBC are defined in Table II
[b] Treatment with TSPP at 0.15 g/kg.

Tortilla diameter was not significantly affected by the amount or ratio of fast- and slow-release NBC (Table B.9). When 3 g/kg of NBC were used, higher opacity tortillas were obtained. Opacity was significantly decreased when slow-release BS193 was used in any ratio and with any combination of NBC. Treatments with non-encapsulated NBC showed significantly lower opacity values than BS180 treatments. As expected, tortilla specific volume decreased significantly when-slow release NBC was used in any combination.

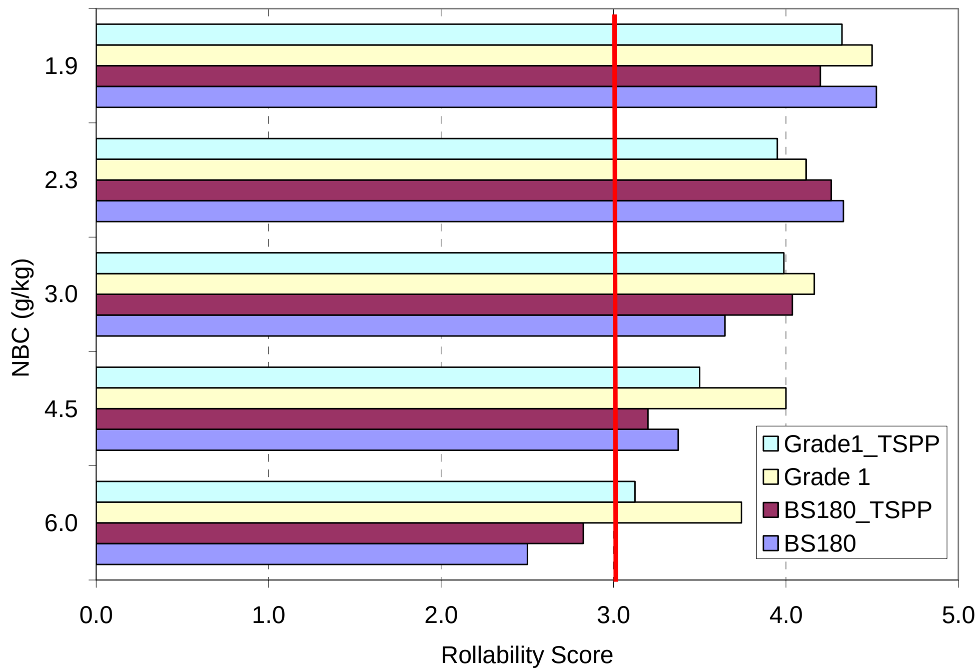

Fig. 15. Effects of amounts and types of NBC and TSPP on rollabilty on flour tortillas. Note: Red line across tables means minimum rollabilty score. LSD = 0.4.

Improved rollabilty was obtained with lower levels of NBC. All treatments with non-encapsulated NBC yielded good properties at 16 days of storage. Rollability scores decreased below 3.0 in treatments with increased opacity, BS180 at 6 g/kg with and without TSPP (Fig. 15). After 20 days of storage RS of treatments with 3 g/kg NBC level, dropped below the acceptable score. Quality Index was not acceptable for the treatments with 1.5g/kg of NBC, neither to the treatment 3 g/kg combination of G1 and BS193 (1:1) ratio (Table XVII).

Objective texture measurements of tortilla shelf stability (Table B.10) showed some variation in force to rupture, distance, work, and gradient. No significant differences were observed when different ratio NBC was tested.

TABLE XVII
Effects of Amounts and Types of NBC Combinations on Rollability Score (RS) and Quality Index (QI)

NBC[a] (g/kg)	NBC[1]	NBC[2]	NBC Ratio	4 day		8 day		12 day	
				RS	QI	RS	QI	RS	QI
3	Grade 1	BS184	(1:1)	4.7	622	5.0	655	3.5	458
3	Grade 1	BS199	(1:1)	4.1	-	4.6	-	3.9	-
3	BS180	BS193	(1:1)	4.4	547	4.5	559	4.5	559
3	BS180	BS199	(1:1)	5.0	732	4.9	717	4.9	717
3	BS184	BS193	(1:1)	4.9	577	4.9	577	3.8	448
3	BS184	BS199	(1:1)	4.7	679	4.6	665	4.5	651
3	Grade 1	BS193	(1:1)	5.0	325	5.0	325	4.8	315
1.5	Grade 1	BS193	(1:2)	4.9	240	5.0	233	4.6	223
1.5	Grade 1	BS193	(2:1)	4.9	276	5.0	262	4.8	268
3	Grade 1	BS180	(1:1)	4.9	635	4.6	596	4.5	578
1.5	Grade 1	BS180	(1:2)	4.9	374	4.9	367	4.9	369
1.5	Grade 1	BS180	(2:1)	5.0	419	4.9	409	4.7	396
1.5	BS180	BS193	(1:1)	4.9	376	4.8	364	4.7	356
1.5	BS180	BS193	(2:1)	5.0	325	5.0	325	4.8	315
1.5	BS180	BS193	(1:2)	5.0	290	4.5	265	4.5	260
1.5[b]	BS180	BS193	(1:1)	5.0	401	4.6	367	4.6	367
LSD	-	-	-	0.5	250	0.7	262	0.8	238

TABLE XVII continued

NBC[a] (g/kg)	NBC$_1$	NBC$_2$	NBC Ratio	16 day		20 day		24 day	
				RS	QI	RS	QI	RS	QI
3	Grade 1	BS184	(1:1)	3.0	393	3.2	425	2.7	360
3	Grade 1	BS199	(1:1)	3.7	-	3.2	-	2.7	-
3	BS180	BS193	(1:1)	3.7	465	3.5	434	2.5	310
3	BS180	BS199	(1:1)	4.5	659	3.5	512	2.7	402
3	BS184	BS193	(1:1)	4.2	501	3.9	460	2.7	324
3	BS184	BS199	(1:1)	3.8	543	3.2	465	2.9	415
3	Grade 1	BS193	(1:1)	4.7	309	4.6	303	4.3	282
1.5	Grade 1	BS193	(1:2)	4.7	227	4.4	214	4.1	199
1.5	Grade 1	BS193	(2:1)	4.7	264	4.6	257	4.3	239
3	Grade 1	BS180	(1:1)	4.5	581	3.8	490	2.7	354
1.5	Grade 1	BS180	(1:2)	4.7	355	4.8	362	4.5	341
1.5	Grade 1	BS180	(2:1)	4.6	388	4.4	370	3.8	318
1.5	BS180	BS193	(1:1)	4.4	334	4.1	311	4.2	318
1.5	BS180	BS193	(2:1)	4.7	309	4.6	303	4.3	282
1.5	BS180	BS193	(1:2)	4.7	276	4.3	252	4.2	244
1.5[b]	BS180	BS193	(1:1)	4.1	328	4.1	333	4.2	341
LSD	-	-	-	0.85	224	1.29	182	1.5	123

[a] Types of NBC are defined in Table II
[b] Treatment with TSPP at 0.15 g/kg

Tortilla Properties Using Different Slow Leavening Acids

The rate of carbon dioxide release can be controlled by using leavening acids varying on their rate of solution (Adams 2001; Adams and Waniska 2002). When SAS vs. SALP were tested, significant differences were observed in subjective dough smoothness and press rate for some G1 treatments when compared at the same NBC level within the acids tested. No significant differences were observed when BS180 was tested at any level for smoothness, softness, and press rate. Toughness was significantly affected for the BS180 at 2.3 g/kg with TSPP treatment (Table XVIII). Objective dough properties of force, equilibrium force, and gradient, were not significantly different for any treatment at the same level for SAS vs. SALP leavening acid tested (Table B.11).

TABLE XVIII
Effects of Amounts and Types of NBC with Different Leavening Acids and TSPP on Subjective Dough Properties

Type of NBC[a]	NBC (g/kg)	TSPP (%)	Acid type	Smoothness	Softness	Toughness	Press Rate
Control	6.0	0	SAS	1.9	1.9	1.9	1.9
	6.0	0	SALP	1.8	1.9	1.9	1.9
Grade 1	3.0	0	SAS	1.9	2.0	1.8	2.1
	2.3	0	SAS	1.8	2.0	1.7	2.0
	3.0	0	SALP	1.8	1.9	1.7	2.0
	2.3	0	SALP	2.0	2.0	1.7	1.9
	3.0	0.15	SAS	1.8	2.0	1.8	2.0
	2.3	0.15	SAS	1.9	2.2	1.6	2.1
	3.0	0.15	SALP	2.0	1.9	1.8	1.8
	2.3	0.15	SALP	1.8	2.1	1.8	1.8
BS180	3.0	0	SAS	1.9	1.9	1.9	1.9
	2.3	0	SAS	1.9	2.0	1.7	1.9
	3.0	0	SALP	1.9	1.8	2.0	1.8
	2.3	0	SALP	1.9	2.2	1.5	1.8
	3.0	0.15	SAS	1.9	1.9	1.9	1.9
	2.3	0.15	SAS	1.9	1.9	1.9	2.0
	3.0	0.15	SALP	2.0	1.9	1.8	1.8
	2.3	0.15	SALP	1.9	2.0	1.6	2.0
LSD				0.2	0.3	0.3	0.2

[a] Types of NBC are defined in Table II

No significant difference in tortilla weight and moisture was observed when treatments were compared at the same NBC level with the two leavening acids. Tortilla height was significantly higher for G1 SALP treatment vs. SAS at 3 g/kg; all other combinations for G1 and BS180 did not show significant differences in height. The pH of SAS treatments was lower than SALP treatments. Significantly lower pH was observed for the treatments with SAS in combination with TSPP, for both G1 and BS180 at 3 g/kg (Table XIX).

TABLE XIX
Effects of Amounts and Types of NBC with Different Leavening Acids and TSPP on Flour Tortilla Properties

Type of NBC[a]	NBC (g/kg)	TSPP (%)	Acid type	Height (cm)	Weight (g)	Moist (%)	pH (24h)
Control	6.0	0	SAS	0.26	40.4	34.0	5.2
	6.0	0	SALP	0.27	39.5	38.6	5.4
Grade 1	3.0	0	SAS	0.25	40.6	32.4	5.2
	2.3	0	SAS	0.21	39.5	32.9	5.2
	3.0	0	SALP	0.22	40.8	33.1	5.3
	2.3	0	SALP	0.22	40.8	32.4	5.3
	3.0	0.15	SAS	0.23	40.8	33.6	5.2
	2.3	0.15	SAS	0.21	38.8	33.4	5.5
	3.0	0.15	SALP	0.24	41.0	32.6	5.5
	2.3	0.15	SALP	0.21	39.0	32.4	5.5
BS180	3.0	0	SAS	0.23	40.7	32.5	5.2
	2.3	0	SAS	0.22	41.4	32.4	5.2
	3.0	0	SALP	0.23	40.4	32.3	5.3
	2.3	0	SALP	0.22	40.4	32.1	5.2
	3.0	0.15	SAS	0.22	39.9	32.6	5.3
	2.3	0.15	SAS	0.22	40.3	32.7	5.3
	3.0	0.15	SALP	0.23	39.6	33.1	5.5
	2.3	0.15	SALP	0.22	41.3	32.5	5.5
LSD				0.03	2.43	4.27	0.23

[a] Types of NBC are defined in Table II

Diameter increased slightly when SAS was used in the G1 treatments; however no significant differences were found for diameter nor specific volume in all NBCs tested (Table B.12).

Overall increased opacity was observed in G1 and BS180 treatments with SALP vs. SAS leavening acid. Use of encapsulated BS180 yielded higher opacity values vs. G1 NBC. The use of TSPP produced significantly opaque tortillas at 3 g/kg G1 NBC with SALP. No significant improvement was observed in BS180 treatments with TSPP (Fig. 16; Fig. 17; Table B.12).

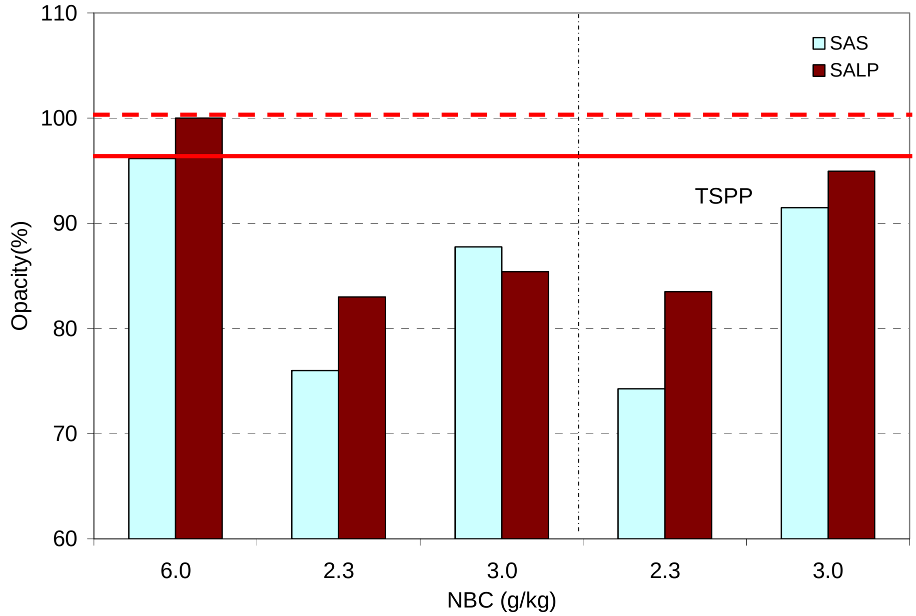

Fig. 16. Effects of amounts and types of leavening acid with various levels of Grade 1 and TSPP on opacity of flour tortillas.
Note: LSD = 8.0.

