An industry-relevant analysis of differences between products made with eggs and those made with egg content reduced by egg replacers.

Final Report of the project conducted by The Food Processing Center, University of Nebraska-Lincoln for The American Egg Board.

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This report was prepared by:

Dr. Wajira S. Ratnayake (Principal Investigator)

Research and Outreach Food Scientist
222 Food Industry Complex
The Food Processing Center
University of Nebraska-Lincoln
Lincoln, NE 68583-0930, USA

and

Mark A. Hutchison (Co-Principal Investigator)

Senior Manager - Food Innovation and Entrepreneurship
60D Filley Hall
The Food Processing Center
University of Nebraska-Lincoln
Lincoln, NE 68583-0930, USA

The Advisory Board Members

Dr. Glenn Froning

Professor Emeritus

Department of Food Science and Technology

University of Nebraska-Lincoln

Craig "Skip" Julius

Sterling Consultants

Aurora, OH

Dr. Erika B. Smith

Principal Scientist

TCM – Dairy and Eggs, General Mills

Minneapolis, MN

Eric Sparks

Director of Product Development

Park 100 Foods, Inc.

Tipton, IN

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Wajira S. Ratnayake (Principal Investigator)
Mark A. Hutchison (Co-Principal Investigator)

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The Food Processing Center
143 Filley Hall
University of Nebraska-Lincoln
Lincoln, NE 68583-0930, USA

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Executive Summary

Egg is a main ingredient traditionally used in many products. Its role in baked products, to provide certain product properties, is particularly important due to its ability to provide multiple functionalities, including, but not limited to, emulsification, coagulation, foaming, solubility, and creating the structure of the product.

Although egg's importance, as an ingredient with many functionalities, in various products is well known, a variety of reasons - mainly ingredient price and cost of production concerns - often encourages commercial food manufacturers to use other ingredients in place of egg in product formulations. Such ingredients are commonly known as "egg replacers" or "egg substitutes".

According to market information, commercially available egg replacers tend to gain market share and penetrate into product lines mainly due to economic reasons. However, raw material handling, storage during the production process, and allergy issues may also play a role in this. Therefore, food manufactures are often faced with trade-offs when selecting relevant ingredients for a particular product.

Based on analyzing product volumes for product sold in U.S. food stores, drug stores, and mass merchandisers, and input from the project advisory board, muffins, yellow cake, cookies, and waffles were selected as products to study in this project.

The objective of this study was to investigate the effects of egg and egg replacers, as functional ingredients in the product formulations, on the quality of the four products selected; muffins, yellow cake, cookies, and waffles. Cost comparisons for each product, for different product formulations studied, were also conducted using pricing information available at the time of ingredient purchase.

Key findings:

- For most products, completely substituting egg with egg replacers would result in unacceptable final product quality. Most egg replacers failed to produce acceptable quality products at 100% egg replacement, as observed in this study.

- Egg, when used as an ingredient, provides characteristic and unique product properties that would not be obtainable by using other ingredients, such as soy flour, whey protein, and gums, etc.

- Partially substituting egg with commercially available egg replacers would enable producing acceptable quality products, with some compromises in specific product properties, which may or may not be readily detectable by consumers.

- Using liquid egg in most formulations generally allows proper mixing and hydration of solids in the ingredient mixture. This not only reduces the time and energy required for the production process, but also results in desired quality in the end products.

- Using soy-based egg replacers in baked product formulations, such as muffins and cakes, might result in unacceptably high levels of off flavors in the final products.

- Some commercial egg replacers, even when used to partially replace egg in the formulations, severely affect the product texture, resulting in unacceptable physical and sensory properties.

- The economics of using egg replacers may depend on the specific product formulation. Sometimes, as observed in this study, using egg replacers would be relatively more expensive compared to using egg, either in dry or liquid form, in the formulation.

Chapter 1: Introduction and Background

Eggs and egg-based food ingredients are commonly used in the production of cakes and sweet baked goods. Eggs are essential for desirable volume, texture and color in food products because of unique foaming, solubility, emulsification and coagulation properties (Pyler 1973). For commercial food manufacturers, eggs are commonly available in the forms of liquid, frozen, or dried eggs. White and yolk fractions are also available in both frozen and dried forms. Modified egg ingredients, such as sugared whole eggs, sugared yolk, etc. are also being used extensively by the baking industry (Pyler 1973).

Eggs are used in baked foods for several important reasons; functionality as an ingredient (in binding, leavening, tenderizing, and emulsifying the mixtures), flavor, color, and food value (Pyler 1973). Nutritionally, egg is considered one of the best foods in terms of "wholesomeness". The functional properties of egg, when used as a food ingredient, come from its unique composition. Egg contains many important nutrients, such as essential amino acids, and important fatty acids, which have been proven to be functional nutrients. The compositions of egg components and whole egg are given in Table 1.1 (Nys and Sauveur 2004).

Eggs and egg ingredients, sometimes, would contribute to, as much as, 50% of the total ingredient cost of the product. In order to reduce costs, food manufacturers have attempted to partially or completely replace eggs with alternatives, which are known as either egg-replacers or egg-extenders, in food products. In the early 1940's, a boom in egg substitutes and extenders was seen in the market because of egg supply shortages during the World War II. These substitutes contained a range of substances: soy flour, wheat flour, starch, gums, casein, rye, whey, blood plasma, etc. These egg substitutes were then labeled as "egg extenders" because they did not accurately duplicate egg functionalities in the products. Thus the use of egg extenders was, mostly, justified by economic reasons, although some of the desirable product characteristics are compromised. It is important to note that the food industry's use of egg alternatives fluctuate based on the trends in egg pricing.

1.1 Egg replacers

Depending on the cost effectiveness, and functionalities of ingredients used, the food industry has adopted a variety of egg-substitutes (Lynn 1978; Chang 1980; Gilbertson and Porter 2001), or alternatives, for use in the products. These egg-substitutes could be categorized based on the major ingredients present in their formulations. There are two major categories of egg substitutes commonly used in the market today; protein concentrate-based, and gum/polysaccharide-based. Protein concentrate-based egg substitutes are prepared by using protein isolates either of plant (e g. soy protein isolates, wheat gluten proteins, etc.), or animal (e g. whey, plasma, etc.). Most commercially available egg substitutes are protein concentrate-based formulations, developed mainly by the ingredient manufacturers (Lynn 1978; Chang 1980; Foegeding and Mleko 2002). There is very little published information available on alternative protein-based formulations and products available to replace eggs in food products.

Protein-based egg-replacers

Whey

Whey protein-based egg-replacers are, probably, the most commonly available commercial egg-replacer category. Whey proteins could effectively mimic egg white's functionalities, especially high foaming capacity and foam stability, to a certain extent (Morr, Swenson et al. 1973; Haggett 1976). Whey is composed of several different proteins, the most common of which are β-lactoglobulin and α-lactalbumin. These two proteins make up roughly 70% of whey. Both of these proteins are highly functional due to their hydrophilic surfaces and hydrophobic centers. Both β-lactoglobulin and α-lactalbumin react with polar (water) and non-polar (oil & air) at the same time because of their physiochemical structure. These whey proteins' functionalities are exploited in various food applications. Partial denaturation of whey proteins, by controlled heat treatments, is one of the popular methods employed to modify protein functionality. Slight denaturation by heat causes proteins to partially unfold exposing hydrophobic regions, and the protein exposes sulfhydrl groups that can form sulfide bonds to increase protein-protein interactions. This slight heating has been shown to improve foaming capacity and stability (Phillips, Schulman et al. 1990; Zhu and Damodaran 1994; Arunepanlop, Morr et al. 1996; Foegeding and Mleko 2002; Pernell, Luck et al. 2002).

Both β-lactoglobulin and α-lactalbumin can act as emulsifiers because of greater flexibility and ability to reduce interfacial tension between water/oil interfaces. Despite the reported functional properties of whey proteins, and their similarities to egg functionality, whey proteins often fail to function exactly as egg proteins during baking (Pernell, Luck et al. 2002).

Laboratory research has predicted that "non-traditional", protein-based ingredients, such as bovine plasma and lupine protein concentrate, could be used, with some limitations, to replace egg in cakes (Johnson, Havel et al. 1979; Lee, Love et al. 1993; Arozarena, Bertholo et al. 2001). These findings, however, have not made significant impacts on commercial egg-replacer manufacturing, due to various reasons; the non-availability of technology to extract and utilize the ingredients from novel sources, lack of reliable information on the cost-effectiveness of scale-up operations, and detrimental effects on some critical aspects of final product quality.

Soy

Soy proteins have very good emulsification properties, specially in stabilizing fats and other ingredients in food formulations (Endres 2001). Soy proteins exhibit both emulsifying and gelling properties, which are very important in baked products manufacturing. Some reports indicate that soy proteins have better emulsifying properties compared to some other food proteins, such as casein and whey (Utsumi, Matsumura et al. 1997). Oftentimes, soy proteins (both isolates and flour) are used in combination with other proteins, such as whey, in egg based products, such as pound cakes, angel food cakes, devil's food cake, up to 100% of non-fat dry milk in the recipes (Endres 2001). In replacing egg with soy protein-based replacers, soy proteins are usually fortified with lecithin (to make "lecithinated" soy proteins) in order to improve the functional properties. The level of egg replacement by soy protein-based alternatives has been reported as much as 50% of total amount of whole egg used in the recipe. According to our experience (and as reported in the other sections of this report), at high levels of soy-based egg replacers use, however, some critical properties, including flavor/taste, of some products may be compromised. One of the main reasons for food manufacturers to select soy protein in place of egg in certain products is ingredient costs; soy is a relatively cheaper replacement for egg. From a nutritional standpoint, one of the arguments made in favor of soy proteins is that they provide some beneficial nutrients, such as isoflavones, which could be helpful in minimizing the risks of certain disease conditions (Jenkins, Kendall et al. 2002). To accomplish such goals, the daily diet should include certain minimum levels of such beneficial compounds. This leads to incorporation of high levels of soy proteins into products, which could be detrimental to product quality and flavor (Klein, Perry et al. 1995). Also, it has long been reported that the metabolisms of soy and egg proteins in the human body could be very different, and egg proteins could be of better quality compared to soy proteins (Steele, Sauberlich et al. 1947). Subsequent studies, however, have both agreed (Wilkinson, Tarnopolsky et al. 2007), and raised concerns (Young, Wayler et al. 1984) regarding similar conclusions on soy protein nutritional quality.

Wheat

Wheat proteins are primarily composed of two main fractions; water soluble albumins and globulins, and insoluble glutenins and gliadins, which serve uniquely different functions in baked goods. During batter mixing, glutenin and gliadins act together to form viscoelastic gluten network. The formation of this network is what gives baked products their unique properties. The gluten network entraps air and gas, expands during baking, and holds structure of finished product. It has been reported that the concentration of water soluble fraction of wheat proteins could decrease cake volume (Donelson and Wilson 1960), batter density, and other important physical properties in cakes (Oomah and Mathieu 1988). Generally, gluten proteins, in cake mixes, provide valuable functions, such as "protecting" the overall structure from collapsing, improving volume, and maintaining the uniform cell structure (Wilderjans, Pareyt et al. 2008). Nutritionally, egg proteins have been historically known to have superior protein value compared to wheat proteins (Mitchell and Carman 1924).

Gums

Gums are commonly used in a variety of commercial food products, specially for achieving and improving product-specific textural properties. Another advantage of using gums is that the improved dietary fiber contents in food products. This, however, is not considered a major reason to include gums in product formulations, compared to the textural attributes gums provide, especially considering the relatively small quantities of gums used in recipes. Studies have found that the addition of gums in to cake formulations could increase volume and improve texture (Lee, Hoseney et al. 1982), along with other important properties (Gómez, Ronda et al. 2007). Most these studies, however, have not used the gums to replace significant amounts of eggs in the formulations. Compared to the other ingredients in a food formulation gums are relatively more expensive. Therefore, the economics of production is effective only when the gums or gum-based replacer would improve or maintain the expected product quality without drastically increasing the cost of ingredients.

Xanthan gum is used in baked (and other) products, mostly in combination with other gums or ingredients to obtain the desirable effects. Among many different types of gums used in the food formulations, Xanthan gum could be the most widely used due to its solubility and stability in a wide range of pH levels and temperatures. Moreover, it acts synergistically with other types of gums, such as guar, and locust bean (Rocks 1971; Sanderson 1982). The Xanthan gum production process and properties, and its role in baked products have been well documented (Ghiasi, Hoseney et al. 1983; Challen and Tower 1993; García-Ochoa, Santos et al. 2000). Studies have been conducted to investigate the ability of Xanthan gum to replace egg in cakes. In general, it has been confirmed that Xanthan gum could stabilize the foam stability and structural integrity of cakes, when the gum is used in reduced amounts of egg formulations (Miller and Setser 1983; Miller and Hoseney 1990; Mott, Hettiarachchy et al. 1999). These studies, however, have not investigated the economics of using Xanthan gum or the effects of loss of critical product sensory properties of using lesser amounts of egg in the products.

Compared to Xanthan, other types of gums are used less commonly in baked product formulations. Guar gum is considered very useful because of its rapid hydration in cold water and good thermostability. Cakes containing small amounts of guar gum; 0.1% to 1.0%, have shown greater moisture retention, increased shelf life, and reduced crumbling tendency (Dogra, Hill et al. 1989). Guar gum has been found to increase foaming stability and decrease drainage (Conrad, Mast et al. 1993). Usually, guar gum is used in blends with Xanthan gum to obtain desired properties in commercial food product formulations.

1.2 Nutritional aspects of using egg as an ingredient in commercial food products

With the recent trends in more healthy, and nutritionally wholesome diets, much attention has been paid to eggs and their uses as common food ingredients. Although the nutritional aspects of eggs were not evaluated in this study, it is important to briefly note few important aspects of wholesomeness of egg as a food in daily diet and misconceptions about egg consumption on a regular basis. The use of egg, as a food ingredient, especially with the increase of new "health food" and related market interests, is increasingly becoming more and more important in making product health claims based on nutritional composition. Eggs contain many bioactive compounds, which are directly related to specific health benefits (Seuss-Baum 2007). A detailed egg composition summary is given in Table 1.1.

Eggs contain high levels of cholesterol compared to many other food ingredients. In the past, arguments have been made linking high cholesterol related health issues to increased consumption of eggs. These arguments, however, proved to be invalid by published research studies (Rainer Huopalahti 2007). Generally, it is accepted that eggs (specially yolk) contain high amounts of saturated fats and cholesterol. The contribution from eggs in the diet to the total LDL cholesterol/HDL cholesterol balance is still being debated (Dawber, Nickerson et al. 1982; Zanni, Zannis et al. 1987; Vorster, Beynen et al. 1995; Weggemans, Zock et al. 2001; Eckel 2008; Mutungi, Ratliff et al. 2008), with both positive and negative conclusions on role of egg in the human diet. It is important to note that the "net sum" of published literature does not conclusively indicate either positive or negative conclusions on role of egg in deciding the cholesterol "balance" in human. As many researchers agree (Kritchevsky and Kritchevsky 2000; Eckel 2008), it would be reasonable to mention that egg could be considered a normal part of the human diet, and the positive/negative effects on health by egg-containing diets could not be completely due to the egg portion of the diet.

1.3 Products selection

Multiple criteria were used in identifying and evaluating potential food systems for the study, including, but not limited to, relative presence of eggs in the food system, product sales volume, Industry Advisory Board recommendations, an assessment of food system vulnerability to egg replacers and consideration of data in a report prepared for the American Egg Board by Strategic Growth Partners, Inc. (SGP). The mission of the American Egg Board is to 'increase demand for egg and egg products on behalf of U.S. egg producers.' Therefore, in considering food systems for inclusion in the study, product volume of potential food systems played a key role in the selections.

It should be noted that products with a Standard of Identity (such as mayonaisse, egg noodles, etc.) as established by Section 401 of the Federal Food, Drug and Cosmetic Act, were not considered candidates for the study. Standards of identity define a given food product, its name, and the ingredients that must be used, or may be used, in the manufacture of the food (FDA 2009).

In the report prepared by SGP, "*Opportunity Assessment: Industrial Eggs & Egg Replacers"*, food manufacturers and foodservice use approximately 43 and 51 percent of eggs broken for further processing, respectively. Therefore, the selection of food systems for the study includes a consideration of volume in both channels. In terms of category analysis, data from the USDA's Economic Census indicated that volume in the bakery category was significant enough for it to be tracked separately. Furthermore, approximately 33% of eggs broken for further processing occurred in the bakery category, according to the SGP report. This analysis provided focus for the subsequent evaluation of potential products for the study.

The amount of egg used in a potential food system was assessed based upon eggs position in the ingredient statement. An empirical, but thorough, review of product ingredient statements in supermarkets was used to identify those food systems containing eggs and their relative presence in the product formulation. Additionally, this facilitated the identification of food systems that may have traditionally contained eggs in the formulation but now have been 'replaced' with egg extending ingredients. Less priority was given to these food systems due to the penetration of egg extending ingredients in those systems in the market.

This information, combined with significant input from the Industry Advisory Board and Food Processing Center food scientists, was used to select food systems on which unit sales volume analysis would be conducted.

Units were identified as pounds of product. This unit sales volume analysis of the food system selection process was a key criterion for final product selection. For example, if a food system contained a higher amount of eggs but had low unit sales volume compared to another product with less egg in the formulation but high unit sales volume, preference was given to the high unit volume product. To assess product unit volume, supermarket scanner data (InfoScan™) was purchased from Information Resources, Inc. (Information_Resources_Inc. 2009). IRI does not track foodservice volume.

InfoScan™ is retail scanner information collected and reported by a sample of Food Stores, Mass Merchandisers, and Drug Stores on a national level. InfoScan™ data was purchased at the Category (e g. baking mixes), Subcategory (e g. muffin mixes), and Stock Keeping Unit (e g. Krusteaz Muffin Mix, Oat Bran, 14 oz. box) levels, as needed to compile volume for a food system under consideration. At the Category and Subcategory level, InfoScan™ data was purchased for the following food systems:

- Pastry/doughnuts
- Baked goods – refrigerated
- Dough/biscuit dough – refrigerated
- Pancake mixes
- Baking mixes
- Cookies
- Frozen breakfast food
- Frozen pies
- Pies and cakes, frozen sweet goods, except cheesecakes

At the Stock Keeping Unit (SKU) level, the following InfoScan™ data was purchased:

- Baking mixes
- Pancake mixes
- Frozen breakfast food
- Cookies

InfoScan™ data was purchased at the SKU level in order to identify targeted segments of the identified categories. The rationale for the specific InfoScan™ data purchased is detailed in each food system section of the report.

Table 1.2 shows the aggregated retail scanner data totals from food stores, drug stores and mass merchandisers (FDMX) for the food systems analyzed. It does not include volume occurring in foodservice applications; however, an estimation of food system use in foodservice applications was a significant part of the evaluation process with the Industry Advisory Board.

Muffins were unanimously selected as the first product after a preliminary analysis of the InfoScan™ data and discussion with the Industry Advisory Board, American Egg Board, and FPC project leaders during a project conference call in August 2009. The remaining product selections were made during a project conference call with the industry advisory board, American Egg Board, and FPC project leaders in October 2009. Final selections included muffins, frozen waffles, yellow cake, cookies, and, as a backup, angel food cake. A more detailed description of the product selection process for each of the selected food product is provided in the corresponding chapters of this report.

