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Executive Summary

The majority of eggs are marketed as shell eggs, however a growing percentage of eggs are being sold to the consumer in the form of egg products (liquid, dried or frozen whole eggs, egg yolks or egg whites). In 2002 there were 203.3 million cases of eggs produced in the US of these 30.6% were further processed and sold to food services, manufacturers, retail and export. Many of these egg products are used as ingredients in bakery products, desserts, noodles, and salad dressings.

Eggs are considered a high profile ingredient because of their multifunctional properties. For these reason food designers have aspired to develop ingredients that emulate egg's polyfunctionality. These egg alternative ingredients are carbohydrate, lipid and/or protein-based.

This research investigated a wide selection of egg alternatives that are commercially available on the market and in many cases advertised as an egg alternative in specific food systems (bakery, ice cream, pasta, or salad dressings). These commercial egg alternatives identified were tested in angel food cake, French vanilla ice cream, mayonnaise, refrigerated pasta, and yellow cake. Physical and sensory analyses were employed to compare and evaluate eggs and egg alternatives in the aforementioned food systems.

The results indicated that there was not one single egg alternative that was competitive in both physical and sensory attributes across all the food systems evaluated. However, in each of the food systems evaluated there was at least one single egg alternative or a blend that was competitive in a single particular physical or sensory test.

Currently eggs do exhibit a competitive advantage with regard to performance. However, as egg alternative blends are further developed and as price decline for these products they may be an attractive alternative for the food manufacturer.

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FINAL REPORT TO THE AMERICAN EGG BOARD

COMPARATIVE STUDY: FUNCTIONALITY OF EGG AND EGG ALTERNATIVES IN SELECTED FOOD SYSTEMS

KANSAS STATE UNIVERSITY

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Chapter I

Egg Alternatives

History

In order to reduce costs, food manufacturers have attempted to partially or completely replace eggs with low-cost and effective egg alternatives in food products. Eggs, however, are essential for desirable volume, texture and color in food products because of unique foaming, solubility, emulsification and coagulation properties (Pyler 1988).

In the early 1940's, a boom in egg substitutes was seen on the market because of egg shortages occurring as a result of World War II. These substitutes contained a range of substances: soy flour, wheat flour, starch, gums, casein, rye, whey, blood plasma, etc. Tests conducted on many of these substitutes found that over 50% replacement of whole eggs yielded a decrease in cake quality. These egg substitutes were then labeled as "egg extenders" because they did not duplicate egg functionality.

Protein-Based

Many of the egg substitutes previously developed were protein based. Proteins are the primary component responsible for many functional characteristics. Eggs were partially and completely replaced in cakes using bovine plasma (Johnson and others 1979, Khan and others 1979, Lee and others 1991, Lee and others 1993, Raeker and Johnson 1995). Albumin in the plasma has similar properties to that of egg albumin. In white layer cake, bovine plasma was shown to produce cake volumes that were only slightly different at 100% replacement (Lee and others 1991). These cakes differed only slightly in terms of symmetry, shrinkage, color, and textural characteristics (Lee and others 1993). Cake crust and crumb were significantly darker (Lee and others 1991).

White lupine protein isolated from lupine (*Lupinus albus*) has been used as a replacement for eggs in both yellow cake (Arozarena and others 2001) and in mayonnaise (Raymundo and others 2002). Lupine proteins have demonstrated good foaming and emulsification properties (Raymundo and others, 1998, Franco and others 1998), but proteins did not have egg-coagulation capacity and produced cake that had decreased volume and a harder crumb than cakes with whole egg (Arozarena and others 2001)

Whey. The ability of whey protein concentrates (WPC) and whey protein isolates (WPI) to behave like egg whites has been noted (Morr and others, 1973, Haggett 1976, Vitti 1981, Morr and Ha 1993, Lawson 1994, Zhu and Damodaran 1994, Arunepanlop and others 1996). Whey's ability to replace egg white comes from high foaming capacity and stability, comparable to egg.

Whey is composed of several different proteins, the most common of which are β-lactoglobulin (β-lg) and α-lactalbumin (α-la). 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 are small in size (<20 kDa), globular in shape, and soluble around there isoelectric point; however, each does react differently in foams and emulsions.

β-lg and α-la react with both polar (water) and nonpolar (oil & air) at the same time because of their physiochemical structure. Slight denaturation by heat causes proteins to partially unfold exposing hydrophobic regions to oil and air. The slight denaturation of protein exposes sulfhydrl groups that can form sulfide bond increasing protein-protein interaction. This slight heating has been shown to improve foaming capacity and stability (Zhu and Damodaran 1994, Arunepanlop and others 1996, Phillips and others 1990, Pernell and others 2002). β-lg and α-la are able to emulsify because of greater flexibility and reduced interfacial tension between water/oil or air.

Once the proteins have correctly oriented themselves at the interface, they form a film. This protein film prevents flocculation and coalescence. Film thickness and stability are the key factors in stabilizing protein films and emulsions. Once an emulsion or foam has been formed, heating will further stabilize the mixture because gelatinized proteins form complexes at film layer.

Whey protein's potential use as an egg replacer in cake has been reported by many researchers (Arunepanlop and others 1996, Pernell and others 2002, Wit and Hontelez-Backx 1982, Swaran and others 2003). Arunelanlop (1996) found that whey may replace up to 25% of egg white in an angel food cake without adversely affecting physical or sensory properties. Pernell (2002) found that heat-treating whey and the addition of xanthan gum can increase cake volume but not to the extent of that produced by egg. He attributed this to whey's decreased ability to prevent collapse at the beginning

of starch gelatinization during baking compared to that of egg whites. Singh (2003) found that a combination of whey protein concentrate (WPC), soy lecithin (SL), and glycerol mono-stearate (GMS) could replace 50% of egg without significant difference in physical properties. At replacements over 50%, however, cakes showed significant loss of volume and overall sensory acceptability.

Hydrolysis of whey protein has been reported to improve functional characteristics. A degree of hydrolysis (DH) of 10% or less has been reported to improve emulsifying ability (Venter, McGill and Lombard 1989). Whey hydrolysates have show correlation between foaming capacity and stability versus DH (Figure 1.5) (Perea and others 1993). It was found in this study that maximum foam expansion occurred at 10% DH but that 10% DH was also associated with minimum foam stability.

Soy. Soy has been used as a replacement for eggs and NFDM in cake. Soy protein and lecithin can be used to reduce the amount of egg in cake (Endres 2001). Some bakery manufactures suggest that a relecithinated soy flour can replace about 50% of whole eggs (Stockwell 2001).

Soy proteins are beneficial because of the emulsification properties and ability to stabilize interfaces. Soy is composed of two main proteins, glycinin and β-conglycinin, both of which contribute to the emulsification ability of soy. β-conglycinin possesses better emulsifying ability because it is lower in molecular weight and is more hydrophobic than glycinin.

In gels, glycinin and β-conglycinin serve varying functions. Glycinin is associated with the hardness of gels while β-conglycinin contributes to the elasticity.

Wheat. Wheat proteins are primarily composed of two main fractions, water soluble albumins and globulins and insoluble glutenins and gliadins. These two types of wheat protein serve different functions in baked goods.

The water soluble fraction, albumins and globulins, accounts for about 10 to 15% of wheat proteins (Bowers 1992). Albumins have low molecular weights of 12,000 to 26,000 Daltons; the globulins are heavier, weighing 40,000 Daltons but occasionally reaching 100,000 Daltons (Pyler 1988). Donelson and Wilson (1960) reported that the water soluble fraction of wheat decreased cake volume and the decrease was linear with the concentration used. Other researchers found that the addition of wheat flour solubles

(WFS) as a replacement of 50% percent of egg in white and yellow layer cakes changed certain characteristics (Oomah and Mathieu 1988). The authors also reported that cake volume and quality of white layer cakes decreased as WFS increased and the textural qualities of yellow cake were reduced when WFS was used even though cake volume did not significantly differ. Guy (1982) and Oomah and Mathieu (1988) both reported that yellow layer cakes with reduced eggs were more fragile and cracks were observed in the crumb.

The more extensively studied water insoluble portion of wheat protein, glutenins and gliadins, serves a different function than that of the water soluble portion. The majority of gliadins have weights of about 30,000 to 35,000 Daltons (Pyler 1988). Mecham and others (1978) found that gliadins are made up of at least 46 separate subunits. The gliadin fraction forms a viscous fluid mass. Glutenins, on the other hand, have higher weighs and a much border range. The glutenin fraction has many different subunits and may range from a molecular weight 100,000 to several million Daltons (Pyler 1988). When hydrated, glutenin subunits form a very tough, rubbery elastic mass.

During 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,

Carbohydrate-Based

Carbohydrates, starches and gums, are a common type of ingredient added to cakes to improve quality and replace eggs. Starches, which can come from a variety of different sources and may be modified, are principally used for their functions such as adhesion, binding, coating, stabilization of emulsions, gelling, moisture holding, and thickening, all of which are important in cake. Research has shown that addition of certain types and sources of starches may improve cake attributes.

Gums are high molecular weight polysaccharides that are obtained from a variety of sources and have a range of functional properties. Because of their structures, they function as water binders, viscosity controllers, thickeners or gelling agents, stabilizers,

emulsifiers, foamers, binders and/or encapsulators (Dziesak 1991, Sanderson 1996, Whistler and BeMiller 1997).

Both gums and starches were originally added to cakes to increase moisture during baking and to prevent staling. Today, research has shown that addition of these ingredients to cake can increase volume or improve texture (Young and Bayfield 1963, Spies 1981, Lee and Hoseney 1982, Miller and Hoseney 1993). The addition of gums has been shown to improve foam stability by decreasing foam drainage (Conrad and others, 1993).

Starches. Starches are composed of linear or branched chains of the sugar D-glucose. These starches form into small spherical particle or granules. The starch granules' size and shape are determined by the source of the starch. Where the starch comes from significantly affects the functional properties of it. The starch granules may also be modified to change the starches properties.

Karaoglu and others (2001) reported that the addition of modified starches can increase softness and extend shelf-life of cakes; however, volume index and appearance of cake was decreased. They recommended a 10% addition of pregelatinized starch to improved cake quality. Miller (1983) indicated that the addition of native wheat starch and water to cakes helped to reduce defects when egg whites were reduced.

Xanthan. Xanthan is a microbial polysaccharide produced by aerobic fermentation of *Xanthomonas capestris*. The backbone chain of xanthan is similar to cellulose with side chains of (3-1)-α-linked D-mannopyranose-(2-1)-β-D-glucuronic acid-(4-1)-β-D-mannopyranose on alternating residues. Xanthan gum has a high molecular weight estimated at 2 X 10^6 Daltons (Whistler and BeMiller 1997).

Xanthan gums are commonly used in the food industry because of good solubility in hot or cold temperatures and high or low pH's, consistently stable viscosity, and stabilizing effects on suspension and emulsions. Xanthan can have a synergistic effect when combined with locust bean gum and guar gum (Rocks 1971).

Xanthan is frequently added to cakes to increase moisture retention, shelf life, volume, and crumb structure (Spies 1981, Lee and Hoseney 1982, Miller and Hoseney 1993, Lee and others, 1982). Miller and Hoseney (1993) reported that xanthan gum increases volume of cakes by keeping cake batter viscous and less elastic at higher

temperatures. This allows the cake to expand more before the structure sets, resulting in volume.

Christianson (1976) suggested that the formation of a xanthan-starch complex helped to retain gas during baking; however, Miller (1981) and Miller and Hoseney (1993) found no evidence of this complex in angel food cakes. Xie and Hettiarachchy (1998) found that the addition of xanthan to soy protein isolate improved foam stability. In 1999, Mott and others (1999) found that xanthan added to whey protein isolates may increase foam stability and foam overrun. These phenomena are due to decreased interfacial tension and increased viscosity (Sanderson 1981

Guar. Guar gum is a high molecular weight galactomannan from the seed of the bean *Cyamopsis tetragonolobus*. Guar's structure consists of a (1-4)-linked β-D-mannopyranose backbone with branch points from their 6-positions linked to α-D-galactose (i.e. 1-6-linked-α-D-galactopyranose). There are between 1.5 - 2 mannose residues for every galactose residue.

Guar is useful because of its rapid hydration in cold water and good thermostability. Cakes containing a small percentage of guar, 0.1% to 1.0%, have shown greater moisture retention, increased shelf life, and reduced crumbling tendency (Dogra and others, 1989). Guar gum increases foaming stability by decreasing drainage (Conrad, and others, 1993)

Other gums. Several other gums have been used in cakes. Young and Bayfield (1963) found that the addition of CMC produced cakes with the highest cake scores. They also reported that other hydrocolloids, gum tragacanth, gum arabic, and carrageenan produced better cakes than the control. Miller and Trimbo (1967) stated that hydrophilic gums may help overcome certain defect in white and yellow cake mixes. Gums can also act as emulsifiers. In separate studies, researchers found that the gum fenugreek can act as a stable emulsifier (Garti and others 1997, Huang, Kakuda and Cui 2001). The ability of fenugreek to stabilize air/water and oil/water interfaces is valuable in a food system.

Lipid-Based

Lipids, which constitute 10% of liquid whole eggs and 41 % of dry whole eggs, are an important part of eggs function in cakes. The yolk of whole egg provides a tenderizing function that contributes moistness and softness rather than toughness to cakes. The components of egg yolk that tenderizes are the lipid and emulsifiers that are present at high levels.

The principle emulsifier, lecithin, helps promote the incorporation of air to form a foam. Handelmann and others (1961) concluded that the volume and grain of cake are affected by the number and size of the air bubbles. Having the right amount of emulsifiers with the right hydrophilic-lipophilic balance (HLB) is essential to producing a good cake.

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Chapter 2

Hypothesis and Preliminary Research Background

Hypothesis

Our hypothesis is that eggs require more than a simple 1:1 replacement with an egg alternatives to acquire similar ingredient functionality in bakery, pasta, frozen desserts and salad dressings. Our research is designed to obtain a variety of commercially available egg alternative (Table 2.1) that are advertised for use in the aforementioned food systems. The eggs and egg alternatives will be compared and their effectiveness as an ingredient evaluated using physical and sensory analysis.