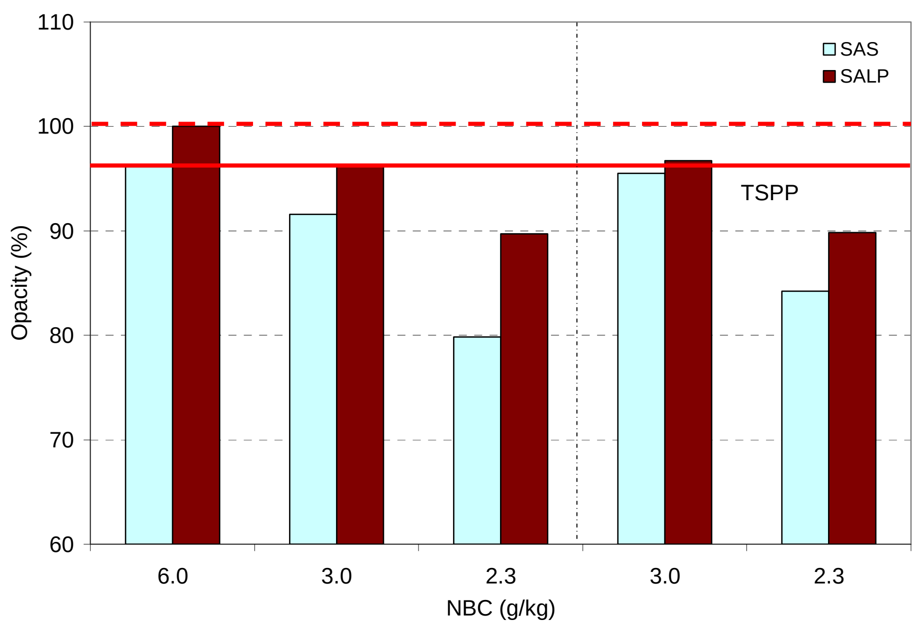

Fig. 17. Effects of amounts and types of leavening acid with various levels of BS180 and TSPP on opacity of flour tortillas.
Note: LSD = 7.5.

Rollability scores (RS) were higher for treatments with SALP. Scores above 3.0 represent good tortilla. Scores below 3.0 were reached after 16 days of storage for SAS at 6 g/kg. All other treatments did not reach scores below 3.0 before 20 days in storage. Significantly lower RS were observed in some TSPP and SALP vs. TSPP and SAS combinations (Tables XX). Quality Index was higher for SALP at 6 g/kg vs. SAS at the same level. Combinations of G1 with SALP showed lower scores than encapsulated BS180 with SALP. Poor quality tortillas were obtained with SAS leavening acid in NBC levels below 3 g/kg. However, SALP with levels below 3 g/kg both BS180 and G1 yielded good quality tortilla up to 20 days of storage. This shows that higher quality tortillas can be obtained using SALP leavening acid (Table XX).

TABLE XX
Effects of Amounts and Types NBC with Leavening Acids and TSPP on Rollability Score (RS) and Quality Index (QI)

Type of NBC[a]	NBC (g/kg)	TSPP	Acid type	4 day		8 day		12 day	
				RS	QI	RS	QI	RS	QI
Control	6.0	0	SAS	4.4	674	3.8	577	3.4	514
	6.0	0	SALP	4.8	807	4.7	786	3.9	652
Grade 1	3.0	0	SAS	4.8	612	4.5	572	4.3	552
	2.3	0	SAS	4.9	490	4.8	478	4.3	422
	3.0	0	SALP	4.9	551	4.8	543	4.8	540
	2.3	0	SALP	4.9	530	4.9	530	4.8	514
	3.0	0.15	SAS	4.8	613	4.8	613	4.4	559
	2.3	0.15	SAS	5.0	481	4.9	474	4.9	472
	3.0	0.15	SALP	4.8	634	4.8	634	4.5	591
	2.3	0.15	SALP	5.0	524	4.9	514	4.1	435
BS180	3.0	0	SAS	4.8	640	4.4	584	4.0	540
	2.3	0	SAS	4.9	513	4.7	492	4.3	448
	3.0	0	SALP	5.0	679	4.7	645	4.5	614
	2.3	0	SALP	5.0	618	4.9	602	4.3	528
	3.0	0.15	SAS	4.9	660	4.7	637	4.5	603
	2.3	0.15	SAS	4.9	563	4.9	558	4.4	504
	3.0	0.15	SALP	4.7	645	4.7	648	4.3	600
	2.3	0.15	SALP	4.8	568	4.9	571	4.6	544
LSD				0.5	141	0.7	135	1.1	181

TABLE XX continued

Type of NBC[a]	NBC (g/kg)	TSPP	Acid type	16 day		20 day		24 day	
				RS	QI	RS	QI	RS	QI
Control	6.0	0	SAS	3.0	455	2.7	417	3.3	509
	6.0	0	SALP	3.3	543	2.0	334	1.4	230
Grade 1	3.0	0	SAS	4.2	535	3.7	479	4.0	507
	2.3	0	SAS	4.1	409	3.9	386	4.0	397
	3.0	0	SALP	4.7	523	4.7	531	4.2	467
	2.3	0	SALP	4.8	511	4.0	425	3.8	404
	3.0	0.15	SAS	4.0	506	3.9	495	3.8	476
	2.3	0.15	SAS	4.0	380	3.1	301	4.5	433
	3.0	0.15	SALP	4.1	538	2.9	386	2.9	380
	2.3	0.15	SALP	4.3	456	4.0	424	2.9	303
BS180	3.0	0	SAS	3.6	489	3.5	465	3.5	465
	2.3	0	SAS	4.3	455	3.1	324	4.0	420
	3.0	0	SALP	3.9	538	3.8	514	3.7	508
	2.3	0	SALP	4.6	568	3.8	473	3.5	432
	3.0	0.15	SAS	4.0	544	3.4	455	4.0	539
	2.3	0.15	SAS	4.3	486	3.6	404	4.0	456
	3.0	0.15	SALP	4.0	554	3.2	444	3.4	468
	2.3	0.15	SALP	4.0	474	3.9	459	3.5	406
LSD				1.0	159	1.0	158	1.2	214

[a] Types of NBC are defined in Table II

Objective shelf stability of tortillas (Table B.13) was slightly modified at the levels tested. Force to rupture increased when SALP vs. SAS was used at levels of 3 and 2.3 g/kg of NBC. When SAS was substituted for SALP in control tortillas at 6 g/kg NBC, decreased force to rupture was observed. This finding was also observed by Adams (2001), and is evidence of fresher tortillas. Distance and work to rupture was also increased when SALP compared to SAS at low levels of NBC with or without TSPP. Gradient was decreased in treatments with SALP.

Cost of Ingredients for Wheat Flour Tortilla Production

Decreasing the level of NBC in tortilla formulations allows the creation of increased shelf stable tortillas. Commercial tortillas are sold in bags by number of tortillas, diameter, and weight. When the level of NBC is decreased, the leavening acids and acidulants must be reduced. The prices of tortilla ingredients are listed in Table XXI. Industrially produced tortillas include fumaric acid as acidulant, and SALP as leavening acid. In research tortillas encapsulated fumaric acid was used as acidulant and SAS as leavening acid. Cost of tortillas with reduced leavening compared to industry and research produced tortillas, was decreased to 1.2% with non-encapsulated grade 1 NBC. Tortilla formulations with BS180 show increased cost (Table XXII).

TABLE XXI
Cost of Ingredients for Wheat Flour Tortilla Production

Ingredient	Cost (US dollars/kg)
Encapsulated Sodium Bicarbonates[a]	5.51
Non-encapsulated Sodium Bicarbonates[b]	0.48
Wheat Flour	0.20
Fumaric Acid (fine)	1.58
Fumaric Acid (encapsulated)[a]	4.96
Sodium Aluminum Sulfate (SAS)[c]	1.32
Sodium Aluminum Phosphate (SALP)[c]	2.64
Tetrasodium Pyrophosphate (TSPP)[c]	1.65
Water	0.007
Salt	0.33
Shortening	0.77
Emulsifier (SSL)	3.97
Sodium propionate	1.10
Potasium sorbate	4.96

[a] Balchem Co
[b] Church and Dwight Co. Inc.
[c] ChemBuyersGuide.com

TABLE XXII
Ingredient Costs of Different Tortilla Formulations

Ingredients	Industry Control	Research Control	Grade1 TSPP	BS180	BS180 SALP TSPP
	Level (g/kg)				
Wheat Flour	1000	1000	1000	1000	1000
Water	525	525	525	525	525
Salt	15	15	15	15	15
Shortening	80	80	80	80	80
Emulsifier (SSL)	3	3	3	3	3
Sodium propionate	5	5	5	5	5
Potassium sorbate	1.5	1.5	1.5	1.5	1.5
Fumaric acid (raw)	1.9	0	0	0	0
Fumaric acid (encap)	0	2.25	1.8	1.8	1.4
Sodium NBC	6	6	3	0	0
Encapsulated NBC	0	0	0	6	4.6
SAS	0	5.8	2.9	2.9	0
SALP	5.8	0	0	0	2.2
TSPP	0	0	1.5	0	1.5
Cost	391.9	392.4	387.4	416.5	411.3
(Increase)/decrease (%)[a]			1.23	(6.20)	(4.87)

[a] Percentage compared to average cost of industry and research control tortillas.

Discussion

Tortilla opacity is an important appearance attribute that relates to the consumer acceptability of tortillas. The use of encapsulated NBC yielded better quality tortillas even at low levels of NBC. In a study conducted by Cepeda (1995), and confirmed by Adams (2001), increasing the level of NBC compensated early reactions of the bicarbonate in the previous stages of dough and tortilla processing. According to Adams (2001), decreasing NBC adversely effected tortilla height, opacity, and volume. Similar findings were obtained on this study. As shown by McDonough et al (1996), air cells are expanded in the first stages of baking, a lack of bicarbonate will yielded fewer air bubbles throughout baking. Decreased opacity, specific volume, and height were obtained when low NBC levels were tested. Tortilla diameter increased with BS180 compared to G1 NBC; this effect might derive from the controlled release of bicarbonate. Dough force in compression revealed decreased values for encapsulated NBC compared to G1 at lower levels of NBC. The force applied to the dough was efficiently distributed due to the lack of expanded air cells in the dough, allowing better dough extension.

Low levels of bicarbonate caused less disruption in the tortilla structure. Excess CO_2 production in the tortilla during baking, can cause over expansion of air cells and damage the structure. Low tortilla quality index was achieved at low NBC levels due to the decreased volume and opacity of tortillas. Best QI values were obtained with BS180.

By adding tetrasodium pyrophosphate (TSPP), force to compress the dough increased in G1treatments. TSPP did not affect tortilla pH, moisture, and weight. Increased thickness of tortillas was observed in non-encapsulated G1 treatments with TSPP, this confirms the theory that TSPP aids in retention of air bubbles that expand in tortilla before starch gelatinizes, increasing air entrapment, and improving tortilla opacity. This was also corroborated in encapsulated treatments, where no effect on tortilla height was indicated. Overall BS180 without TSPP yielded tortillas similar to G1 with 1.5 g/kg TSPP. Specific volume, diameter, and shelf stability were not effected by the use of TSPP. Improved QI was attained in G1 treatments due to increased opacity.

Combinations fast- and slow-reacting NBCs at levels of 3 g/kg and 1.5 g/kg did not show improvement in overall tortilla properties.

When two slow reacting leavening acids were tested, non-encapsulated NBC yielded significantly improved properties vs. BS180 NBC. However, with the use of SALP at levels below 3 g/kg of encapsulated BS180 and with TSPP good quality tortillas were obtained. The pH of tortillas produced with SAS was lower than tortillas produced with SALP. Overall, SAS and SALP tortillas had similar properties, this could be due to the similar neutralization values or rate of reaction in both leavening acids, thus similar results should be expected.

Decreased ingredient costs were achieved by reducing the amount of NBC in tortilla formulation. The decrease to 50% of NBC non-encapsulated and with addition of TSPP at 1.5%, yielded tortillas with improved opacity, shelf stability, and 1.2% ingredient cost reduction. Tortillas with encapsulated BS180 did not reduce overall ingredient cost. With these formulations; reduced dough levels can yield good diameter, opacity and extended shelf stable tortillas.