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Table 1.1. Composition of whole egg, egg yolk and white (in 100 g, without shell; adapted from (Nys and Sauveur 2004).

Nutrients	Egg White	Egg Yolk	Whole Egg[a]	CV (%)[b]
Proportion[c]	60	30.7	90.7	-
Energy content (kcal)	47	364	154	-
Water (g)	88.6	49	74.4	1.2
Protein (g)	10.6	16.1	12.3	4.7
Carbohydrates (g)	0.8	0.5	0.7	-
Ash (g)	0.5	1.6	0.9	4.6
Fat (g)	0.1	34.5	11.9	6.9
Triglycerides (g)	-	22.9	7.7	-
Phospholipids (g)	-	10.0	3.4	-
Cholesterol (g)	0	1.2	0.42	9.5
Lecithin (g)	-	7.2	2.30	-
Saturated fatty acids (g)	-	13.0	4.4	-
16:0 palmitic acid	-	7.3	2.5	21.4
18:0 stearic acid	-	2.5	0.86	23
Unsaturated fatty acids (g)		20.7	7.0	-
16:1 palmitoleic acid	-	1.1	0.4	-
18:1 oleic acid	-	12	4.1	-
18:2 linoleic acid	-	3.6	1.25	30.4
18:3 linolenic acid (n-3)	-	0.12	0.04	18
20:4 arachidonic acid (n-6)	-	0.6	0.2	40
20:5 EPA[d] (n-3)	-	0	0	-
22:6 DHA[e] (n-3)	-	0.4	0.15	-
Essential amino acids (mg)				
Histidine	-	-	-	-
Isoleucine	240	410	290	-
Leucine	560	870	660	-
Lysine	880	1,390	1,040	-
Methionine + Cystine	660	1,170	820	-
Phenylalanine + Tyrosine	670	660	640	-
Threonine	1,020	1,420	1,150	-
Tryptophan	470	850	590	-
Valine	170	240	190	-

[a]Egg without shell
[b]Coefficient of variation (Gittins and Overfield 1991)
[c]Proportion of whole egg including shell
[d]EPA = Eicosapentanoic acid
[e]DHA = Docosahexanoic acid

Table 1.2. InfoScan™ unit volume analysis of egg containing food items sold in U.S. food stores, drug stores, and mass merchandisers. Latest 52 weeks ending June 14, 2009.

Category	Sales (lbs)
Cakes	485,556,510
Cookies (soft)	346,656,498
Cookies (all)	1,244,925,000
Pancakes/waffles	313,012,960
Pies/piecrust	253,520,369
Muffins	209,106,500
Angel food cake/pound cake	7,151,995

Chapter 2: Muffins

Introduction and Background

Muffin is a popular breakfast food and approximately 91% of the bakeries in the United States sell muffins. Most retail and food service bakers make their own muffins using in-house formulas or pre-mixes (AIB_International 2009). Therefore, the selection of ingredients and formulas vary slightly depending on the manufacturer. Fresh muffins has the largest market share, well exceeding frozen and refrigerated muffins sold in the United States. Most manufacturers often tend to make different varieties of muffins; blueberry, bran, chocolate chip, cranberry, and lemon-poppy are the most commonly available variations (AIB_International 2009).

As indicated in Table 2.1, Food Stores, Drug Stores and Mass Merchandisers combined unit volume of muffins was approximately 209 million pounds of product (Information_Resources_Inc. 2009). This is an aggregated number that includes all products in the following categories: muffin mixes, prepared muffins, frozen muffins, and refrigerated muffins. Individual totals for each of these categories are also shown in Table 2.1. An additional volume consideration was muffins' growth and presence in foodservice at hotels, fast casual restaurants, such as Panera Bread, and coffee houses. In a review of ingredient statements at Omaha/Lincoln, NE supermarkets, almost all muffin mixes were found to contain eggs with some having a combination of eggs and gums. Input from the Industry Advisory Board of this project indicated that, while egg replacers have not significantly penetrated muffin formulations yet, it was a food system that many product developers were looking at in this regard. This fact also made muffins a key target for the study.

Information on muffins, especially related to the functionalities of egg and egg-substitutes, is not commonly available in the published literature. With the recent trends, mainly governed by economic reasons, in replacing egg with egg-replacers in muffin formulations, it is important to investigate and understand the role of egg and the consequences of substituting egg with egg-replacers in muffins on product quality characteristics. The goal of this study was to evaluate the sensory and functional properties of muffins made with eggs and egg replacers. An economic analysis of using egg and egg replacers in muffin manufacturing was also performed.

Materials and Methods

Ingredients

Muffin samples were prepared from all purpose flour (Gooch Milling and Elevator Co., Lincoln, NE), cake flour (ConAgra Inc., Omaha, NE), sugar (United Sugars Co., Minneapolis, MN), buttermilk powder (SACO Foods, Inc., Middleton, WI), baking powder (Caravan Ingredients, Lenexa, KS), guar gum (TIC Gums, Baltimore, MD), soybean oil (ConAgra Inc., Omaha, NE), vanilla extract (Custom Blending Inc., Fort Collins, CO), salt (Cargill Inc., Minneapolis, MN), water and liquid whole egg or dry whole egg (Michael Foods, Minnetonka, MN) or a combination of dry whole egg and egg replacers. Detailed information on these ingredients is available in Appendix 2.A.

Egg replacers

Three egg replacers, designated as replacer 1 (R1), replacer 2 (R2) and replacer 3 (R3), representing a broad range of ingredient make-up and specific to bakery applications were used. The commercial identifications/names of these ingredients are not revealed here for obvious reasons. The ingredients of these egg replacers, as provided by suppliers, are shown in Table 2.2. The nutritional information of egg replacers provided by suppliers is provided in Table 2.3.

Sample preparation

Five formulations, (a) dry whole egg, (b) liquid whole egg, (c) R1 (25% dry whole egg + 75% Replacer 1), (d) R2 (25% dry whole egg + 15% Replacer 2 + 60% w/w water, as a fraction of total dry egg used, per ingredient manufacturer's guidelines), and (e) R3 (50% dry whole egg + 50% Replacer 3) were used in this study. The amounts of the ingredients used in these formulations are given, in detail, in Table 2.4.

Sugar, buttermilk powder and dry whole egg (if present in the formulation) were mixed using a paddle in a mixer (Model K45, Hobart manufacturing Co., Troy, OH) for 30s at speed 1 (mixing was stopped momentarily after 15s of mixing to scrape sides of the bowl). The rest of the dry ingredients (all purpose flour, cake flour, baking powder, guar gum, and salt and egg replacer, if included in the formulation), were then added and mixed for additional 30s at speed-1. The sides of the bowl were scrapped with a spatula and the liquid ingredients; water, vegetable oil, liquid egg (if present in the formulation), and vanilla extract, were added to the blend and mixed for 30s at speed-1, while sides of the mixing bowl was scraped and added to the mix after 15s. At the end of mixing, the paddle and sides of the mixing bowl were scraped thoroughly and added to the batter. Each paper muffin cup (Reynolds Food Packaging, Richmond, VA), placed in a baking tray (Recipe Right®, Wilton Industries, Woodridge, IL), was filled with 62.4-62.6g of prepared batter. The initial weights of the trays with poured batter were recorded. The muffins were baked in a commercial reel oven (Model 4-26x56, Reed oven Co., Kansas City, MO) for 16min at 218.3°C (425ºF). The time between the end of mixing and placement of the muffin pan in the oven was kept constant for all samples. After baking, muffins were cooled in muffin pan for 5min, transferred on to cooling racks, and further cooled for 30min. The weights of baked muffins were recorded. The muffins were then packaged in plastic clamshells (Product SL36, Inline plastics corp., Shelton, CT). The muffins for each formulation were prepared thrice on different days with 40 muffins per batch (*i.e.* three independent replicates of 40 muffins each).

Basic physical properties

Muffin heights were measured using a digital caliper (Model CD-6" CS, Mitutoyo Corp., Japan). Moisture content of muffin samples stored for 1 and 5 days of production was determined according to AOAC method 945.43 (AOAC 1990).

Bake loss estimation

Bake loss (%) during baking was calculated as the ratio of weight loss during baking (weight after cooling to room temperature, on trays, was measured) to the initial weight of the batter. The weights of all baked muffins were used for this estimation.

Color analysis

The color of muffin crust was measured with a chromameter (Minolta CR-300, Konica Minolta, Inc., Ramsey, NJ) using CIELab L*, *a**, *b** color space. The chromameter was calibrated using a color standard supplied by the manufacturer. For each replicate, crust color was measured at three random areas and averaged. The crust of the muffin was gently cut off with a serrated bread knife to expose the crumb for color measurement. For each replicate of crumb, color was measured at two random points. The crust and crumb color analyses were performed on muffin samples stored for 1 day after production in order to match the conditions of samples used for sensory analysis.

Texture analysis

The textural characteristics of muffin crust and crumb were determined using a TA-XT2i texture analyzer (Stable Micro Systems Ltd, Surrey, UK). The crust texture analysis was performed using a 4mm needle probe (TA-54). Crust firmness was determined at three different points per replicate; center point and two side points, which were approximately 10mm apart from the center. Texture analysis program parameters were set as follows: pretest speed = 5mm/s; test speed = 1mm/s; posttest speed = 2mm/s; test distance = 5mm, and distance = 10mm. Crust texture analysis was performed on muffin samples stored for 1 day after production at room temperature. The crust of the muffin was gently cut off with a serrated bread knife to expose the crumb for texture measurement. Crumb texture measurement was performed by compressing twice using texture profile analysis (TPA) with pretest speed = 5mm/s; test speed = 1mm/s; posttest speed = 2mm/s; and distance = 10mm. Hardness (peak force during the first compression), work (area under peaks), cohesiveness (ratio of the positive force area during the second compression to that of first compression), and time between peaks (time difference between ends of peak-1 and peak-2) were determined (Bourne 1978). Crumb texture analysis was performed on muffins stored for 1 and 5 days after production, at room temperature.

Volume analysis

Bulk densities and volumes of muffin samples were determined using a laser scanning volume measuring instrument (Model BVM-L370LC, TexVoL Instruments AB, Viken, Sweden). Each muffin sample was placed on a FSPR1540-10 attachment on a 225mm shaft and scanned for 45s. The equipment was calibrated using a manufacturer supplied standard disk (100mm). Data were collected and processed using VolCalc software (version 3.2.3.10).

Sensory analysis

Whole muffins individually wrapped in plastic food wrap (Johnson & Sons, Racine, WI) and placed on coded white plates prior to serving. A total of 39 panelists participated in the sensory panels, which were conducted in two sessions. Panelists were provided with water (at room temperature) to clear their palates between samples. Five samples were served, one at a time, to each panelist. General appearance characteristics, texture, flavor/taste, off flavor and overall acceptability were evaluated using an attribute rating scale (Appendix 2.B).

Statistical analysis

A randomized complete block design (RCBD) was used. The analysis of variance (ANOVA) and Fisher's least significant difference (LSD) were calculated to determine significant effects at $p < 0.05$ among treatments. Three independent replicates of muffin samples (each replicate was made as a single batch, one batch per day) were produced. For a given replicate, color, texture, and volume analyses were performed on six randomly selected muffins, while muffin heights were measured in 20 samples. For the two sensory analyses, two independent batches of samples were produced within a day. SAS (Version 9.2, SAS Institute Inc., Cary, NC) was used for statistical analyses.

Cost comparison

The economics of using different ingredients were systematically compared using a financial comparison. As ingredients were sourced for each formulation, pricing data were obtained from respective suppliers. In the food industry, bracketed pricing (*i.e.,* incrementally higher discounts for buying in volume) is frequently used. For the purposes of this project, pallet pricing was used for all egg and egg substitute products. Formulations that were documented during the sample preparations, with exact quantities of each ingredient, were used as the basis for cost comparison.

Results and Discussion

It is generally known that the quality of muffins greatly depend on the ingredient composition or formula used. A good quality muffin is characterized as of symmetrical shape, with a golden brown color, rounded top, uniform cells in the crumb, tender and slightly moist in texture, could be easily broken apart, sweet taste, and with pleasant aroma, and aftertaste (Cross 2007). These "acceptable characteristics" however, would differ depending on the region, and culture (*e g.* Europe vs. Americas).

For the ingredient functionality studies, five different formulas of muffins were used; two "controls" using liquid whole egg, and dry whole egg, and three formulas containing different, commonly used commercially available egg replacers, in varying amounts (see "Material and Methods" section above for more details), which were determined by a series of preliminary studies. Three replacers R1, R2, and R3, (Table 2.2) were selected for this study to cover a broad range of ingredients make-up, and based on the commercially available, product specific, egg-replacer types. The replacers are not identified by their commercial names in this report, due to obvious reasons. Prepared muffins were kept at room temperature until analysis. Samples were also analyzed after five days at room temperature to detect product quality changes over time. For the sensory panels, muffins were prepared a day ahead of time stored, and served at room temperature.

A series of preliminary studies were conducted to determine the highest replacer levels that provide acceptable quality (appearance and flavor) products. None of the egg replacers used in this study could produce acceptable products at 100% (w/w) dry whole egg replacement. Therefore, following respective ingredient manufacturer's guidelines, a series of preliminary studies were conducted to determine the maximum levels of egg replacers that could be used in the formulations without considerably affecting product quality. Based on those preliminary studies, 75% w/w amounts were selected for R1 and R2 formulas, and 50% was used for R3 (Notes: These amounts were calculated based on dry whole egg amount in the formula. All three egg replacers were received in dry powder form).

The loss of weight during baking was estimated as "bake loss" for all formulas. The estimation of bake loss is an important aspect, especially if the products need to meet certain, weight related regulatory requirements, and also for economic reasons. In other words, a very high bake loss would result in greater production costs. This calculation estimates, basically, the loss of moisture and other "volatiles" during baking. There were significant differences in bake loss among the formulations; liquid egg, dry egg, and R2 yielded the lowest bake loss, while R1 and R3 resulted in higher bake losses (Table 2.5). The moisture contents of prepared muffins, at room temperature, after 1 and 5 days at room temperature were also determined. The moisture contents of muffins containing egg replacers, stored for a day at room temperature, were slightly higher than those of controls (dry and liquid whole egg) (Table 2.5). Although these are small variations, the differences in the moisture levels would have critical impacts on water activities and shelf-lives of the products.

Muffins made with dry whole egg had the highest mean height (Table 2.6). The lowest muffin height was observed for R1, which was statistically ($p>0.05$) not different from liquid whole egg. Although there are not set standards available for muffin height, when the five samples were compared, the appearance of muffins with greater heights were relatively more acceptable, in terms of their shapes (Fig 2.1, 2.2). The volume of muffins formulated with dry egg had the highest volume, and, correspondingly, lowest density. Liquid egg, R1 and R2 formulas were all comparable to each other in terms of volumes and densities (Table 2.6). In general, dry egg formula yielded muffins with greater volume per unit weight, which would be economically important.

The general appearance, specially color, of the product is an important attribute for consumers. Minor differences in the general color properties, however, are usually impossible to detect visually (Fig 2.1). Therefore, a more advanced color measurement technique was employed to determine colors of muffins made with different formulas. The color measurements were performed based on CIELAB, L*, *a**, *b** color space; L* value measuring black (0)/white (100), a* value measuring green (-)/red (+), and *b** value measuring blue (-)/yellow (+). The crust color values of five formulations are shown in Table 2.7. The crust colors of the muffins from two controls (liquid and dry egg) and R3 (whey protein containing replacer) were darker (lower L* values), and more yellowish (high *b** values) compared to R1 and R2 formulas. Soy flour-based (R1) and, fiber/gum-based egg replacer (R2) gave the highest L* values (lighter crust colors) among formulations. It should be noted that muffins made with R1 and R2 had slightly higher moisture contents relative to controls and R3 formulations. This could have resulted in less browning, due to less caramelization, etc., at the surface, creating a relatively lighter color.

This assumption was further supported by overall visual comparison (digital images) of muffins (Fig 2.1). Muffins made with liquid egg formula yielded more yellowish crust and crumb colors, which are desirable for the product. The least yellowish crumb color was produced by the R2 formula. All formulas produced whiter crumb colors compared to the liquid egg formula (Table 2.7). Generally speaking, the liquid egg containing formula produced better color properties in muffins.

Texture profile analysis results of crumbs for muffins stored for 1 and 5 days (after production) at room temperature (~23ºC) are shown in Table 2.8. The muffins were tested after one day at room temperature upon production to match the conditions under which the sensory panels were conducted. The maximum force of peak1, which represents hardness of the product, was highest for liquid egg formulation, followed by dry egg and R3 formulations. Out of the three egg replacers used in this study, whey protein concentrate based replacer (R3) had higher mean hardness, indicating the importance of protein in creating the appropriate food matrix properties contributing to product texture. However, it is not clear which protein containing ingredient, whey or dry egg (R3 contained both whey protein based replacer and dry egg), contributed to what extent towards this effect in the R3 containing muffins. The highest peak 2 force, and cohesiveness values were displayed by liquid egg formula muffins, indicating the importance of relatively unmodified egg proteins in establishing the structural integrity of baked muffins. The amount of work required to break the muffin matrix during texture profile analysis is potentially a function of the presence, amount, and type of protein; higher peak 1 areas were observed for liquid egg, dry egg, and R3 formulations (for Day 1).

Cohesiveness, the ratio of the area under the second compression peak to that of first compression, was higher for control formulations, suggesting that the muffins made with egg formulas were relatively more resistant to collapse during the first compression. This is further confirmed by longer times between the two peaks for egg-replacers containing muffins. Regardless of the formulation, storage has increased the general texture, *i e.*, hardness (measured by first peak force), of muffins by approximately 16.3% in dry egg, 19.3% in liquid egg, 19.5% in R2, 25% in R3, and 26.5% in R1. These increments in muffin matrix hardness could be attributed to starch retrogradation (*i e.*, staling), as well as other changes in structure over time.

It should also be noted here that the cohesiveness of the muffins decreased over the five days storage at room temperature indicating the loss of structural integrity of the crumb. The lowest cohesiveness was observed in R1, while the liquid egg formula had the highest measured cohesiveness value after five days storage time.

The crusts of muffins have very different textural properties compared to the crumb because of direct exposure to high heat and rapid moisture loss during baking. Therefore, the texture profiles of the crusts were analyzed separately. A single peak profile was used to analyze texture of the crusts because cohesiveness was not deemed to be an important parameter to estimate, due to the naturally hard nature of the crusts. Adhesiveness (*i e.,* negative work) was measured to determine the "sticky nature" of the top layer of the crust. The texture properties of the approximate geometric center and two randomly selected points between the center and periphery of the crust were analyzed (Table 2.9). The liquid egg formula produced muffins with generally acceptable adhesive properties; low adhesiveness in the center of the crust, and an acceptable level of adhesiveness in the other areas on the crust. The least hard crust texture was observed in R1 muffins and, generally, R1 muffins had inferior texture properties compared to those of other formulas (see the cross-section in Fig 2.2).