TABLE 2.1: Selected egg alternatives and their commercial sources that were evaluated through the study.

	Sample Name	Company Name	Sample Description
	Eggs	Ballas Egg Products and M.G. Waldbaum	Dry whole eggs and liquid egg yolks
Carbohydrate	Advanta-GEL P75	National Starch & Chemical	Pregelatinized potato starch
	Novelose 260	National Starch & Chemical	Resistant corn starch
	Instant Pure-Flo F	National Starch & Chemical	Pregelatinized corn starch
	Wheat starch	MGP Ingredients, Inc	Native wheat starch
	N-Creamer 46	National Starch & Chemical	Modified waxy maize starch
	FrigeX	National Starch and Chem	Modified corn starch
	Ultra Tex	National Starch & Chemical	Modified waxy maize starch
Gums	Ticaxan Xanthan Gum	TIC Gums	Xanthan gum
	CMC 2500	TIC Gums	Carboxyl methylcellulose gum
	Gum Guar 8/22 NF/FCC	TIC Gums	Guar gum
	Canafen Gum	Emerald Seed	Fenugreek gum
	PB-S-GSP	TIC Gums	PGA, Locust Bean and Guar Gums

	Sample Name	Company Name	Sample Description
Protein	BiPRO	Davisco International	95% Whey protein isolate
	BioZate 1	Davisco International	5.5% Hydrolyzed whey protein isolate
	Ardex F	ADM Company	90% Soy protein isolate
	Nitrosoy 220T	ADM Company	50% Soy protein concentrate
	SoyLec-15	ADM Company	Lecithinated soy flours, 46% protein
	Arise 5000	MGP Ingredients, Inc	90% Wheat protein isolate
	Vital wheat gluten	MGP Ingredients, Inc	Native Vital Wheat Gluten
	PRO-FAM 781	ADM Company	90% Isolated soy protein
	Eggstend 220	Parmalat Ingredients	35% whey protein concentrate
	Eggstend 300	Parmalat Ingredients	60% whey protein concentrate
	Zein	Sigma Chemical Company	Corn Protein
	Collagen	Great Lakes	
	Cryogel-Gelatin	PB Gelatins/Tessender lo Group	
	Gelatin	Rousselat	
	Collagen	PB Gelatins	Solugel Hydrosets
	PeptanF-Collagen	Protein Products	Hydrolysets (fish protein)
	Propulose (pea)	Parrheim Foods	
	Remy Pro W 70	A & B Ingredients	Rice Protein Concentrate
	Pasta Power	MGP Ingredients Inc	Atchison, KS
	Soy Flour	ADM Company	Decatur, IL
Lipid	BFP 65K	American Ingredients	Alpha-monoglyceride
	Ultralec	ADM Company	Soy lecithin
	Starplex 90	American Ingredients	Distilled monoglycerides

The initial phase for each food system involved a preliminary screening of the egg alternatives selected for each respective food system. A few critical evaluation tests were identified for the screening process. These tests are listed below. Based on the preliminary data collected the researchers approve the continued evaluation of each of the egg alternatives to be used in the experimental design portion of this project.

Yellow Cake

All egg alternatives were screened using the minimum criteria of contour, symmetry and volume. The minimum criteria included: (1) Cakes had to have a volume over 100 index units. This volume is roughly 75% of the volume of the control cakes. (2) Cakes had to have a contour index of zero or greater and (3) Cakes had to have a symmetry index of two units or less.

Mayonnaise

All egg alternatives were screened using the minimum criteria of emulsion stability and viscosity. The minimum criteria for emulsion stability and viscosity was set at 10 hr and 4.62 Pa-s, respectively. These values for emulsion stability and viscosity represents 25% and 50% of the control mayonnaise values respectively.

Pasta

The only critical screening process for the pasta was the ability for the dough to be sheeted. If the dough was able to be processed into noodles, then the egg alternative was designated to be placed in the experimental design.

Angel Food Cake

There were many stages of screening for egg alternatives to be considered for use in angel food cakes. The initial screening was the ability of the egg alternative to form a stable foam. The next screening consideration was the ability of the stable foam to be baked under processing conditions (temperature and time) that would be used in the production of angel food cake. Therefore, only the egg alternatives that passed the baked meringue test were used in the final experimental design.

Ice Cream

There are a limited amount of commercial advertised egg alternatives for use in ice cream or more specifically, French vanilla. Therefore, all egg alternatives designated for use in ice cream were included in the experimental design.

Chapter 3

EVALUATION OF EGG ALTERNATIVES IN A YELLOW CAKE SYSTEM

INTRODUCTION

Egg substitutes that are low in cost are desired by the baking industry because of the high cost of eggs. However, eggs' multifunctional properties of foaming, emulsification, coagulation, flavor, and color make them essential in cake production (Pyler 1988). The use of other ingredients and blends of those ingredients have been used to try to replace egg partially or in full.

Whey is commonly used to replace egg because of its functional properties. Arunepanlop (1996) found that whey can partially replace egg whites in angel food cake. Swaran (2003) reported that replacement of up to 50% of egg with a blend of whey protein concentrate, soy lecithin and glycerol mono-stearate produce cakes that are not significantly different that control.

The addition of gums such as xanthan and guar has been reported to enhance cake quality. Miller and Hoseney (1993) reported that the addition of xanthan increased cake volume. Mott and others (1999) reported that the addition of xanthan to whey protein isolates increased foaming ability. A blend of xanthan, wheat starch, and water was reported to replace 35% of egg in cake (Miller and Setser 1983). Guar gum has been reported to improve foam stability (Conrad, Mast and MacNeil 1993) and improve moisture retention, increase shelf life, and reduce crumbling tendency (Dogra, Hill and Strange 1989).

Preliminary research resulted in the selection of six ingredients into the experimental design. Ingredients were used singularly and in combination to form blends. Overall a total of ten treatments were conducted. Cakes were evaluated in terms of volume, contour, hardness of crumb, springiness of crumb, and *Lab* color values of crumb. The goal of this study was to evaluate the ability of egg replacers to emulate the functionality of whole egg in a yellow cake.

MATERIALS AND METHODS

Yellow Cake Preparation

Cake batters were made according to the formula and method described in the Kansas State University Baking Science Laboratory Manual (Payne 1995). Ten treatments along with a control (Table 3.1) were analyzed. Cakes were mixed in a Hobart A-100 12-quart mixer (Hobart Corp., Troy, OH). Four cakes from each treatment are made by pouring 400 g of batter into 8-inch diameter circular cake pans. Cakes were baked in a Reed four-reel oven (Reed Oven Co., Kansas City, MO) at 350^{o}F for approximately 30 min (Figure 3.1). After baking, cakes are cooled for 10 min before being depanned and cooled to ambient temperature. Once cakes have fully cooled they are bagged in a polyethylene film bag until testing.

Figure 3.1. Reel oven used to bake yellow cake treatments.

Cake Volume, Symmetry, and Contour

Cakes volume, symmetry, and contour indexes (Figure 3.2)were determined one day after baking by AACC Baking Quality Method 10-91 (American Association of Cereal Chemists 2000). Two cakes into two similar sized halves. The index template was placed up against the cut edges of cakes and the height of designated positions B, C, and D were recorded. These recorded heights were used to compute volume, symmetry, and contour as instructed in AACC method (Figure 3.3) Volume is computed by B + C + D, symmetry by |B – D|, and contour by 2C – B – D. Measurements were then averaged.

Control Whey Protein Isolate Hydrolyzed Whey Protein

Figure 3.2 Representative yellow cake treatments depicting volume, contour and symmetry

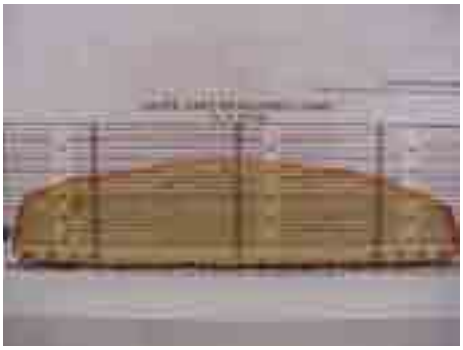

Figure 3.3. Template used to measure volume, contour and symmetry

TABLE 3.1: Selected egg substitutes and their commercial sources.

Ingredient name	Company name	Sample Description
Control	Ballas Egg Products	Dry whole eggs
BiPRO	Davisco International	95% whey protein isolate
Wheat gluten	MGP Ingredients, Inc	Native vital wheat gluten
Wheat starch	MGP Ingredients, Inc	Native wheat starch
TICAXAN Xanthan Gum	TIC Gums	Xanthan Gum
Gum Guar 8/22 NF/FCC	TIC Gums	Guar gum

List of treatments and their respective abbreviation used in the study.

1) (Control) 18.2%* Dry Whole egg
2) (WPI) 18.2% Whey Protein Isolate
3) (WPI-HT) 18.2% Whey Protein Isolate; heat treated at 55^{o}C for 30 min
4) (GLU) 18.2% Wheat Gluten
5) (WS) 18.2% Wheat Starch
6) (GS) 1% Gum Guar & 17.2% Wheat Starch
7) (GP) 1% Gum Guar & 17.2% Whey Protein Isolate
8) (GPS) 1% Gum Guar/ 6.9% Whey Protein Isolate/ 6.9% Wheat Starch
9) (XS) 1% Xanthan Gum & 17.2% Wheat Starch
10) (XP) 1% Xanthan Gum & 17.2% Whey Protein Isolate
11) (XPS) 1%Xanthan Gum / 6.9% Whey Protein Isolate/ 6.9% Wheat Starch

* Percent flour basis, percentages reflect 100% replacement of egg

Cake Texture

Texture was determined with TA-XT2 Texture Analyzer (Texture Technologies Scarsdale, NY) using the AIB standard procedure for cake (American Institute of Baking 1996). The 20.32 cm (8 in) round cake was sliced down the center and two cuts were made 3.81 cm (1.5 in) on either of the center slice. Cutout sections were placed on their side with the center cut face up and tested with a 2.54 cm (1 in) diameter cylinder probe. Individual sections were probed in three different locations near the center of the pieces. This procedure was performed on two cakes per treatment, thus producing twelve measurements per treatment. The hardness and springiness of each measurement was recorded. Cakes were tested at day one and day five after baking. Measurements on the texture analyzer using the following setting: test mode: T.P.A., pre-test speed: 3 mm/second, test speed: 1.7 mm/second, post-test speed: 1.7 mm/second, distance: 6 mm, trigger: auto at 20g, acquisition rate: 200 pps.

Cake Color

Crumb color was measured using a Hunter Miniscan portable colorimeter (HunterLab, Reston, VA). The colorimeter was calibrated using a light trap and white tile according to procedure set forth by the Hunterlab owner's manual. Color was measured using natural light (A) at a 10^{o} angle. Three measurements of each sample were taken and then averaged. The *L*, *a,* and *b* values were all recorded. Hue angle, ($\tan^{-1}$ b/a), was calculated to define crumb color. Procedures for color were adapted from Lee and others (1991).

Experimental Design

Treatments were analyzed in a complete block design. Three replications and four sub-samples per replication were performed for both a 50% replacement group and 100% replacement group. The experimental design included eleven different samples (Table 3.1).

Differences between treatments were determined using analysis of variance (ANOVA) procedure with a significance level of 0.05. All objective results were determined using a least significant difference (LSD) test. Results were used to detect significant differences between individual treatments.

RESULTS AND DISCUSSION

Volume

Data showed that replacing eggs with a single ingredient did not produce volumes close to that of cakes with whole eggs (Figure 3.1). At 100% replacement of eggs, cakes had significantly reduced volume. At 50% replacement, cake volume significantly improved from 100% replacement volumes. Cake volume was still significantly less that control cakes for all treatments except wheat starch (WS) at 50% replacement. Comparison between WPI and WPI-HT showed that heat treatments consistently improved cake volume but improvement was not statistically noticeable at 100% replacement. These results were similar to those of Arunepanlop and others (1996) and Pernell and others (2002). WPI will be use in further treatments instead of WPI-HT since WPI-HT requires added processing that would not be economically viable.