Chapter Summary

The addition of tetrasodium pyrophosphate (TSPP) decreased the dough compression (stiffness) and equilibrium forces in both types of NBC. Less force in compression was achieved with BS180 compared to G1 treatments. Improved opacity and thickness of tortillas at lower NBC levels were observed when TSPP was added to treatments with G1 NBC. Use of TSPP with encapsulated BS180 had less effects in tortilla properties. This suggests that TSPP interacts with the proteins to retain more air prior to starch gelatinization, and is not a leavening agent. Improved shelf life attributes were observed when lower levels of NBC were used in combinations with and without TSPP.

Combinations of fast- and slow-release sodium bicarbonates yield poor quality tortillas at the levels tested. Dough properties were not affected by any combination. The tortilla moisture, pH, and diameter were not affected, however height, opacity, specific volume were decreased in all treatments with slow-release NBC. The use of SALP did improve tortilla opacity and combinations with encapsulated NBC at levels below 3 g/kg with addition of TSPP can yield good quality tortillas.

A tortilla formula with reduced level of non-encapsulated NBC, leavening acid, and acidulants decreased overall cost of tortilla ingredients to 1.2%, when compared to industrially produced tortillas. Other proposed formulations did not indicate a decrease in cost. However, the amount of dough used to produce these tortillas can be lowered.

CHAPTER V

CONCLUSIONS

The use of various types of encapsulated and non-encapsulated sodium bicarbonates produced tortillas with different quality.

Encapsulated sodium bicarbonates allowed a temperature release leavening reaction in tortillas. Using the correct sodium bicarbonate higher opacity, diameter, and volume of tortillas were obtained.

Shelf stable tortillas with low opacity were obtained with reduced levels of NBC (50% less than control). Using encapsulated BS180 NBC, tortilla opacity, thickness, and shelf stability were greatly improved. Other types of encapsulated sodium bicarbonates (BS184 and BS199) can also give similar quality tortillas. Combinations of different fast- and slow-release NBC did not improve tortilla properties.

Non-encapsulated Grade 1 sodium bicarbonate at 3 g/kg with 1.5 g/kg TSPP produced tortillas with high opacity, thickness and shelf stability. The use of TSPP represents a high potential due to its unique properties of stabilizing foams and allowing more air retention during flour tortilla baking.

Use of slow reacting leavening acids, SALP and SAS resulted in similar quality tortillas. Encapsulated NBC at levels below 3 g/kg with SALP and TSPP can improve tortilla opacity.

Decreasing NBC reduces the leavening and preservation acids used in tortillas. This does not adversely impacts tortilla flavor nor weight. Flour tortillas are sold by the piece, size and weight. Reducing the level of ingredients and forming the same amount of dough balls per kg of flour processed will not decrease the tortilla weight. Tortillas produced with the formulations proposed in this study have longer shelf stabilities with similar properties, this benefits the tortilla consumers. Manufacturing costs for ingredients are 1.2% less using 0.15% TSPP with 3 g non-encapsulated NBC/kg flour.

Further Research

Accurately determine the optimum level for tetrasodium pyrophosphate (TSPP) that can be used in the production of wheat flour tortillas.

Evaluate TSPP in combination with other types of leavening acids commonly used in wheat flour tortilla production.

Test different types of sodium bicarbonates with similar activity to BS180, in order to determine other possible ranges of encapsulated NBCs to achieve better tortillas with reduced production costs.

Test different fast-acting leavening acids in combination of encapsulated NBCs.

Calculate the actual CO_2 produced and retained in the dough and the tortillas during processing and baking.

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APPENDIX A

Titration Curve

TABLE A.1
Milliequivalents $NaHCO_3$ of the Different NBC Types

Type of NBC[a]	Temperature (°C)									
	22.5	35	40	45	50	55	60	65	75	85[b]
Control	0.45	0.84	1.14	1.36	1.63	1.92	2.15	2.44	2.75	3.26
Grade 1	0.36	0.83	1.17	1.48	1.72	2.08	2.37	2.75	3.09	3.35
Grade 2	0.50	0.89	1.13	1.38	1.55	1.91	2.17	2.49	2.78	3.05
Grade 3	0.54	0.94	1.33	1.53	1.72	2.03	2.36	2.71	3.16	3.48
Blend	0.46	0.92	1.23	1.53	1.67	1.99	2.24	2.59	2.93	3.19
BS180	0.21	0.47	0.65	0.87	0.98	1.26	1.47	1.79	2.15	2.60
BS184	0.15	0.49	0.66	0.83	0.98	1.22	1.50	1.88	2.27	2.69
BS193	0.01	0.07	0.12	0.17	0.21	0.29	0.51	0.81	1.15	1.53
BS195	0.07	0.17	0.28	0.37	0.41	0.52	0.83	1.33	1.76	2.26
BS199	0.10	0.34	0.58	0.76	0.96	1.26	1.53	1.90	2.34	2.68
HM50	0.00	0.03	0.03	0.05	0.06	0.08	0.17	0.51	1.07	1.49
HM70	0.01	0.02	0.04	0.05	0.07	0.11	0.23	0.68	1.22	1.62

[a] Type of NBC defined in Table II
[b]Note: LSD at 85°C = 1.12

Effects of NBC in tortilla properties

TABLE A.2
Effects of NBC Types on Objective Dough Properties

Type of NBC[ab]	Peak Force (N)	EQ Force (N)	Gradient (N/mm)
Control	17.0	5.9	19.1
Grade 1	18.8	6.6	20.8
Grade 2	18.8	6.9	20.1
Grade 3	21.3	7.5	23.6
Blend	18.8	6.7	20.5
BS180	17.4	6.2	19.1
BS184	17.6	6.3	19.2
BS193	14.6	5.0	16.4
BS195	21.1	6.6	21.8
BS199	15.3	5.6	16.5
HM50	16.3	5.3	18.7
HM70	15.8	5.2	18.0
LSD	9.0	2.9	10.4

[a] NBC level 6g/kg
[b] Types of NBC defined in Table II

TABLE A.3
Effects of NBC Types on Objective Tortilla Properties

Type of NBC[ab]	Diameter (cm)	Opacity (%)	Sp. Vol (cm^3/g)
Control	17.8	96.1	1.6
Grade 1	17.7	97.1	1.7
Grade 2	17.4	97.2	1.6
Grade 3	17.6	96.7	1.6
Blend	17.6	97.9	1.8
BS180	18.6	98.2	1.7
BS184	18.5	97.8	1.7
BS193	18.1	77.3	1.4
BS195	17.7	89.7	1.5
BS199	18.3	97.5	1.8
HM50	18.3	82.9	1.4
HM70	18.0	73.3	1.3
LSD	0.6	6.0	0.2

[a] NBC level 6g/kg
[b] Types of NBC defined in Table II

TABLE A.4
Effects of NBC Types on Objective Shelf Stability

Type of NBC[ab]	Force (N)					
	4 day	8 day	12 day	16 day	20 day	24 day
Control	5.9	6.4	6.5	6.7	6.8	7.2
Grade 1	5.6	6.2	6.9	6.8	6.7	7.4
Grade 2	6.2	7.0	7.0	7.5	6.4	7.3
Grade 3	6.1	6.8	6.7	6.9	7.3	7.8
Blend	6.2	6.7	6.8	7.0	7.3	7.3
BS180	5.5	5.9	6.5	6.3	6.4	7.0
BS184	5.4	7.6	6.6	6.5	6.5	7.0
BS193	6.7	6.5	7.8	8.2	7.1	8.8
BS195	6.5	7.3	7.7	8.1	7.6	8.9
BS199	5.3	7.5	5.8	6.5	5.4	6.5
HM50	6.8	6.2	9.4	10.0	9.0	10.0
HM70	6.8	6.1	8.1	9.3	9.9	10.2
LSD	1.1	1.3	1.1	1.2	1.7	1.2

TABLE A.4 continued

Type of NBC[ab]	Distance (mm)					
	4 day	8 day	12 day	16 day	20 day	24 day
Control	2.0	1.6	1.5	1.5	1.4	1.3
Grade 1	2.1	1.5	1.5	1.4	1.4	1.5
Grade 2	2.0	1.7	1.5	1.5	1.5	1.5
Grade 3	1.9	1.8	1.4	1.4	1.3	1.5
Blend	1.8	1.6	1.5	1.4	1.3	1.4
BS180	1.9	2.4	1.5	1.4	1.2	1.1
BS184	1.7	1.5	1.5	1.2	1.1	1.3
BS193	1.8	1.4	1.3	1.3	1.0	1.1
BS195	1.6	1.5	1.4	1.4	1.4	1.3
BS199	1.7	1.7	1.3	1.3	1.2	1.2
HM50	1.9	1.4	1.5	1.4	1.1	1.1
HM70	1.8	1.4	1.5	1.6	1.2	1.4
LSD	0.4	1.0	0.3	0.4	0.3	0.3

TABLE A.4 continued

Type of NBC[ab]	Work (N.mm)					
	4 day	8 day	12 day	16 day	20 day	24 day
Control	10.0	9.0	8.5	8.3	8.2	8.0
Grade 1	10.2	8.4	9.0	8.4	8.0	9.2
Grade 2	10.4	10.5	8.8	9.9	8.8	9.0
Grade 3	9.9	10.5	8.1	8.3	8.2	10.1
Blend	9.4	9.5	8.6	8.8	8.3	8.5
BS180	8.8	8.6	8.3	7.4	6.8	6.5
BS184	7.8	9.6	8.4	6.8	6.0	7.6
BS193	10.3	7.8	8.7	9.5	6.3	8.4
BS195	9.8	9.7	9.7	9.7	9.0	9.2
BS199	7.5	11.0	6.4	7.3	6.8	6.5
HM50	10.8	7.4	12.1	12.1	9.9	9.5
HM70	10.5	8.8	10.6	12.4	9.9	12.2
LSD	2.7	3.2	2.6	2.6	2.2	2.4

TABLE A.4 continued

Type of NBC[ab]	Gradient (N/mm)					
	4 day	8 day	12 day	16 day	20 day	24 day
Control	2.2	2.1	2.2	2.3	2.2	2.5
Grade 1	2.1	2.0	2.2	2.2	2.2	2.6
Grade 2	2.3	2.0	2.3	2.3	2.2	2.7
Grade 3	2.2	2.0	2.1	2.2	2.4	2.9
Blend	2.2	2.1	2.2	2.3	2.4	2.8
BS180	2.1	2.0	2.1	2.0	1.9	2.1
BS184	2.5	1.9	2.2	2.1	2.0	2.2
BS193	2.1	2.2	2.4	2.6	2.0	2.5
BS195	2.4	2.1	2.5	2.6	2.5	3.1
BS199	2.3	1.8	1.7	2.0	1.4	1.9
HM50	2.0	2.3	3.0	3.2	2.8	3.1
HM70	2.6	2.3	2.6	2.9	3.0	3.1
LSD	0.6	1.1	0.5	0.4	0.7	0.9

[a] NBC level 6g/kg
[b] Types of NBC defined in Table II

APPENDIX B

Effect of the level of sodium bicarbonate used in flour tortillas properties

TABLE B.1
Effects of Amounts and Types of NBC on Objective Dough Properties

Type of NBC	NBC (g/kg)	Force (N)	EQ Force (N)	Gradient (N/mm)
Control	6.0	16.4	6.4	18.0
	3.0	13.5	4.3	15.6
	2.1	11.8	3.7	13.6
	1.2	18.5	5.9	21.5
LSD		8.4	2.5	10.2
Grade 1	6.0	18.8	6.6	20.8
	4.5	18.4	5.9	21.1
	3.0	18.4	6.3	20.7
	2.3	16.8	5.3	19.4
	1.9	14.2	4.5	16.5
	1.5	16.4	5.4	18.8
LSD		7.2	2.6	7.9
BS180	6.0	16.4	5.8	18.1
	4.5	13.2	4.7	14.8
	3.0	14.4	4.6	16.5
	2.3	20.6	6.8	23.5
	1.9	12.8	4.0	14.9
	1.2	10.4	3.3	12.2
LSD		11.0	3.2	13.3

TABLE B.2
Effects of Amounts and Types of NBC on Objective Tortilla Properties

Type of NBC	NBC (g/kg)	Diameter (cm)	Opacity (%)	Sp. Vol (cm^3/g)
Control	6.0	17.8	96.1	1.6
	3.0	17.9	83.9	1.3
	2.1	18.0	79.0	1.2
	1.2	18.2	77.0	1.1
LSD		0.5	5.1	0.1
Grade 1	6.0	17.7	97.1	1.6
	4.5	17.8	92.7	1.5
	3.0	17.6	87.8	1.5
	2.3	17.6	76.0	1.3
	1.9	17.9	63.0	1.2
	1.5	17.2	49.9	1.1
LSD		0.5	17.6	0.1
BS180	6.0	18.6	98.2	1.7
	4.5	18.2	97.4	1.6
	3.0	18.2	91.6	1.5
	2.3	17.7	79.8	1.3
	1.9	17.9	68.8	1.3
	1.5	17.6	74.6	1.3
LSD		0.6	14.1	0.2