A visual/manual comparison of the crumb structures revealed that the cell distribution of all samples were acceptable, except for R1 (Fig 2.2). The R1 containing formula produced an uneven cell structure in the crumb and a more fragile (during manual handling and cutting) crumb matrix.

Muffins from each formula were prepared 24h prior to conducting the sensory panels, and they were kept at room temperature in plastic muffin storage cases. Sensory attributes of muffins evaluated by panelists per questionnaire given in Appendix 2.B. A total of 39 panelists participated in the sensory panels, which were conducted in two separate sessions.

The results of sensory analysis are summarized in Table 2.10. The R2 replacer produced the least desirable cap color, as well as internal crumb color. This could be due to the "less yellowish" and whiter color of R2 muffins (Table 2.7). Although the colors of the rest of the formulations were slightly different from each other (Table 2.7), they were not statistically different as perceived by the panelists (Table 2.10). Based on both the laboratory color analysis (colorimeter) and sensory analysis (human), it is reasonable to conclude that the liquid egg containing formula produced muffins with best color characteristics. The overall product appearance, mainly based on color/visual perception, was best for R3 containing muffins.

Muffins are generally expected to have slightly moist texture and mouth-feel (Cross 2007). Sensory analysis revealed that dry and liquid egg formulas produced relatively dry muffins whereas the egg replacers produced more "moist" muffins. As indicated previously, this sensory attribute may depend on the personal preferences as well as other factors, such as region and culture. The results observed in the sensory analysis on dryness/moistness closely correspond to the laboratory analysis of moisture (Table 2.5); dry and liquid egg formulas produced muffins with lower moisture contents. The overall texture acceptability, however, among samples was statistically the same (Table 2.10, $p>0.05$).

The flavor plays an important role in muffin quality and the product's overall acceptability from a customer's point of view. Egg flavor is expected from a typical muffin. In this sensory analysis, we collected customer/panelist responses for egg flavor, vanilla flavor, sweetness, off flavor, and aftertaste (Appendix 2.B). Egg flavor, vanilla flavor, and sweetness were statistically similar ($p>0.05$) for all formulas. The formula containing R1 (contains soy flour) produced muffins with the highest off flavor, least desirable overall flavor, and most intense aftertaste - which were all considered to be unfavorable for expected product quality. As a result, R1 muffins had the least overall acceptability (Table 2.10).

All ingredient pricing information was obtained at the time of purchase from respective ingredient manufacturers. All efforts were made to obtain pricing on the highest amount available to potential commercial muffin producers, in order to provide realistic pricing information and analysis. While some ingredients may be purchased in greater volume, others, especially some egg alternatives, may be purchased in less volume. Pallet pricing was selected not only to provide consistency across all formulations for comparison purposes but also to reflect industry level quantity buying. The cost of production analysis (Table 2.12) revealed that the R2 formulation had the lowest overall cost among the five formulations investigated in this study. The next lowest was liquid egg formulation. Dry whole egg formula is cost competitive with R1 and R3.

Conclusions

None of the egg replacers used in this study could produce acceptable quality muffins at 100% replacement, in place of egg. The highest level of any replacer that produced reasonably good quality products was 75% (w/w). Even at the optimized levels of egg replacers use there were significant differences in product quality characteristics, among the various formulas containing liquid whole egg, dry whole egg, and commercial egg replacers. Storing muffins for five days at room temperature caused changes in quality parameters. This study suggests that egg ingredients play a critical role in deciding the overall quality of muffins. At least a small amount of egg, as an ingredient, should be used along with egg-replacers to produce acceptable quality products. The choice of ingredients for commercial production, however, could depend on the level of acceptability as determined by both the product quality and economic factors at a given time.

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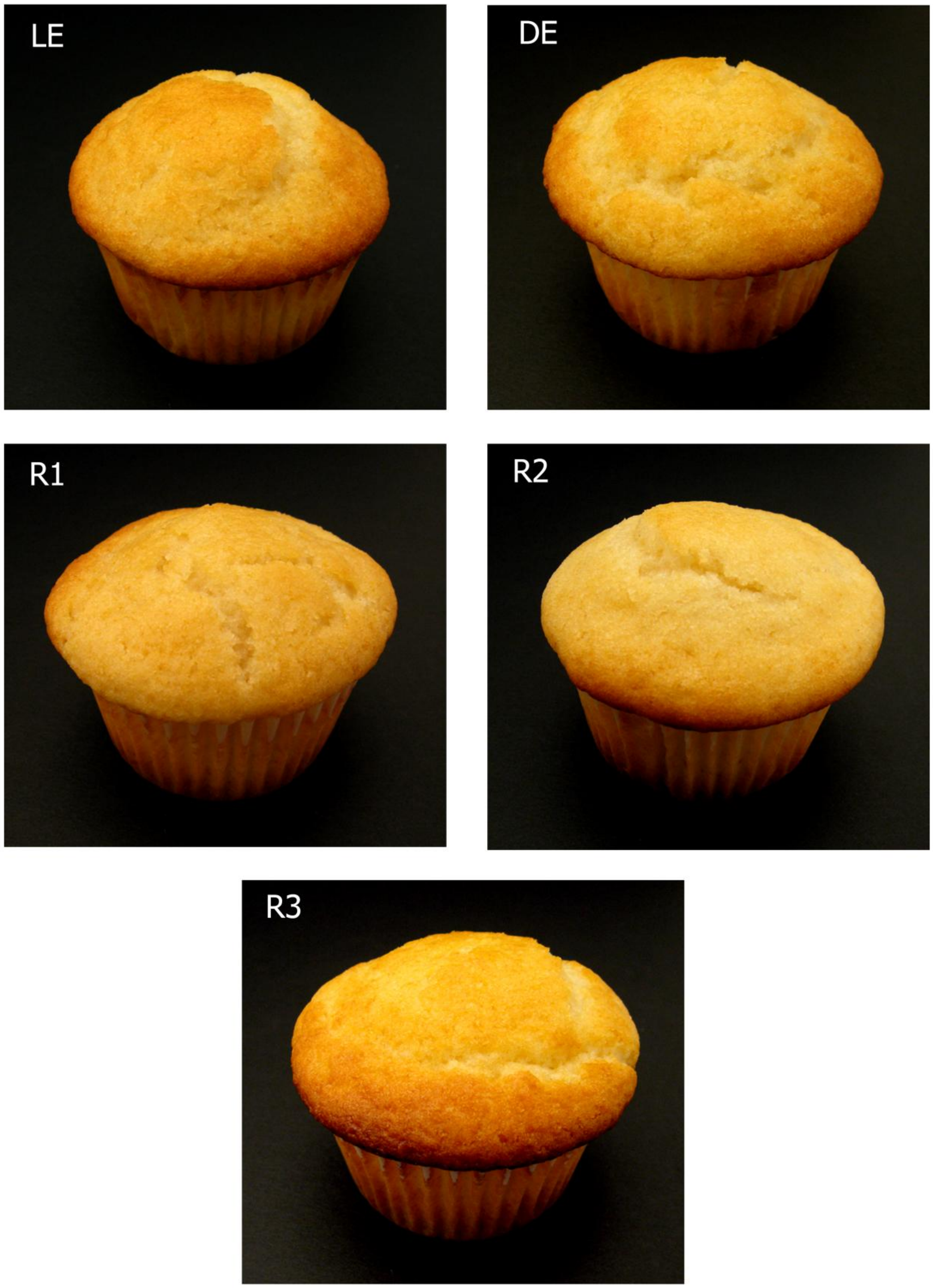

Fig 2.1. Representative samples of muffins prepared with egg ingredients and egg replacers. LE = Liquid whole egg, DE = Dry whole egg, R1 = Replacer 1, R2 = Replacer 2, and R3 = Replacer 3.

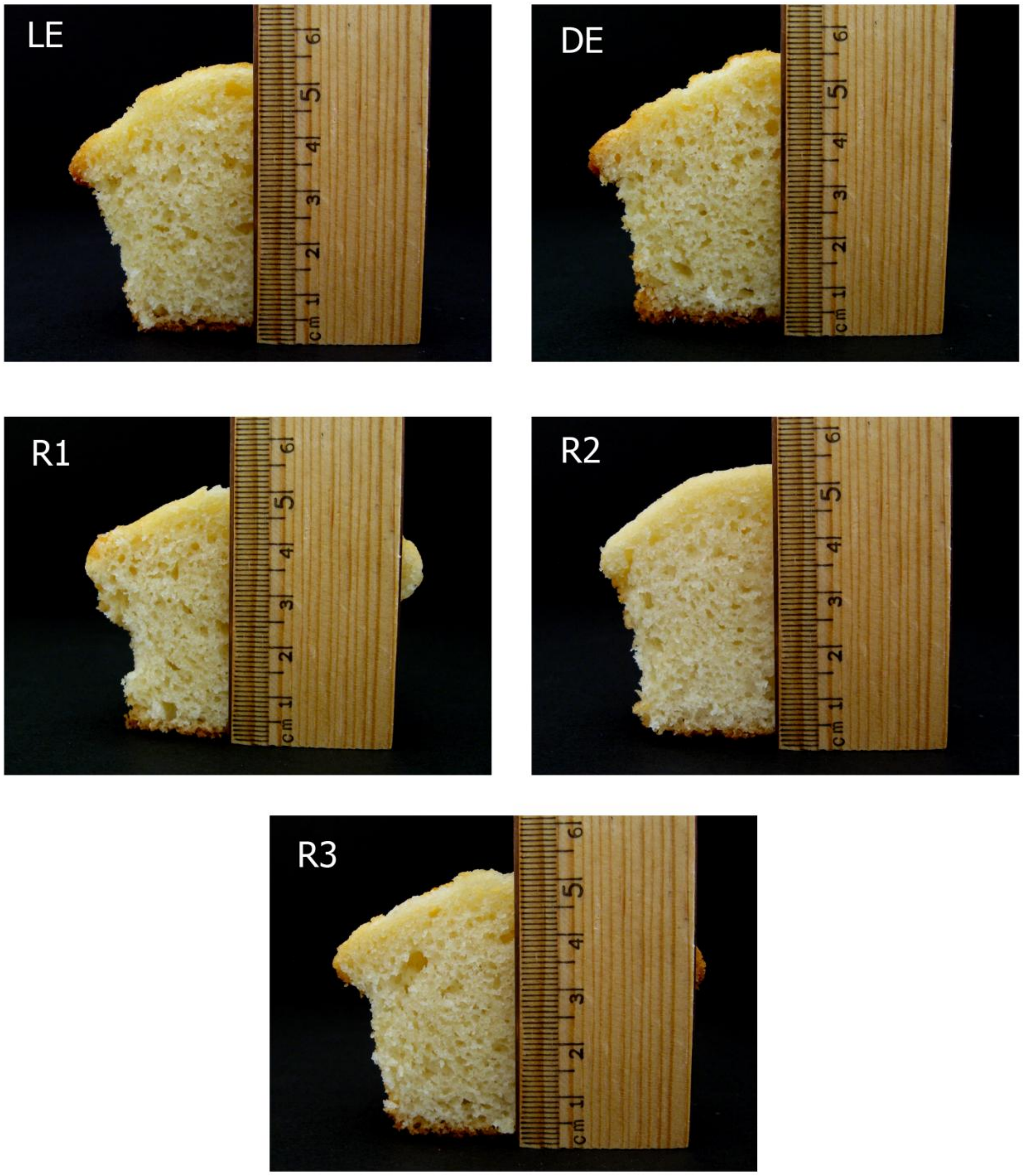

Fig 2.2. Height comparison of muffins prepared with egg and egg replacers. LE = Liquid whole egg, DE = Dry whole egg, R1 = Replacer 1, R2 = Replacer 2, and R3 = Replacer 3.

Table 2.1. InfoScan™ unit volume analysis of total U.S. muffins sold in food stores, drug stores, and mass merchandisers. Latest 52 weeks ending June 14, 2009.

Category	Sales (Pounds)
Mix – muffins	129,103,200
Regular muffins	74,310,450
Frozen muffins	5,677,175
Refrigerated muffins	15,675
Total	209,106,500

Table 2.2. Ingredients of egg replacers used to replace dry whole egg in muffins

Egg Replacer	Ingredients*
Replacer 1 (R1)	Roasted soy flour or soy flour, wheat gluten, corn syrup solids, algin or sodium alginate
Replacer 2 (R2)	Sugar cane fiber, Xanthan gum, and Guar gum
Replacer 3 (R3)	Whey protein concentrate (60% protein)

*Per ingredient statement provided by the manufacturer.

Table 2.3. Nutritional compositions of egg replacers used in this study

Component	R1	R2	R3
Total calories[a]	450	386	394
Total fat (g)	17	0.3	5.5
Saturated (g)	2.5	0	3.42
Mono unsaturated fat (g)	-	0	1.37
Poly unsaturated fat (g)	-	0	0.25
Trans fat (g)	-	0	0.13
Cholesterol (mg)	0	0	145
Carbohydrates (g)	32	95	29
Sugars (g)	17	0	26.9
Dietary fiber (g)	11	92	-
Protein (g)	43	1	57
Ash (g)	-	1	5
Moisture(g)	6	<5	3.5

[a] per 100 g of material

Table 2.4. Muffin formulation* with egg and egg replacers

Ingredient	Liquid Egg	Dry Egg	R1	R2	R3
Sugar	24.00	24.00	24.00	24.00	24.00
Powdered buttermilk	2.33	2.33	2.33	2.33	2.33
All purpose flour	22.68	22.68	22.68	22.68	22.68
Cake flour	7.56	7.56	7.56	7.56	7.56
Baking powder	1.55	1.55	1.55	1.55	1.55
Guar gum	0.05	0.05	0.05	0.05	0.05
Salt	0.83	0.83	0.83	0.83	0.83
Dry whole egg	-	2.61	0.65	0.65	1.31
Egg replacer-1	-	-	1.96	-	-
Egg replacer-2	-	-	-	0.39	-
Egg replacer-3	-	-	-	-	1.31
Water	18.00	25.82	25.82	25.82	25.82
Vegetable oil	12.38	12.38	12.38	12.38	12.38
Vanilla extract	0.20	0.20	0.20	0.20	0.20
Liquid whole egg	10.42	-	-	-	-
Total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*

*All numbers are % values (w/w).

Table 2.5. Bake loss and moisture levels* of muffins (%, w.b.) stored at room temperature for 1, and 5 days.

Formulation	Bake loss (%)	Day1 Moisture content (%)	Day 5 Moisture content (%)
Liquid egg	13.4ab	23.3cd	22.7b
Dry egg	13.5a	23.1d	22.7b
R1	13.1b	23.7b	23.5a
R2	13.6a	25.2a	23.8a
R3	13.2b	23.6bc	23.0b

*Means followed by the same letter, within the same column, are not significantly different (p>0.05).

Table 2.6. Heights, volumes, and densities* of muffins prepared with different formulations.

Formula	Height (mm)	Volume (cm^3)	Density (g/cm^3)
Liquid whole egg	51.1d	125.7c	0.45a
Dry whole egg	54.9a	133.8a	0.43c
R1	50.9d	124.9c	0.46a
R2	52.2c	124.8c	0.46a
R3	53.2b	129.6b	0.44b

* Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

Table 2.7. Color parameters[a] of muffins

	Crust (top)			Crumb		
Formula	L*	*a**	*b**	L*	*a**	*b**
Liquid whole egg	54.0b	3.9a	20.0a	64.4a	-2.6cd	13.0a
Dry whole egg	53.0b	3.6a	19.1b	62.6b	-2.7d	12.1b
R1	56.7a	2.3b	18.9b	63.1b	-2.1a	12.1b
R2	57.7a	0.4c	17.8c	63.3b	-2.3ab	10.8c
R3	53.6b	3.5a	19.3b	63.4b	-2.4bc	11.7b

[a]Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

Table 2.8. Texture profile parameters* of muffin crumbs stored for 1 and 5 days, at room temperature.

Egg/Replacer	Peak 1 force (g)	Peak 1 area (N*s)	Time between peaks (s)	Peak 2 force (g)	Peak 2 area (N*s)	Cohesiveness**
Stored for 1 day						
Liquid whole egg	1417.9a	27.2a	7.94cd	1152.9a	11.3a	0.41a
Dry whole egg	1231.1b	26.1a	7.90d	999.2b	10.5b	0.40b
R1	1141.8c	23.4b	8.90a	898.7c	7.9c	0.34e
R2	1062.2c	20.8c	8.687b	846.0c	7.7c	0.37d
R3	1307.45b	27.0a	8.05c	1052.2b	10.6b	0.39c
Stored for 5 days						
Liquid whole egg	1691.1a	35.3b	8.36cd	1315.0a	11.9a	0.34a
Dry whole egg	1431.3b	32.1b	8.24d	1114.1b	10.5b	0.33b
R1	1444.0b	32.4b	8.99a	1049.9b	8.6c	0.26e
R2	1269.7c	27.7c	8.76b	645.4c	8.0c	0.29d
R3	1644.9a	35.7a	8.46c	1266.9a	11.3ab	0.32c

*Means followed by different letters, within same column for each category, are not significantly different ($p>0.05$)

** Peak2 Force/Peak1 Force

Table 2.9. Texture profile parameters* of muffin crusts[a]

Egg/Replacer	Center			Sides		
	Peak force (g)	Work (Ns)	Negative work[b] (Ns)	Peak force (g)	Work (Ns)	Negative work[b] (Ns)
Liquid whole egg	46.8b	3.4b	-0.27a	61.5a	4.4ab	-0.35bc
Dry whole egg	53.8a	3.9a	-0.33b	62.2a	4.6a	-0.38c
R1	37.6c	2.7c	-0.31ab	43.5b	3.2c	-0.32ab
R2	40.1c	2.8c	-0.30ab	45.7b	3.3c	-0.31a
R3	46.2b	3.4b	-0.34b	57.9a	4.3b	-0.37c

*Means followed by different letters, within same column, are not significantly different ($p>0.05$).

[a] The crusts were separated from muffins and analyzed using Texture Analyzer. Samples were analyzed after keeping one day at room temperature.

[b] Negative peak height.

Table 2.10. Least means square values* of evaluated sensory parameters

Recipe	Cap color[1]	Internal color[2]	Overall appearance[3]	Dryness/ Moistness[5]	Overall texture[3]	Egg flavor[5]	Vanilla[5]	Sweetness[5]	Off flavor[5]	Overall flavor[3]	Aftertaste[5]	Overall acceptability[3]
Dry egg	9.09c	7.24a	9.87b	5.70a	7.45	7.19	6.75	7.08	5.96a	8.04b	6.10a	7.92a,b
Liquid egg	9.53c	6.91a	9.69b	5.35a	7.17	6.98	6.74	7.36	5.34a	8.37b	5.36a	8.33b
R1	7.57b	6.46a	9.72b	7.57c	7.46	6.48	6.12	6.95	7.24b	6.73a	7.23b	7.09a
R2	4.47a	4.89b	8.18a	8.44c	8.36	7.11	6.64	7.91	5.67a	8.48b	6.21a	8.14a,b
R3	10.94d	6.92a	10.77c	6.50b	7.97	6.60	6.87	7.39	5.80a	8.04b	5.42a	8.05a,b

*Means with the same letter, within the same column, are not significantly different ($p>0.05$).