When comparing cake volumes with guar gum (Figure 3.2), data showed that at both 100% and 50% replacement, addition of guar gum to WS and WPI substitutes

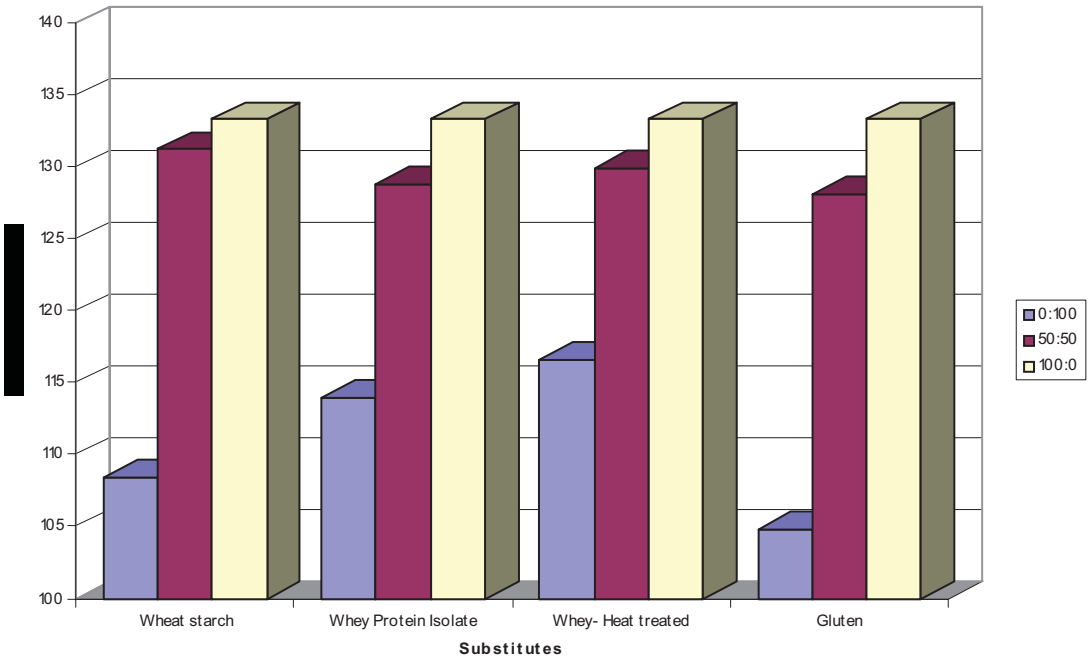

FIGURE 3.1: Comparison of volume index of yellow cake formulated with whole egg or egg substitutes

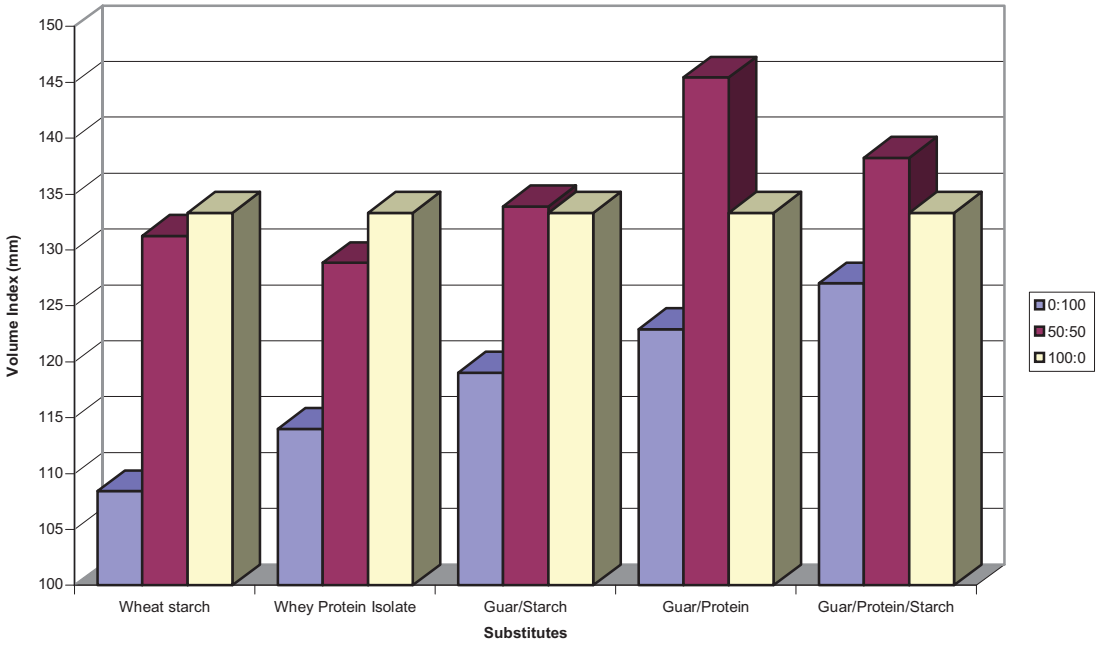

FIGURE 3.2: Comparison of volume index of yellow cake formulated with whole egg or guar gum egg substitutes

significantly improved volume of cakes. Substitute GPS, containing starch, protein and guar gum, showed even further improvement in volume. At 50% replacement, substitute GP and GPS produced cakes with significantly higher volumes that the control; however, these cakes had a crumb with large holes and an open grain. Ingredients used in combination performed better than they did individually.

The addition of xanthan gum at both 100% and 50% replacement to WS and WPI substitutes significantly improved volume of cakes (Figure 3.3). Miller (1981) found that the addition of xanthan and wheat starch improved cakes with a reduced amount of eggs. Mott *et al* (1999) found that the adding xanthan gums to whey can increase foam stability. Pernell (2002) found that adding xanthan can increase the volume of angel food cakes. Substitute XPS, containing starch, protein and guar gum, showed even further improvement in volume. At 50% replacement, substitutes XS and XP produced cakes with volumes that were statically the same as the control. Substitute XPS produced cakes that were significantly larger in volume than the control. Again ingredients used in combination performed better than they did individually and had volumes as high as or higher than whole egg cakes.

Contour

Figure 3.4 shows contour indexes of cakes with ingredients used individually. At 100% replacement all substitutes fail to mimic the contour of the whole egg cakes. At 50% replacement, contour significantly improved and began to emulate that of the control. Only WS achieve a contour that was the same as that of the control

At 100% replacement of eggs with treatments containing guar, ingredients used in combination performed better that those used individually (Figure 3.5). At 50% replacement, contour was sporadic with no visible trend. The contour of substitutes WS and GPS was not significantly different than the whole egg cakes.

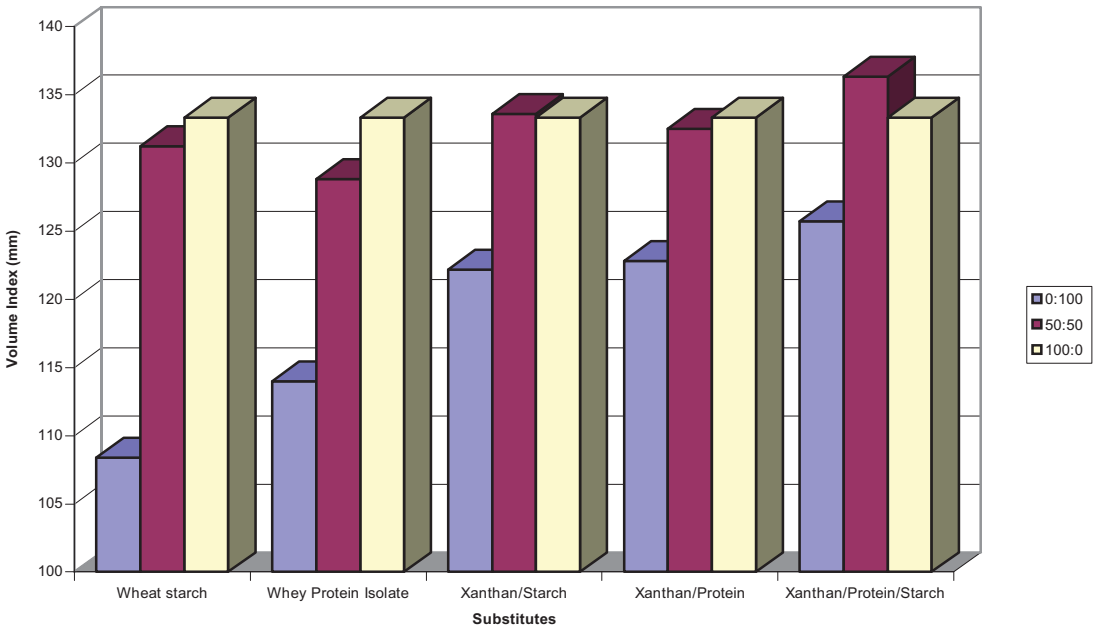

FIGURE 3.3: Comparison of volume index of yellow cake formulated with whole egg or xanthan gum egg substitutes

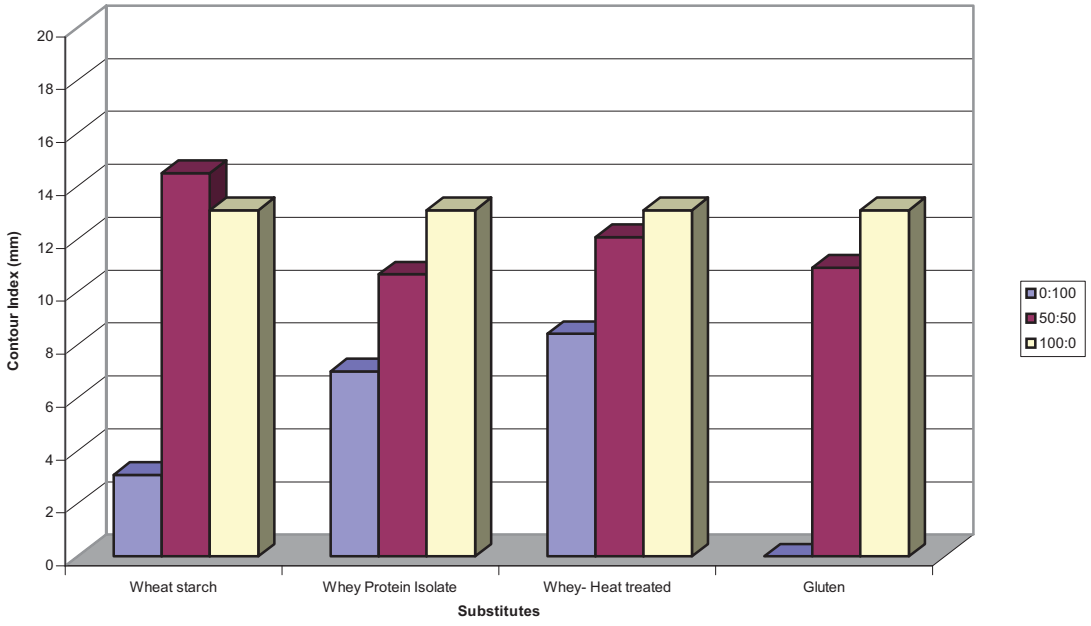

FIGURE 3.4: Comparison of contour index of yellow cake formulated with whole egg or egg substitutes

Contours of cakes with xanthan showed improvements similar to that of guar (Figure 3.6). When treatments with xanthan were replaced at 100%, ingredients used in combination performed better that those used individually. At 50% replacement, contours migrated towards the contour of the whole egg cake from that of those at 100% replacement. Treatments XS and XP at 50% replacement were not significantly different in contour from that of the whole egg cake

Whole Egg Control

Wheat Starch

Blend
(guar, whey protein
and wheat starch)

Texture

Texture was also affected by replacing whole eggs with other ingredients. Hardness data showed that at 100% replacement, all treatment containing whey protein (WPI, WPI-HT, GP, GPS, XP, and XPS) had significantly higher values, whereas those without whey protein (WS, GS, XS and GLU) were significantly less firm (Table 3.2). Treatments with protein, starch, and gum (GPS and XPS) were fairly close to the control but not statistically the same. When replacement was 50%, hardness for cakes with whey protein decreased. At 50% replacement, treatments GPS, XPS, and XS were not significantly different from control cakes at day 1 and day 5. All cake exhibited significant increase in hardness from day 1 to day 5. At 100% replacement, springiness was not significantly different from the control for XPS on both day 1 and 5 (Table 3.3). Springiness at 50% was not significantly different from control for GPS on both day 1 and day 5. Some treatments were similar in springiness to whole egg cakes on only one day but not the other.

TABLE 3.2: Hardness of Yellow Cake Measured at Days 1 and 5 After Baking				
	Day 1		Day 5	
	100:0	50:50	100:0	50:50
Control	295.33 ^{f}	^{cd}	400.80 ^{d}	^{d}
Wheat Starch	261.15 ^{g}	230.43 ^{g}	363.23 ^{e}	311.25 ^{ef}
Whey Protein Isolate	720.29 ^{a}	364.42 ^{b}	921.89 ^{a}	489.03 ^{bc}
Whey – Heat Treated	676.89 ^{b}	369.10 ^{b}	912.50 ^{a}	524.82 ^{ab}
Gluten	284.49 ^{f}	256.94 ^{ef}	342.46 ^{ef}	304.21 ^{f}
Guar/Starch	245.58 ^{h}	234.31 ^{fg}	332.26 ^{f}	415.50 ^{d}
Guar/Protein	606.82 ^{c}	376.29 ^{b}	775.50 ^{b}	470.75 ^{c}
Guar/Protein/Starch	329.35 ^{e}	280.00 ^{de}	450.12 ^{c}	395.75 ^{d}
Xanthan/Starch	258.14 ^{gh}	295.84 ^{cd}	342.94 ^{ef}	426.74 ^{d}
Xanthan/Protein	618.03 ^{c}	446.43 ^{a}	795.43 ^{b}	556.95 ^{a}
Xanthan/Protein/Starch	355.06 ^{d}	314.41 ^{c}	470.66 ^{c}	344.66 ^{e}
LSD (+/-)	14.65	25.97	21.14	36.42

TABLE 3.3: Springiness of Yellow Cake Measured at Days 1 and 5 After Baking				
	Day 1		Day 5	
	100:0	50:50	100:0	50:50
Control	0.945 ^{b}	^{a}	0.896 ^{cde}	^{b}
Wheat Starch	0.934 ^{c}	0.930 ^{bcd}	0.901 ^{cde}	0.865 ^{d}
Whey Protein Isolate	0.937 ^{c}	0.926 ^{de}	0.963 ^{ab}	0.896 ^{b}
Whey - Heat Treated	0.943 ^{bc}	0.931 ^{bc}	0.934 ^{bc}	0.898 ^{b}
Gluten	0.900 ^{e}	0.925 ^{ef}	0.929 ^{bc}	0.868 ^{d}
Guar/Starch	0.913 ^{d}	0.928 ^{cde}	0.836 ^{f}	0.884 ^{c}
Guar/Protein	0.910 ^{de}	0.931 ^{bc}	0.921 ^{bcd}	0.920 ^{a}
Guar/Protein/Starch	0.970 ^{a}	0.941 ^{a}	0.977 ^{a}	0.896 ^{b}
Xanthan/Starch	0.914 ^{d}	0.931 ^{bcd}	0.866 ^{ef}	0.878 ^{c}
Xanthan/Protein	0.907 ^{de}	0.920 ^{f}	0.898 ^{cde}	0.919 ^{a}
Xanthan/Protein/Starch	0.945 ^{bc}	0.934 ^{b}	0.883 ^{de}	0.881 ^{c}
LSD (+/-)	0.013	0.005	0.039	0.007

Color

L values for whole egg cakes were significantly less than all substitutes except gluten on both days and at both levels (Table 3.4). Gluten had L values that were not significantly different for 100% on day 5 and 50% on day 1. Cakes with all other substitutes were much whiter than the cake with eggs. There was no change in L value over time.