TABLE B.3
Effects of Amounts and Types of NBC on Objective Shelf Stability

Type of NBC	NBC (g/kg)	Force (N)					
		4 day	8 day	12 day	16 day	20 day	24 day
Control	6.0	5.9	6.4	6.5	6.7	6.9	7.2
	3.0	6.5	7.4	7.6	7.3	7.9	8.3
	2.1	6.8	6.9	8.1	7.7	11.0	8.6
	1.2	8.7	9.0	8.4	8.7	9.3	8.9
LSD		0.9	1.0	0.9	1.0	1.2	1.1
Grade 1	6.0	5.6	6.2	6.9	6.9	6.7	7.4
	4.5	5.6	5.7	6.5	6.3	7.0	6.4
	3.0	6.0	6.7	6.7	7.0	7.1	7.3
	2.3	6.1	6.6	6.6	6.7	7.4	7.6
	1.9	6.4	6.2	7.5	6.9	8.3	8.1
	1.5	6.5	7.6	7.7	7.5	7.6	8.5
LSD		1.1	1.3	0.7	0.9	1.7	0.8
BS180	6.0	5.5	5.9	6.5	6.3	6.4	6.8
	4.5	4.8	5.4	5.6	6.6	5.9	6.4
	3.0	6.2	7.1	7.0	7.3	7.2	7.1
	2.3	6.0	6.7	6.8	6.9	7.0	7.7
	1.9	6.1	5.5	6.1	7.0	7.7	7.3
	1.2	8.2	8.5	9.1	8.6	9.1	9.1
LSD		1.1	1.6	1.4	1.0	1.7	1.6

TABLE B.3 continued

Type of NBC	NBC (g/kg)	Distance (mm)					
		4 day	8 day	12 day	16 day	20 day	24 day
Control	6.0	2.0	1.6	1.5	1.5	1.4	1.3
	3.0	1.9	1.7	1.5	1.4	1.4	1.2
	2.1	2.0	1.8	1.7	1.5	1.8	1.4
	1.2	1.8	1.8	1.4	1.6	1.4	1.6
LSD		0.2	0.2	0.2	0.2	0.3	0.9
Grade 1	6.0	2.1	1.6	1.5	1.4	1.4	1.5
	4.5	2.1	1.8	1.5	1.2	1.4	1.3
	3.0	2.0	1.6	1.5	1.5	1.4	1.4
	2.3	2.1	1.7	1.5	1.4	1.4	1.5
	1.9	2.2	1.6	1.5	1.3	1.4	1.2
	1.5	1.9	1.5	1.5	1.5	2.2	1.3
LSD		0.4	0.3	0.4	0.3	1.4	0.3
BS180	6.0	1.9	2.4	1.5	1.4	1.2	1.1
	4.5	2.2	1.3	1.2	1.5	1.2	1.2
	3.0	1.9	1.7	1.4	1.4	1.4	1.7
	2.3	2.0	1.6	1.7	1.6	1.4	1.2
	1.9	2.0	1.8	1.5	1.4	1.3	1.5
	1.2	1.9	1.8	1.6	1.7	1.4	1.6
LSD		0.5	1.4	0.3	0.2	0.3	1.3

TABLE B.3 continued

Type of NBC	NBC (g/kg)	Work (N.mm)					
		4 day	8 day	12 day	16 day	20 day	24 day
Control	6.0	10.0	9.0	8.5	8.3	8.2	8.0
	3.0	10.2	10.6	9.7	9.5	8.5	8.4
	2.1	11.0	10.5	12.0	9.7	16.6	9.9
	1.2	13.2	14.0	10.3	11.5	10.7	12.2
LSD		1.6	2.1	1.8	2.0	2.9	2.0
Grade 1	6.0	10.2	8.3	9.0	8.5	8.0	9.2
	4.5	9.6	8.4	8.5	6.5	8.1	7.4
	3.0	10.8	9.3	8.8	8.9	8.8	8.4
	2.3	11.0	9.3	8.6	8.3	9.1	9.7
	1.9	11.3	7.7	9.5	7.4	10.1	8.5
	1.5	11.0	9.4	9.5	9.8	9.8	9.7
LSD		2.5	2.4	2.9	2.1	3.7	2.5
BS180	6.0	8.8	8.6	8.4	7.4	6.8	6.5
	4.5	8.0	5.9	5.9	8.3	6.1	6.5
	3.0	9.9	10.0	8.5	8.9	8.8	8.3
	2.3	10.0	9.2	9.7	9.7	8.6	8.0
	1.9	9.9	8.1	7.6	8.4	8.7	9.7
	1.2	13.1	12.8	12.3	12.5	10.8	12.3
LSD		3.1	2.7	3.1	1.9	3.6	2.8

TABLE B.3 continued

Type of NBC	NBC (g/kg)	Gradient (N/mm)					
		4 d	**8 d**	**12 d**	**16 d**	**20 d**	**24 d**
Control	6.0	2.2	2.3	2.2	2.3	2.2	2.5
	3.0	2.2	2.4	2.5	2.5	2.4	2.7
	2.1	2.2	2.5	2.6	2.5	3.5	2.9
	1.2	2.8	2.9	2.8	2.7	3.1	3.0
LSD		0.5	0.9	0.4	0.3	0.5	0.6
Grade 1	6.0	2.0	2.1	2.2	2.2	2.2	2.6
	4.5	2.2	2.3	2.1	2.1	2.1	2.1
	3.0	2.2	2.1	2.1	2.2	2.3	2.6
	2.3	2.2	2.3	2.1	2.3	2.4	2.5
	1.9	2.4	2.6	2.3	2.4	2.6	2.5
	1.5	2.5	2.4	2.4	2.4	2.4	2.5
LSD		0.5	0.3	0.2	0.3	0.4	0.9
BS180	6.0	2.0	2.1	2.1	2.0	1.9	2.1
	4.5	2.3	2.0	1.8	2.0	1.9	2.1
	3.0	2.2	2.4	2.3	2.4	2.4	2.5
	2.3	2.2	2.0	2.1	2.2	2.1	2.3
	1.9	2.4	2.1	2.0	2.3	2.3	2.4
	1.2	2.8	2.8	3.1	2.8	3.0	3.3
LSD		0.5	0.6	0.6	0.4	0.5	0.6

Effect of tetrasodium pyrophosphate (TSPP)

TABLE B.4
Effects of Amounts and Types of NBC and TSPP on Objective Dough Properties

Type of NBC	NBC (g/kg)	TSPP	Force (N)	EQ Force (N)	Gradient (N/mm)
Grade 1	6.0	0	18.8	6.6	20.8
	4.5	0	18.4	5.9	21.1
	3.0	0	18.4	6.3	20.7
	2.3	0	16.8	5.3	19.4
	1.9	0	14.2	4.5	16.5
	1.5	0	16.4	5.4	18.8
	6.0	0.15	16.2	5.5	18.6
	4.5	0.15	14.7	5.1	16.7
	3.0	0.15	14.1	4.7	16.1
	2.3	0.15	19.5	6.0	22.8
	1.9	0.15	16.7	5.5	19.3
	1.5	0.15	17.3	5.7	19.8
LSD			2.6	0.9	2.9
BS180	6.0	0	16.4	5.8	18.1
	4.5	0	13.2	4.7	14.8
	3.0	0	14.4	4.6	16.5
	2.3	0	20.6	6.8	23.5
	2.1	0	12.5	4.0	14.5
	1.9	0	12.8	4.0	14.9
	1.5	0	16.4	5.3	18.9
	1.2	0	10.4	3.3	12.2
	6.0	0.15	14.1	4.8	16.2
	4.5	0.15	15.7	5.4	17.8
	3.0	0.15	13.6	4.5	15.5
	2.3	0.15	15.3	5.1	17.4
	1.9	0.15	16.7	5.2	19.4
	1.5	0.15	15.7	5.1	18.1
LSD			3.2	0.9	3.9

TABLE B.5
Effects of Amounts and Types of NBC and TSPP on Tortilla Properties

Type of NBC	NBC (g/kg)	TSPP	Diameter (cm)	Opacity (%)	Sp. Vol (cm^3/g)
Grade 1	6.0	0	17.7	97.1	1.7
	4.5	0	17.8	92.7	1.5
	3.0	0	17.6	87.8	1.5
	2.3	0	17.6	76.0	1.3
	1.9	0	17.9	63.0	1.2
	1.5	0	17.2	49.9	1.1
	6.0	0.15	17.9	98.6	1.5
	4.5	0.15	17.8	97.9	1.5
	3.0	0.15	17.7	91.5	1.4
	2.3	0.15	17.5	74.3	1.3
	1.9	0.15	17.6	58.9	1.2
	1.5	0.15	17.6	58.8	1.2
LSD			0.2	11.8	0.1
BS180	6.0	0	18.6	98.2	1.7
	4.5	0	18.2	97.4	1.6
	3.0	0	18.2	91.6	1.5
	2.3	0	17.7	79.8	1.3
	1.9	0	17.9	68.8	1.4
	1.5	0	17.6	74.6	1.3
	1.2	0	-	72.7	1.1
	6.0	0.15	18.3	99.2	1.7
	4.5	0.15	17.9	98.6	1.6
	3.0	0.15	17.9	95.5	1.4
	2.3	0.15	17.7	84.2	1.4
	1.9	0.15	17.9	80.0	1.3
	1.5	0.15	17.9	73.6	1.3
LSD			0.2	7.8	0.1

TABLE B.6
Effects of Amounts and Types of NBC and TSPP on Objective Shelf Stability

Type of NBC	NBC (g/kg)	TSPP	Force (N)					
			4 d	8 d	12 d	16 d	20 d	24 d
Grade 1	6.0	0	5.6	6.3	6.9	6.9	6.7	7.4
	4.5	0	5.6	5.8	6.5	6.3	7.0	6.4
	3.0	0	6.0	6.7	6.7	7.0	7.1	7.3
	2.3	0	6.1	6.6	6.6	6.7	7.4	7.6
	1.9	0	6.4	6.2	7.5	7.0	8.3	8.1
	1.5	0	6.5	7.6	7.7	7.5	7.6	8.5
	6.0	0.15	4.7	5.3	5.7	5.8	5.7	6.4
	4.5	0.15	4.7	6.0	6.3	6.3	5.8	6.6
	3.0	0.15	5.9	6.7	6.6	6.2	7.2	6.4
	2.3	0.15	6.2	5.8	6.6	6.9	8.1	7.3
	1.9	0.15	6.1	7.4	7.4	7.0	7.3	7.5
	1.5	0.15	6.6	6.9	7.7	7.7	7.0	8.3
LSD			0.6	0.6	0.5	0.4	0.6	0.6
BS180	6.0	0	5.5	5.9	6.5	6.3	6.4	6.8
	4.5	0	4.8	5.4	5.6	6.5	5.9	6.4
	3.0	0	6.2	7.1	7.0	7.3	7.2	7.1
	2.3	0	6.0	6.7	6.8	6.9	7.0	7.7
	2.1	0	6.7	7.7	7.8	7.8	8.4	7.3
	1.9	0	6.1	5.5	6.1	6.9	7.7	7.3
	1.5	0	6.1	6.5	6.3	7.0	7.2	7.9
	1.2	0	8.2	8.5	9.1	8.6	9.1	9.1
	6.0	0.15	4.7	5.9	5.0	5.1	5.3	6.1
	4.5	0.15	4.9	5.7	6.0	6.0	6.6	5.9
	3.0	0.15	5.6	5.5	6.2	6.8	7.0	6.8
	2.3	0.15	5.8	6.2	6.4	6.4	6.9	7.2
	1.9	0.15	6.2	6.1	6.4	7.2	7.6	7.7
	1.5	0.15	6.5	6.5	7.4	7.5	6.9	7.5
LSD			0.5	0.6	0.6	0.5	0.6	0.6

TABLE B.6 continued

Type of NBC	NBC (g/kg)	TSPP	Distance (mm)					
			4 d	8 d	12 d	16 d	20 d	24 d
Grade 1	6.0	0	2.1	1.5	1.5	1.4	1.4	1.5
	4.5	0	2.4	1.7	1.5	1.2	1.4	1.3
	3.0	0	1.9	1.6	1.5	1.5	1.4	1.4
	2.3	0	2.1	1.8	1.5	1.4	1.4	1.5
	1.9	0	2.2	1.6	1.5	1.3	1.4	1.2
	1.5	0	1.9	1.5	1.5	1.5	1.2	1.3
	6.0	0.15	2.1	1.7	1.7	1.7	1.4	1.3
	4.5	0.15	2.5	1.6	1.8	1.5	1.3	1.4
	3.0	0.15	2.1	1.7	1.6	1.6	1.4	1.4
	2.3	0.15	2.1	1.8	1.5	1.3	1.2	1.3
	1.9	0.15	2.0	1.6	1.5	1.2	1.3	1.2
	1.5	0.15	2.0	1.5	1.6	1.4	1.4	1.2
LSD			0.2	0.1	0.1	0.1	0.1	0.1
BS180	6.0	0	1.9	2.4	1.5	1.4	1.2	1.1
	4.5	0	2.2	1.3	1.2	1.5	1.2	1.2
	3.0	0	1.9	1.7	1.4	1.4	1.4	1.7
	2.3	0	2.0	1.6	1.6	1.6	1.4	1.2
	2.1	0	1.9	1.6	1.5	1.5	1.4	1.3
	1.9	0	2.0	1.8	1.5	1.4	1.3	1.5
	1.5	0	1.9	2.4	1.5	1.5	1.4	1.3
	1.2	0	1.9	1.8	1.6	1.7	1.4	1.6
	6.0	0.15	2.1	1.9	1.2	1.3	1.4	1.4
	4.5	0.15	2.1	2.0	1.5	1.4	1.4	1.4
	3.0	0.15	2.1	1.7	1.5	1.4	1.5	1.5
	2.3	0.15	2.1	1.7	1.5	1.6	1.9	1.2
	1.9	0.15	2.1	1.7	1.5	1.3	1.4	1.3
	1.5	0.15	2.1	1.8	1.5	1.5	1.4	1.4
LSD			0.1	0.4	0.1	0.1	0.2	0.3