[1]Where 0 = Light Beige/Tan and 15 = Golden Brown

[2]Where 0 = White and 15 = Light Yellow

[3] Where 0 = Very Undesirable and 15 = Very Desirable

[4] Where 0 = Very Dry and 15 = Very Moist

[5] Where 0 = Lacking and 15 = Intense

Table 2.11. Pricing information on the ingredients used in muffin formulations.

Ingredient	Price ($)	Per*	Price per lb ($)	Price per 100 lb ($)
Sugar	31.63	50 lbs	0.63	63.26
Powdered buttermilk	1.28	1 lb	1.28	128.00
All purpose flour	15.02	50 lbs	0.30	30.04
Cake flour	17.96	50 lbs	0.36	35.92
Baking powder	32.95	20 lbs	1.65	164.75
Guar gum	1.85	1 lb	1.85	185.00
Salt	10.81	25 lbs	0.43	43.24
Vegetable oil	44.14	30 lbs	1.47	147.13
Vanilla extract	11.97	pint	23.94	2,394.00
Water*	-	-	-	-
Liquid whole egg	0.55	1 lb	0.55	55.00
Dry whole egg	2.61	1 lb	2.61	261.00
Egg replacer 1	2.39	1 lb	2.39	239.00
Egg replacer 2	3.49	1 lb	3.49	349.00
Egg replacer 3	2.58	1 lb	2.58	258.00

*Pricing information was provided by ingredient manufacturers for this amount.

**Considered as part of utilities requirements in the production process.

Table 2.12. The ingredient and total cost comparison of the muffin formulations studied (all numbers represent pricing, in US $, for 100lb of muffins).

	Formulation				
Ingredient	Liquid egg	Dry egg	R1	R2	R3
Sugar	15.18	15.18	15.18	15.18	15.18
Powdered buttermilk	2.98	2.98	2.98	2.98	2.98
All Purpose flour	6.81	6.81	6.81	6.81	6.81
Cake flour	2.72	2.72	2.72	2.72	2.72
Baking powder	2.55	2.55	2.55	2.55	2.55
Guar gum	0.09	0.09	0.09	0.09	0.09
Salt	0.36	0.36	0.36	0.36	0.36
Vegetable oil	18.22	18.22	18.22	18.22	18.22
Vanilla extract	4.79	4.79	4.79	4.79	4.79
Water	-	-	-	-	-
Liquid whole egg	5.73	-	-	-	-
Dry whole egg	-	6.80	1.70	1.70	3.42
Egg replacer 1	-	-	4.68	-	-
Egg replacer 2	-	-	-	1.36	-
Egg replacer 3	-	-	-	-	3.38
Total	*59.43*	*60.50*	*60.08*	*56.76*	*60.50*

Appendix 2.A. Ingredients used in this study

Ingredient	Commercial name	Remarks	Company
All purpose flour		14% moisture	Gooch Milling & Elevator Co. (Lincoln, NE)
Cake flour	Pikes Peak® High Ratio Cake Flour	14% moisture	ConAgra Inc. (Omaha, NE)
Sugar	Fine Granulated Sugar	Cane sugar	United Sugars Co (Minneapolis, MN)
Buttermilk powder			SACO Foods, Inc. (Middleton, WI)
Baking powder	Caravan Ingredient Baking Powder 129306	<3.5% moisture	Caravan Ingredients (Lenexa, KS)
Guar gum	GuarNT®		TIC Gums (Baltimore, MD)
Soybean oil	Pure Wesson 100% Natural Vegetable Oil		ConAgra Inc. (Omaha, NE)
Vanilla extract	Rodelle Pure Vanilla Extract		Custom Blending Inc. (Fort Collins, CO)
Salt	Top-Flo® Evaporated Salt		Cargill Inc. (Minneapolis, MN)
Liquid whole egg	Easy Egg® Liquid Whole Eggs with Citric Acid		Michael Foods (Minnetonka, MN)
Dry whole egg	Dry Egg	Moisture 5% maximum	Michael Foods (Minnetonka, MN)

Appendix 2.B. Sensory attributes rating form used to evaluate muffins

Evaluation of Muffins

Name ______________________ Date __________________

You will be given 5 samples, one sample at a time. Please evaluate each sample for the following attributes. **Make a vertical line** on the provided horizontal line at the point that best describes your perception of the attribute. Each sample will have its own evaluation form.

Sample Code _____

Appearance:

Color
Light Yellow Dark Yellow

|____|____|

Visual Texture
Very Compact/Dense Very Airy/Fluffy

|____|____|

Overall Appearance Acceptability
Very Undesirable Very Desirable

|____|____|

Texture:

Very Dense Very Fluffy
|____|____|

Very Dry Very Moist
|____|____|

Stickiness (Sticks/adheres to the teeth/mouth)
Extremely Sticky Clears Quickly

|____|____|

Flavor:

Egg Flavor
Lacking Intense
|__________________________________|__________________________________|

Vanilla
Lacking Intense
|__________________________________|__________________________________|

Sweetness
Lacking Intense
|__________________________________|__________________________________|

Off Flavor
Lacking Intense
|__________________________________|__________________________________|

Overall Flavor Acceptability
Very Undesirable Very Desirable
|__________________________________|__________________________________|

Aftertaste:

Off Flavor
Lacking Intense
|__________________________________|__________________________________|

Overall Sample Acceptability

Very Undesirable Very Desirable
|__________________________________|__________________________________|

Comments:

Chapter 3: Yellow Cake

Introduction

As indicated in the Chapter 1 of this report, there are numerous reports in the published literature on using egg replacers and alternatives in cake formulations. These egg replacers include both traditional and non-traditional ingredients, and have been tested to obtain comparable properties/qualities to those of conventional (*i e.*, made using eggs) products. Generally, commercial egg replacers used for cakes include egg replacers made with whey protein, gums, and flours.

According to the market analysis data obtained for the product selection, cakes represented the second highest volume product in the analysis of InfoScan™ data (Information_Resources_Inc. 2009). With over 485 million pounds of product moving through food stores, drug stores and mass merchandisers in the U.S., the category warranted consideration. Additional insight provided by an Industry Advisory Board member regarding cake volume in foodservice applications further solidified its strong position as a candidate for the functionality study. Discussion among the project principals regarding the type of cake to select (chocolate, yellow, angel food, or pound), not only included discussions on the relative volume, but also considered egg's functional role and their vulnerability to egg replacers in each formulation. Chocolate cake was excluded based on the fact that strong chocolate flavor might mask the effects of egg replacers, thereby losing egg's true contribution to cake formulations.

The objective of this study was to evaluate the effects of egg and three selected commercial egg replacers on yellow cake product quality, sensory attributes, and cost of production.

Materials and Methods

Volume data from the InfoScan™ survey on cakes and related products are provided in Table 3.1. Overall cake volume is shown including data from each subcategory. Yellow cake products were screened using product descriptions in the SKU level data.

Ingredients

Yellow cake samples were prepared from wheat flour (Gold Medal All purpose Baker's High Yield cake flour, General Mills, Minneapolis, MN), sugar (United Sugars Co., Minneapolis, MN), shortening (All Purpose Shortening, Bunge Oils, St. Louis, MO), milk powder (ConAgra Inc., Omaha, NE), emulsifier (Solec 8160, Deoiled Enzyme Modified Soy Lecithin, Solae, St. Louis, MO), baking powder (Caravan Ingredients, Lenexa, KS), xanthan gum (Danisco USA Inc., New Century, KS), dextrose (Clintose Brand Dextrose, Archer Daniels Midland Co., Decatur, IL), corn starch (Cargill Inc., Minneapolis, MN), vanilla extract (Custom Blending Inc., Fort Collins, CO), salt (Cargill Inc., Minneapolis, MN), color (08038 regular bakers egg shade, Sensient Technologies Co., St. Louis, MO), water, and liquid whole egg or dry whole egg (Michael Foods, Minnetonka, MN) or combination of dry whole egg and egg replacers, as given in the Table 3.4.

Egg replacers

Three egg replacers, designated as Replacer 1 (R1), Replacer 2 (R2), and Replacer 3 (R3), specific to bakery applications, were used to prepare the test samples. The ingredients of these egg replacers, as provided by suppliers, are shown in Table 3.2. The nutritional compositions of egg replacers are given in Table 3.3. The commercial identities of these egg replacers are not revealed here for obvious reasons. These replacers were selected to cover the major categories (soy, whey protein, and gum-based) of such ingredients used in cakes, and also considering their availability to commercial bakery operations.

Sample preparation

Five yellow cake formulations (whole liquid egg, whole dry egg, R1 (30% w/w whole dry egg + 70% Replacer 1), R2 (25% whole dry egg + 75% Replacer 2), and R3 (25% whole dry egg + 75% Replacer 3) were tested. The relative percentages of ingredients used in the five formulations are shown in Table 3.4.

Shortening, sugar, and dextrose were creamed using a paddle in a commercial mixer (Hobart Model K45, Hobart manufacturing Co., Troy, OH) for 4min at speed 1, stopping after every 1min to scrape the paddle, bottom and sides of the bowl. Dry eggs or combinations of dry eggs and egg replacers, emulsifier, and vanilla extract were added to the creamed mixture and further mixed at speed 3 for 3min. The paddle, bottom and sides of bowl were scraped after every 1min. Rest of the dry ingredients (wheat flour, baking powder, milk powder, xanthan gum, salt, corn starch, and color) were then added and mixed for 2min at speed 2. After every 30s, the paddle, sides and bottom of the bowl were scraped and added back to the mixture. After 2min, the mixing speed was changed to level 4 and mixed for 2min, while stopping after 1min for scraping the side of the bowl. A half of total amount of water was then added and mixed for 1min at speed 1. After 30s and at the end of 1min, the paddle, sides and bottom of the bowl were scraped and blended into the mixture. The remaining half of water and liquid eggs (if included) in the formulation were then added. The paddle speed was set at level 1 and mixed for 2min. After every 30s, the paddle, sides and bottom of the bowl were scraped. Cake pan (8" diameter, 2" deep - Chicago Metallic, Vernon Hills, IL) was uniformly coated with cooking spray (Pam® Original, ConAgra Foods, Inc., Omaha, NE); batter was poured and baked at 176.67ºC (350°F) for 24min in a reel oven (National Mfg. Co., Lincoln, NE). Following baking, the cakes were cooled in pans, on cooling racks, for 30min. Then the cakes were removed from baking pans and transferred onto cooling racks and cooled for additional 30min, and packaged in cake boxes (Reynolds Food Packaging, Rogers, MN).

Three independent batches of samples were prepared for laboratory analyses and sensory panels. For sensory analysis, the samples were prepared 24h in advance and kept at room temperature, packaged in cake boxes.

Bake loss and moisture analysis

Bake loss (%), which is defined as the difference between the weight of batter and baked cake relative to batter weight, was calculated by weighing the batter prior to baking and weighing the cakes after baking. Moisture contents of cake samples stored for 1 and 7 days of production was determined according to AOAC approved method 945.43 (AOAC 1990).

Color analysis

The color of yellow cake (crust and crumb) was measured with a chromameter (Minolta CR-300, Konica Minolta, Inc., Ramsey, NJ) using CIELab L*, *a**, *b** color space. The chromameter was calibrated using a color standard supplied by the manufacturer. Approximately 2 sq. inch (surface area) samples were randomly selected for a given cake to measure color. Color analysis was performed on cake samples stored for 1 day (at room temperature) in order to match the conditions of samples used for sensory panels.

Texture analysis

The textural characteristics of cake samples were determined using a TA-XT2i texture analyzer (Stable Micro Systems Ltd, Surrey, UK). The textural properties of samples were profiled by puncturing with a 4mm probe (TA-54) and also using texture profile analysis (TPA) with double compression with a 1" probe.

For the puncture test, approximately 2 sq. inch cake samples were placed centrally under the probe on the sample platform. The probe descended at 1mm/s until a set force (0.05N) was detected. The probe penetrated 20mm in to the cake sample at a speed of 1mm/s, followed by probe withdrawal at 1mm/s speed. Firmness (peak force), work (area under the peak), and adhesiveness were recorded.

In compression testing, the experimental parameters were set as follows: Pretest speed = 5mm/s; test speed = 1mm/s; posttest speed = 2mm/s; and distance = 10mm. Firmness (peak 1 force), work (peak 1 area), time between peaks, peak 2 force, peak 2 area, and cohesiveness were recorded.

Volume analysis

Bulk densities of yellow cake samples were determined using a laser scanning volume measuring instrument (Model BVM-L370LC, TexVoL Instruments AB, Viken, Sweden). Prior to analysis, the cakes were cut into two halves. One half was further cut into four wedge shaped samples which were used for the analysis. The sample weight was measured, and then placed on the attachment (FSPR1540-10) mounted on a rotating support shaft

(225mm) and scanned for 45s. Data were collected and processed using VolCalc® software (version 3.2.3.10). The equipment was calibrated using a manufacturer supplied standard disk (100mm).

Sensory analysis

Just prior to conducting sensory panel, three cakes from each formulation were cut into approximately 1sq. inch (surface area) pieces. Randomly selected pieces were placed on 6" styrofoam plates. The plates were covered with Saran® wrap until served. Panelists were given water, at room temperature, to clear their palates between samples. Panelists evaluated appearance, texture, flavor, off flavor and overall acceptability using an attribute rating scale (Appendix 3.A). Samples were served one at a time to the panelists. Sensory panels were conducted in two sessions. A total of 47 panelists participated in sensory panels.

Statistical analysis

A randomized complete block design (RCBD) was used. The analysis of variance (ANOVA) and Fisher's least significant difference (LSD) were calculated to determine significant effects at $p<0.05$ among treatments. At least three independent replicates of cake samples were used for all analyses. Within a given replicate, color, texture, and volume analyses were performed on 4 (or more) randomly selected samples. SAS version 9.2 (SAS Institute Inc., Cary, NC) was used for statistical analyses.

Cost comparison

The economics of using different ingredients were systematically compared using a financial comparison. As ingredients were sourced for each formulation, pricing data were obtained from respective suppliers (Appendix 3.B). In the food industry, bracketed pricing (*i.e.*, incrementally higher discounts for buying in volume) is frequently used. For the purposes of this project, pallet pricing was used for all egg and egg substitute products. Formulations that were documented during the sample preparations, with exact quantities of each ingredient, were used as the basis for cost comparison.

Results and Discussion

The three egg replacers used in this study (Table 3.2), soy/wheat gluten-, whey protein-, and fiber/gum-based, were chosen for two main reasons; (a) they are specially prepared for bakery applications, as advertised by respective manufacturers, and (b) to cover a broad range of egg replacers prepared using a variety of ingredients. Several other, non-traditional egg replacers have been developed for use in cake formulations, but such egg replacers are not readily available for regular yellow cake manufacturers. The compositions of the three egg replacers used in this study are given in Table 3.3. Out of the three egg replacers, the R2 has a relatively "unhealthy" fat composition, and a high amount of sugars. The R1 has the highest total fat content and calories (Table 3.3). These factors would be of importance in nutritional labeling of the product.

A series of preliminary tests were conducted to determine the maximum amounts of egg replacers that could be used in the formulations without significantly affecting the product quality. Yellow cake samples made with R1 at 100% replacement had an unacceptable after taste; while R2, at 100% replacement, produced cakes those could not be easily removed from baking pans although they had a taste comparable to that of the dry egg formulation. Yellow cake samples made with R3 at 100% replacement (20% egg replacer + 80% water, mixed per ingredient manufacturer's recommendations) produced cakes with unacceptable texture (too moist). These trials showed that none of the egg replacers were able to produce acceptable quality products at 100% (w/w) replacement of dry egg in the formulation. Based on these trials, dry egg was replaced with R1 at 70%, R2 at 75% R2, and R3 at 75% (15% egg replacer + 60% water). The exact amounts of ingredients used in the finalized formulations used in this study are given in Table 3.4.

Bake loss values (Table 3.5) of yellow cake samples were significantly ($p<0.0001$) affected based on whether egg, either in dry or liquid form, was included in the formulation. The egg containing formulations resulted in the lowest bake losses, compared to those prepared with high amounts of egg replacers. The highest bake loss was observed in the R3 (fiber/gum-based egg replacer) containing yellow cakes. Bake loss is an economic disadvantage to the production process. These results also revealed that the water binding capacities of egg containing yellow cake formulations were higher compared to that of the formulations prepared with egg replacers. It is important to note that the egg replacers containing formulations also contained smaller proportions (Table 3.4) of dry egg.

Bulk densities of yellow cake samples (Table 3.6) varied within a narrow range, from 0.38 to 0.41g/cm^3. Although statistically significant differences were observed, these differences might be of less importance in differentiating the functionalities of ingredients in formulations due to the very narrow range (0.38 – 0.41g/cm^3) of the results.

The laboratory color analysis results (Table 3.7) showed that almost all surface color parameters were essentially similar among all five formulations tested. Liquid egg and R2 formulations yielded relatively more yellowish (high b^*) colors, but the sensory panelists (Table 3.10) did not observe a significant difference between the samples in overall appearance. In crumb color analysis (Table 3.7), it was found that the liquid egg formula resulted in a significantly darker (low L*) color compared to the yellow cakes made with the other four formulas. Also, it was found that the R1 formula resulted in the least yellowish color (low b^*). These color differences, however, were nearly impossible to detect by the naked eye (Fig. 3.1). The sensory analysis revealed that liquid egg yellow cakes were the least yellowish (Table 3.10). The reason for this observation is unclear. It should also be noted that artificial food coloring was used at equal levels in all five formulations, and therefore the minor color differences observed among the products could be of less importance, unless the origin of the product color would have been caused by ingredient interactions and/or reactions, such as caramelization, etc.

The textural properties of prepared samples were analyzed by both laboratory tests, using a texture analyzer, and by sensory panels. The samples were analyzed by compression test at 1 day after preparation (to match the conditions of the samples used for sensory panels), and at 7 days after preparation. The cakes were stored at room temperature in commercial cake packaging cases during this period. The samples, after 1 day of storage at room temperature, were also analyzed by the puncture test in order to determine the product matrix (crumb) integrity. The R1 formulation resulted in yellow cake with the highest firmness (Table 3.8).

The measured firmness values increased in all five types of cakes after 7 days at room temperature. The most cohesive cakes were produced by egg containing formulations (Table 3.8). The crumbs of the liquid and dry egg cakes, along with R3, were firmer and relatively more difficult to break compared to the R1 and R2 containing cakes (Table 3.9). The R2 containing yellow cakes displayed the lowest resistance (firmness) against puncture (Table 3.9) and this complemented the compression test results; lower peak 1 area (Table 3.8). The highest second peak firmness, indicating less relaxation of the crumb structure after the first compression, among the 1 day stored samples, was observed in R1 (soy/wheat gluten based egg replacer) yellow cakes. The R1 formulation also produced least cohesive cakes (Table 3.8). The time between peaks was generally higher for egg replacers containing cakes, for both day 1 and day 7 analyses (Table 3.8). This means that the egg replacers containing cakes take longer times to recover (relaxation of structure) after the first compression. This observation coincides with their lesser cohesiveness (Table 3.8) and higher "moistness" (Table 3.10) compared to liquid and dry whole egg containing cakes. The results of textural attributes analysis by sensory panels are given in Table 3.10. Egg replacers produced cakes with high "moistness", and "harder to clear" with increased stickiness texture, as perceived by the panelists (Table 3.10). Although these attributes did not affect the overall sample acceptability, these characteristics could be considered unfavorable for yellow cake product quality. The R2 formulation (whey protein based egg replacer) yielded cakes with least structural integrity (Table 3.9 - lowest values for firmness and work). This could be an important aspect to consider, especially when automated production operations are employed. For example, when the product is prone to physical damage (or "fragile"), certain operations such as moving and handling might require special care to avoid breakage, and damaged products.