Cakes with 100% replacement by substitutes, had *b*-values less than the control cake. At 50% replacement, *b*-values increased but did not achieve a value similar to that of the control. The *b*-values for treatments are given in Table 3.5.

Hue angles for whole egg cakes were significantly less than all substitutes, except gluten, on both days and at both levels (Table 3.6). Treatments that contained more whey protein were found to have the highest hue angle while treatments having more starch had lower hue angles. Treatments containing both whey protein and starch (GPS and XPS) were found on the border between these two regions. There did not appear to be any trend between type of gum, xanthan or guar, and hue angle.

CONCLUSION

At 100% replacement, no egg substitute used was able to emulate all attributes of whole egg in a yellow cake system. Treatments with blends GPS (guar/whey/starch) and XPS (xanthan/whey/starch) were closest to whole egg cakes compared to other treatment. At 50% replacement, again no replacement exactly emulated whole eggs in all aspects of volume, contour, hardness, springiness, and color. The blend GPS (guar/whey/starch) and XPS (xanthan/whey/starch) and XS (xanthan/starch) showed the most potential. Each of these three treatments had similarities to whole egg in volume, contour, hardness, and springiness. Sensory analysis will be conducted using 100% replacement of whole eggs with blends GPS and XPS.

TABLE 3.4: L Color Values of Cake at Days 1 and 5				
	Day 1		Day 5	
	100:0	50:50	100:0	50:50
Control	76.94		76.29	
Wheat Starch	80.35	81.58	79.90	80.05
Whey Protein Isolate	82.79	81.95	81.76	81.21
Whey - Heat Treated	83.84	83.17	84.05	81.68
Gluten	79.88	78.87	78.38	79.24
Guar/Starch	80.65	81.21	81.28	80.00
Guar/Protein	84.68	83.92	83.57	82.24
Guar/Protein/Starch	84.10	81.13	83.28	80.77
Xanthan/Starch	80.33	82.67	81.04	81.05
Xanthan/Protein	84.61	82.14	84.12	81.78
Xanthan/Protein/Starch	83.71	82.18	84.39	80.24
LSD (+/-)	2.55	1.53	3.19	2.24

TABLE 3.5: *b* Color Values of Cake		
	100:0	50:50
Control	18.63 +/- 0.47	
Wheat Starch	13.84 +/- 0.88	15.58 +/- 0.50
Whey Protein Isolate	13.79 +/- 0.43	15.92 +/- 0.46
Whey - Heat Treated	13.41 +/- 0.32	16.28 +/- 0.55
Gluten	15.45 +/- 0.35	16.90 +/- 0.63
Guar/Starch	13.65 +/- 1.09	15.77 +/- 0.52
Guar/Protein	12.85 +/- 0.13	14.86 +/- 0.36
Guar/Protein/Starch	13.39 +/- 0.79	15.80 +/- 1.23
Xanthan/Starch	13.38 +/- 0.99	15.76 +/- 0.68
Xanthan/Protein	12.67 +/- 0.37	15.49 +/- 0.04
Xanthan/Protein/Starch	13.69 +/- 0.86	15.52 +/- 0.31

TABLE 3.6: Hue Angle (tan $^{-1}$ b/a) Color Values of Cake at Days 1 and 5				
	Day 1		Day 5	
	100:0	50:50	100:0	50:50
Control	85.08 ^{e}	84.67 ^{f}	86.12 ^{e}	85.22 ^{e}
Wheat Starch	83.32 ^{d}	83.10 ^{bcde}	83.95 ^{cd}	83.81 ^{cd}
Whey Protein Isolate	79.97 ^{ab}	82.52 ^{ab}	80.52 ^{a}	83.30 ^{bcd}
Whey - Heat Treated	79.94 ^{ab}	82.74 ^{bcd}	80.30 ^{a}	83.40 ^{bcd}
Gluten	85.82 ^{e}	85.08 ^{f}	85.98 ^{e}	85.46 ^{e}
Guar/Starch	83.74 ^{d}	83.44 ^{e}	83.24 ^{c}	84.05 ^{d}
Guar/Protein	79.52 ^{a}	81.99 ^{a}	80.11 ^{a}	82.29 ^{a}
Guar/Protein/Starch	80.93 ^{bc}	83.23 ^{cde}	81.86 ^{b}	83.10 ^{abc}
Xanthan/Starch	83.64 ^{d}	83.28 ^{de}	84.39 ^{d}	83.89 ^{cd}
Xanthan/Protein	79.44 ^{a}	82.65 ^{bc}	79.87 ^{a}	82.60 ^{ab}
Xanthan/Protein/Starch	81.77 ^{c}	82.89 ^{bcde}	81.85 ^{b}	83.43 ^{cd}
LSD (+/-)	1.005	0.610	0.993	0.83

SENSORY ANALYSIS

INTRODUCTION

The palatability of a food product is usually the determining factor for a consumer to eat and continue purchasing a given product (Lawless and Heymann 1999). Palatability is determined by the sensory characteristics of a product such as appearance, color, texture, flavor and aroma. Cake, in the minds of consumers, falls into very specific sensory characteristic ranges. When replacing an ingredient, especially one as multifunctional as egg, it is important to keep in mind these sensory characteristics. Therefore, an evaluation of sensory attributes requires standards that serve as examples of the presence and intensity of each attribute (Rainey 1986).

Low-cost egg replacers are desired in the baking industry because eggs are usually the most expensive ingredients. Vitti (1981) reported that whey protein's composition and functional properties are such that it can be used to partly replace egg in bread and cake. Swaran (2003) reported that a 50% replacement of egg with whey protein concentrate did not differ significantly from the control in terms of overall acceptability. Borstein and Bartov (1966) reported that the visual appearance of egg yolk determines consumer acceptability of eggs. Other researchers have reported that flavor was the most important characteristic associated with acceptability (Hard and others 1963, Romanoff and Romanoff 1949). No matter what attribute is most important it is important to keep in mind the functionality and overall acceptability of egg replacers.

The goal of this research was to characterize sensory attributes of yellow cake made with egg replacements and compare that to those of a yellow cake made with whole egg. A consumer test was performed to evaluate acceptability of egg replacements in yellow cake to that of whole egg.

MATERIALS AND METHODS

Quantitative Descriptive Analysis (QDA)

Panelist Selection. Ten panelists were selected (6 female and 4 male) from Kansas State University who were recruited to participate in the panel. Panelists were between the ages of 22 and 30 and all successfully completed the study. Prior to sensory

testing, all panelist signed a consent form (Appendix A) in compliance with the Kansas State University Institutional Review Board and Committee for Research Involving Human Research.

Panelist Training. Training was adapted from Archilla (2001). Panelists took part in three training sessions, each of which lasted approximately one hour. During training periods, panelists were introduced to testing procedures, which allowed them to build skill and confidence to achieve valid and reliable results (Meilgaard, Civille and Carr 1999). Panelists were asked to rate cakes based on six characteristics: crust stickiness, color, springiness, moistness, firmness, and egg flavor.

During the first training session, panelists were first asked to read and sign consent forms (Appendix A). The group of panelists was then trained on the first three cake attributes (crust stickiness, color, and springiness) the other three attributes were presented in the second training session. Panelists were given attribute definitions and testing protocol. Reference samples for word anchors (Appendix B) were presented to panelists during training in order to reduce variability and increase confidence. These references and definitions were adapted from (Munoz 1986, Bramesco 1991, Lin, Hwang and Yeh 2003). Panelists were presented samples that fell between reference samples in each category. The group then came to a consensus on where each sample fell in between the reference anchors. The second training session was similar to the first except the last three attributes (moistness, firmness, and egg flavor) were presented.

In the third training session, all attributes were examined and reviewed by panelists. At the end of this training, a practice sensory test was performed to determine the consistency of the panel as a whole. Two different cake formulations were presented to panelists. Each cake sample consisted of a 1 in^3 cube and a 1.5 in^2 piece of cake crust, at ambient temperature. Samples were placed on a white paper plate with a three-digit code and given to panelist along with a glass of distilled water, some napkins, and a list of reference anchors. Panelist evaluated samples individually in room 206 Call Hall, Kansas State University, Manhattan, Kansas. Results were recorded on the sensory ballot (Appendix C) by placing a vertical mark on a 5 inch unstructured line.

At the end of the practice sensory tests, each individual shared their approximate results with the group to compare consistency. Panelists requested that there be three or four 1 in^3 cubes for each sample in final testing so that better analysis could be done.

Testing Procedure. The ten panelists evaluated three cake formulations, a control (whole egg) and two 100% replacement blends. These blends were GPS (guar/whey/starch) and XPS (xanthan/whey/starch). Each sample was again assigned a three-digit random code and presented in a random order to each panelist. Two replications of the sensory test were performed over the course of 1 week. Each testing session lasted approximately 15 minutes. Testing procedures, test location, and room environment were the same as the practice test procedures performed in session three. Sample presentation consisted of three 1 in^3 cubes and a 1.5 in^2 piece of cake crust.

Consumer Acceptance Test

A total of 104 untrained consumers of both genders (57 females and 47 males) volunteered to participate in the acceptance test. Panelist ages ranged from 18 to 80 years old. All panelists were prescreened for food allergies and for how much they consumed cake (Appendix D). Prior to starting acceptance test, all panelists signed an informed consent statement (Appendix E).

Consumer acceptance test procedure was adapted from Khouryieh (2003). The test was conducted in a Food Science Laboratory, Call Hall 156, at Kansas State University. This laboratory was equipped with white light and individual stations for evaluation. Each panelist evaluated two samples of cake during the session. One sample was the whole egg control and the other sample was a 100% replacement of whole egg with xanthan/whey protein/wheat starch. Both cake formulations had FD&C Yellow #5 added to batter to provide color to crumb. Added yellow color negated differences between crumb color to prevent bias by consumers. Cake samples were served to panelists in 1.5 in. cubes on plates at room temperature. Each sample was given a three digit random number and given to panelist in a random order. Sensory ballots (Appendix F), distilled water, and unsalted crackers were given along with cake samples. Panelists were instructed to cleanse mouth before tasting each sample. Cake was evaluated using a 9-point hedonic scale to determine liking of product (9 = like extremely, 5 = neither like nor dislike, 1 = dislike extremely). The cake samples were evaluated on appearance,

texture flavor, and overall acceptability. For each cake, consumers were also asked if they would be willing to buy a product like this in stores.

Statistical Analysis

Statistical analysis was performed using the Statistical Analysis System version 9.0 (SAS Institute, Inc., SAS Circle, Box 8000, Cary, NC). An Analysis of Variance (ANOVA) and Least Standard Difference (LSD) comparison was performed on all data. Significant differences between treatments was detected at a $p < 0.05$ level.

For QDA, each mark was measured from the left-end of the line scale. Marks were measure in inches and then converted to numbers by multiplying by 2 (i.e. 1 inch = 2). This resulted in a 10-point scale for each attribute. Treatments were compared to each other for each attribute.

RESULTS

Quantitative Descriptive Analysis (QDA)

QDA of cake attributes is shown in Table 4.1. Panelists reported that crust surface of cake variations containing xanthan and guar gums were stickier than that of the whole egg control. Cake crust on GPS and XPS in some instances actually adhered so firmly to fingers that the crust detached from crumb upon removing finger.

Cakes containing xanthan and guar gums have been found to produce sticky cakes (Villaudy, Noelck and Tilly 1989). A similar phenomenon was found by Neville (1986), who reported that cakes with reduced foaming ability were gummy with softer and stickier crusts. The stickiness/gumminess on the cake surface comes from the foams instability and drainage of liquid (Mizukoshi 1983b, because of gradients within cake (Miller, Trimbo and Sandstedt 1967). This moisture most frequently accumulates at the bottom of cake (Mizukoshi 1983a). The addition of gums can reduce moisture migration and gummy layers in cake (Miller, Trimbo and Sandstedt 1967) by holding excess water and thereby enhancing foam stability (Miller 1981). A small amount of moisture may have migrated to the crust causing the sticky char Mizukoshi 1983a). Moisture from drainage may transfer from one section to another acter.

Sensory data showed that whole egg control was significantly more yellow than both the XPS and GPS variations. XPS and GPS did not contain any added colors to account for whole egg xanthophyll content.

Whole egg control cakes were found to be higher springiness values than variations XPS and GPS. Panelists found that XPS was not statistically different than

TABLE 1 : Quantitative Descriptive Analysis by a Trained Panel of Control Cake Compared to Two Formulations of Yellow Cake Without Whole Egg

	Surface stickiness	Crumb Yellowness	Springiness	Moistness	Firmness	Egg favor
Control	1.64 [b]	4.94 [a]	7.99 [a]	6.13 [b]	4.87 [a]	5.74 [a]
Xanthan/whey/starch	3.87 [a]	1.79 [b]	7.42 [ab]	6.60 [ab]	4.73 [a]	2.17 [b]
Guar/whey/starch	3.65 [a]	2.02 [b]	7.18 [b]	6.90 [a]	3.97 [b]	2.28 [b]
LSD (+/-)	.79	.47	.76	.77	.80	.83

Means with different superscripts in columns indicate significant difference ($p<0.05$).

control, but GPS was different than control. The decrease in springiness may have been caused by the decreased foaming abilities of whey protein over that of egg. Lee and others (1993) found that substitution of 25% or more of eggs caused a decrease in springiness.

Control cakes were found to have lower moistness values than XPS and GPS. Data showed that the whole egg control was significantly less moist that GPS but there was no difference found between the control and XPS. Villaundy and others (1989) reported that in chocolate cake, the addition of hydrocolloids increased moistness. Increased moistness may be caused by foam drainage causing excess free water in cake. Differences between XPS and GPS may be due to the water binding ability of xanthan compared to guar.

Firmness of control was not significantly different than that of XPS. Treatment GPS was significantly different than both control and XPS. The decrease in firmness of GPS may have been caused by excess free water leading to gumminess.

Egg flavor of whole egg control cakes was significantly greater than of variations XPS and GPS. Since variations contained no egg, this result was expected. This attribute was used more to gauge ability of panelist and effectiveness of training; however,

panelists reported that XPS and GPS contained a small amount of egg flavor. This result may be caused by background flavors of vanilla and butter. The panel also reported a slight off flavor in treatment GPS. This flavor was characterized as “beany”; this is most likely a result of guar in the treatment.