TABLE B.6 continued

Type of NBC	NBC (g/kg)	TSPP	Work (N.mm)					
			4 d	8 d	12 d	16 d	20 d	24 d
Grade 1	6.0	0	10.2	8.3	9.0	8.4	8.0	9.2
	4.5	0	9.5	8.4	8.5	6.5	8.1	7.4
	3.0	0	10.8	9.2	8.8	8.9	8.7	8.4
	2.3	0	11.0	9.3	8.6	8.3	9.1	9.7
	1.9	0	11.3	7.7	9.5	7.4	10.1	8.5
	1.5	0	11.0	9.4	9.5	9.7	9.8	9.6
	6.0	0.15	8.6	7.7	8.1	8.5	6.9	7.0
	4.5	0.15	9.4	7.9	9.6	7.8	6.1	7.9
	3.0	0.15	10.7	9.9	8.8	8.6	8.9	7.7
	2.3	0.15	10.9	8.7	8.4	7.7	8.6	8.2
	1.9	0.15	10.6	10.0	9.7	7.1	8.2	7.8
	1.5	0.15	11.1	8.6	10.3	9.4	8.5	8.7
LSD			1.0	0.8	1.1	0.9	1.1	0.9
BS180	6.0	0	8.8	8.6	8.3	7.4	6.8	6.5
	4.5	0	8.0	5.8	5.9	8.3	6.1	6.5
	3.0	0	9.9	10.0	8.5	8.9	8.8	8.3
	2.3	0	10.0	9.2	9.7	9.7	8.6	8.0
	2.1	0	10.3	10.6	9.9	10.0	10.2	7.9
	1.9	0	9.9	8.1	7.6	8.4	8.7	9.6
	1.5	0	10.3	10.2	8.1	8.9	8.5	8.6
	1.2	0	13.1	12.8	12.3	12.5	10.8	12.3
	6.0	0.15	9.2	9.5	4.9	5.6	6.1	7.6
	4.5	0.15	8.8	9.6	7.9	7.3	8.1	6.7
	3.0	0.15	9.9	7.7	8.0	8.6	8.9	8.7
	2.3	0.15	10.1	9.4	8.1	8.8	8.9	7.6
	1.9	0.15	10.7	8.7	8.6	7.7	9.0	8.9
	1.5	0.15	11.4	9.7	9.7	9.3	8.1	8.8
LSD			1.1	1.1	1.2	0.9	1.1	1.1

TABLE B.6 continued

Type of NBC	NBC (g/kg)	TSPP	Gradient (N/mm)					
			4 d	8 d	12 d	16 d	20 d	24 d
Grade 1	6.0	0	2.0	2.1	2.2	2.2	2.2	2.6
	4.5	0	2.2	2.3	2.1	2.1	2.1	2.1
	3.0	0	2.2	2.1	2.1	2.2	2.2	2.6
	2.3	0	2.2	2.3	2.1	2.3	2.3	2.5
	1.9	0	2.4	2.6	2.2	2.4	2.6	2.5
	1.5	0	2.5	2.4	2.3	2.4	2.4	2.5
	6.0	0.15	2.2	1.8	1.9	1.8	1.8	1.9
	4.5	0.15	2.2	1.9	2.0	2.1	1.9	2.1
	3.0	0.15	2.1	2.1	2.1	2.0	2.2	2.0
	2.3	0.15	2.4	2.3	2.2	2.2	2.3	2.4
	1.9	0.15	2.7	2.3	2.4	2.1	2.1	2.4
	1.5	0.15	2.5	2.2	2.4	2.4	2.2	2.6
LSD			0.2	0.2	0.1	0.1	0.1	0.1
BS180	6.0	0	2.0	2.1	2.1	2.0	1.9	2.1
	4.5	0	2.3	2.0	1.8	2.0	1.9	2.1
	3.0	0	2.2	2.4	2.3	2.4	2.4	2.5
	2.3	0	2.2	2.0	2.1	2.2	2.1	2.3
	2.1	0	2.3	2.6	2.6	2.6	2.7	2.5
	1.9	0	2.4	2.1	2.0	2.3	2.3	2.4
	1.5	0	2.2	2.5	2.3	2.4	2.3	2.4
	1.2	0	2.8	2.8	3.1	2.8	3.0	3.3
	6.0	0.15	2.1	2.0	2.0	1.8	1.7	1.9
	4.5	0.15	2.0	1.8	2.0	1.8	1.9	2.0
	3.0	0.15	2.1	2.0	2.0	2.2	2.2	2.2
	2.3	0.15	2.0	2.0	2.0	2.0	2.2	2.3
	1.9	0.15	2.5	2.4	2.1	2.4	2.3	2.5
	1.5	0.15	2.3	2.5	2.5	2.5	2.2	2.4
LSD			0.2	0.2	0.2	0.2	0.2	0.2

TABLE B.7
Sensory Evaluation

Wheat Flour Tortilla Evaluation

HOWDY!
This is a sensory test of wheat flour tortillas.
Please follow the instructions and don't forget to pick up a treat after you have finished.

Instructions:
1. You will be given 5 tortilla halves, each numbered differently.
2. Start your evaluations form left to right, and answer the questions in the order given.
3. Mark the answer that best describes what you think about the tortilla attributes.
4. A glass of water is given if you need to rinse your mouth between samples.
5. When you have finish please return the evaluation, and pick up your treat.

AGE : _____
SEX : F M
NATIONALITY: ________________
YEARS LIVING IN U.S. :_________

Sample ________

Aroma (Smell you perceive)
___ Like extremely
___ Like very much
___ Like moderately
___ Like slightly
___ Neither like nor dislike
___ Dislike slightly
___ Dislike moderately
___ Dislike very much
___ Dislike extremely

Texture (How does it feel in your mouth; bite)
___ Like extremely
___ Like very much
___ Like moderately
___ Like slightly
___ Neither like nor dislike
___ Dislike slightly
___ Dislike moderately
___ Dislike very much
___ Dislike extremely

Appearance (How does it look)
___ Like extremely
___ Like very much
___ Like moderately
___ Like slightly
___ Neither like nor dislike
___ Dislike slightly
___ Dislike moderately
___ Dislike very much
___ Dislike extremely

Flavor (How does it taste)
___ Like extremely
___ Like very much
___ Like moderately
___ Like slightly
___ Neither like nor dislike
___ Dislike slightly
___ Dislike moderately
___ Dislike very much
___ Dislike extremely

Comments: ____
____

Combination of fast and slow release sodium bicarbonates

TABLE B.8
Effects of Amounts and Types of NBC Combinations on Objective Dough Properties

NBC (g/kg)	Type of NBC_1	Type of NBC_2	NBC Ratio	Force (N)	EQ Force (N)	Gradient (N/mm)
3	Grade 1	BS184	(1:1)	15.3	4.9	17.6
3	Grade 1	BS199	(1:1)	16.3	5.3	18.7
3	BS180	BS193	(1:1)	16.4	5.3	18.8
3	BS180	BS199	(1:1)	12.8	4.3	14.5
3	BS184	BS193	(1:1)	16.6	5.3	19.4
3	BS184	BS199	(1:1)	16.1	5.4	18.3
3	Grade 1	BS193	(1:1)	17.7	5.8	20.2
1.5	Grade 1	BS193	(1:2)	17.4	5.6	20.0
1.5	Grade 1	BS193	(2:1)	18.6	6.0	21.5
3	Grade 1	BS180	(1:1)	16.8	5.5	19.1
1.5	Grade 1	BS180	(1:2)	14.7	4.8	16.8
1.5	Grade 1	BS180	(2:1)	15.4	5.1	17.5
1.5	BS180	BS193	(1:1)	16.7	5.4	19.1
1.5	BS180	BS193	(2:1)	17.7	5.8	20.2
1.5	BS180	BS193	(1:2)	16.9	5.5	19.4
1.5*	BS180	BS193	(1:1)	15.5	5.1	17.6
LSD				7.1	2.2	8.4

TABLE B.9
Effects of Amount and Type of NBC Combinations on Tortilla Properties

NBC (g/kg)	Type of NBC_1	Type of NBC_2	NBC Ratio	Diameter (cm)	Opacity (%)	Sp. Vol (cm^3/g)
3	Grade 1	BS184	(1:1)	17.5	92.5	1.4
3	Grade 1	BS199	(1:1)	17.4	95.0	-
3	BS180	BS193	(1:1)	17.9	88.5	1.4
3	BS180	BS199	(1:1)	18.0	98.0	1.5
3	BS184	BS193	(1:1)	17.6	87.0	1.4
3	BS184	BS199	(1:1)	17.7	97.1	1.5
3	Grade 1	BS193	(1:1)	17.4	55.5	1.2
1.5	Grade 1	BS193	(1:2)	17.6	43.2	1.1
1.5	Grade 1	BS193	(2:1)	17.4	47.3	1.2
3	Grade 1	BS180	(1:1)	17.8	91.5	1.4
1.5	Grade 1	BS180	(1:2)	17.8	62.7	1.2
1.5	Grade 1	BS180	(2:1)	17.5	68.7	1.2
1.5	BS180	BS193	(1:1)	17.5	66.0	1.2
1.5	BS180	BS193	(2:1)	17.4	55.5	1.2
1.5	BS180	BS193	(1:2)	17.7	51.2	1.1
1.5*	BS180	BS193	(1:1)	17.5	67.1	1.2
LSD				0.7	32.6	0.2

*Treatment with 0.15% TSPP

TABLE B.10
Effects of Amounts and Types of NBC Combinations on Objective Shelf Stability

NBC (g/kg)	Type of NBC_1	Type of NBC_2	NBC Ratio	Force (N)					
				4 d	8 d	12 d	16 d	20 d	24 d
3	Grade 1	BS184	(1:1)	7.2	6.2	6.1	5.6	6.7	7.7
3	Grade 1	BS199	(1:1)	5.7	6.9	6.9	6.8	7.2	7.2
3	BS180	BS193	(1:1)	6.1	7.1	7.1	6.7	7.4	8.2
3	BS180	BS199	(1:1)	5.9	6.5	6.6	6.3	6.7	6.9
3	BS184	BS193	(1:1)	6.4	7.7	7.1	6.5	8.0	7.5
3	BS184	BS199	(1:1)	6.9	6.3	7.1	6.9	7.1	7.3
3	Grade 1	BS193	(1:1)	6.7	7.6	8.1	7.4	8.1	8.3
1.5	Grade 1	BS193	(1:2)	7.2	7.8	8.2	7.6	8.0	8.2
1.5	Grade 1	BS193	(2:1)	7.1	7.0	7.8	6.7	7.5	8.6
3	Grade 1	BS180	(1:1)	6.2	6.2	6.6	6.5	7.0	6.9
1.5	Grade 1	BS180	(1:2)	6.8	7.1	7.8	6.9	7.2	7.7
1.5	Grade 1	BS180	(2:1)	6.6	7.7	7.2	6.7	7.5	8.0
1.5	BS180	BS193	(1:1)	6.3	7.5	7.8	7.5	7.8	8.9
1.5	BS180	BS193	(2:1)	6.7	7.6	8.1	7.4	8.1	8.3
1.5	BS180	BS193	(1:2)	6.8	6.8	7.8	7.5	7.8	8.1
1.5*	BS180	BS193	(1:1)	6.4	7.2	7.1	6.7	7.6	8.9
LSD				1.2	1.7	1.4	1.9	1.3	1.8