The results of sensory analysis are given in Table 3.10. It is important to note that the overall acceptability of yellow cake samples were statistically the same for egg containing formulations, R2, and R3. The R1 formulation (roasted soy flour based egg replacer) had lesser acceptability, mainly due to the higher off flavor - as determined by the panelists. All other flavor attributes were comparable among the five formulations tested.

The cost comparison of the five formulations used in this study is given in Table 3.11. The dry whole egg (100%) containing formulation resulted in the lowest overall ingredients cost. The liquid whole egg formulation was less expensive compared to the R1 and R2 formulations. It should be noted that the R1 formulation had the highest overall ingredients cost.

Conclusions

Liquid whole egg and dry whole egg containing yellow cake formulations produced yellow cakes with lesser bake loss, and generally acceptable quality characteristics. None of the egg replacers could completely replace egg in the formulation to produce yellow cakes of acceptable quality. Among the five formulations of yellow cakes evaluated by this study, the soy/wheat gluten based egg replacer (R1) resulted in a less acceptable product, mainly due to the high levels of off flavor. The R1 formulation had the highest total ingredient cost. Considering the product quality and overall cost of production, dry whole egg formulation could be recommended to be the best among the five formulations tested in this study.

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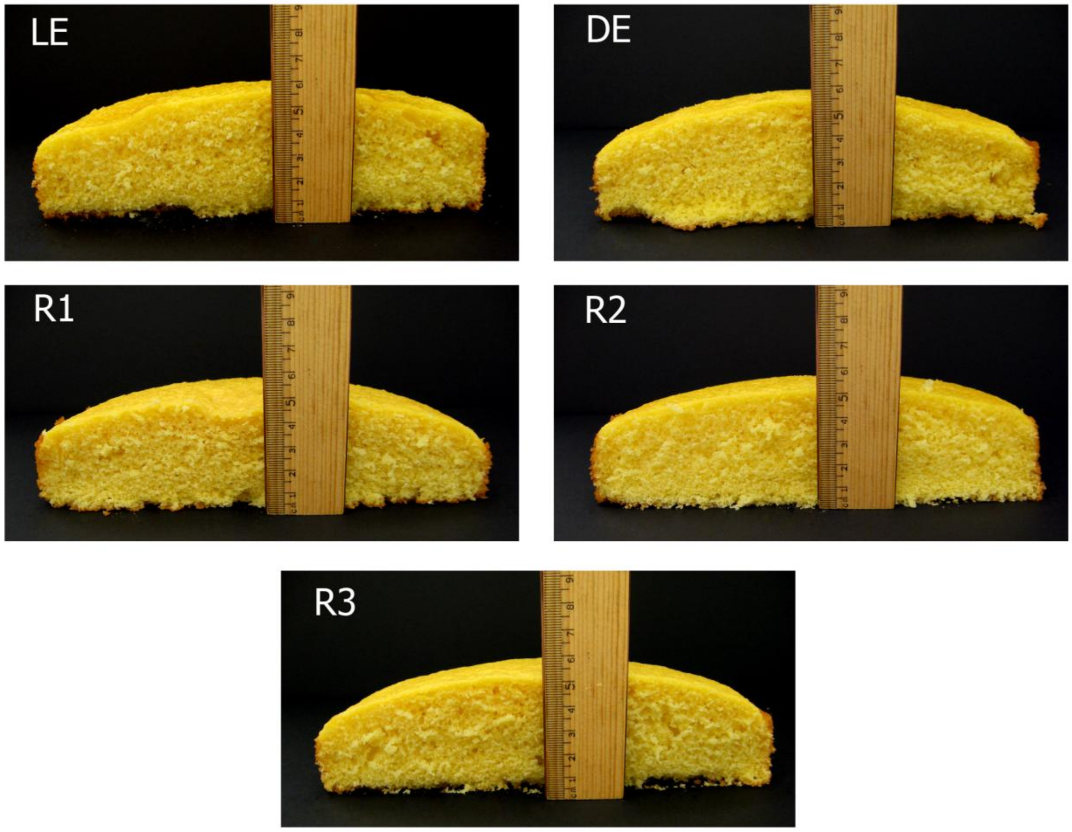

Figure 3.1. Yellow cake samples prepared with different formulations (LE = Liquid whole egg, DE = Dry whole egg, and R1, R2, R3 are the three egg replacers used in this study).

Table 3.1. InfoScan™ unit volume analysis of total cakes sold in the U.S. food stores, drug stores, and mass merchandisers. Latest 52 weeks ending June 14, 2009.

Category	Sales (lbs)
Cakes	290,830,699
Doughnuts	215,754,800
Cakes (no snack/coffee cakes)	177,944,600
Frozen sweet goods (cake, cupcake, donut)	32,326,896
Refrigerated cakes (no snack/coffee cakes)	15,598,030
Total	*732,455,025*
Yellow cake mix*	60,019,453

*Compiled from the categories listed above. The volume is included in the category total.

Table 3.2. Ingredients of egg replacers used in yellow cake formulations

Egg Replacer	Ingredient Statement*
Replacer 1 (R1)	Roasted soy flour or soy flour, wheat gluten, and corn. syrup solids, algin or sodium alginate.
Replacer 2 (R2)	Whey protein concentrate (35% protein).
Replacer 3 (R3)	Sugar cane fiber, Xanthan gum, and Guar gum.

*Provided by the manufacturer.

Table 3.3. Nutritional compositions[a] of egg replacers used in this study

Component	R1	R2	R3
Total calories	450	376	386
Total fat (g)	17	3.6	0.3
Saturated fat (g)	2.5	2.2	0
Mono unsaturated fat (g)	-	0.9	0
Poly unsaturated fat (g)	-	0.2	0
Trans fat (g)	-	0.1	0
Cholesterol (mg)	0	88	0
Carbohydrates (g)	32	50.8	95
Sugars (g)	17	47.4	0
Dietary fiber (g)	11	-	92
Protein (g)	43	35.1	1
Ash (g)	-	6.8	1
Moisture (g)	6	3.7	<5

[a] per 100 g of material

Table 3.4. Compositions* of yellow cake formulations

Ingredient	Liquid Egg	Dry Egg	R1	R2	R3
Sugar	24.93	24.93	24.93	24.93	24.93
Dextrose	0.50	0.50	0.50	0.50	0.50
Shortening	8.69	8.69	8.69	8.69	8.69
Liquid whole egg	9.10	2.27	-	-	-
Dry whole egg	-	-	0.68	0.57	0.57
Egg replacer 1	-	-	1.59	1.71	-
Egg replacer 2	-	-	-	-	-
Egg replacer 3	-	-	-	-	0.34
Emulsifier	0.50	0.50	0.50	0.50	0.50
Vanilla extract	0.67	0.67	0.67	0.67	0.67
Wheat flour	22.74	22.74	22.74	22.74	22.74
Baking powder	1.97	1.97	1.97	1.97	1.97
Salt	0.29	0.29	0.29	0.29	0.29
Corn starch	0.50	0.50	0.50	0.50	0.50
Bakers Shade® color	0.00	0.00	0.00	0.00	0.00
Milk powder	2.11	2.11	2.11	2.11	2.11
Xanthan gum	0.08	0.08	0.08	0.08	0.08
Water	27.93	34.75	34.75	34.75	36.12
Total	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*

* All numbers are % values (w/w).

Table 3.5. Bake loss estimations

Formulation	Bake loss (%, w/w)*
Liquid whole egg	8.26c
Dry whole egg	8.54c
R1	8.88b
R2	9.11a,b
R3	9.36a

* Means followed by the same letter are not significantly different (p>0.05).

Table 3.6. Density analysis* of yellow cakes

Formulation	Bulk density (g/cm^3)
Liquid whole Egg	0.39a
Dry whole egg	0.38b
R1	0.39b
R2	0.38b
R3	0.41a

* Means followed by the same letters are not significantly different ($p>0.05$).

Table 3.7. Crust and crumb color parameters[a] of yellow cakes

Formulation	Crust (top)			Crumb		
	L*	*a**	*b**	L*	*a**	*b**
Liquid whole egg	50.74a	0.24a	22.33c	56.34a	-0.82a	21.98b
Dry whole egg	51.69a	-0.27a	22.12b,c	62.08c	-1.66b	21.07a,b
R1	50.16a	0.58a	21.43a	61.32b,c	-0.90a	20.75a
R2	51.23a	0.47a	22.69c	62.06c	-1.76c	21.67b
R3	51.44a	0.24a	21.55a,b	62.04c	-1.19a,b	21.35a,b

[a]Means followed by the same letter, within the same column, are not significantly different (p>0.05).

Table 3.8. Texture profile parameters* of yellow cakes stored for 1 and 7 days, at room temperature.

Formulation	Peak 1 force (g)	Peak 1 area (Ns)	Time between Peaks (s)	Peak 2 force (g)	Peak 2 area (Ns)	Cohesiveness**
Stored for 1 day						
Liquid whole egg	264.75b	6.06a	6.05b	235.15a,b,c	3.62a	0.89a
Dry whole egg	270.02b	5.98a	6.16b	240.80a,b	3.50a	0.89a
R1	295.22a	6.00a	6.63a	248.26a	3.07b	0.84c
R2	260.17b	5.33b	6.52a	223.52b,c	2.83b	0.86b
R3	235.82b	5.66a,b	6.45a	219.97c	3.06b	0.86b
Stored for 7 days						
Liquid whole egg	357.20b	7.88b	6.55c	295.92b	3.79a	0.83 a
Dry whole egg	419.53a	9.52a	6.59c	335.64a	4.11a	0.80b
R1	394.41a	8.74a	6.90b	308.04b	3.51b	0.78b,c
R2	330.29b	7.13b	7.21a	253.98c	2.80c	0.77c
R3	339.68b	7.57b	7.13a	263.41c	3.03c	0.77c

*Means followed by same letters, within same column - for each category, are not significantly different (p>0.05)

** Peak 2 force/Peak 1 force

Table 3.9. Texture analysis, by puncture test, results.

Formulation	Firmness/force (g)	Work (Ns)
Liquid whole egg	52.27a	1.23a
Dry whole egg	52.70a	1.22a
R1	44.12b	1.06b
R2	35.42c	0.87c
R3	52.60a	1.18a

*Means followed by same letters, within same column, are not significantly different ($p>0.05$).

Table 3.10. Sensory parameters (least square means) of yellow cake samples

Formulation	Appearance			Texture			Flavor						Overall sample acceptability[3]
	Color[1]	Visual texture[2]	Overall appearance[3]	Dryness/ Moistness[5]	Denseness[4]	Stickiness[6]	Egg flavor[7]	Vanilla[7]	Sweetness[7]	Off flavor[7]	Overall flavor acceptability[3]	Aftertaste[7]	
Dry Egg	7.61a	7.69a,b	9.69a	8.03a,b	8.30a	7.85c	7.27a	8.10c	8.82a	7.20b	8.70b	6.97a	8.68b
Liquid Egg	8.12b	7.90a	9.89a	7.39a	8.22a	8.07c	6.73a	7.00a,b	8.16a	6.87a	8.75b	6.61a	8.54b
R1	8.20b	7.02a	9.27a	8.93b,c	7.72a	5.34a	7.18a	6.60a	7.80a	8.19c	6.73a	7.79a	6.70a
R2	8.05b	8.56c	9.66a	9.65c	8.84a	5.88a	6.95a	7.27a,b	8.61a	7.17a	8.21b	7.24a	8.22b
R3	8.29b	7.69a,b	9.28a	9.11c	7.46a	6.82b	7.70a	7.66b,c	8.27a	6.47a,b	8.92b	6.85a	8.64b

* Means followed by same letters, within same column - for each category, are not significantly different ($p>0.05$).

[1]Where 0 = Light yellow and 15 = Dark yellow

[2]Where 0 = Very compact/dense and 15 = Very airy/fluffy

[3]Where 0 =Very undesirable and 15 = Very desirable

[4]Where 0 = Very dense and 15 = Very airy

[5]Where 0 = Very dry and 15 = Very moist

[6]Where 0 = Very hard to clear and 15 = Clears quickly

[7]Where 0 = Lacking and 15 = Intense

Table 3.11. The ingredient and total cost comparison of the yellow cake formulations studied. All numbers represent pricing, in US $, for 100lb of yellow cake.

Ingredient	Liquid egg	Dry egg	R1	R2	R3
Sugar	15.77	15.77	15.77	15.77	15.77
Dextrose	0.19	0.19	0.19	0.19	0.19
Shortening	6.52	6.52	6.52	6.52	6.52
Emulsifier	1.45	1.45	1.45	1.45	1.45
Vanilla extract	15.97	15.97	15.97	15.97	15.97
Cake flour	7.81	7.81	7.81	7.81	7.81
Baking powder	3.25	3.25	3.25	3.25	3.25
Salt	0.12	0.12	0.12	0.12	0.12
Corn starch	0.17	0.17	0.17	0.17	0.17
Bakers shade color	0.06	0.06	0.06	0.06	0.06
Milk powder	3.08	3.08	3.08	3.08	3.08
Xanthan gum	0.34	0.34	0.34	0.34	0.34
Water	-	-	-	-	-
Liquid whole egg	5.00	1.25	-	-	-
Dry whole egg	-	-	1.78	1.48	1.48
Egg replacer 1	-	-	3.80	4.08	-
Egg replacer 2	-	-	-	-	-
Egg replacer 3	-	-	-	-	1.19
Total	*59.74*	*55.98*	*60.32*	*60.29*	*57.41*

Appendix 3.A. Attributes rating form used to evaluate yellow cakes

Evaluation of Yellow Cake

Name ______________________ Date __________________

You will be given 5 samples, one sample at a time. Please evaluate each sample for the following attributes. **Make a vertical line** on the provided horizontal line at the point that best describes your perception of the attribute. Each sample will have its own evaluation form.

Sample Code _____

Appearance:

Color
Light Yellow Dark Yellow

|____|____|

Visual Texture
Very Compact/Dense Very Airy/Fluffy

|____|____|

Overall Appearance Acceptability
Very Undesirable Very Desirable

|____|____|

Texture:

Very Dense Very Fluffy
|____|____|

Very Dry Very Moist
|____|____|

Stickiness (Sticks/adheres to the teeth/mouth)
Extremely Sticky Clears Quickly

|____|____|

Flavor:

Egg Flavor
Lacking Intense
|________________________________|________________________________|

Vanilla
Lacking Intense
|________________________________|________________________________|

Sweetness
Lacking Intense
|________________________________|________________________________|

Off Flavor
Lacking Intense
|________________________________|________________________________|

Overall Flavor Acceptability
Very Undesirable Very Desirable
|________________________________|________________________________|

Aftertaste:

Off Flavor
Lacking Intense
|________________________________|________________________________|

Overall Sample Acceptability

Very Undesirable Very Desirable
|________________________________|________________________________|

Comments:

Appendix 3.B. Pricing information on the ingredients used in yellow cake formulations.

Ingredient	Price ($)	Per*	Price per lb ($)	Price per 100lb ($)
Sugar	31.63	50 lbs	0.6326	63.26
Dextrose	0.39	1 lb	0.39	38.69
Shortening	37.50	50 lbs	0.75	75.00
Emulsifier	2.9	1 lb	2.8929	289.29
Vanilla extract	11.97	Pint	23.94	2,394.00
Cake flour	17.17	50 lbs	0.3434	34.34
Baking powder	32.95	20 lbs	1.6475	164.75
Salt	10.81	25 lbs	0.4324	43.24
Corn starch	0.35	1 lb	0.35	34.79
Bakers Shade® color	17.00	1 lb	17.00	1,700.00
Milk powder	1.4589	1 lb	1.46	145.89
Xanthan gum	4.47	1 lb	4.47	447.29
Water**	-	-	-	-
Liquid whole egg	0.55	1 lb	0.55	55.00
Dry whole egg	2.61	1 lb	2.61	261.00
Egg replacer 1	2.39	1 lb	2.39	239.00
Egg replacer 2	1.9	1 lb	1.89	189.00
Egg replacer 3	3.49	1 lb	3.49	349.00

*Pricing information was provided by ingredient manufacturers for this amount.

**Considered as part of utilities requirements in the production process.

Chapter 4: Cookies

Introduction

Among the products studied in this project, cookies was the leading product category by the total amount of sales in the United States, during the time period surveyed (Table 1.2, Chapter 1). Generally egg is used in cookie formulations in order to obtain specific product characteristics, such as flavor and texture. In the cookie category, soft cookies were of particular interest as a result of the review of ingredient statements in Omaha/Lincoln, NE supermarkets. The ingredient statements of soft cookies tended to contain eggs more frequently than other types of cookies.

In the review of InfoScan™ data (Information_Resources_Inc. 2009), it was difficult to isolate soft cookies from the overall category, because not all soft cookies had the word "soft" included in the product description (Table 4.1). The category leaders in the soft cookie category were identified to maximize the likelihood of the majority of the volume was captured. The product volume from this sorted list was combined with volume from cookie mixes and refrigerated cookie dough. All types of cookies mixes, *i e.,* complete (egg is included in the mix), original (egg is added by the consumer), and 'hard' and 'soft' cookies, were included in the total because soft cookies were difficult to isolate. Refrigerated dough was added due to the fact that almost all such products contained egg in the ingredient statements. As mentioned previously, refrigerated and/or frozen products were more likely to contain eggs, instead of shelf stable alternatives. The combined volume of sorted soft cookies, cookie mixes and refrigerated cookie dough totaled over 346 million pounds of product, the second most of the categories evaluated. Of this reported volume, the all-inclusive cookie mixes contributed approximately 43 million pounds and refrigerated cookie dough contributed approximately 154 million pounds (Table 4.1).

An expanded ingredient statements review of the category determined that eggs were also included in a broader segment of the overall category, including cookies of various types and textures. Given the enormous size of the overall category (prepared cookies alone account for over 1.2 billion pounds of volume) the advisory board members, the American Egg

Board, and FPC Project Leaders selected traditional cookie as one of the products for the ingredient functionality evaluation.

Although there are numerous reports on the effects of different ingredients and processing conditions on cookie quality (Kissell and Yamazaki 1975; Yamazaki and Donelson 1976; Abboud, Hoseney et al. 1985), information is scarce in published literature in regards to the effects of replacing egg with egg alternatives on cookie product quality characteristics. The objectives of this project were (a) to investigate the effect of replacing eggs with egg alternatives on cookie product properties, and (b) to compare the effect of using egg alternatives, in place of eggs, on total ingredient costs.

Materials and Methods

Two "controls", liquid whole egg and dry whole egg, and three egg replacers, that are commercially available to cookie manufacturers, were used to prepare the samples used in this study. The samples were prepared, and stored at room temperature until analyses. Details of these steps are given below.