Consumer Acceptance Test

One hundred four consumers participated in the acceptance test. The prescreening data (Table 4.2) showed that a majority of consumer were between the age of 18 and 25 and had completed at least some college, 56.7% and 54.8% respectively. Data showed that almost 75 percent of consumers consumed cake once every two weeks to once a month.

Consumers found that the cake formula XPS was significantly more favorable than the whole egg control cake in appearance, texture, flavor, and overall acceptability (Table 4.3). Lee and other (1993) found that cakes with egg replaced with bovine plasma had a higher hedonic score than white layer cakes with egg. Some consumer commented that the whole egg control was drier than the XPS formulation. Others stated that the control needed more flavor. Consumers also stated that they would be more willing to buy the XPS formulation than the whole egg control. Only 54% of consumer said they would be willing to purchase the whole egg control, whereas 70% stated they would purchase the XPS formulation.

TABLE 4.2: Demographic Information about Sensory Panelist for Consumer Acceptance Test of Cake

Information	Percent
Age:	
18 – 25	56.7 %
26 – 30	9.6 %
31 – 35	4.8 %
36 – 40	4.8 %
41 – 45	3.8 %
46 – 50	6.7 %
51 – 55	2.9 %
56 – 60	3.8 %
61 – 70	5.8 %
71 – 80	1.0 %
>80	0.0 %
Gender:	
Male	45.2 %
Female	54.8 %
Education:	
High School	6.7%
Some College	54.8%
B.S	15.4%
M.S.	13.5%
Ph.D	7.7%
MD	0.0%
Other	1.9%
Cake Eating Frequency:	
Every day	0.0%
At least once a week	11.5%
Once every two weeks	26.0%
Once a month	47.1%
Once a year	15.4%
Never	0.0%

ABLE 4.3: Consumer Acceptance of Control Cake Compared to Formulation of Cake Without Whole Egg

	Appearance	Texture	Flavor	Overall Acceptability
Control	6.12 [b]	5.88 [b]	6.12 [b]	6.09 [b]
Xanthan/whey/starch	7.09 [a]	6.62 [a]	6.82 [a]	6.90 [a]
LSD (+/-)	.36	.42	.42	.38

Means with different superscripts in columns indicate significant difference ($p<0.05$).
Hedonic Scale: 1- dislike extremely, 5- neither like nor dislike, 9- like extremely.
Mean values of 104 consumer panelists

CONCLUSION

Sensory data showed that egg replacement blends XPS and GPS did not emulate the sensory attributes of dry whole egg in yellow cake. Both blends significantly differed in surface stickiness, color, and egg flavor. XPS was closest to control in firmness, springiness, and moistness. In consumer acceptance test, replacement blend XPS had significantly higher ratings than dry whole egg in appearance, texture, flavor, and overall acceptability.

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APPENDIX A

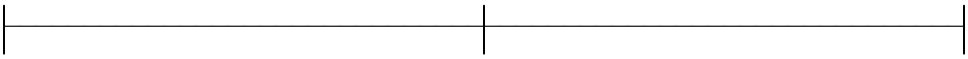
Sensory Evaluation of Cakes

Panelist #: _____ Date:_____

Instructions: Please evaluate each sample presented to you and place a mark on each scale representing the intensity of each attribute. Write the numbered code of each sample above the corresponding vertical mark.

Surface Stickiness

Definition: Degree of adhesion of product to surface of index finger when surface is touched and then removed



Not Sticky Somewhat Very Sticky

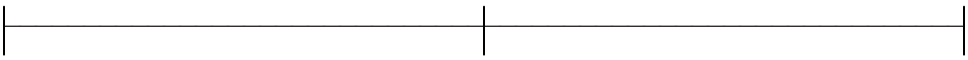
Color

Definition: Yellowness of the cake crumb when examine visually

White Somewhat Yellow

Springiness

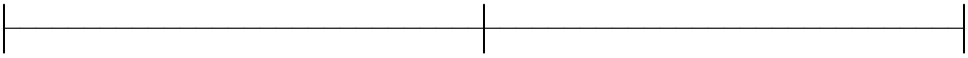
Definition: Degree of return to original size after 50% compression between thumb and forefinger.



No Springiness Somewhat Very Springy

Firmness

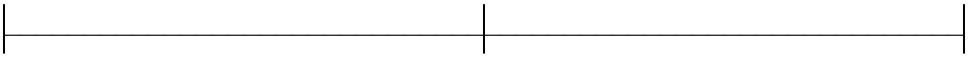
Definition: Force required to compress product completely when placed in mouth



Very Soft Somewhat Very Firm

Moistness

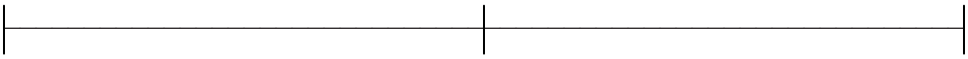
Definition: The amount of moisture perceived on surface of product when in contact with mouth



Very Dry Somewhat Very Moist

Egg Flavor

Definition: The amount of egg flavor in product when placed in mouth and eaten



No Egg Somewhat Very Eggy

APPENDIX B

Consumer Pre-screening Form

Please complete the following information:

Age:

□ 18-25 □ 26-30 □ 31-35 □ 36-40 □ 41-45 □ 46-50
□ 51-55 □ 56-60 □ 61-70 □ 71-80 □ Over 80

Gender:

□ Male □ Female

Education:

□ High School □ Some College □ B.S. □ M.S. □ Ph.D. □ MD □ Other

About how often do you eat Cake?

□ Every day □ At least once a week □ Once every two weeks
□ Once a month □ Once a year □ Never

Do you suffer from any food allergies?

□ Yes □ No

If you have food allergies, you cannot participate in this study. Thank you for your willingness to help.

APPENDIX C

Kansas State University Informed Consent for Participation in Consumer Test

The purpose of this project is to determine the consumer acceptance of 2 formulations of yellow cake. Testing is expected to take less than 10 minutes. All ingredients in these products are food grade and approved by FDA. If you have no food allergies, there are no known risks or discomforts associated with consumption of these products. Your data will be treated as research data and will in no way be associated with you other than for identification purposes, thereby assuring your confidentiality.

1. I (print) _____ , agree to participate as a panelist in a sensory consumer test, conducted by Dr. Tom Herald and Dane Kohrs.

2. I understand that this study is part of a thesis project.

3. I understand that there will be a free ice cream certificate upon completion of the test.

4. I understand that I do not have to participate in this research and there will be no penalty if I choose not to participate

5. I understand that I may withdraw from the research at any time

6. If I have any questions concerning this study, I understand that I am free to contact Dr. Herald at 220 Call Hall (785) 532-1221.

7. If I have questions about my rights as a panelist or about the manner in which the study is conducted, I may contact the Committee for Research Involving Human Subjects, 1 Fairchild Hall, Kansas State University, Manhattan, KS, 66505, at 785-532-3224.

SIGNATURE: _____ DATE:_____

APPENDIX D

Panelist #: ___

Instructions:

You will be testing two samples of cake. You will be served one sample at a time. Please be sure to answer the questions completely and honestly. Please, check the box that best describes your answer. Take a drink of water and a bite of cracker before you start or any time during the test if you need to.

Sample: _____

Please check only one box that represents you response (X)

1. How much do you like or dislike the appearance of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

2. How much do you like or dislike the texture of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

3. How much do you like or dislike the flavor of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

4. Please rate your overall acceptability of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

5. Would you purchase this product in a store?

☐	☐
Yes	No

Additional comments: _____

CHAPTER 4

Evaluation of Chemical, Physical, and Sensory Properties of Egg Yolk and Egg Yolk Substitutes in a Model Mayonnaise System

Mayonnaise is a thick and creamy dressing that is often used in salads, sandwiches, and as a base for tartar sauce and thousand island dressing. Mayonnaise is a large industry in the United States and in 2002 an estimated 119 million gallons of mayonnaise were produced and valued at 466 million dollars (US Census Bureau 2004).

Several ingredients have been evaluated as emulsifying agents in o/w emulsions including proteins, gums, and starches. Whey proteins are often used in food systems for their functional properties in addition to their high nutritional value, bland flavor, and low cost. Whey proteins are effective emulsifying agents; they can rapidly unfold at the interface and form an interfacial film. Whey protein can be used to replace egg yolk in low pH emulsions (Zayas 1997). Whey protein has been evaluated and has shown success as an emulsifier for mayonnaise like products (Daugaard 1993a, Daugaard 1993b, Jost, Danneberg and Rosset 1989, Turgeon and others 1996). Daugard (1993a 1993b) found that several whey protein products produced emulsions with similar organoleptic viscosity and creaminess values as the egg control. Turgeon *et al* (1996) reported that several whey protein fractions produced emulsions with complex viscosity measurements comparable to a commercial mayonnaise.

Caseinates are widely used in the food industry as emulsifiers, particularly in ice creams and frozen desserts. Caseinates are highly soluble in water, rapidly form interfacial films, and are heat resistant, making them ideal in many systems (Zayas 1997). Srinivasan *et al* (2001) used sodium caseinate to stabilize o/w emulsions at a neutral pH.

Wheat protein can also be used as an emulsifier, although its emulsifying properties are highest in acidic conditions (Takeda, Matsumura and Shimizu 2001). Heat-treatment of wheat proteins improved the emulsifying properties, due to increased protein flexibility. Takeda *et al* (2001) reported that wheat gluten was an excellent emulsifying agent at acidic pH. They attributed these results to the glutenin and gliadin fractions forming a viscoelastic protein film around the oil droplets preventing coalescing.

Soy proteins are often used in the food industry for their emulsifying and stabilizing properties and several researchers have found success when using soy protein in oil/water emulsions (Aoki, Taneyama and Inami 1980, Rir and others 1994, Yao, Tanteeratarm and

Wei' 1990).

Carbohydrates including starches and gums are often used in food emulsions. However they are not typically classified as emulsifiers since they do not have hydrophilic and hydrophobic sections that are absorbed at the interface (Garti and others 1997). Carbohydrate based ingredients increase the viscosity of the food system and many are able to form gels that create a three dimensional network. The movement of oil droplets in highly viscous systems is restricted, decreasing the rate of coalescing (Chouard 2004). The carbohydrate solutions can also form a thick film around the oil droplets keeping the phases separate.

Garti *et al* (1997) evaluated fenugreek gum individually in o/w emulsions. They reported that fenugreek gum was able to significantly reduce the interfacial tension of oil/water and form a thick interfacial film on oil droplets, which creates a stable emulsion with small oil droplets. Chiralt (1994) found when processing emulsions containing egg yolk and locust bean gums, that an increase in gum from 0.5 to 1% increased the apparent viscosity of the samples.

The objective of this project was to evaluate the functional properties of several ingredients as egg substitutes in a model mayonnaise system by evaluating their physical, chemical, and sensory characteristics in comparison to an egg yolk control.

Materials

The ingredients used in all mayonnaise formulations included ionized salt (Kroger Co., Cincinnati, OH), pure cane sugar (C&H Sugar Co., Crockett, CA), apple cider distilled vinegar (H.J. Hentz Co., Pittsburgh, PA), ground dry mustard (Kroger Co., Cincinnati, OH), and corn oil (Kroger Co., Cincinnati, OH).

The egg and egg substitutes evaluated in the mayonnaise formula were either donated or purchased (Table 4.1) they included: pasteurized liquid egg yolk purchased from Cutler Egg Products (Abbeville, AL), Arise 5000 (MGP Ingredients, Atchison, KS), Eggstend 220 (Parmalat Ingredients, Ontario, Canada), N-Creamer 46 (National Starch and Chemical, Bridgewater, NJ), Canafen Gum (Emerald Seeds, El Centro, CA), PB-S-GSP gum blend (TIC Gum, Belcamp, MD), and BiPRO (Davisco International, Eden Prairie, MN).

Table 4.1:Source of Egg yolk and egg alternatives used in the mayonnaise formulations.

Sample Name	Company Name	Sample Description
Liquid Egg Yolk	Cutler Egg Company	Pasteurized Liquid Egg Yolk
Arise 5000	MGP Ingredients, Inc	90% Wheat Protein Isolate
Eggstend 220	Parmalat Ingredients	35% Whey Protein Concentrate
BiPRO	Davisco International	97% Whey Protein Isolate
N-Creamer 46	National Starch and Chemical	Modified Waxy Maize Starch
Canafen Gum	Emerald Seed	Fenugreek Gum
PB-S-GSP	TIC gums	Propylene Glycol Alginate, Locust Bean and Guar Gums

Mayonnaise Preparation

The mayonnaise was prepared using a modified procedure (Table 4.2) of Yang and Cotterill (1989).

Table 4. 2: Basic mayonnaise formulation..

Ingredient	Usage (g)	Percent (%)
Cider vinegar	54	10.6
Salt	5.64	1.1
Sugar	7.8	1.5
Egg yolk	60	11.7
Dry mustard	2.28	0.5
Corn oil	381	74.6
Total		**100%**

The salt, sugar, dry mustard and 24 mL (44%) of the vinegar were mixed with a rubber spatula in a mixing bowl of a kitchen mixer (Kitchen Aid Inc., St. Joseph, Michigan). The egg yolk or egg substitute was added and mixed with a rubber spatula. A 90 mL aliquot of corn oil was added dropwise from a 100 mL buret at a rate of 3mL/min while continuously being blended with the Kitchen Aid mixer at speed 8 using a whisk attachment. The mixer was stopped and the bowl scraped. The mayonnaise was mixed at speed 8 for 3 min. An additional 90 mL of corn oil was added dropwise over 20 min while blending at speed 8. The mixer was stopped and the bowl scraped. The mayonnaise was mixed on high speed for 3 min. The remaining 30 mL of cider vinegar was added, and mixed on speed 4 for 30 sec. Mixing was resumed at speed 8 and the remaining 234 mL of corn oil was added dropwise over 50 min. The bowl was scraped a final time and the mayonnaise mixed at speed 8 for 3 min. The mayonnaise was placed into three 150 mL glass sample cups and placed at 4° C for 24 hrs. The wattage being sent to the mixer was monitored using a electric current monitor ECM 1200 (Brultech, Ontario, Canada) and ranged between 65-100 watts.