TABLE B.10 continued

NBC (g/kg)	Type of NBC_1	Type of NBC_2	NBC Ratio	Distance (mm)					
				4d	8 d	12 d	16 d	20 d	24 d
3	Grade 1	BS184	(1:1)	1.7	1.6	1.3	1.7	1.5	-
3	Grade 1	BS199	(1:1)	1.9	1.4	1.3	1.8	1.4	-
3	BS180	BS193	(1:1)	1.9	1.3	1.5	2.1	1.7	-
3	BS180	BS199	(1:1)	1.7	1.3	1.3	1.8	1.6	-
3	BS184	BS193	(1:1)	1.9	1.7	1.4	1.7	1.7	-
3	BS184	BS199	(1:1)	1.9	1.6	1.4	2.0	1.6	-
3	Grade 1	BS193	(1:1)	2.0	1.7	1.5	1.5	1.4	1.4
1.5	Grade 1	BS193	(1:2)	1.9	1.6	1.3	1.7	1.2	1.2
1.5	Grade 1	BS193	(2:1)	1.9	1.6	1.6	1.6	1.4	1.3
3	Grade 1	BS180	(1:1)	1.8	1.6	1.3	1.5	1.4	1.2
1.5	Grade 1	BS180	(1:2)	2.0	1.7	1.5	1.5	1.3	1.3
1.5	Grade 1	BS180	(2:1)	1.8	1.7	1.6	1.5	1.4	1.3
1.5	BS180	BS193	(1:1)	1.8	1.6	1.6	1.6	1.3	1.3
1.5	BS180	BS193	(2:1)	2.0	1.7	1.5	1.5	1.4	1.4
1.5	BS180	BS193	(1:2)	1.5	1.5	1.5	1.5	1.6	1.3
1.5*	BS180	BS193	(1:1)	1.8	1.7	1.5	1.5	1.4	1.2
LSD				0.4	0.5	0.4	0.6	0.4	0.2

TABLE B.10 continued

NBC (g/kg)	Type of NBC_1	Type of NBC_2	NBC Ratio	Work (N.mm)					
				4 d	**8 d**	**12 d**	**16 d**	**20 d**	**24 d**
3	Grade 1	BS184	(1:1)	10.5	8.3	6.6	7.8	8.3	11.9
3	Grade 1	BS199	(1:1)	9.5	8.4	7.6	10.0	8.5	10.0
3	BS180	BS193	(1:1)	10.3	7.9	8.9	11.2	10.6	11.7
3	BS180	BS199	(1:1)	8.5	7.1	7.3	9.6	8.8	9.5
3	BS184	BS193	(1:1)	10.6	10.9	8.5	8.8	11.3	10.3
3	BS184	BS199	(1:1)	11.0	8.9	8.7	11.3	9.2	11.9
3	Grade 1	BS193	(1:1)	11.5	10.6	10.0	9.6	10.0	10.0
1.5	Grade 1	BS193	(1:2)	11.7	10.5	9.4	10.6	8.5	8.2
1.5	Grade 1	BS193	(2:1)	11.5	9.1	10.6	8.7	8.8	9.6
3	Grade 1	BS180	(1:1)	9.6	8.5	7.7	8.2	8.5	8.2
1.5	Grade 1	BS180	(1:2)	11.6	10.0	10.0	8.5	8.0	8.6
1.5	Grade 1	BS180	(2:1)	10.0	11.3	9.5	8.2	9.1	8.9
1.5	BS180	BS193	(1:1)	9.8	10.0	10.4	10.2	9.0	10.0
1.5	BS180	BS193	(2:1)	11.5	10.6	10.0	9.6	10.0	10.0
1.5	BS180	BS193	(1:2)	8.8	8.5	9.9	9.3	10.5	9.0
1.5*	BS180	BS193	(1:1)	9.8	10.0	9.0	8.0	9.2	9.2
LSD				3.5	3.9	2.8	3.3	3.2	3.2

TABLE B.10 continued

NBC (g/kg)	Type of NBC_1	Type of NBC_2	NBC Ratio	Gradient (N/mm)					
				4 d	8 d	12 d	16 d	20 d	24 d
3	Grade 1	BS184	(1:1)	5.3	4.5	2.1	2.7	3.3	3.3
3	Grade 1	BS199	(1:1)	3.9	5.3	2.3	3.4	3.4	3.2
3	BS180	BS193	(1:1)	4.2	5.5	2.4	3.3	3.4	3.8
3	BS180	BS199	(1:1)	4.2	5.0	2.2	3.2	3.1	3.4
3	BS184	BS193	(1:1)	4.4	5.6	2.4	3.5	3.7	3.4
3	BS184	BS199	(1:1)	4.9	4.4	2.3	3.4	3.3	3.3
3	Grade 1	BS193	(1:1)	2.1	2.6	3.0	2.7	2.4	2.6
1.5	Grade 1	BS193	(1:2)	2.2	2.8	2.8	2.7	2.6	2.7
1.5	Grade 1	BS193	(2:1)	2.3	2.6	2.8	2.5	2.3	2.7
3	Grade 1	BS180	(1:1)	2.8	2.9	2.0	2.4	2.7	2.6
1.5	Grade 1	BS180	(1:2)	2.2	2.6	2.9	2.4	2.3	2.5
1.5	Grade 1	BS180	(2:1)	2.1	2.7	2.6	2.5	2.4	2.6
1.5	BS180	BS193	(1:1)	2.1	2.7	2.7	2.8	2.4	2.7
1.5	BS180	BS193	(2:1)	2.1	2.6	3.0	2.7	2.4	2.6
1.5	BS180	BS193	(1:2)	2.2	2.6	2.8	2.8	2.5	2.6
1.5*	BS180	BS193	(1:1)	2.1	2.7	2.6	2.6	2.4	2.7
LSD				1.6	2.4	1.3	0.9	0.8	0.8

Properties of flour tortillas when a different leavening acid is used

TABLE B.11
Effects of Amounts and Types of NBC with Different Leavening Acids on Objective Dough Properties

Type of NBC	NBC (g/kg)	TSPP	Acid type	Force (N)	EQ Force (N)	Gradient (N/mm)
Control	6.0	0	SAS	16.4	6.4	18.0
	6.0	0	SALP	14.6	4.8	16.7
Grade 1	3.0	0	SAS	18.4	6.3	20.7
	2.3	0	SAS	16.8	5.3	19.4
	3.0	0	SALP	17.0	5.5	19.4
	2.3	0	SALP	17.0	5.5	19.4
	3.0	0.15	SAS	14.1	4.7	16.1
	2.3	0.15	SAS	19.5	6.0	22.8
	3.0	0.15	SALP	16.5	5.4	18.8
	2.3	0.15	SALP	18.5	6.1	21.3
BS180	3.0	0	SAS	14.4	4.6	16.5
	2.3	0	SAS	20.6	6.8	23.5
	3.0	0	SALP	20.2	6.4	23.4
	2.3	0	SALP	17.6	5.7	20.3
	3.0	0.15	SAS	13.6	4.5	15.5
	2.3	0.15	SAS	15.3	5.1	17.4
	3.0	0.15	SALP	17.8	5.7	20.5
	2.3	0.15	SALP	18.9	6.3	21.6
LSD				9.6	3.0	11.3

TABLE B.12
Effects of Amounts and Types of NBC with Different Leavening Acids on Tortilla Properties

Type of NBC	NBC (g/kg)	TSPP	Acid type	Diameter (cm)	Opacity (%)	Sp. Vol (cm^3/g)
Control	6.0	0	SAS	17.8	96.1	1.6
	6.0	0	SALP	17.8	100.0	1.7
Grade 1	3.0	0	SAS	17.6	87.8	1.4
	2.3	0	SAS	17.6	76.0	1.3
	3.0	0	SALP	17.6	85.4	1.3
	2.3	0	SALP	17.5	83.0	1.3
	3.0	0.15	SAS	17.7	91.5	1.4
	2.3	0.15	SAS	17.5	74.3	1.3
	3.0	0.15	SALP	17.5	95.0	1.4
	2.3	0.15	SALP	17.3	83.5	1.3
BS180	3.0	0	SAS	18.2	91.6	1.5
	2.3	0	SAS	17.7	79.8	1.3
	3.0	0	SALP	17.8	96.3	1.4
	2.3	0	SALP	17.8	89.7	1.4
	3.0	0.15	SAS	17.9	95.5	1.4
	2.3	0.15	SAS	17.7	84.2	1.4
	3.0	0.15	SALP	17.9	96.7	1.4
	2.3	0.15	SALP	17.7	89.9	1.3
LSD				0.7	9.8	0.2

TABLE B.13
Effects of Amounts and Types of NBC with Different Leavening Acids on Objective Shelf Stability

Type of NBC	NBC (g/kg)	TSPP	Acid type	Force (N)					
				4 d	8 d	12 d	16 d	20 d	24 d
Control	6.0	0	SAS	5.9	6.4	6.5	6.7	6.9	7.2
	6.0	0	SALP	5.2	5.5	5.4	5.7	5.7	5.9
Grade 1	3.0	0	SAS	6.0	6.7	6.7	7.0	7.1	7.3
	2.3	0	SAS	6.1	6.6	6.6	6.7	7.4	7.6
	3.0	0	SALP	6.2	6.0	6.7	6.2	6.9	7.4
	2.3	0	SALP	6.3	6.9	6.4	7.8	6.9	7.4
	3.0	0.15	SAS	5.9	6.7	6.6	6.2	7.2	6.4
	2.3	0.15	SAS	6.2	5.8	6.6	6.9	8.1	7.3
	3.0	0.15	SALP	6.3	6.5	6.7	7.2	7.1	7.0
	2.3	0.15	SALP	6.6	6.2	6.7	7.1	7.9	8.3
BS180	3.0	0	SAS	6.2	7.1	7.0	7.3	7.2	7.1
	2.3	0	SAS	6.0	6.7	6.8	6.9	7.0	7.7
	3.0	0	SALP	6.3	5.6	6.6	6.7	6.5	6.9
	2.3	0	SALP	6.5	6.5	5.9	7.2	7.5	7.8
	3.0	0.15	SAS	5.6	5.5	6.2	6.8	7.0	6.8
	2.3	0.15	SAS	5.8	6.2	6.4	6.4	6.9	7.2
	3.0	0.15	SALP	5.8	5.7	6.2	6.7	6.7	6.4
	2.3	0.15	SALP	6.4	7.0	6.1	7.5	7.6	7.2
LSD				1.2	1.2	1.2	1.1	1.4	1.2

TABLE B.13 continued

Type of NBC	NBC (g/kg)	TSPP	Acid type	Distance (mm)					
				4 d	8 d	12 d	16 d	20 d	24 d
Control	6.0	0	SAS	2.0	1.6	1.5	1.5	1.4	1.3
	6.0	0	SALP	2.2	2.0	1.7	1.7	1.6	1.4
Grade 1	3.0	0	SAS	2.0	1.6	1.5	1.5	1.4	1.4
	2.3	0	SAS	2.1	1.7	1.5	1.4	1.4	1.5
	3.0	0	SALP	2.4	1.8	1.8	1.9	1.7	1.6
	2.3	0	SALP	2.2	1.9	1.8	1.7	1.7	1.3
	3.0	0.15	SAS	2.1	1.7	1.6	1.6	1.4	1.4
	2.3	0.15	SAS	2.1	1.8	1.5	1.3	1.2	1.3
	3.0	0.15	SALP	2.2	1.9	1.7	1.6	1.5	1.4
	2.3	0.15	SALP	2.2	1.8	1.5	1.9	1.5	1.5
BS180	3.0	0	SAS	1.9	1.7	1.4	1.4	1.4	1.7
	2.3	0	SAS	2.0	1.6	1.6	1.6	1.4	1.2
	3.0	0	SALP	2.1	1.7	1.6	1.4	1.6	1.4
	2.3	0	SALP	2.2	1.7	1.6	1.6	1.5	1.4
	3.0	0.15	SAS	2.2	1.7	1.5	1.4	1.5	1.5
	2.3	0.15	SAS	2.1	1.7	1.5	1.6	1.9	1.2
	3.0	0.15	SALP	2.2	1.7	1.5	1.4	1.5	1.2
	2.3	0.15	SALP	2.2	1.9	1.7	1.7	1.6	1.3
LSD				0.4	0.3	0.4	0.3	0.4	1.0

TABLE B.13 continued

Type of NBC	NBC (g/kg)	TSPP	Acid type	Work (N.mm)					
				4 d	**8 d**	**12 d**	**16 d**	**20 d**	**24 d**
Control	6.0	0	SAS	10.0	9.0	8.5	8.3	8.2	8.0
	6.0	0	SALP	10.0	9.6	7.9	8.5	7.9	7.2
Grade 1	3.0	0	SAS	10.1	9.2	8.8	8.9	8.7	8.4
	2.3	0	SAS	11.0	9.3	8.6	8.3	9.1	9.7
	3.0	0	SALP	12.7	9.7	10.4	10.0	10.2	10.1
	2.3	0	SALP	12.2	11.2	10.3	11.1	10.0	8.2
	3.0	0.15	SAS	10.7	9.9	8.8	8.7	8.9	7.7
	2.3	0.15	SAS	10.9	8.7	8.4	7.8	8.6	8.2
	3.0	0.15	SALP	12.0	10.6	9.9	10.1	9.3	8.3
	2.3	0.15	SALP	12.3	9.4	8.6	11.5	10.2	10.5
BS180	3.0	0	SAS	9.9	10.0	8.5	8.9	8.8	8.3
	2.3	0	SAS	10.0	9.2	9.7	9.7	8.6	8.0
	3.0	0	SALP	11.5	8.0	9.0	8.1	8.7	8.1
	2.3	0	SALP	12.1	9.7	8.1	10.0	9.9	9.2
	3.0	0.15	SAS	9.9	7.7	8.0	8.6	8.9	8.7
	2.3	0.15	SAS	10.1	9.4	8.1	8.8	8.9	7.6
	3.0	0.15	SALP	10.8	8.6	8.1	8.2	8.8	6.4
	2.3	0.15	SALP	12.1	11.6	9.0	11.2	10.2	8.1
LSD				2.5	2.5	2.7	2.5	3.2	2.2