Egg replacers

Three egg replacers were designated as Replacer 1 (R1), Replacer 2 (R2), and Replacer 3 (R3). They were selected to cover a broad range of ingredient compositions (Table 4.2); soy flour, gums, and whey protein based egg replacers were used. The nutritional compositions of egg replacers provided by suppliers are provided in Table 4.3.

Ingredients

Cookies were prepared from all purpose flour (Chefs Delight®, ConAgra Foods, Inc., Omaha, NE), pastry flour (White Spray®, ConAgra Foods, Inc., Omaha, NE), shortening (Vream RighT®, Bunge Oils Co., St. Louis, MO), sugar (United Sugars Co., Minneapolis, MN), brown sugar (Brownulated®, Domino Foods, NY), fructose (Krysta®, Tate & Lyle, Decatur, IL), soy lecithin (Solae, St. Louis, MO), baking soda (Arm & Hammer®, Church & Dwight Co., Princeton, NJ), pure vanilla extract (Custom Blending Inc., Fort Collins, CO), salt (Top-

Flo®, Cargill Inc., Minneapolis, MN), water and liquid whole egg or dry whole egg (Michael Foods, Minnetonka, MN) or a combination of dry whole egg and egg replacers.

Production process

Five formulations (whole liquid egg, whole dry egg, 100% R1, 100% R3, and 25% whole dry egg + 75% R2) were tested. The relative percentages of ingredients used in the five formulations are shown in Table 4.4.

Shortening, sugar, and brown sugar were creamed using a paddle in a mixer (Model K45, Hobart manufacturing Co., Troy, OH) for 5min at speed 2. Mixing was momentarily stopped after 1, 3, and 5min to scrape the paddle, bottom, and sides of the bowl to ensure proper mixing. Eggs and egg replacers, emulsifier, fructose, vanilla extract and a portion (~50% v/v) water were then added to the creamed mixture. The ingredients were mixed at speed 2 for 3min, while stopping after ~1.5min to scrape the paddle, bottom, and sides of the bowl. Rest of the dry ingredients (flours, salt, and baking soda) were added and mixed at stir speed for 30s. The paddle, sides and bottom of the bowl were scrapped. The speed was changed to level 1 and mixed for additional 30s, and the paddle, sides and bottom of the bowl were scrapped. Mixing was then continued for 2min at speed 1, while stopping after 1min to scrape the paddle, sides, and bottom of the bowl. The rest of the remaining water was then added and mixed for 1.5min, while stopping every 30s to scrape paddle, sides, and bottom of the bowl.

A wire cut, automatic cookie depositor (Rhodes Kook-E-King®, Practical Baker Equipment Co., Harvard, IL) was used to deposit cookie dough on the baking trays (Appendix 4.C). The cookie depositor die slot was fitted with four 1 3/4” openings round die (Kook-E-King die 189-114). The prepared dough was placed in feed hopper, and dough was then spread uniformly across the length of the feeder. The deposit speed and table speed (to move the sheet pan) were set at 1.2 and 1.0, respectively on the control panel. Deposited cookies were received on to 18” sheet pans.

Deposited cookies were baked in a commercial reel oven (Model 4-26x56, Reed oven Co., Kansas City, MO) for 13min at 218.33°C (350 °F).

Baked cookies were promptly removed from the oven and the pans were kept on steel-wire shelves, for 15min at room temperature. Then the cookies were manually transferred onto cooling racks and cooled for additional 30min. The cookies were then stored in plastic clamshell cases (Product 10055, Reynolds Food Packaging, Rogers, MN), and kept at room temperature until further analysis.

Bake loss and moisture analysis

Bake loss (%, w/w), the difference between the weight of dough and baked cookies, expressed as a % ratio to dough weight, was calculated using the weights of all baked cookies. Moisture contents of cookie samples stored for 1, 7, and 14 days were determined according AOAC method 945.4 (AOAC 1990).

Color

The color of cookies were measured with a chromameter (Minolta CR-300, Konica Minolta, Inc., Ramsey, NJ) using CIELab L*, *a**, *b** color space. The chromameter was calibrated using a color standard supplied by the manufacturer. For each reading, color of the cookie was measured at two random spots and averaged. Color analysis was performed on cookie samples stored for 1, 7, and 14 days at room temperature.

Bulk density

Bulk densities of cookies were determined using a laser-based volume measuring equipment (BVM-L370LC Tex VoL Instruments AB, Viken, Sweden). Each cookie sample was mounted on a FSPR1540-10 attachment on a 225mm shaft and scanned for 45s. The equipment was calibrated using a manufacturer supplied standard disk (100mm) and data were collected and processed using VolCalc software (version 3.2.3.10).

Spread factor

The thickness and diameter of representative cookies were measured using a digital caliper (Model No: CD-6" CS, Mitutoyo Corp., Japan). Spread factor was calculated according to the AACC approved method 10-50D (AACC_International 2000). Six cookies were stacked in random order, the height was measured five times, and averaged. The diameter of cookies was obtained by laying cookie edge-to-edge and measuring the width. The cookies were then rotated by 90° and the width re-measured. The two width values were averaged to obtain the mean width of cookies. The spread factor was calculated as the mean diameter divided by corresponding mean thickness of the cookie sample.

Texture

The textural characteristics of cookies were determined using a TA-XT2i texture analyzer (Stable Micro Systems Ltd, Surrey, UK). The mechanical properties were profiled by, (a) puncturing the center and sides of a cookie (Perry, Swanson et al. 2003), with a 4mm probe (TA-54), and (b) snapping cookies in a three point bend test rig (Appendix 4.D). For puncture test, the center and sides of cookies were placed centrally over the 10mm diameter opening containing plate (TA-101) mounted on TA-XT2i's platform. The probe descended at 1mm/s until a set force (0.05 N) was detected. The probe descended 20mm into and through the cookie at a speed of 1mm/s followed by probe withdrawal at 1mm/s. Firmness (peak force), and work (area under the peak), were recorded. For the three point bend test, cookies were placed on the supports spaced 30mm apart. The rounded-end knife (TA-42) descended at 1mm/s until a set force (0.05 N) was detected, and the probe descended 20mm into and through the cookie at a speed of 1mm/s followed by probe withdrawal at 1mm/s. Firmness (peak force), and work (area under the peak), were recorded using the manufacturer supplied software.

Sensory analysis

Two sensory panels were conducted, in two days, for a total of 55 panelists rating different sensory attributes (Appendix 4.B) in the form of a consumer panel. The samples prepared 24h prior to conducting the panels. Cookies were served to panelists on 6" Styrofoam plates. A randomized complete block design (RCBD) was used for the experiment, *i e.*, each panelist evaluated all five samples. Panelists were given room temperature water to clear their palates between samples. Panelists evaluated appearance, texture/mouth feel, flavor, off flavor and overall acceptability using an attribute rating scale (Appendix 4.B).

Statistical analysis

A randomized complete block design (RCBD) was used for this study. The analysis of variance (ANOVA) and Fisher's least significant difference (LSD) were carried to determine significant effects at $p<0.05$ level among the treatments (*i e.,* the five formulations). Three independent replicates of cookie samples (made on three different days) were produced for each formulation. For each replicate, 90-100 cookies were produced, and product properties were analyzed on, at least four, randomly selected samples. SAS Version 9.2 (SAS Institute Inc., Cary, NC) was used for statistical analyses.

Cost comparison

The economics of using different ingredients were systematically compared using a financial comparison. As ingredients were sourced for each formulation, pricing data were obtained from respective suppliers. In the food industry, bracketed pricing (*i.e.,* incrementally higher discounts for buying in volume) is frequently used. For the purposes of this project, pallet pricing (or the pricing information for the highest available amount at the time of purchase) was used for all egg and egg substitute products. Formulations that were documented during the sample preparations, with exact quantities of each ingredient, were used as the basis for cost comparison (Appendix 4.A).

Results and Discussion

The three egg replacers (R1, R2, and R3) used in this study were chosen as these were marketed by ingredient suppliers for bakery applications including cookies. A series of preliminary experiments were conducted to determine the maximum amount of each egg replacer that could be used in place of egg (*i e.,* dry egg) without noticeably compromising the final product quality. Based on the preliminary evaluations it was concluded that, egg could be replaced with 100% (w/w) R1, 75% (w/w) R2 (that is 15% R2 egg replacer and 60% water - mixed per ingredient manufacturer's recommendations), and 100% R3. The R2 replacer, at 100% (20% R2 egg replacer + 80% water) substitution, produced a sticky dough, and the cookies produced had a wet and doughy texture, which was unacceptable (detailed results are not reported here). The final formulations used for each category are given in Table 4.4).

Dry whole egg and R3 formulations displayed significantly lower bake losses compared to the other three formulations tested (Table 4.5). Bake loss is an important parameter for food manufacturers. For example, a low cost cookie formulation, such as R1 or R2 in this study (Table 4.11), with high bake loss may affect the overall economics of the production process.

The moisture contents of samples stored at 1 day (conditions similar to those of the samples served at the sensory panels), and 7 days at room temperature were analyzed (Table 4.5). The moisture contents of samples were analyzed after 7 days storage to determine any differences in moisture losses during storage, which is a potentially important factor in determining the shelf life of samples. Regardless of storage time, R1 (soy flour based egg replacer) egg replacer had the lowest moisture content, while the R2 (fiber and gum based replacer) had the highest moisture content, which was comparable with liquid egg and R3 formulations after 7 days storage at room temperature. This corresponded well with the sensory results (Table 4.6), which found that the moistness was highest in the R2 formulation made cookies.

Color is an important factor in cookies, as color and appearance are among the first product characteristics to register in consumer's perception, and often dictates product acceptability and purchasing decision. The R2 egg replacer produced cookies with a darker color (low L*) compared to the other formulations, and those cookies were the darkest even after 7 days storage (Table 4.7). Both dry and liquid egg containing formulations produced more reddish color (high *a**) cookies. The most yellowish (the highest *b**) cookies were produced by liquid and dry egg formulations, whereas the lest yellowish cookies were from R2 formulation (Table 4.7). It could be concluded that, specially considering the absence of artificial colors in the formulations, both liquid and dry egg contributed to the yellow color in cookies. Despite the fact that the overall appearances were statistically the same for all samples (Table 4.6), more yellowish color could be considered beneficial for the cookie quality. The observed differences in color, revealed by the laboratory test were not readily visualized by the naked eye (Figure 4.1).

The bulk densities of the cookies made out of egg containing formulations were significantly lower compared to those made with egg replacers (Table 4.8). The highest spread factor was seen in the cookies made with the R2 formulation, and the lowest was observed in cookies made with dry whole egg formulation (Table 4.8). A visual inspection also collaborated this finding, *i e.,* dry egg formulation resulted in considerably "thicker" cookies with low diameter (Figure 4.1). This, however, did not significantly affect the consumer perception either on the appearance or the texture of the five samples (Table 4.6). The data collected by these tests were insufficient to determine what would be the optimal spread factor for the cookies. However, it was obvious that the lowest spread factor, which was observed in dry egg formulation made cookies was unacceptable. The differences in cookie spread factor may be associated with the protein composition of the formulation, protein hydration, and the formulation's water retention capacity (Kissell and Yamazaki 1975). Accordingly, it could be suggested that the proteins in the formulation prepared with dry whole egg has a low hydration and water retention capacity, when the same production process is followed for the other formulations studied here. This could be overcome by adjusting the production process to accommodate further hydration of ingredients prior to baking, but such aspects were not studied in this investigation. It has been suggested that both water loss during baking and starch gelatinization could also contribute to the spread of dough during baking (Abboud, Hoseney et al. 1985).

The texture of cookies were evaluated in the laboratory, by texture analyzer, as well as in the sensory analysis. Three point bend test textural parameters of cookies, stored for 1 and 7 days at room temperature, are shown in Table 4.9. Regardless of storage time, dry egg formulation made cookies were the most stiff and brittle as they had higher mean peak force among the five formulations. This finding, however, was not apparent in the sensory analysis (Table 4.6). One of the reasons for observed differences in the laboratory analysis (Table 4.9) could be the higher thickness of the dry egg formulation made cookies (Table 4.8). The force required to bend the cookies increased over storage time (Table 4.9). The R2 and R3 formulations resulted in the "most fragile", or "easily breakable" cookies. These cookies were evaluated as more chewy. The R3 formulation (whey protein based) made cookies were determined to be the least acceptable in textural properties by the sensory analysis (Table 4.6).

The puncture test hardness values of cookies stored for 1 and 7 days at room temperature are shown in Table 4.10. The R1 (relecithinated soy flour) egg replacer cookies had highest hardness values among the five formulations. The lowest hardness value, after 1 day storage, was found for cookies made with the R2 (fiber and gum based) egg replacer. Lower hardness might have contributed to the highest chewiness and the lowest grittiness observed in cookies made with the R2 formulation (Table 4.6). Although the chewiness and grittiness characteristics of the R2 cookies did not make them different from egg and R1 containing samples, in terms of overall texture acceptability (Table 4.6), these parameters may be of importance in product quality control, especially in obtaining desired textural attributes. The hardness of the cookies increased over storage time (Table 4.10). This could be due to changes in the product, caused by specific ingredient compositions, and other factors such as starch retrogradation, etc.

Among the other sensory attributes tested, flavor was relatively less acceptable (higher off flavor) in cookies made with R3 (whey protein based) replacer (Table 4.6). This, most probably, could have affected the overall sample acceptability, which was the lowest for R3 made cookies. Among five formulations, sweetness intensity was the highest for R2 (fiber and gum based) egg replacer made cookies (Table 4.6). The differences in sweetness, however, did not affect the overall flavor acceptability of R2 cookies compared to egg and R1 containing cookies (Table 4.6).

The ingredient pricing information used for the cost comparison is given in Appendix 4.A. The R1 formulation (soy flour based egg replacer) resulted in the lowest cost of ingredients (Table 4.11) among the five formulations studied. The R3 formulation (whey protein based egg replacer) was the most expensive. The overall trend of ingredient costs, of the five formulations, followed the pattern R1 < R2 < Liquid egg < Dry egg < R3.

Conclusions

Whey protein based egg replacer (R3) made the least acceptable cookies among the five formulations tested in this study. The dough spread during baking, which determines the diameter and thickness of the cookie, was the lowest in cookies made with dry egg. Therefore, dry egg and the R3 formulations could be considered unacceptable for cookies production unless appropriate changes are made to the production process to further optimize the end product quality. Dry egg and R3 were the two most expensive formulations, in terms of ingredient cost, among the five formulations studied. According to the results, both liquid egg and R1 (soy flour based egg replacer) produced superior quality cookies. It should be noted that the ingredient cost of the R1 formulation is much lower compared to liquid egg formulation.

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Figure 4.1. Representative images of cookies prepared for this study. LE = Liquid whole egg, DE = Dry whole egg, R1 = Replacer 1, R2 = Replacer 2, and R3 = Replacer 3.

Table 4.1. InfoScan™ unit volume analysis of total cookies sold in U.S. food stores, drug stores, and mass merchandisers. Latest 52 weeks ending June 14, 2009.

Category	Sales (lbs)
Soft cookies* in packaged cookies category	148,441,968
Refrigerated cookie/brownie dough	154,592,300
Cookie/cookie bar mixes**	43,622,230
Total	346,656,498

*'Soft Cookies' includes those designated as 'soft' in the product description.. Volume was captured from top category performers (total packaged cookie volume is over 1.2 billion lbs). May not represent all 'soft' cookie volume in the category.

**Includes all cookie mixes; complete (includes eggs in mix), and original (eggs added by consumer) - for all cookie types(*i e.,* 'hard', 'soft', etc.).

Table 4.2. Ingredients of egg replacers.

Egg replacer	Ingredients*
Replacer 1 (R1)	Relecithinated soy flour
Replacer 2 (R2)	Sugar cane fiber, xanthan gum, and guar gum
Replacer 3 (R3)	Whey protein concentrate (35% protein)

*Per ingredient statement provided by the manufacturer.

Table 4.3. Nutritional compositions* of egg replacers.

Component	R1	R2	R3
Total calories	326	386	376
Total fat (g)	6.8	0.3	3.6
Saturated (g)	1.3	0	2.2
Mono unsaturated fat (g)	1.2	0	0.9
Poly unsaturated fat (g)	4.3	0	0.2
Trans fat (g)	0.03	0	0.1
Cholesterol (mg)	0	0	88
Carbohydrates (g)	31	95	50.8
Sugars (g)	8	0	47.4
Dietary fiber (g)	15	92	-
Protein (g)	49	1	35.1
Ash (g)	6	1	6.8
Moisture(g)	7	<5	3.7

* per 100 g of material

Table 4.4. Ingredient compositions of the cookie formulations*

Ingredient	Liquid egg	Dry egg	R1	R2	R3
All purpose shortening	21.7	21.7	21.7	21.7	21.7
Sugar, granulated	8.2	8.2	8.2	8.2	8.2
Brown sugar	14.7	14.7	14.7	14.7	14.7
Emulsifier	0.7	0.7	0.7	0.7	0.7
Liquid whole egg	9.6	0.0	0.0	0.0	0.0
Dry whole egg	0.0	2.4	0.0	0.6	0.0
Egg replacer 1	0.0	0.0	2.4	0.0	0.0
Egg replacer 2	0.0	0.0	0.0	0.4	2.4
Egg replacer 3	0.0	0.0	0.0	0.0	0.0
Vanilla flavor	0.7	0.7	0.7	0.7	0.7
Crystalline fructose	4.1	4.1	4.1	4.1	4.1
Pastry flour	26.3	26.3	26.3	26.3	26.3
All purpose flour	13.1	13.1	13.1	13.1	13.1
Baking soda	0.7	0.7	0.7	0.7	0.7
Salt	0.2	0.2	0.2	0.2	0.2
Water	0.0	7.2	7.2	8.7	7.2
Total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*

* % (w/w).

Table 4.5. Bake loss and moisture content* determinations.

Formulation	Bake loss	Day 1 moisture content	Day 7 moisture content
Liquid whole egg	4.1a	6.3c,d	6.6a,b
Dry whole egg	3.8b	6.5bc	6.3b,c
R1	4.3a	6.0d	6.2c
R2	4.3a	7.3a	6.9a
R3	3.5b	6.7b	6.5a,b,c

*Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

Table 4.6. Least square mean values* of the evaluated sensory parameters.