Preparation of Egg Alternatives

Egg substitutes were prepared based on recommendation from the suppliers and preliminary research. The egg substitutes were combined with water to form egg substitute solutions. These substitute solutions were used to replace the egg yolk in the mayonnaise formulation at 100% (100:0) and 50% (50:50) replacement.

Wheat Protein Isolate

A mixture of 12.5% wheat protein isolate and 87.5% distilled water was prepared. The pH was adjusted by mixing 52.5 mL water with a 24 mL aliquot of vinegar in a 150 mL beaker. The water and vinegar solution was stirred continuously at a vortex over medium heat (level 4). The wheat protein isolate was slowly added to the water solution until fully dispersed. The solution was heated to 70° C. To prevent protein precipitation salt was excluded from the formulations containing Arise 5000. The solution was used to replace the egg yolk in the basic mayonnaise formulation and the standard procedure was followed.

Whey Protein Concentrate

A mixture of 35% whey protein concentrate and 65% distilled water was prepared. The water was placed in a 150 mL beaker and stirred continuously at a vortex on a magnetic hot plate. The whey protein concentrate was added slowly to the water until completely dispersed. The standard mayonnaise procedure was followed.

Whey Protein Isolate

A mixture of 31.5% whey protein isolate and 68.5% distilled water was used to replace the egg yolk in the mayonnaise formulation. The water was placed in a 150 mL beaker and stirred continuously at a vortex on a magnetic hot plate. The BiPro was added slowly to the water until completely dispersed. The standard mayonnaise procedure was followed.

Modified Corn Starch

A mixture of 15% modified cornstarch and 85% distilled water was prepared.

The water was placed in a 150 mL beaker and stirred continuously at a vortex over medium heat (level 4) on a magnetic hot plate. The modified cornstarch was added slowly to the water until completely dispersed. The solution was heated over medium heat to 70 °C while stirred continuously at a vortex. The standard mayonnaise procedure was followed.

Fenugreek Gum and Whey Protein Concentrate

A combination of 22.5% whey protein concentrate, 0.4% fenugreek Gum, and 77% distilled water replaced the egg yolk in the formulation. The whey protein concentrate was mixed with the dry ingredients. In a separate beaker, the fenugreek Gum and water were continuously mixed at a vortex and the solution heated over medium (level 4) heat on a magnetic stir plate until the solution reached 70 °C. The standard mayonnaise procedure was followed.

Gum Blend and Whey Protein Concentrate

A combination of 22.5% whey protein concentrate, 0.4% gum blend, and 77% distilled water was used to replace the egg yolk in the formulation. The whey protein concentration was mixed with the dry ingredients. In a separate beaker, the gum blend and water were continuously mixed at a vortex and the solution heated over medium (level 4) heat until the solution reached 70 °C. The standard mayonnaise procedure was followed.

Figure 4.1. Images showing the egg yolk control mayonnaise to a potential egg alternative

Viscosity Measurement

Apparent viscosity of the mayonnaise was determined using the Bohlin VOR rheometer (Bohlin Rheology, AB Lund Sweden). The samples were removed from

refrigerated (4° C) temperatures and placed between a cone and plate geometry with a 30 mm diameter, 5° cone angle, and a torque element of 91.1 g-cm. The gap between the cone and plate was set at .150 mm. The rheometer was cooled to 4° C prior to the sample being placed onto the lower plate to simulate refrigeration temperatures. Samples were removed from 4° C storage and were allowed to rest between the cone and plate for 60 sec to allow the samples to relax. The apparent viscosity was calculated within shear rates .925 s^{-1} to 92.5 s^{-1}. A shear rate of 9.26 s^{-1} was used for statistical analysis, because Morris and Taylor (1982) found that viscosity measured at 10 s^{-1} shows a high correlation (R^2=95) with trained panel scores.

Texture measurement

A texture analyzer TAXT2 (Texture Technologies, Scarsdale, New York) was used to evaluate the firmness (spreadability) of the mayonnaise samples. The samples were removed from 4°C storage and were placed directly under a 25 mm cylinder probe. The probe speed was set at 1.0 mm/s, penetrate 10 mm into the sample with a post speed of 10 mm /s (Stable Micro Systems 1995). The firmness value for each sample was measured.

Color Measurement

Mayonnaise samples were measured with a Hunter Lab Miniscan MS/S 4000S Spectrocolorimeter (Hunter Lab Inc. Reston, VA) calibrated with a white tile and light trap. The mayonnaise was measured according to the procedure described for translucent semi solid foods (Hunter Associates Laboratory, Inc 2004). The sample was placed into a 2.5 inch glass sample cup with a 10 mm black ring and white ceramic disk. Values of lightness (L), redness (a), and yellowness (b) were determined using illuminant C and a 10° viewing angle. Hue angle was calculated with the formula $\tan^{-1}(b/a)$.

pH

The pH of the mayonnaise was measured with a Fisher Scientific (Saint Louis, MO) pH meter AP63 calibrated with buffer solutions of pH 4 and 7.

Emulsion Stability

A modified procedure of Harrison and Cunningham (1986) was used to evaluate the emulsion stability of mayonnaise samples. Stability of the mayonnaise was determined by placing 100 g of mayonnaise in a 250 mL beaker at 24°C and checked every 4 hr until the emulsion broke. A broken emulsion is defined as the time when oil becomes visible on the surface of the mayonnaise.

Trained Sensory Panel

A panel consisting of 5 females and 5 males was assembled to evaluate the descriptive characteristics of the mayonnaise samples. The panel received 4 hr of training using commercial mayonnaise and salad dressings. The training focused on the products surface shine, spreadability and firmness in the mouth, mouth coating, and sour flavor. Appropriate references and characteristic definitions (Table 4.3) were presented during the training sessions. The panelists were given the 0 and 10 anchor references along with samples that had values are between the anchors. The panel discussed and agreed upon these sample's reference values.

To avoid sensory fatigue, the panelists only evaluated the descriptive characteristics of five mayonnaise treatments: control, modified cornstarch, wheat protein isolate, whey protein concentrate, and fenugreek gum\ whey protein concentrate. Only one whey protein treatment (whey concentrate) and one blend (fenugreek gum/whey concentrate) were evaluated, these treatments were chosen based on the results of the physiochemical evaluation. Substitute treatments were colored to have the same yellow appearance as the control. The panelist used a ballot to evaluate the sensory attributes of the mayonnaise formulations (Appendix A).

For the firmness in the mouth, mouth coating, and sour flavor evaluation the panelists were given samples of the references and mayonnaise samples in 75 mL paper cups. The panelists used spoons to sample the products. Panelists were provided with saltine

crackers and water to help cleanse their pallet between samples. For the evaluation of the mayonnaise spreadability the panelists used plastic knives to spread the references and mayonnaise samples on pieces of white sandwich bread. The panelists evaluated the force required to spread the sample across the bread and how uniform the sample spread. They used these characteristics to determine the spreadbility score of the mayonnaise samples. To evaluate surface shine, the references and the mayonnaise samples were placed on a white Styrofoam plate for viewing. The panelists determined the amount of shine / light reflected off the surface of each sample.

Consumer Sensory Test

One hundred and ten panelists participated in the study. Panelists, representing a university population were recruited based on availability and health (no food allergies). Majority of the panelists (74%) were between the ages of 18-30, and 64% of the panelists were female. Sixty six percent of the panelists reported that they consume mayonnaise at least once per week. Panelists signed an informed consent form (Appendix A) and completed a demographic survey (Appendix A) before participating in the study.

The panelists used a ballot to evaluate the appearance, odor, mouth feel/texture, flavor, and overall acceptability of the mayonnaise formulations (Appendix A). A 9-point hedonic scale was used (1= dislike extremely 5= neither like nor dislike and 9= like extremely) to evaluate the products attributes. The panelists were asked about their intent to purchase the product and were given space to indicate what specifically they liked or disliked about the products attributes.

Table 4.3: Descriptive Evaluation Definitions and References Used for The trained Sensory Panel

A	Surface Shine	The amount of shine on the surface of the sample	
		Reference:	*Score:*
		Cream Cheese	0
		Honey	10
		Peanut butter	3.5
		Sour cream	8.5
B	Spreadability	The amount of force required to spread the sample on a slice of bread.	
		Reference:	*Score:*
		Ranch Dressing	0
		Cold Butter	10
		Peanut butter	5
C	Firmness in the mouth	The amount of force required to press the sample against the roof of the mouth	
		Reference:	*Score:*
		Stirred yogurt	0
		Velveeta cheese	10
		cream cheese	6
D	Mouth coating	The degree to which the sample coats the mouth.	
		Reference:	*Score:*
		Water	0
		Vegetable oil	10
		half and half	3
		Heavy whipping cream	7.5
E	Sour Flavor	The amount of sour flavor in the sample.	
		Reference:	*Score:*
		Water	0
		20% vinegar/water solution	10
		10% vinegar/water solution	5

Three mayonnaise formulations were chosen for evaluation; control, modified cornstarch, and fenugreek gum\ whey protein concentrate. These formulations were selected based on their performance in the physiochemical and trained sensory evaluations. Consumers will typically experience sensory fatigue and decreased concentration when more than three samples are presented to them. The egg substitute treatments were colored to have the same yellow appearance as the control. Each formulation was randomly assigned a 3-digit code and the samples were randomly distributed to the panelist. The samples were placed into marked clear 40 mL plastic cups. The panelists were given spoons to sample the mayonnaise. Distilled drinking water and crackers were used to cleanse the palate between samples. Data was collected during one session, over 4 hr. Consumer data between panelists was expected to be variable, but consistent within panelists.

Statistical Analysis

The physical measurements were evaluated in a modified incomplete block design. The experiment was conducted over 12 days (blocks). The control was done each day for a total of 12 replications. Three replications were made for each egg substitute and they were distributed over the 12 blocks and duplicate pairing was avoided. Three sub samples of each replication were taken, and measurements were made on each sub sample. The effects analyzed were between treatments and the control. Analysis was done using SAS GLMMIX (SAS 9.1 2003). When treatment effects were found significantly different, the least square means with Tukey-Kramer groupings were used to differentiate treatment means. The trained panel results were evaluated in a randomized block design, where blocking was based on panelists, n=10. The consumer test results were evaluated in a randomized complete block design, where blocking was based on consumers, n=110. Consumer data between panelists was expected to be variable, but consistent within panelists. For statistical analysis, the panelists' answers to the intent to purchase question were converted to numerical values, yes=1 and no=2. The sensory data was evaluated with SAS GLM procedures (SAS 9.1 2003) Differences in treatment means were evaluated using Tukey-Kramer. A level of significance was observed at $\alpha=$

0.05 for all statistical calculations.

Results

Emulsion Stability

Whey isolate and the control exhibited emulsion stability values that were not significantly different at 100% replacement (100:0) (Table 4.4). All other 100:0 samples had emulsion stability values that were significantly higher than the control. Takeda *et al* (2001) found similar success when evaluating wheat gluten in o/w emulsions. They reported that gluten was an excellent emulsifying agent at acidic pH. They attributed these results to the glutenin and gliadin fractions forming a viscoelastic protein film around the oil droplets preventing coalescing. Garti *et al* (1997) evaluated fenugreek gum individually in o/w emulsions. They reported that fenugreek gum was able to significantly reduce the interfacial tension of oil/water and form a thick interfacial film on oil droplets, which creates a stable emulsion with small oil droplets.

Despite the 12.5% decrease in whey concentrate, the whey concentrate blends produced mayonnaise with stability values that were comparable to that of the whey concentrate treatment. The thickening properties of gums may have caused an increase in viscosity, which slowed down the migration rate of oil droplets (Chouard 2004). Although the two blends were used at the same level, the mayonnaise containing fenugreek gum exhibited higher emulsion stability than the sample containing the TIC gum blend. This corresponds with data reported by Garti (1997), who found that fenugreek gum had a superior emulsification properties compared to those of locust bean and guar gums.

Figure 4.2 Representative images of a stable and broken mayonnaise emulsions.

Table 4:4 Comparison of emulsion stability values of mayonnaise samples prepared with either egg yolk or egg substitute at two replacement levels at ambient temperatures.

	Emulsion Stability (hrs)	
TREATMENTS	**100:0**	**50:50**
Control- Liquid Egg Yolk	25.50 ^{e}	n/a
Wheat Isolate	54.33 ^{cd}	35.33 ^{de}
Whey Concentrate	74.67 ^{b}	22.67 ^{e}
Whey Isolate	31.33 ^{e}	17.33 ^{e}
Modified Corn Starch	90.67 ^{ab}	26.00 ^{e}
Fenugreek Gum & Whey Concentrate	96.00 ^{a}	20.00 ^{e}
TIC Gum Blend & Whey Concentrate	72.33 ^{bc}	18.33 ^{e}

Means with different superscripts indicate significant differences among all treatments, ($p \geq 0.05$)

The emulsion stability of all treatments at 50% replacement (50:50) was not significantly different from that of the control. Whey concentrate, whey concentrate blends, and modified cornstarch treatments had significantly lower emulsion stability values than their respective 100:0 samples. Emulsion stability often decreases with a decrease in viscosity, which allows the movement of oil droplets through the aqueous phase (Chouard 2004, Ramachandra-Rao and Hemantha-Kumar 1998). Most of the 50:50 treatments exhibited lower viscosity values than the 100:0 samples, which may lead to their decreased stability.

Commercial mayonnaise is shelf stable and can remain at refrigerated temperatures for up to six months. The extended stability of commercial mayonnaise is due to a homogenization step during production. Homogenization is the use of intense shearing to increase the number and reduce the size of the oil droplets in the dispersed phase. The droplet size is an important factor in emulsion stability, and an emulsion containing a high number of small droplets is more stable. In the current work, no homogenization step is performed which resulted in the lower stability values compared to a commercial mayonnaise.

pH

Microbial growth and sour flavor notes are influenced by pH, therefore this attribute was measured in the mayonnaise samples. The control mayonnaise had a pH value of 3.78 (Table 4.5), which is similar to average commercial mayonnaise samples studied by Gomex and Fernandex-Salguero (1992) and Chirife *et al* . (1989), 3.88 and 3.84 respectfully. Commercial mayonnaise typically has a pH between 3.5-4.2. Modified cornstarch was the only egg substitute that produced mayonnaise below this pH range.