TABLE B.13 continued

Type of NBC	NBC (g/kg)	TSPP	Acid type	Gradient (N/mm)					
				4 d	8 d	12 d	16 d	20 d	24 d
Control	6.0	0	SAS	2.2	2.3	2.2	2.3	2.2	2.5
	6.0	0	SALP	1.6	1.7	1.8	1.8	1.9	1.9
Grade 1	3.0	0	SAS	2.2	2.1	2.1	2.2	2.2	2.6
	2.3	0	SAS	2.2	2.3	2.1	2.3	2.3	2.5
	3.0	0	SALP	1.8	1.8	2.0	2.0	2.2	2.2
	2.3	0	SALP	1.9	1.9	2.0	2.4	2.3	2.2
	3.0	0.15	SAS	2.1	2.1	2.1	2.0	2.2	2.0
	2.3	0.15	SAS	2.4	2.3	2.2	2.2	2.4	2.4
	3.0	0.15	SALP	1.9	1.9	2.1	2.2	2.2	2.2
	2.3	0.15	SALP	2.0	1.9	2.2	2.1	2.4	2.5
BS180	3.0	0	SAS	2.2	2.4	2.3	2.4	2.4	2.5
	2.3	0	SAS	2.2	2.0	2.1	2.2	2.1	2.3
	3.0	0	SALP	1.9	1.8	2.0	2.1	2.1	2.1
	2.3	0	SALP	1.9	1.9	1.8	2.2	2.2	2.2
	3.0	0.15	SAS	2.1	2.0	2.0	2.2	2.2	2.2
	2.3	0.15	SAS	2.0	1.9	2.0	2.0	2.2	2.3
	3.0	0.15	SALP	1.8	1.8	1.9	2.2	2.1	2.0
	2.3	0.15	SALP	1.9	2.0	1.9	2.4	2.4	2.3
LSD				0.6	0.8	0.5	0.4	0.5	0.8

TABLE B.14
Effects of Types and Amounts of NBC with TSPP at 0.1 and 0.2%
on Dough Properties

Type of NBC	TSPP (%)	Smoothness	Softness	Toughness	Press Rate	Peak Force (N)	EQ Force (N)	Gradient (N/mm)
Control	0.1	2.1	2.3	2.1	2.0	13.6	4.4	15.7
	0.20	1.9	1.9	2.0	2.0	13.1	4.2	15.0
	0.20	2.2	2.6	2.6	2.6	11.3	3.6	13.1
	0.20	1.8	1.8	1.8	2.0	10.3	3.4	11.9
BS180	3.0	1.9	2.0	1.9	2.0	18.3	5.7	21.3
	2.1	2.0	2.1	1.9	2.0	16.0	5.0	18.9
	1.2	2.0	2.0	2.1	2.1	16.9	5.1	20.1
	3.0	1.9	1.9	1.9	2.0	20.5	6.2	24.2
	2.1	2.0	2.2	1.9	2.0	16.6	5.2	19.3
	1.2	1.9	2.0	2.0	2.0	17.7	5.5	20.7
LSD		0.1	0.2	0.1	0.1	6.1	1.7	7.5

TABLE B.15
Effects of Types and Amounts of NBC with TSPP at 0.1 and 0.2%
on Tortilla Properties

Type of NBC	NBC (g/kg)	TSPP (%)	Diameter (cm)	Opacity (%)	Sp.Vol (cm3/g)	Height (cm)	Weight (g)	Moist (%)	pH (24 h)
Control	3.0	0.10	17.8	93.1	1.41	0.23	40.0	32.5	5.3
	3.0	0.20	18.0	93.5	1.25	0.20	41.0	33.1	5.3
	2.1	0.20	-	76.0	1.06	0.23	43.1	34.7	5.4
	1.2	0.20	18.1	70.5	1.08	0.19	44.7	33.0	5.4
BS180	3.0	0.10	18.4	94.8	1.41	0.22	42.0	33.1	4.2
	2.1	0.10	18.2	90.8	1.31	0.21	40.8	32.0	4.2
	1.2	0.10	18.3	75.8	1.13	0.17	40.5	33.0	3.5
	3.0	0.20	18.4	95.8	1.42	0.22	40.1	33.1	4.3
	2.1	0.20	18.1	89.8	1.30	0.21	40.6	33.1	5.3
	1.2	0.20	18.0	72.3	1.23	0.19	40.4	33.0	3.5
LSD			0.3	7.0	0.1	0.01	1.5	0.8	0.1

TABLE B.16
Effects of Types and Amounts of NBC with TSPP at 0.1 and 0.2% on Rollability Score (RS) and Quality Index (QI)

Type of NBC	NBC (g/kg)	TSPP (%)	4 day		8 day		12 day		16 day		20 day		24 day	
			RS	QI	RS	QI	RS	QI	RS	QI	RS	QI	RS	QI
Control	3.0	0.10	5.0	658.1	4.1	536.3	4.8	631.7	3.5	457.4	3.5	460.6	4.4	579.1
	3.0	0.20	4.6	538.2	3.9	457.3	4.2	497.1	3.7	431.9	3.4	401.6	3.9	460.2
	1.2	0.20	3.9	297.4	4.3	324.0	3.9	297.4	4.1	312.6	3.2	244.0	3.9	297.4
BS180	3.0	0.10	4.8	643.7	4.4	587.5	4.2	560.4	3.8	513.9	3.5	461.7	3.7	497.4
	2.1	0.10	4.8	566.7	4.5	539.2	4.1	486.1	3.9	470.0	3.9	462.3	3.9	460.8
	1.2	0.10	4.4	378.8	4.3	370.2	4.2	362.3	3.8	328.8	3.8	328.0	3.7	315.2
	3.0	0.20	4.6	628.4	4.4	592.4	3.9	528.8	3.8	518.8	3.6	488.0	3.6	494.8
	2.1	0.20	4.6	537.6	4.4	516.6	4.2	489.4	3.7	427.8	3.6	414.9	3.6	425.1
	1.2	0.20	4.6	411.4	4.1	367.0	4.3	377.3	4.1	362.5	3.9	346.3	3.6	317.4
LSD			0.2	91	0.3	98	0.2	73	0.3	78	0.3	98	0.5	125

TABLE B.17
Effects of Types and Amounts of NBC with TSPP at 0.1 and 0.2% on Objective Shelf Stability

Type of NBC	NBC (g/kg)	TSPP (%)	Force (N)						Distance (mm)					
			4 day	8 day	12 day	16 day	20 day	24 day	4 day	8 day	12 day	16 day	20 day	24 day
Control	3.0	0.10	6.3	6.8	6.7	6.9	6.9	7.5	2.1	1.8	1.6	1.4	1.4	1.3
	3.0	0.20	6.2	6.2	6.9	7.4	7.9	7.2	1.8	2.0	1.5	1.6	1.5	1.2
	1.2	0.20	7.7	8.4	8.5	7.9	9.0	9.7	2.3	1.7	1.6	1.6	1.5	1.4
BS180	3.0	0.10	6.3	6.9	7.2	7.6	7.3	7.8	1.8	1.6	1.5	1.5	1.3	1.4
	2.1	0.10	6.8	7.1	7.6	7.8	8.6	7.9	1.9	1.7	1.6	1.7	1.5	1.4
	1.2	0.10	8.0	8.1	8.3	8.6	9.2	8.8	1.8	1.7	1.5	1.5	1.4	1.4
	3.0	0.20	6.4	6.7	6.9	7.4	8.0	7.8	1.8	1.5	1.4	1.4	1.4	1.2
	2.1	0.20	7.3	6.9	7.7	7.6	8.6	7.9	2.0	1.7	1.6	1.7	1.5	1.6
	1.2	0.20	7.3	8.8	9.0	8.9	8.0	8.6	2.0	1.8	1.5	1.6	1.4	1.3
LSD			0.7	0.9	0.9	0.6	0.9	0.9	0.1	0.2	0.1	0.1	0.1	0.2

TABLE B.17 continued

Type of NBC	NBC (g/kg)	TSPP (%)	Work (N.mm)						Gradient (N/mm)					
			4 day	8 day	12 day	16 day	20 day	24 day	4 day	8 day	12 day	16 day	20 day	24 day
Control	3.0	0.10	11.0	10.4	9.2	8.3	7.9	8.2	2.1	2.2	2.4	2.3	2.2	2.6
	3.0	0.20	9.4	8.1	8.6	9.9	9.9	7.6	2.1	2.3	2.3	2.4	2.6	2.6
	1.2	0.20	15.0	12.3	10.8	10.6	11.8	11.5	2.5	2.9	2.9	2.6	2.9	3.3
BS180	3.0	0.10	9.4	9.1	9.1	9.4	8.5	9.3	2.1	2.3	2.4	2.5	2.5	2.6
	2.1	0.10	10.9	10.2	10.4	11.0	10.9	9.2	2.3	2.4	2.5	2.6	2.9	2.6
	1.2	0.10	12.3	11.7	10.5	11.1	11.2	10.3	2.7	2.6	2.8	2.8	2.9	2.8
	3.0	0.20	9.8	8.6	8.0	9.0	9.3	8.2	2.2	2.3	2.4	2.5	2.6	2.7
	2.1	0.20	12.5	9.6	10.5	10.5	10.8	10.6	2.4	2.4	2.5	2.6	2.7	2.7
	1.2	0.20	12.2	13.4	11.9	12.0	9.7	9.3	2.6	2.9	3.1	2.9	2.7	2.8
LSD			1.7	1.9	1.7	1.5	1.5	2.1	0.3	0.3	0.3	0.2	0.3	0.2

TABLE B.18
Effects of Other Types and Amounts of NBC on Dough Properties

Type of NBC	NBC (g/kg)	Smoothness	Softness	Toughness	Press Rate	Peak Force (N)	EQ Force (N)	Gradient (N/mm)
Grade 2	6.0	1.8	2.0	1.8	2.0	21.2	7.8	22.7
	3.0	2.0	2.2	2.1	2.1	21.2	7.0	24.2
Grade 3	6.0	1.8	2.2	1.9	2.0	21.3	7.4	23.6
	3.0	1.9	2.0	1.9	2.0	21.9	7.4	24.7
Blend	6.0	1.8	2.1	1.9	1.9	16.5	6.0	17.8
	3.0	1.9	1.9	2.0	2.0	23.5	7.8	26.7
BS184	6.0	1.8	2.0	1.7	1.8	17.6	6.3	19.2
	3.0	1.9	2.0	2.1	1.8	21.0	6.8	24.1
BS193	6.0	1.9	2.1	1.6	2.2	14.7	5.0	16.4
	3.0	1.9	1.9	1.9	2.0	14.5	4.7	16.7
	1.5	1.9	1.7	1.7	2.0	15.0	4.9	17.1
BS195	6.0	1.9	2.1	1.8	1.8	24.0	8.2	26.9
	3.0	2.0	1.9	2.1	1.9	25.6	8.6	29.0
BS199	6.0	1.7	1.8	1.6	1.8	15.3	5.6	16.6
	3.0	1.8	1.9	2.1	1.9	17.0	5.7	19.2
HM50	6.0	1.8	2.0	1.8	2.1	16.3	5.3	18.7
	3.0	2.0	2.0	2.2	2.0	13.1	4.0	15.4
HM70	6.0	1.8	2.1	1.7	2.1	15.9	5.3	18.0
	3.0	2.0	2.0	2.0	2.2	11.1	3.6	12.8
LSD		0.7	0.9	0.8	0.8	12.5	4.1	14.4

TABLE B.19
Effects Other Types and Amounts of NBC on Tortilla Properties

Type of NBC	NBC (g/kg)	Diameter (cm)	Opacity (%)	Sp.Vol (cm3/g)	Height (cm)	Weight (g)	Moisture (%)	pH (24 h)
Grade 2	6.0	17.4	97.2	1.62	0.30	40.9	31.4	5.1
	3.0	17.5	88.4	1.45	0.25	42.2	31.8	4.9
Grade 3	6.0	17.6	96.7	1.57	0.27	41.5	31.7	5.1
	3.0	17.6	94.0	1.52	0.26	41.9	30.2	5.0
Blend	6.0	17.6	97.9	1.77	0.29	39.4	31.0	5.2
	3.0	17.5	84.8	1.49	0.25	41.2	32.7	5.0
BS184	6.0	18.5	97.8	1.74	0.26	39.9	32.9	5.3
	3.0	17.6	90.0	1.52	0.24	40.4	32.0	5.1
BS193	6.0	18.1	77.3	1.35	0.22	41.8	32.7	5.3
	3.0	18.0	65.5	1.27	0.20	40.1	33.2	5.2
	1.5	17.7	32.3	1.10	0.18	40.6	32.0	5.2
BS195	6.0	17.7	89.7	1.48	0.24	40.3	31.2	5.2
	3.0	17.8	77.5	1.41	0.23	39.8	30.8	-
BS199	6.0	18.3	97.5	1.78	0.26	38.2	32.7	5.2
	3.0	17.9	93.8	1.60	0.25	39.1	32.1	5.1
HM50	6.0	18.3	82.9	1.44	0.23	42.7	32.7	5.4
	3.0	18.2	72.7	1.29	0.20	41.3	32.5	5.4
HM70	6.0	18.0	73.3	1.28	0.20	40.9	31.8	5.2
	3.0	18.4	57.5	1.23	0.19	40.0	32.5	5.1
LSD		0.5	18.3	0.2	0.03	15.8	3.7	4.0