Formulation	Appearance		Texture						Flavor				Aftertaste			Overall sample acceptability[2]
	Color[1]	Overall appearance acceptability[2]	Dryness/ Moistness[3]	Chewiness[4]	Grittiness[5]	Oilness[5]	Clearing[6]	Overall texture acceptability[2]	Sweetness[5]	Vanilla[5]	Off flavor[5]	Overall flavor acceptability[2]	Off flavor intensity[5]	Oiliness[5]	Overall aftertaste acceptability[2]	
Liquid egg	9.1a	9.4a	7.9b	7.8c	7.4a	8.1a	7.2a,b	8.3a	7.9b	6.6a	6.5b	8.1a	7.9	6.5b	8.4a	8.3a
Dry egg	8.9a	9.0a	6.7c	7.0c	8.0a	7.7a	7.5a	7.7a	7.3b	7.0a	6.7b	7.7a	7.8	6.7b	7.8a	7.7a
R1	7.4b	9.2a	6.8c	7.1c	8.0a	8.0a	6.5c,d	8.0a	7.8b	6.8a	6.6b	7.9a	8.1	6.6b	8.0a	7.9a
R2	7.5b	9.2a	9.6a	9.6a	6.4b	8.3a	6.9b,c	8.4a	8.4a	7.0a	6.0b	8.1a	7.9	6.4b	8.4a	8.6a
R3	6.0c	8.5a	7.5b	8.4b	7.4a	8.4a	5.5e	6.7b	6.7b	6.2a	8.7a	5.5b	8.1	9.0a	5.3b	5.5b

* Means followed by same letters, within same column, for each category, are not significantly different ($p>0.05$).

[1]Where 0 = Light Tan/Beige and 15 = Golden brown

[2]Where 0 = Very undesirable and 15 = Very desirable

[3]Where 0 = Very dry and 15 = Very moist

[4]Where 0 = Very chewy and 15 = Very crumbly

[5]Where 0 = Lacking and 15 = Intense

Table 4.7. Color parameters[a] of cookies.

	L*		*a**		*b**	
Formula	Day 1	Day 7	Day 1	Day 7	Day 1	Day 7
Liquid egg	44.8a	44.7a	2.5a	2.6a	12.1a	12.0a
Dry egg	46.4a	46.5a,b	2.6a	2.7a	12.5a	12.5a
R1	44.7a	43.5b,c	2.2b	2.1b	11.2b	10.5b
R2	41.9b	40.6d	1.9c	1.8c	9.6c	8.9c
R3	44.6a	41.8c,d	1.8c	1.9b,c	10.4b,c	9.5b,c

[a]Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

Table 4.8. Bulk density and spread factor* analysis.

Formulation	Bulk density (g/cm^3)	Spread factor
Liquid whole egg	0.62b	1.1c
Dry whole egg	0.63b	0.9d
R1	0.66a	1.1c
R2	0.67a	1.5a
R3	0.68a	1.4b

*Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

Table 4.9. Three point bend test of cookies stored for 1 and 7 days.

Formulation	Force (g)*	
	Day 1	Day 7
Liquid whole egg	732.7c	1224.5b
Dry whole egg	1060.2a	1472.5a
R1	819.2b	1108.7b
R2	461.6d	737.2c
R3	570.2d	834.4c

[a]Means followed by the same letter, within the same column, are not significantly different (p>0.05).

Table 4.10. Puncture test of cookies stored for 1 and 7 days.

Formulation	Force (g)*	
	Day 1	Day 7
Liquid whole egg	426.0c	1177.1b
Dry whole egg	501.0a,b	1470.0a
R1	544.9a	1365.5a
R2	357.7d	816.1c
R3	458.2b,c	951.2c

*Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

Table 4.11. The ingredient and total cost comparison of the yellow cake formulations studied. All numbers represent pricing, in US $, for 100lb of cookies.

Ingredient	Liquid egg	Dry egg	R1	R2	R3
All purpose shortening	16.26	16.26	16.26	16.26	16.26
Sugar, granulated	5.18	5.18	5.18	5.18	5.18
Brown sugar	14.14	14.14	14.14	14.14	14.14
Emulsifier	1.90	1.90	1.90	1.90	1.90
Vanilla flavor	16.41	16.41	16.41	16.41	16.41
Crystalline fructose	3.29	3.29	3.29	3.29	3.29
Flour, pastry	12.61	12.61	12.61	12.61	12.61
All purpose flour	4.26	4.26	4.26	4.26	4.26
Baking Soda	0.61	0.61	0.61	0.61	0.61
Salt	0.09	0.09	0.09	0.09	0.09
Water	-	-	-	-	-
Liquid whole egg	5.31	-	-	-	-
Dry whole egg	-	6.30	-	1.57	-
Egg Replacer 1	-	-	0.73	-	-
Egg Replacer 2	-	-	-	1.26	8.42
Egg Replacer 3	-	-	-	-	-
Total	*80.06*	*81.05*	*75.48*	*77.59*	*83.17*

Appendix 4.A. Pricing information on the ingredients used in cookie formulations.

Ingredient	Price ($)	Per*	Price per lb	Price per 100lb ($)
All purpose shortening	37.50	50 lbs	0.75	75.00
Sugar, granulated	31.63	50 lbs	0.63	63.26
Brown sugar	48.00	50 lbs	0.96	96.00
Emulsifier	2.89	1 lb	2.89	289.29
Vanilla flavor	11.97	pint	23.94	2,394.00
Crystalline fructose	40.00	50 lbs	0.80	80.00
Pastry flour	24.00	50 lbs	0.48	48.00
All purpose flour	16.22	50 lbs	0.32	32.44
Baking Soda	21.46	24 lbs	0.89	89.42
Salt	10.81	25 lbs	0.43	43.24
Water**	-	-	-	-
Liquid whole egg	0.55	1 lb	0.55	55.00
Dry whole egg	2.61	1 lb	2.61	261.00
Egg Replacer 1	0.30	1 lb	0.30	30.18
Egg Replacer 2	3.49	1 lb	3.49	349.00
Egg Replacer 3	1.89	1 lb	1.89	189.00

*Pricing information was provided by ingredient manufacturers for this amount.

**Considered as part of utilities requirements in the production process.

Appendix 4.B. Attributes rating form used to evaluate cookies

Evaluation of Cookies

Name ______________________ Date __________________

You will be given 5 samples, one sample at a time. Please evaluate each sample for the following attributes. **Make a vertical line** on the provided horizontal line at the point that best describes your perception of the attribute. Each sample will have its own evaluation form.

Sample Code _____

Appearance

Color

Light Tan/Beige Golden Brown

|____|____|

Too Light Just About Right Too Dark

|____|____|

Overall Appearance

Very Undesirable Very Desirable

|____|____|

.

Texture

Very Dry Very Moist

|____|____|

Very Chewy Very Crumbly

|____|____|

Grittiness

Lacking Intense

|____|____|

Mouthfeel:

Oiliness

Lacking Intense

|____|____|

Clearing of the mouth
Lingers | Readily Clears
|________________|________________|

Overall Texture
Very Undesirable | Very Desirable
|________________|________________|

Flavor:

Sweetness
Lacking | Intense
|________________|________________|

Vanilla
Lacking | Intense
|________________|________________|

Off Flavor
Lacking | Intense
|________________|________________|

Overall Flavor
Very Undesirable | Very Desirable

|________________|________________|

Aftertaste:
Off Flavor
Lacking | Intense
|________________|________________|

Oiliness
Lacking | Intense
|________________|________________|

Overall Aftertaste
Very Undesirable | Very Desirable

|________________|________________|

Overall Acceptability

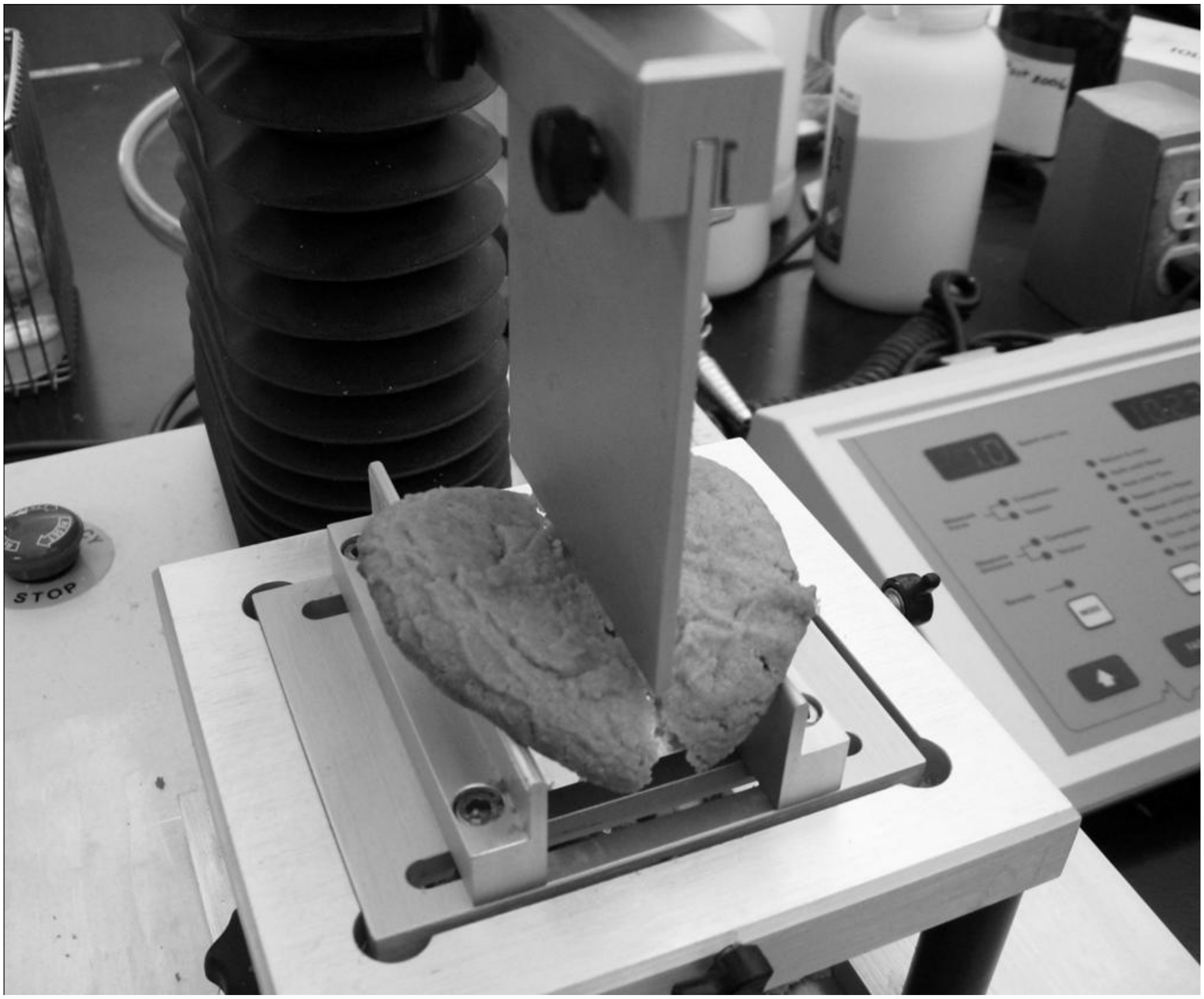
Very Undesirable | Very Desirable

|________________|________________|

Comments:

Appendix 4.C. Cookies production using Kook-E-King® automatic cookie depositor.

Appendix 4.D. Analysis of cookies using the three-point bend test.



Chapter 5: Waffles

Introduction

Waffle was selected as a potential food item for the study due to its alignment with many of the key criteria considered for product selection, as described in Section 1.3. Waffles and pancakes often are prepared using identical ingredient mixes, which are commercially available as pre-mixes. Complete pancake mixes, many of which are also promoted as appropriate for preparing waffles, have not yet experienced significant market penetration from egg replacers/extenders. There are, however, some mixes with a combination of eggs and egg extending ingredients, such as gums and modified starches on the ingredient statements, as noted during a market product review in Omaha/Lincoln, Nebraska supermarkets. Similar to muffins, these mixes are potential targets for egg extenders/replacers.

InfoScan™ data (Information_Resources_Inc. 2009) was analyzed to assess food stores, drug stores, and mass merchandisers volume in the product category. Pancake Mixes includes all pancake and waffle mixes, both complete (*i.e.*, add water) and traditional (*i.e.*, add multiple ingredients). The pancake/waffle products of interest were complete mixes, as those would be most vulnerable to egg replacers. Therefore, SKU level data were acquired for evaluation. The SKUs were sorted to isolate those identified as complete mixes and those volumes were compiled. The volume for frozen (prepared) waffles was also compiled and represents the majority of volume in the category as shown in Table 5.1. The breakdown of the available and relevant pancake and waffle volume is show in Table 5.1. It was noted that, during the supermarket ingredient statement review, egg used in refrigerated and frozen products is more common compared to the same category in a non-refrigerated and/or non-frozen form. Similar to most other products, such as muffins, waffle is a common product offered in foodservice establishments, such as restaurants and hotels. The combination of these factors, in particular the high unit volume of frozen waffles, led to a frozen waffle being selected by the industry advisory board of this project, the American Egg Board and FPC project leaders as a product for the functionality study.

There is not much information available on waffle quality and the effects of ingredient functionality on the product in published literature. The objective of this study was to evaluate the effects of whole egg (both liquid and dry forms) and commercially available egg replacers on the quality of frozen waffles.

Materials and Methods

Two "controls", liquid whole egg and dry whole egg, and three commercially available (to commercial waffle manufacturers) egg replacers were used to prepare the samples used in this study. The samples were prepared, and stored frozen (-20ºC) until analyses. Details of these steps are given below.

Ingredients

All ingredients were acquired from commercial sources as follows: Cake flour (Pikes Peak®, ConAgra Foods, Omaha, NE); all purpose flour (Gingham Girl®, Gooch Milling & Elevator Company, Lincoln, NE), soybean oil (Wesson® Vegetable Oil, ConAgra Foods, Omaha, NE), sugar (United Sugar Co., Minneapolis, MN), whey protein (Grande 8000®, Grande Cheese Company, Brownsville,WI), maltodextrin (M100®, Grain Processing Corporation, Muscatine, IA), baking powder (Caravan Ingredients, Lenexa, KS), salt (Cargill Inc., Minneapolis, MN), calcium carbonate (Mineral Technologies, Adams, MA), lecithin (Solec 8160®, Solae, St. Louis, MO), water and liquid whole egg or dry whole egg (Michael Foods, Minnetonka, MN), or a combination of water, dry whole egg, and egg replacers.

Egg replacers

Three egg replacers, designated as Replacer 1 (R1), Replacer 2 (R2), and Replacer 3 (R3), specific to bakery applications, and recommended to use in waffles, were used to prepare the samples. These egg replacers were selected to cover a variety of types commercially available for waffle production. The ingredients and nutritional compositions of these egg replacers, as provided by the corresponding manufacturers, are given in Tables 5.2 and 5.3, respectively.

Sample preparation

A series of preliminary tests were performed to determine the maximum levels of each egg replacer that could be used to obtain reasonable quality products. A total of five formulations; liquid whole egg, dry whole egg, R1 (75% R1+ 25% whole dry egg), R2, and R3, were used to prepare samples. The amounts of ingredients used in the five formulations are shown in Table 5.4. All ingredients, except egg and egg-replacers, were kept constant in all formulations. Flour, whey protein, maltodextrin, salt, calcium carbonate, and lecithin were mixed using a paddle in a Kitchen Aid mixer (Model KP26M1XLC Professional 600, Kitchen Aid, St. Joseph, MI) for 1min on speed 1. Liquid ingredients; oil, water, liquid whole egg, or combination of dry whole egg and egg replacers, and sugar were added in to the dry ingredients and then mixed at speed 1 for an additional 1min. The paddle, sides, and bottom of the bowl were scraped and mixed with the content. The batter was mixed again for 2min at speed 2.

A professional waffle maker (Star - Model B8SQE, Star Manufacturing International Inc., Smithville, TN), with a built-in thermostat, and a timer, was used to bake the waffles. The waffle maker was pre-heated to 125°C. Then the interior of the waffle maker was uniformly coated with cooking spray (Pam® Original, Con Agra Foods, Omaha, NE); batter was poured on to the waffle maker using a Traex Batter Boss® (Model 2803, Libbey Inc., Dane, WI) device (at setting 6, poured 3 times to obtain an approximate batter weight of 260g of batter in to the waffle maker) and baked at 125°C for 2min and 30s. The first set of waffles for each formulation/batch was discarded, in order to equilibrate the baking conditions for subsequent samples. Following baking, the waffles were promptly transferred on to cooling racks and cooled for 15min at room temperature. The waffles were then packaged in plastic freezer bags (Great Value® Double Zipper Freezer Bags, gallon volume, Walmart Inc., Bentonville, AR) and stored in a -20ºC freezer (Arctic Air F22CWF4, Arctic Air, Eden Prairie, MN) for two weeks prior to sensory and other analyses. Prior to sensory and laboratory analyses, the frozen samples were toasted, for 4min, using regular household toasters (Kitchen Aid - KMTT200ER, Kitchen Aid, St. Joseph, MI).

Color measurement

The color of waffle surface was measured with a chromameter (Minolta CR-300, Konica Minolta, Inc., Ramsey, NJ) using CIELAB L*, *a**, *b** color space. The chromameter was calibrated using a color standard supplied by the manufacturer. Approximately one square inch portions of randomly selected, and toasted samples were used to measure color.

Texture analysis

The texture characteristics of waffle samples were determined using a TA-XT2i texture analyzer (Stable Micro Systems Ltd, Surrey, UK). The mechanical properties were profiled by rupturing with a TA-54 probe. Firmness (peak force) and work (area) were measured on randomly selected samples and recorded.

Volume analysis

Bulk densities of waffles were determined using a laser scanning volume measuring instrument (BVM-L370LC, TexVoL Instruments, AB, Viken, Sweden) equipped with VolCalc® software (version 3.2.3.10). The equipment was calibrated with a standard disk provided by the manufacturer prior to analysis. Each waffle sample was mounted on a HA2P17 attachment on a 225mm shaft and scanned for 45s.

Moisture analysis

Moisture content of waffle samples was determined according to AOAC method 945.43 (AOAC 1990).

Sensory analysis

The samples were served freshly toasted, slightly warm to the panelists. The sensory panel was conducted as an attributes rating consumer panel. The panelists were appointed time slots in order to serve samples under comparable conditions.

Samples were toasted using a Kitchen Aid (Model KMTT200ER) toaster for 2min and 30s. Immediately after removing from the toaster each waffle was cut into quarters using a serrated knife and each quarter was placed on a labeled 6” styrofoam plate. Panelists were also given water, at room temperature, to clear their palates between samples. Samples were evaluated using an attribute rating scale (Appendix 5.A). Samples were served one at a time to the panelists. A total of 43 panelists participated in the sensory panel.

Statistical analysis

A randomized complete block design (RCBD) was used for the experiments. The analysis of variance (ANOVA) and Fisher's least significant difference (LSD) were calculated to determine significant effects at $p<0.05$ among formulations. Three independent replicates of waffle samples (each replicate was made as a single batch) were produced. SAS Version 9.2 (SAS Institute Inc., Cary, NC) was used for statistical analyses.

Cost comparison

The economics of using different ingredients were systematically compared using a financial comparison. As ingredients were sourced for each formulation, pricing data were obtained from respective suppliers.

Results and Discussion

As indicated above, under 'Introduction', frozen waffles contribute a major portion of the total amount of waffles and pancakes sold in food and drug stores, and mass merchandisers in the United States (Table 5.1). Hence, frozen waffle was selected as a product to study the egg and egg replacers' functionalities in this study. The three egg replacers used in this study (Table 5.2) were selected to cover the commonly available types of such ingredients for waffles and based on commercial availability. The three replacers are identified as R1, R2, and R3 in this discussion. Nutritional compositions of these egg replacers are given in Table 5.3. It is important to note that R2 contains cholesterol and a high amount of saturated fat. R1 had the highest fat content among the three replacers used (Table 5.3).