The protein-based treatments with 100% substitution made mayonnaise with significantly higher pH values compared to the modified cornstarch. The control's pH was significantly lower than the two whey treatments, however was not significantly

different from either of the whey concentrate blends.

The pH values of the 50:50 treatments lays between the control and their respective 100:0 sample. All 50:50 treatments, except modified cornstarch, had pH values that were not significantly different from the control.

Table 4.5: Comparison of pH values for mayonnaise samples prepared with either egg yolk or egg substitute at two replacement levels

	pH	
TREATMENTS	**100:0**	**50:50**
Control- Liquid Egg Yolk	3.78 [b]	n/a
Wheat Isolate	3.52 [c]	3.73 [b c]
Whey Concentrate	4.17 [a]	3.98 [a b]
Whey Isolate	4.17 [a]	4.03 [a b]
Modified Corn Starch	3.04 [d]	3.52 [c]
Fenugreek Gum & Whey Concentrate	3.88 [a b]	3.95 [a b]
TIC Gum Blend & Whey Concentrate	3.94 [a b]	3.90 [a b]

Means with different superscripts indicate significant differences among all treatments, ($p \geq 0.05$)

Color

All treatments exhibited L values (Table 4.6) that were not significantly different and ranged from 79.74-84.47.

The control exhibited a significantly lower hue value (more color) than all other treatments (Table 7, Figure 5). This may be due to the egg substitute treatments not containing the yellow pigments that egg yolk does, i.e. xanthophylls, lutein, carotene, and cryptoxanthin. Vulink, (2000) observed similar results when comparing whey protein emulsions with those made with egg yolk. The 50:50 treatments all had hue values that were between the control and their respective 100:0 samples. All 50:50 treatments exhibited hue values that were not significantly different.

Apparent Viscosity

The control exhibited an apparent viscosity value that was not significantly different from modified cornstarch and whey isolate at 100% replacement (Table 8). Whey concentrate 100:0 had a significantly lower viscosity than the control, whereas the whey concentrate blends 100:0 and wheat protein 100:0 were significantly higher. These results indicate that the egg substitute treatments at 100% replacement are capable of forming emulsions similar to those made by egg yolk. Whey protein has been evaluated and has shown success as an emulsifier for mayonnaise like products (Daugaard 1993a, Daugaard 1993b, Jost, Danneberg and Rosset 1989, Turgeon and others 1996). Daugard (1993a 1993b) found that several whey protein products produced emulsions with similar organoleptic viscosity and creaminess values as the egg control. Turgeon *et al* (1996) reported that several whey protein fractions produced emulsions with complex viscosity measurements comparable to a commercial mayonnaise.

The whey concentrate blends had apparent viscosities significantly higher than the whey concentrate treatment, despite the 12.5% decrease in whey concentrate. This is due to the gelling/thickening and emulsifying effects of the gums. The TIC gum blend contains alginate, locust bean and guar gums. Locust bean gum can produce a heat irreversible gel, whereas guar gum is an excellent emulsifier and thickening agent; and alginate has emulsifying, gelling, and shear-thinning thickening properties. Chiralt (1994) found when processing emulsions containing egg yolk and locust bean gums, that an increase in gum from 0.5 to 1% increased the apparent viscosity of the samples. All protein-based treatments at 50% replacement had apparent viscosity values that were significantly lower than that of the control. The 50:50 protein-based treatments had significantly lower viscosities than their respective 100:00 samples. This data may suggest an antagonistic effect between egg yolk protein and either whey or wheat proteins. This is contradictory to what Daugard (1993a 1993b) reported. Their study found there was no synergistic or antagonistic effects between egg yolk and whey protein when cold processing was used, however they did find an antagonistic effect when their process involved the heating of the proteins (Daugaard 1993a, Daugaard 1993b). There was no significant difference between modified cornstarch at 100% and 50% replacement indicating there was no antagonistic or synergistic relationship between egg yolk and the

modified cornstarch.

Table 4.6: L values of mayonnaise samples prepared with either egg yolk or egg substitute at two replacement levels, using a Hunter Lab Miniscan.

	L Value	
TREATMENTS	**100:0**	**50:50**
Control- Liquid Egg Yolk	79.74 [a]	n/a
Wheat Isolate	82.72 [a]	82.29 [a]
Whey Concentrate	80.32 [a]	80.35 [a]
Whey Isolate	81.85 [a]	80.01 [a]
Modified Corn Starch	84.47 [a]	83.42 [a]
Fenugreek Gum & Whey Concentrate	82.00 [a]	81.76 [a]
TIC Gum Blend & Whey Concentrate	81.61 [a]	80.83 [a]

Means with different superscripts indicate significant differences among all treatments, ($p \geq 0.05$)

Table 4.7: Comparison of hue values of mayonnaise samples prepared with either egg yolk or egg substitute at two replacement levels, using Hunter Lab Miniscan.

	Hue Value	
TREATMENTS	**100:0**	**50:50**
Control- Liquid Egg Yolk	91.00 [d]	n/a
Wheat Isolate	96.80 [b]	92.97 [c]
Whey Concentrate	97.89 [a b]	93.24 [c]
Whey Isolate	99.18 [a]	93.21 [c]
Modified Corn Starch	98.12 [a b]	92.94 [c]
Fenugreek Gum & Whey Concentrate	97.57 [a b]	93.06 [c]
TIC Gum Blend & Whey Concentrate	98.11 [a b]	93.73 [c]

Means with different superscripts indicate significant differences among all treatments, ($p \geq 0.05$)

Control **Fenugreek gum/whey concentrate**

Figure 4.3: Comparison of mayonnaise color between two treatments, egg yolk control and fenugreek gum/whey concentrate treatment.

Table 4.8: Comparison of apparent viscosities of mayonnaise samples prepared with either egg yolk or egg substitute at two replacement levels at 4°C and shear rate 9.25 s-1.

	Apparent Viscosity (Psa)	
TREATMENTS	**100:0**	**50:50**
Control- Liquid Egg Yolk	34.44 ^{c}	n/a
Wheat Isolate	44.71 $^{a\,b}$	3.08 ^{e}
Whey Concentrate	22.32 ^{d}	9.35 ^{e}
Whey Isolate	34.83 $^{b\,c}$	15.82 $^{d\,e}$
Modified Corn Starch	33.17 ^{c}	33.31 ^{c}
Fenugreek Gum & Whey Concentrate	40.94 $^{a\,b}$	12.95 $^{d\,e}$
TIC Gum Blend & Whey Concentrate	52.94 ^{a}	13.58 $^{d\,e}$

Means with different superscripts indicate significant differences among all treatments, ($p \geq 0.05$)

Figure 4.4. A comparison between stable and unstable emulsions during viscosity measurements

Texture

Modified cornstarch at 100% replacement exhibited a significantly lower firmness value compared to the control (Table 4.9). However, the modified cornstarch and control had similar apparent viscosity values, approximately 35 Pas. These results would indicate that apparent viscosities are the same, the force required to start the flow of the sample is much less for modified cornstarch than the control, since less force was required to penetrate the sample.

Whey Isolate had a firmness value that was significantly higher than that of the control. The remaining 100:0 treatments (whey concentrate, wheat isolate, fenugreek gum/whey protein concentrate, and gum blend/whey concentrate) had firmness values that were not significantly different from that of the control. This indicated the egg substitutes were able to produce mayonnaise like emulsions at 100% replacement.

Table 4.9: Comparison of firmness values of mayonnaise samples prepared with either egg yolk or egg substitute at two replacement levels. Mayonnaise samples were at 4°C.

	Firmness (g -force)	
TREATMENTS	**100:0**	**50:50**
Control- Liquid Egg Yolk	1142.70 ^{bc}	n/a
Wheat Isolate	1182.78 ^{abc}	223.78 ^{f}
Whey Concentrate	1031.91 ^{c}	372.77 ^{ef}
Whey Isolate	1369.20 ^{a}	503.01 ^{de}
Modified Corn Starch	626.75 ^{d}	720.45 ^{d}
Fenugreek Gum & Whey Concentrate	1162.04 ^{abc}	592.25 ^{de}
TIC Gum Blend & Whey Concentrate	1311.27 ^{ab}	526.38 ^{de}

Means with different superscripts indicate significant differences among all treatments, ($p \geq 0.05$)

As seen with viscosity, all 50:50 protein-based treatments had significantly lower firmness values than their 100:0 samples, suggesting an antagonistic relationship between egg protein and either whey or wheat proteins. The modified cornstarch 50:50 and 100:0 treatments had firmness values that were not significantly different, suggesting no antagonistic relationship between egg protein and the modified cornstarch. All 50:50 treatments were significantly lower than that of the control.

Trained Sensory Panel

Surface Shine

The control and wheat isolate exhibited surface shine scores that were not significantly different, however both the treatments were significantly higher than the other treatments (Table 4.10). Whey concentrate, modified cornstarch, and fenugreek gum/whey concentrate all had surface shine values that did not differ significantly. The surface shine seems to be correlated to the emulsion stability values. The control and wheat isolate 100:0 had lower emulsion stability values than the other treatments evaluated by the panel, which may have caused them to have a shiny appearance as the emulsion starts to breakdown.

Spreadability

Wheat isolate and fenugreek gum/whey concentrate exhibited significantly higher spreadability values than that of the control. This does not follow the physical measurements of mayonnaise firmness, where wheat isolate and fenugreek gum/whey concentrate were not significantly higher compared to the control. Whey concentrate and modified cornstarch had spreadability values that were not significantly different from the control.

Table 4. 10: Attribute scores for mayonnaise made with the egg yolk and selected egg substitutes as measured with a trained sensory panel.

SENSORY ATTRIBUTE	TREATMENTS				
	Control Liquid Egg Yolk	Modified Corn Starch	Fenugreek Gum & Whey Concentrate	Wheat Isolate	Whey Concentrate
Surface shine	8.60[a]	4.95[b]	5.00[b]	7.45[a]	5.30[b]
Spreadability	1.40[b]	1.85[a b]	2.65[a]	2.80[a]	2.30[a b]
Mouth Firmness	2.30[b]	2.20[b]	3.65[a]	4.35[a]	2.67[b]
Mouth Coating	7.15[a b]	7.55[a b]	6.20[b]	8.75[a]	6.75[a b]
Sour Flavor	5.40[a b]	6.88[a]	4.88[a b]	5.50[a b]	4.35[b]

Means with different superscripts within rows indicate significant differences among treatments, ($p \geq 0.05$)

Mouth Firmness

Wheat isolate and fenugreek gum/whey concentrate had significantly higher firmness values than that of the remaining treatments, including the control. These values corresponded with the spreadability values.

Mouth Coating

All the egg substitute treatments had mouth-coating scores that were not significantly different from that of the control. Wheat isolate and fenugreek gum/ whey concentrate were the only treatments that exhibited significantly different mouth coating scores.

Sour Flavor

All the egg substitutes treatments had sour flavors scores that were not significantly different from that of the control. Modified cornstarch and whey concentrate were the only treatments that had significantly different sour flavor scores, with modified cornstarch having a higher value. This corresponds to the pH of the samples; modified cornstarch exhibited a significantly higher pH value than that of whey concentrate.

Consumer Panel

Appearance

Modified cornstarch and fenugreek/whey concentrate had higher appearance scores than that of the control, with modified cornstarch having the highest score (Table 4.11). Several consumers commented that the control had an oily/greasy appearance and that modified cornstarch had a smooth creamy appearance. This corresponds to the trained panels evaluation of the surface shine, finding the control had a higher shine than that of modified cornstarch and fenugreek gum/whey concentrate Consumers commented that all three samples had more yellow pigment than typical mayonnaise.

Odor

All three treatments exhibited odor values that were not significantly different. Consumers' comments were divided between no odor and vinegar/acetic acid odor for all treatments.

Table 11: Acceptability scores for mayonnaise samples made with the control and selected egg substitutes as measured by a consumer panel. n=110

	TREATMENTS		
SENSORY ATTRIBUTES	**Control Liquid Egg Yolk**	**Modified Corn Starch**	**Fenugreek Gum & Whey Concentrate**
Appearance	4.60 [c]	6.00 [a]	5.50 [b]
Odor	5.14 [a]	5.28 [a]	5.31 [a]
Mouth Feel/ texture	5.40 [b]	6.30 [a]	5.75 [b]
Flavor	4.76 [b]	5.19 [a b]	5.41 [a]
Acceptability	4.84 [b]	5.48 [a]	5.45 [a]

Means with different superscripts within rows indicate significant differences among treatments, ($p \geq 0.05$)

Mouth Feel

Modified cornstarch had the highest mouth feel score. Consumers commented that the sample was very smooth in texture. The control and fenugreek gum/whey concentrate had mouth feel scores that were not significantly different. Several

consumers commented that the control had a greasy mouth feel and that fenugreek gum/whey concentrate felt too thick.

Flavor

Fenugreek gum/whey concentrate had a higher flavor score than that of the control, however was not significantly higher than the modified cornstarch. The control and modified cornstarch had multiple consumer comments about the high acid/sour flavors.

Acceptability and intent to purchase

The control had a lower acceptability score than the egg substitute treatments. Modified cornstarch and Fenugreek gum/whey concentrate were not significantly different. All three treatments had intent to purchase scores that were not significantly different and Table 4.12 has the percentage breakdown of the consumers' intent to purchase answers.