TABLE B.20

Effects of Other Types and Amounts of NBC on Rollability Score (RS) and Quality Index (QI)

Type of NBC	NBC (g/kg)	4 day		8 day		12 day		16 day		20 day		24 day	
		RS	QI	RS	QI	RS	QI	RS	QI	RS	QI	RS	QI
Grade 2	6.0	4.5	708.8	3.7	584.3	3.4	527.5	3.7	584.3	3.2	502.6	3.1	492.2
	3.0	5.0	639.4	4.6	584.0	4.4	561.1	4.2	532.3	3.5	447.6	3.5	447.6
Grade 3	6.0	4.8	723.3	4.2	642.4	4.1	623.9	3.8	571.0	4.1	618.9	2.9	440.4
	3.0	4.7	668.4	4.6	661.8	4.6	650.8	3.8	544.1	3.6	510.2	3.5	492.4
Blend	6.0	4.6	795.6	4.0	696.1	3.9	672.8	3.6	618.3	3.3	562.1	2.5	426.6
	3.0	4.6	577.6	4.6	584.9	4.3	547.6	3.7	462.9	3.2	400.8	4.0	505.0
BS184	6.0	4.1	702.8	3.4	570.7	3.8	651.7	3.0	511.1	2.9	494.1	3.1	523.9
	3.0	5.0	679.7	4.6	626.1	3.9	528.6	4.1	561.1	4.0	542.9	3.4	460.8
BS193	6.0	4.0	412.4	3.4	349.7	3.6	378.4	3.3	339.3	3.7	381.1	3.9	404.5
	3.0	5.0	416.6		0.0	3.8	316.6	3.7	304.1	4.3	354.1	3.7	304.1
	1.5	4.8	171.3	4.7	166.5	4.7	167.1	4.7	167.7	4.4	154.7	3.9	139.3
BS195	6.0	4.2	559.2	3.9	519.3	3.3	432.7	3.4	454.9	3.1	416.1	2.8	372.8
	3.0	4.4	479.9	4.4	474.4	4.5	493.5	3.8	417.2	3.6	397.0	3.5	381.7
BS199	6.0	4.7	816.1	3.3	564.3	3.8	655.5	3.7	642.5	3.7	633.8	3.5	599.0
	3.0	5.0	744.3	4.5	678.1	4.1	620.0	3.8	562.0	4.1	616.9	3.1	462.0
HM50	6.0	4.4	517.9	3.8	446.5	3.5	416.7	3.3	386.9		0.0	3.3	386.9
	3.0	4.9	459.1		0.0	3.5	327.9	3.4	313.9	3.5	327.9	3.2	295.1
HM70	6.0	4.7	434.8	4.8	448.8	3.5	327.3	3.5	327.3	4.3	397.4	3.3	303.9
	3.0	5.0	353.1		0.0	4.5	317.8	3.3	229.5	4.0	282.5	3.8	264.9
LSD		0.6	210	1.0	153	0.8	130	0.8	153	0.9	216	0.9	197

TABLE B.21
Effects of Other Types and Amounts of NBC on Objective Shelf Stability

Type of NBC	NBC (g/kg)	Force (N)						Distance (mm)					
		4 day	8 day	12 day	16 day	20 day	24 day	4 day	8 day	12 day	16 day	20 day	24 day
Grade 2	6.0	6.2	7.1	7.0	7.5	6.4	7.3	2.0	1.8	1.5	1.5	3.0	1.5
	3.0	6.2	6.9	7.0	7.4	7.0	8.3	2.1	1.8	1.5	1.4	1.5	1.6
Grade 3	6.0	6.1	6.8	6.7	6.9	7.3	7.8	1.9	1.8	1.4	1.4	1.3	1.5
	3.0	6.2	6.9	7.0	7.7	7.3	7.7	1.8	1.6	1.5	1.4	1.6	1.5
Blend	6.0	6.2	6.7	6.8	7.0	7.3	7.3	1.9	1.6	1.5	1.5	1.3	1.4
	3.0	6.2	6.9	7.1	7.4	7.2	8.1	1.8	1.6	1.4	1.4	1.4	1.3
BS184	6.0	5.4	7.6	6.6	6.5	6.5	7.0	1.7	1.5	1.5	1.2	1.1	1.3
	3.0	5.7	6.5	6.5	7.8	6.9	8.1	2.0	1.6	1.4	1.3	1.3	1.3
BS193	6.0	6.7	6.5	7.8	8.2	7.1	8.8	1.8	1.4	1.3	1.3	1.0	1.1
	3.0	6.5	-	7.8	7.9	8.5	8.4	2.1		1.5	1.2	1.1	1.2
	1.5	7.6	7.8	8.2	8.1	8.3	7.8	1.8	1.6	1.4	1.5	1.4	1.3
BS195	6.0	6.5	7.3	7.7	8.1	7.6	8.3	1.6	1.5	1.5	1.4	1.4	1.3
	3.0	5.6	6.7	8.1	6.9	6.6	8.4	1.8	1.7	1.7	1.5	1.1	1.4
BS199	6.0	5.3	7.5	5.8	6.5	5.4	6.5	1.7	1.7	1.3	1.3	1.2	1.2
	3.0	6.4	6.9	7.1	7.3	7.0	7.7	2.0	1.5	1.5	1.5	1.3	1.3
HM50	6.0	6.8	6.2	9.4	10.0		10.0	1.9	1.4	1.5	1.4		1.1
	3.0	7.5	-	7.2	8.0	6.9	8.5	2.0		1.3	1.4	1.2	1.3
HM70	6.0	6.8	7.6	8.1	9.3	9.9	10.2	1.8	1.4	1.5	1.6	1.2	1.4
	3.0	7.9	-	7.4	9.8	8.9	8.9	2.2		1.6	1.3	1.2	1.5
LSD		1.6	1.0	1.4	1.4	1.5	1.6	0.4	0.4	0.3	0.4	0.4	0.5

TABLE B.21 continued

Type of NBC	NBC (g/kg)	Work (N.mm)						Gradient (N/mm)					
		4 day	8 day	12 day	16 day	20 day	24 day	4 day	8 day	12 day	16 day	20 day	24 day
Grade 2	6.0	10.4	10.5	8.8	9.9	8.8	9.0	2.0	2.3	2.3	2.3	2.2	2.7
	3.0	11.3	10.4	9.3	8.5	9.0	11.1	2.0	2.2	2.2	2.2	2.2	3.3
Grade 3	6.0	9.9	10.5	8.1	8.3	8.3	10.1	2.0	2.2	2.1	2.2	2.4	2.9
	3.0	9.4	9.5	9.0	9.2	9.7	9.7	2.1	2.3	2.3	2.5	2.4	3.1
Blend	6.0	10.6	9.5	8.6	8.8	8.3	8.5	2.3	2.2	2.2	2.3	2.4	2.8
	3.0	9.6	9.9	8.6	8.8	8.5	8.8	2.1	2.3	2.3	2.4	2.2	3.2
BS184	6.0	7.8	9.6	8.4	6.9	6.1	7.6	1.9	2.5	2.2	2.1	2.1	2.2
	3.0	9.2	9.0	7.8	8.4	7.7	9.3	2.0	2.2	2.1	2.5	2.2	2.9
BS193	6.0	10.4	7.8	8.7	9.5	6.3	8.4	2.2	2.1	2.4	2.6	2.1	2.5
	3.0	11.3		9.7	8.2	8.0	8.9	2.1		2.5	2.5	2.6	2.5
	1.5	11.7	10.1	9.8	10.0	9.6	8.5	2.5	2.8	3.0	2.9	2.6	2.6
BS195	6.0	9.8	9.7	9.7	9.7	9.0	9.2	2.1	2.4	2.5	2.6	2.5	3.1
	3.0	8.6	9.4	11.5	8.7	6.1	9.9	1.8	2.3	2.6	2.4	2.1	3.5
BS199	6.0	7.6	11.0	6.4	7.3	5.6	6.5	1.8	2.3	1.7	2.0	1.4	1.9
	3.0	10.7	9.1	9.1	9.0	7.8	8.6	2.1	2.3	2.3	2.4	2.4	2.9
HM50	6.0	10.8	7.4	12.1	12.1		9.5	2.2	2.0	3.0	3.2		3.1
	3.0	12.8		8.0	9.5	6.8	9.5	2.4		2.4	2.6	2.5	2.7
HM70	6.0	10.5	8.9	10.6	12.4	10.0	12.2	2.3	2.7	2.6	2.9	3.0	3.1
	3.0	14.7		9.9	11.1	8.9	11.3	2.5		2.5	3.0	2.7	2.9
LSD		3.2	2.1	3.0	2.8	3.4	3.6	0.6	0.5	0.6	0.5	0.5	1.0

APPENDIX C

Fig. C.1. Measurement technique for height.

Fig. C.2. Measurement technique for diameter.

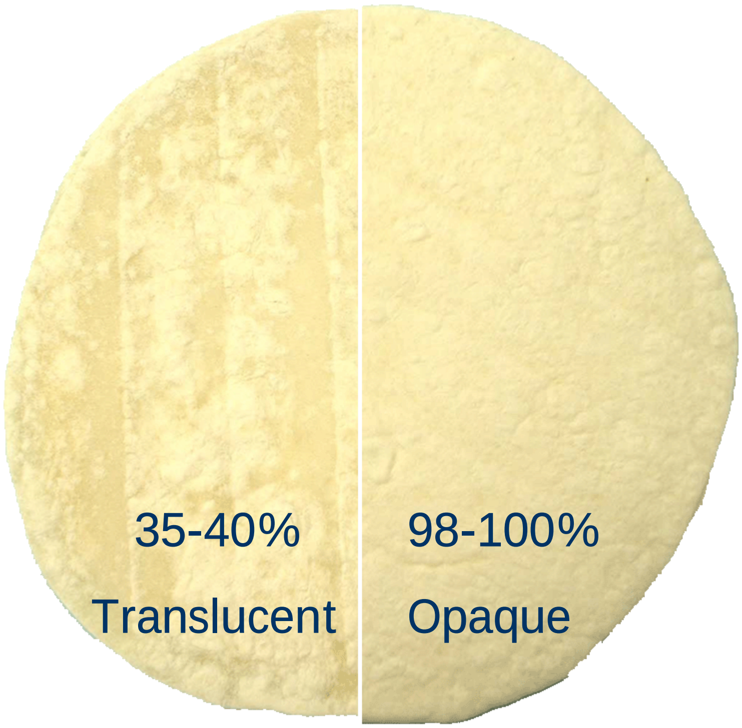

Fig. C.3. Opacity and translucency comparison.
Note: opacity was measured after 24 hr of tortilla production. Scale means 100% = opaque tortilla, 30% = translucent tortilla.

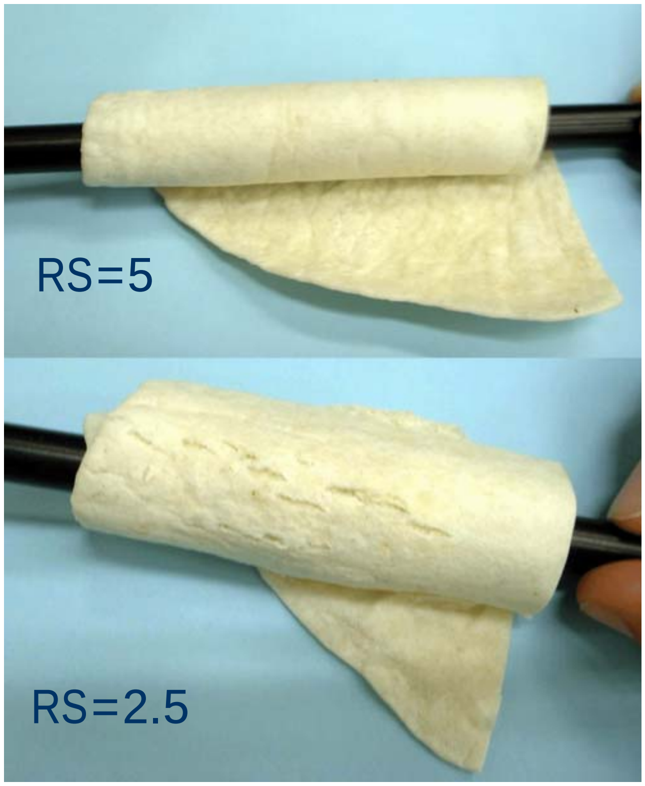

Fig. C.4. Rollability technique.
Note: rollability scale means 5 = excellent rollable tortilla, 1 = poor non-rollable tortilla.

VITA

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