A series of preliminary trials were conducted to determine the maximum amounts of dry whole egg (w/w basis) that could be replaced with each egg replacer in the formulation, to produce an acceptable product in terms of color, volume, texture, and flavor. Commercially available frozen waffles were used as references for these preliminary tests. The tests determined that R2 and R3 were able to replace dry whole egg completely, *i. e.*, 100% (w/w). However, R1 could successfully replace only 75% (w/w) dry egg to yield an acceptable product. After the preliminary tests, five formulations were identified to be tested in the functionality investigations; (a) Liquid whole egg, (b) Dry whole egg, (c) R1, (d) R2, and (e) R3. All samples were prepared and stored under identical conditions, as given in the 'Materials and Methods' section above. The only variation among the five samples was the egg and egg replacers used (except for the slight adjustment in water content to accommodate water in liquid egg formulation).

Waffle surface color is important and critical for product acceptability. Being an uneven surface, with highly differential color variations even on the same waffle, color measurement of waffles posed a considerable challenge. It is also important to note here that the uneven heating caused by toasters also created much variations in surface color of waffle samples. It was assumed that these conditions were very similar to what a potential consumer, under normal circumstances, would encounter in preparing frozen waffles for consumption. The color was analyzed by measuring L*, *a**, and *b** values on randomly selected spots on waffle surfaces. R2 samples had the lightest color, whereas both liquid egg and R3 produced significantly darker color (the highest L*) waffles (Table 5.5). Dry egg and R2 formulations produced more yellowish color (higher *b** values) waffles. General visual observations did not readily reveal some of the subtle differences in color among the waffle samples (Fig 5.1). The sensory analysis, however, analyzed three color attributes (Table 5.9) and the results revealed that R2 formulation produced the most undesirable color characteristics among the five samples tested. This could be due to the lighter colors of both ridges and wells of the waffle surfaces. The best overall color acceptability was observed in liquid egg and 100% dry egg made waffles (Table 5.9).

The texture of the samples were analyzed both using a laboratory instrument and during the sensory analysis. The laboratory analysis revealed that there were no significant differences among the samples in firmness, which was measured as peak force (Table 5.6). The values ranged from 476.5 to 564.8g, but the high variation, probably caused by uneven sample toasting, and variable surface characteristics, such as differences in thicknesses in randomly selected points, could have contributed to statistically insignificant ($p>0.05$) differences. Soy flour (R3) containing formula yielded waffles with more "hard to break" texture, *i. e.*, more work was required to puncture the sample (Table 5.6). Sensory analysis corroborated this; R2 and R3 waffles had more denser texture compared to the other samples, and R2 had the lowest crispness (Table 5.9). Although the laboratory analysis did not reveal any significant differences between liquid egg and other samples (Table 5.6), sensory analysis revealed better textural attributes in liquid egg made waffles. Liquid egg, along with R3, produced waffles with the highest overall texture acceptability, with a lighter waffle texture (Table 5.9).

The R1 formula produced waffles with lowest moisture content, and the R2 formula produced highest moisture levels in waffles (Table 5.7). High moisture in R2 made waffles might have contributed to the highest density observed in R2 waffles (Table 5.8). Although the prepared waffles are kept frozen, high moisture contents could increase the water activity and affect the shelf life of the product. The differences observed in measured volumes among the five formulations (Table 5.8) could be due to the changes that took place during frozen storage and subsequent toasting, for example, among other factors, changes caused by additional starch and other differences in the ingredient composition.

The taste of the product is of paramount importance for the consumer acceptability. Although most of the taste attributes tested by sensory panel were not significantly different among the five formulations, liquid egg, along with the R3, waffles had the highest overall flavor acceptability (Table 5.9). The overall sample acceptability was statistically the same ($p>0.05$) for all five formulations.

Pricing information (Appendix 5.B), used for the cost comparison, on the ingredients were obtained from the respective suppliers at the time of purchase, and they were used to perform the cost comparison of five formulas tested in this study (Table 5.10). In the food industry, bracketed pricing (*i.e.,* incrementally higher discounts for buying in volume) is frequently used. For the purposes of this project, pallet pricing was used for all egg and egg replacer products. Formulations that were documented during the sample preparations, with exact quantities of each ingredient, were used as the basis for cost comparison. Among the five formulas tested, the R3 formula had estimated lowest cost of production, whereas the other four formulas were relatively comparable (Table 5.10).

Conclusions

Frozen waffle is an important category within the broader group of food products that fall under waffles/pancakes, which uses high amounts of egg in their formulations. Commercial egg replacers could be used in frozen waffles manufacturing process to obtain reasonably acceptable products. The quality of waffles, however, would be compromised based on the type and amount of egg replacer used in the formulation. It was found that liquid egg formulation yielded the best quality waffles out of the five formulations investigated in this study, although using egg replacers could be relatively more economical.

References

AOAC (1990). Official methods of analysis of the Association of Official Analytical Chemists. Arlington, VA, Accociation of Official Analytical Chemists Inc.

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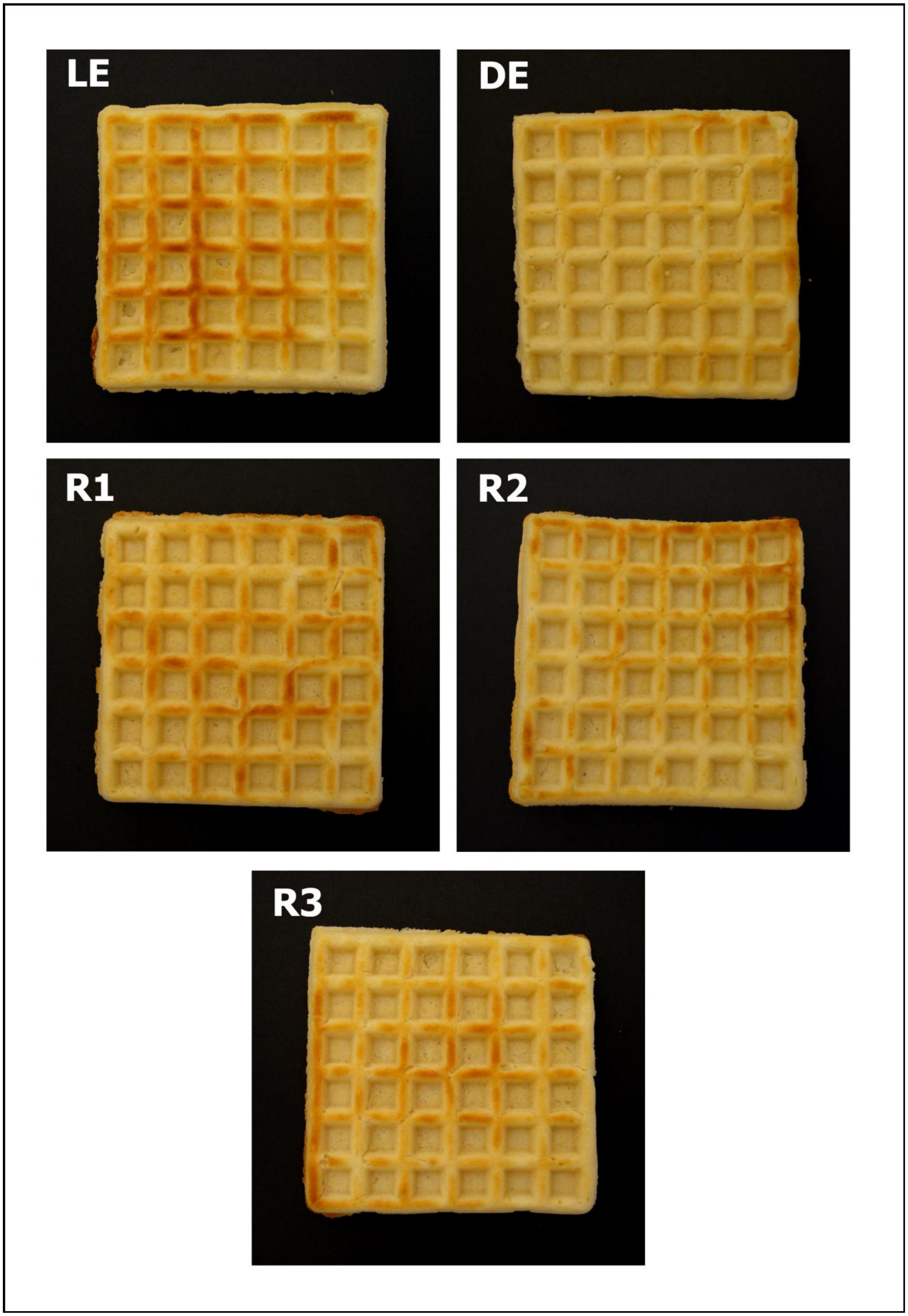

Figure 5.1. Representative samples prepared from different waffle formulas. LE = Liquid whole egg, DE = Dry whole egg, R1 = Replacer 1, R2 = Replacer 2, and R3 = Replacer 3.

Table 5.1. InfoScan™ unit volume analysis of total U.S. waffles and pancakes sold in food stores, drug stores, and mass merchandisers. Latest 52 weeks ending June 14, 2009.

Category	Sales (lbs)
Frozen waffles	413,589,238
Mix - pancakes/waffles	125,533,021
Pancakes only	47,060,771
Waffles only	4,154,775
Total	590,337,805

Table 5.2. Ingredients of egg replacers used in this study

Egg replacer	Ingredient statement*
Replacer 1 (R1)	Roasted soy flour or soy flour, wheat gluten, corn syrup solids, algin or sodium alginate
Replacer 2 (R2)	Whey protein concentrate, potato starch, and sodium stearoyl lactylate
Replacer 3 (R3)	Defatted soy four

*Provided by the manufacturer.

Table 5.3. Nutritional compositions* of egg replacers used in this study

Component	Replacer 1	Replacer 2	Replacer 3
Total calories	450	390	299
Total fat (g)	17	4.6	2.5
Saturated (g)	2.5	3.03	0.6
Mono unsaturated fat (g)	-	1.04	0.3
Poly unsaturated fat (g)	-	0.43	1.6
Trans fat (g)	-	0.10	0.01
Cholesterol (mg)	0	142.2	0
Carbohydrates (g)	32	24.1	33
Sugars (g)	11	-	8
Dietary fiber (g)	17	-	16
Protein (g)	43	62.1	51
Ash (g)	-	3.3	6.5
Moisture (g)	6	3.5	7.0

* per 100 g of material

Table 5.4. Compositions (%, w/w) of waffle formulations with egg and egg replacers

Ingredient	Liquid Whole Egg	Dry Whole Egg	R1	R2	R3
Cake flour	18.00	18.00	18.00	18.00	18.00
All purpose flour	18.00	18.00	18.00	18.00	18.00
Soybean oil	8.00	8.00	8.00	8.00	8.00
Sugar	4.00	4.00	4.00	4.00	4.00
Liquid egg	6.00	-	-	-	-
Dried whole egg	-	1.50	0.37	-	-
Egg replacer 1	-	-	1.13	-	-
Egg replacer 2	-	-	-	1.50	-
Egg replacer 3	-	-	-	-	1.50
Whey protein	1.50	1.50	1.50	1.50	1.50
Maltodextrin	1.25	1.25	1.25	1.25	1.25
Baking powder	2.25	2.25	2.25	2.25	2.25
Salt	1.00	1.00	1.00	1.00	1.00
Calcium carbonate	1.00	1.00	1.00	1.00	1.00
Soy lecithin	0.20	0.20	0.20	0.20	0.20
Water	38.00	43.30	43.30	43.30	43.30
Total	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*

Table 5.5. Color analysis[a] of waffles

Formula	L*	a*	b*
Liquid whole egg	47.0c	3.6a	13.3cd
Dry whole egg	51.0b	3.5a	14.7a
R1	52.0b	2.5bc	13.9bc
R2	54.0a	2.1c	14.5ab
R3	48.8c	3.1ab	13.1d

[a]Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

Table 5.6. Texture analysis* of waffles

Formula	Peak Force (g)	Area (N*s)
Liquid whole egg	564.8a	32.2b
Dry whole egg	523.2a	33.2b
R1	519.8a	34.7a,b
R2	476.5a	29.9b
R3	533.4a	38.7a

* Means followed by the same letter, within the same column, are not significantly different ($p > 0.05$).

Table 5.7. Moisture analysis of waffles

Formula	% Moisture content* (w/w, fresh basis)
Liquid whole egg	30.3b
Dry whole egg	30.5b
R1	29.2c
R2	32.5a
R3	30.4b

* Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

Table 5.8. Volume and density analysis results*

Formula	Volume (cm^3)	Density (g/cm^3)
Liquid whole egg	111.8a	0.431b
Dry whole egg	111.4a,b	0.431b
R1	105.2b,c	0.437b
R2	104.5c	0.497a
R3	108.2a,b,c	0.433b

* Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

Table 5.9. Sensory attributes* of waffle samples

Formula	Appearance			Texture					Taste					Aftertaste		Overall Sample Acceptability[3]
	Color of Ridges[1]	Color of Wells[2]	Overall Appearance[3]	Crispness (First Bite)[4]	Waffle Texture[5]	Moistness[6]	Clearing of the Mouth[7]	Overall Texture Acceptability[3]	Waffle[4]	Sweetness[4]	Burnt[4]	Off Flavor[4]	Overall Flavor Acceptability[3]	Off Flavor[4]	Aftertaste Acceptability[3]	
Liquid Egg	9.86a	6.17a	9.50a	9.00a	6.53c	7.79b	8.22a	9.09a	7.35a	5.78a	5.98a	5.08a	8.72a	5.35b	9.05a	8.68a
Dry Egg	9.41a	6.15a	9.47a	7.40b	7.69b	8.12a	7.54b	7.85c	6.42a	5.16a	5.35a	5.97a	7.23b	6.11a	7.79b	7.56a
R1	9.27a	5.80a	8.56b	9.14a	7.44b	8.21a	7.51b	8.31b	6.09b	5.07a	4.59a	6.62b	7.16b	6.08a	7.50b	7.53a
R2	7.72b	4.34b	7.36c	6.66b	8.40a	8.07a	6.98b	7.84c	7.04a	5.48a	4.63a	4.88a	7.65b	5.05b	8.53a	7.50a
R3	9.15a	5.74a	8.30b	8.45a	8.46a	8.46a	7.50b	8.58a,b	6.14b	5.35a	4.60a	5.52a	7.98a,b	5.41b	8.07a	7.98a

*Means followed by the same letter, within the same column, are not significantly different ($p>0.05$).

[1] Where 0 = Light yellow and 15 = Dark brown

[2] Where 0 = Light yellow and 15 = Golden brown

[3] Where 0 = Very undesirable and 15 = Very desirable

[4] Where 0 = Lacking and 15 = Intense

[5] Where 0 = Very airy/light and 15 = Very dense/doughy

[6] Where 0 = Very dry and 15 = Very moist

[7] Where 0 = Hard to clear and 15 = Readily clears

Table 5.10. The ingredient and total cost comparison of the muffin formulations studied (all numbers represent pricing, in US $, for 100lb of waffles).

Ingredient	Liquid egg	Dry egg	R1	R2	R3
Cake flour	6.47	6.47	6.47	6.47	6.47
All purpose flour	5.41	5.41	5.41	5.41	5.41
Soybean oil	11.77	11.77	11.77	11.77	11.77
Sugar	2.53	2.53	2.53	2.53	2.53
Whey protein	2.84	2.84	2.84	2.84	2.84
Maltodextrin M100	0.48	0.48	0.48	0.48	0.48
Baking powder	3.71	3.71	3.71	3.71	3.71
Salt	0.43	0.43	0.43	0.43	0.43
Calcium Carbonate	0.79	0.79	0.79	0.79	0.79
Lecithin	0.58	0.58	0.58	0.58	0.58
Water	-	-	-	-	-
Liquid egg	-	3.30	-	-	-
Dried whole egg	3.92	-	0.97	-	-
Blue 100®	-	-	2.70	-	-
Egg-Mate®	-	-	-	3.72	-
Prolia 200/70®	-	-	-	-	0.60
Total	*38.91*	*38.29*	*38.66*	*38.72*	*35.59*

Appendix 5.A. Attributes rating form used for Sensory Evaluation

Evaluation of Waffles

Name___________________ Date_______________

You will be given 5 samples, one sample at a time. Please evaluate each sample for the following attributes. **Make a vertical line** on the provided horizontal line at the point that best describes your perception of the attribute. Each Sample will have its own evaluation form.

Sample Code_________

Appearance:

Color of the Ridges

Light Yellow Dark Brown

|_________________________________|_________________________________|

Color of the "Wells"

Light Yellow Golden Brown

|_________________________________|_________________________________|

Overall Appearance Acceptability

Very Undesirable Very Desirable

|_________________________________|_________________________________|

Texture:

First Bite (Crust) Crispness

Lacking Intense

|_________________________________|_________________________________|

Internal Texture

Very Light Very Doughy

|_________________________________|_________________________________|

Very Dry Very Moist

|_________________________________|_________________________________|

Stickiness (Sticks/adheres to the teeth/mouth)

Extremely Sticky Clears Quickly

|_________________________________|_________________________________|

Overall Texture Acceptability

Very Undesirable Very Undesirable

|_______________________________|_______________________________|

Flavor:

Waffle Flavor

Lacking Intense

|_______________________________|_______________________________|

Sweetness

Lacking Intense

|_______________________________|_______________________________|

Burnt Flavor

Lacking Intense

|_______________________________|_______________________________|

Off Flavor

Lacking Intense

|_______________________________|_______________________________|

Overall Flavor Acceptability

Very Undesirable Very Undesirable

|_______________________________|_______________________________|

Aftertaste:

Off Flavor

Lacking Intense

|_______________________________|_______________________________|

Overall Sample Acceptability

Very Undesirable Very Undesirable

|_______________________________|_______________________________|

Comments:

Appendix 5.B. Pricing information on the ingredients used in waffle formulations.

Ingredient	Price ($)	Per*	Price per lb ($)	Price per 100lb ($)
Cake flour	17.96	50 lbs	0.36	35.92
All purpose flour	15.02	50 lbs	0.30	30.04
Soybean oil	44.14	30 lbs	1.47	147.13
Sugar	31.63	50 lbs	0.63	63.26
Whey protein	1.890	1 lb	1.89	189.00
Maltodextrin M100	0.380	1 lb	0.38	38.00
Baking powder	32.95	20 lbs	1.65	164.75
Salt	10.81	25 lbs	0.43	43.24
Calcium carbonate	0.790	1 lb	0.79	79.00
Lecithin	2.9	1 lb	2.89	289.29
Water**	-	-	-	-
Liquid egg	0.55	1 lb	0.55	55.00
Dried whole egg	2.61	1 lb	2.61	261.00
Blue 100®	2.39	1 lb	2.39	239.00
Egg-Mate®	2.483	1 lb	2.48	248.25
Prolia® 200/70	0.400	1 lb	0.40	40.00

*Pricing information was provided by ingredient manufacturers for this amount.

**Considered as part of utilities requirements in the production process.