Table 12: Consumer's Intent to Purchase Mayonnaise Samples Made with the Control and Selected Egg Substitutes as Measured by a Consumer Panel, n=110

	TREATMENTS (%)		
	Control Liquid Egg Yolk	Modified Cornstarch	Fenugreek Gum & Whey Concentrate
YES	38.7	45.7	43.8
NO	61.3	54.3	56.2

Significance of Findings

The present study demonstrated that several commercially available ingredients can successfully replace 100% of the egg yolk in a mayonnaise formulation. All four whey based treatments exhibited texture properties that were similar to those of the control and emulsion stability values that exceeded the control's. The sensory evaluations found that the whey based treatments exhibited attributes similar to the control and consumers preferred the whey-based treatment's appearance and flavor to that of the control. These results demonstrate the ability of whey proteins to successfully replace egg yolk in a mayonnaise formulation. The addition of gums to the whey concentrate treatment produced mayonnaise similar to that of the control and whey concentrate treatments. However, the amount of whey concentrate used was decreased by 12.5%. which could be advantageous when evaluating the cost of ingredients. Wheat protein showed similar success in the mayonnaise formulation. When used at 50% replacement, both the whey and wheat proteins exhibited an antagonistic relationship with egg yolk. Modified cornstarch had a viscosity value that was similar to the control and higher emulsion stability. The texture values of modified cornstarch were significantly lower than the control, however the trained panel did not detect this difference. The pH of the modified cornstarch was not typical for mayonnaise. The consumer's overall acceptance score was higher for the cornstarch than the control.

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Panelist name: _____ **Date_____**

SAMPLE NUMBER_____

Surface gloss/ shine:

The amount of shine on the surface of the sample

Low 0 1 2 3 4 5 6 7 8 9 10 High

Spreadability:

The amount of force required to spread the sample on a slice of bread.

Low 0 1 2 3 4 5 6 7 8 9 10 High

Mouth coating:

The degree to which the sample coats the mouth.

Low 0 1 2 3 4 5 6 7 8 9 10 High

Firmness:

The amount of force required to press the sample against the roof of the mouth.

Low 0 1 2 3 4 5 6 7 8 9 10 High

Sour/ acid taste:

The amount of acid or sour flavor in the sample.

Low 0 1 2 3 4 5 6 7 8 9 10 High

Chapter 5

Physical and Sensory Properties of Fresh Egg Noodles Formulated with either Total or Partial Replacement of Whole Egg using Soy, Wheat or Whey Based Alternatives

Eggs are one of the most common ingredients used in pasta/noodles. Eggs have several influences on the finished pasta product. The addition of egg enhances the formation of an extensive protein network during mixing and kneading, thus improving the cooking quality of the product (Dalbon, 1996). Eggs give a darker and more yellow color to the fresh pasta, and promote a more rapid darkening due to the high protein and enzyme content of the egg (Dalbon, 1996). Finally, there is a significant increase in the nutritional value of pasta containing egg (Kill, 2001).

The quantity of egg in pasta dough is prescribed by the legal requirements of each country. As a rule, the amount of egg added is 10-20% of the semolina weight: in high quality products, the egg percentage can be more then 35% (Dalbon, 1996). Eggs can be added in either liquid or dry forms. The following is the code of federal regulation's definition for noodle products.

CFR Sec. 139.150 Noodle products

Noodle products are the class of food each of which is prepared by drying formed units of dough made from semolina, durum flour, farina, flour, or any combination of two or more of these, with liquid eggs, frozen eggs, dried eggs, egg yolks, frozen yolks, dried yolks, or any combination of two or more of these, with or without water and with or without one or more of the optional ingredients: onions, salt, gum gluten and concentrated glyceryl monostearate.

The Food and Drug Administration (FDA) classified pasta products into either macaroni or egg noodles. The standard of identity require egg noodles to contain 5.5% egg solids on a dry basis in the form of egg yolk, whole egg, or a combination of the two (21 CFR, 139.110-139.180).

MATERIALS & METHODS

Materials

Semolina (14% mb) was generously donated by the American Italian Pasta Co, (Kansas City, MO), Dried whole egg was purchased from Ballas Egg Products Corp. (Zanesville, OH), the following egg substitutes were donated by their respective companies: pasta power (MPG Ingredients, Inc., Atchison, KS); soy flour (ADM Company, Decatur, IL); Eggstend300 (Parmalat Company, Ontario, Canada) ; Biozate1 and Bipro (Davisco, Food International, Inc., Le Sueur, MN). Specifications for whole egg and egg alternatives are shown in Table 5.1.

Table 5.1. Percent of Egg and Egg Substitutes Components According to Manufacturer Specifications

Egg Substitute*	Protein	Carbohydrates	Lipids	Ash	Moisture
Whole egg	**43.0**	**5.0**	**40.0**	**3.65**	**5.0**
Pasta power	**85.0**	**5.0**	**1.0-2.0**	**6.5**	**7.0**
Soy flour	**46.0**	**26.0**	**15-19**	**---**	**8.0**
Eggstend 300	**57.0**	**26.0**	**5.5**	**5.0**	**3.5**
Biozate1	**90.0**	**1.0**	**1.0**	**6.0**	**5.5**
Bipro	**95.0**	**1.0**	**1.0**	**3.0**	**5.0**

*** Pasta power contains wheat protein, Eggstend 300, Biozate 1 and Bipro contain whey protein**

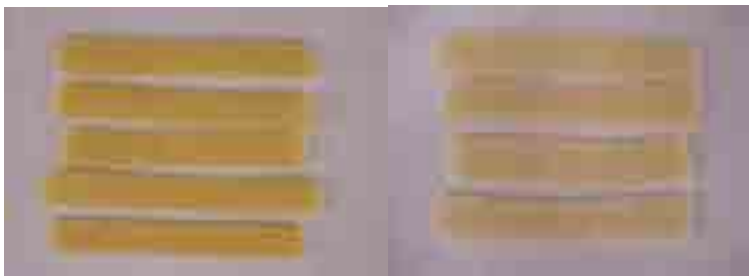
Noodle Preparation

Semolina (200g, 14%mb), whole egg (24 or 12g) and/or egg substitutes (24 or 12g) were mixed with distilled water in a Hobart mixer for 1 min at low speed and then for 1 min at high speed. The noodles were prepared with optimum water absorption to have a uniform, smooth, and non-sticky noodle dough. The optimum water absorption was determined based on appearance and sheeting and handling properties of the dough during the noodle-making process. The dough was folded and sheeted twice through the noodle machine (Atlas, model 150, Italy) with the gap set at 4mm. The sheet was cut into strips ~30 cm in length. (Figure 5.1). The noodles were double bagged in plastic bags and stored at 4 C. Noodles were formulated at 50 and 100% egg replacement levels and evaluated at days 0, 15, and 30.

Figure 5.1. Image of a representative sheeted pasta sample.

Pasta and Pasta Cooking Quality

Optimum Cooking Time. The noodles optimum cooking time for each sample was determined using the AACC method 66-50 (AACC 2000). Optimum cooking time corresponded to the disappearance of the opaque core of noodle when squeezed between two glass plates (Figure 5.2).



before cooking after cooking

Figure 5.2 Representative pasta samples before and after cooking.

Cooking Loss. Cooking loss was determined by evaporating the noodle cooking water to dryness overnight in a conventional oven at 100 C, using the AACC method 66-50 (AACC 2000). Cooking loss (%) was calculated as described by Lee *et al*., (1998):

Cooking loss(%)= [dried residue in cooking water(g)/ noodle weight before cooking(g)]x 100

Water Absorption. To measure the degree of noodle hydration, the water absorption was determined as the difference between noodle weight before and after cooking. Approximately 25 g of noodles were cooked in 300 mL of distilled water in a 500 mL beaker, rinsed in cold water and drained for 30 sec before being weighted (Approved Method 66-50, AACC 2000).

Color Analysis. The color of the noodles was measured using a Hunterlab Ultrascan Sphere Spectrocolorimeter (Hunter Associates Laboratory Inc., Reston, VA) at ambient temperature. The colorimeter was calibrated using white and black standards. The color values L*, a*, b* were recorded. The dimension "L*" means lightness with 100 for white and 0 for black, "a*" value indicates redness when positive and greenness when negative, "b*" value represents yellowness when positive and blueness when negative.

before cooking after cooking

Figure 5.3 Representative pasta samples exhibiting color changes before and after cooking.

Texture Analysis. The noodle firmness was measured according to the Approved Method 66-50 (AACC 2000) with some modifications. The TA.XT2 Texture Analyzer (Stable Micro System, Scarsdale, NY) with 25 kg load cell was used to measure the firmness of cooked noodles. A noodles blade (5 X 5 cm) was used to compress the cooked noodles (Figure 5.4). Based on preliminary trials, texture parameters were set as pretest speed = 0.5 mm/sec; test speed 0.2 mm/sec; post test speed = 10 mm/sec; and distance = 0.5 mm. Five strands of cooked noodles were placed parallel on a flat plastic plate and compressed by noodles blade to distance 0.5mm. Noodles samples were evaluated within 5 min after cooking.

Figure 5.4 Representative image of pasta being analyzed for firmness.

Noodles Thickness

Five noodle strands were selected randomly before and after cooking and their thickness determined with an electronic digital micrometer (Fisher Scientific, St. Louis, MO). The before cooking thickness of the control pasta was 1.39 mm. The treatment thicknesses ranged from 1.42 to 1.47 for the 100% substitute to 1.31 to 1.40 mm for the 50% substituted. The noodle thickness was similar to other studies (Hatcher et al. 2002; Park and Baik, 2004). After cooking the control pasta increased 36.69%, whereas the treatment thickness for the 100% substituted increased 25.5 to 33.6% and for the 50% substituted increased from 33.58% and 36.73%.

Sensory Analysis

Sensory attributes were pre-determined for their relevance and comparative value. A trained descriptive panel (nine-member panel who had experience and served on descriptive panels) spent 4 hrs of training to become familiar with the definitions and references. Definitions of the attributes are provided in Table 5.2. The panelists evaluated the intensity of noodles color, roughness, stickiness, firmness, and flavor.

Testing of the samples was done in 2 one-hour sessions. Each attribute was evaluated on a 9- point scoring ballot.

Statistical Analysis- All noodle samples were analyzed using SAS (Software Release 8.1, 1999- 2000). A completely randomized design was conducted. The Analysis of Variance (ANOVA), Mixed Procedure (Mixed) Model and Fishers' Least Significant Difference (LSD) were carried out to ascertain significant effects at $p < 0.05$ among treatments and days. Three replications of all experiments conducted.

Table 5.2. Sensory Descriptors and Definitions Used in Descriptive Analysis of Refrigerated Noodles.

Descriptor	Definition
Color Light- dark	the intensity or strength of color from light to dark
Roughness Smooth- grainy/bumpy	the amount of grainy particles and bumps on the noodle surface
Stickiness Non sticky- very sticky	the tackiness of the coating left in the mouth
Firmness Soft-firm	the force requires to compress while chewing the mass of the noodles
Flavor None- strong	the intensity of the overall flavor of cooked noodles which includes aroma and taste

Sensory attributes definitions are adapted from Meilgaard et al. (1991).

Results and Discussion

The whey protein treatments did not process well enough to sheet the dough. Therefore, no noodles were manufactured using whey based egg alternatives as a 100% egg substitute in the noodle formulation. However, the whey proteins were successfully incorporated as partial replacements.

In the 100% substitute noodle formulations, the cooking loss of 100% replacement Pasta power and control were not significantly different, whereas 100% replacement with soy flour exhibited a significantly higher cooking loss (Table 5.3). Pasta power and soy flour exhibited a significantly higher cooking loss over storage time, whereas the cooking loss for the control did not significantly change with time.

The 100% pasta power treatment exhibited a significantly higher water uptake compared to the other treatments (Table 5. 3). Water uptake significantly declines over time for the pasta power, whereas the other treatments did not significantly change. The control was significantly harder than all 100% egg alternative treatments.

Prior to cooking the soy flour 100% replacement treatment exhibited a significantly higher L value compared to the control. The L value of all treatment significantly decline as a function of storage time (Table 5.4). After cooking the soy flour full replacement treatment exhibited a significantly lower L value compared to the control and 100% wheat alternative. Only the control did not significantly change in L value during storage. The b values for all cooked pasta was lower than the uncooked pasta. The control exhibited a significantly higher b values compared to the alternatives. The b value for all treatments declined over time.

Table 5. 3. Means of cooking quality and hardness of 100% egg substitute treatments compared to control

	Cooking time (min)	Cooking loss (%)			Water uptake (%)			Hardness (g)		
		0	15	30	0	15	30	0	15	30
Whole egg	11.0	4.10^{Aa}	4.10^{Aa}	4.2^{Aa}	129.8^{Aa}	128.3^{Aa}	130.0^{Aa}	714.3^{Aa}	682.7^{Aa}	687.0^{Aa}
Pasta power	11.0	4.47^{Aa}	4.85^{Ba}	5.40^{Bb}	140.3^{Ba}	125.4^{ABb}	131.1^{Ac}	517.0^{Ba}	542.0^{Ba}	491.0^{Ba}
Soy flour	11.0	5.64^{Ba}	7.29^{Cb}	6.99^{Cc}	118.8^{Ca}	120.2^{Ba}	115.0^{Ba}	445.3^{Ca}	406.0^{Ca}	437.0^{Ba}

AB Means with different superscripts in columns indicate significant difference among treatments ($p< 0.05$).
abc Means with different superscripts in columns indicate significant difference among days ($p < 0.05$).

The 1:1 blends of either pasta power: egg or Biopro:egg exhibited a significantly lower cooking loss a day zero compared to the other treatments and did not differ from the control (Table 5). All blend treatments except the control and control:Biopro blend exhibited significantly higher cooking loss over time. The control and control:Biopro blend did not have any significantly cooking loss over time. Bejosano and Corke (1998) and Vadlamani R.K. and Seib P.A. (1996) reported that approximately 5% cooking loss in noodles.

Only Biozate1: control blend treatment exhibited a significant increase in water uptake at day zero compare to all treatments(Table 5). Over time the Eggstend 300:control blend decreased significantly. All other treatments did not change significantly in water uptake over time. Bejosano and Corke (1998) reported that the increase in water uptake was approximately 120% similar to the current study. Although, Vadlamani and Seib (1996) reported cooked weight gains of approximately 100%.

Table 5.4. Color means of 100% egg substitute treatments compared to control

	Color											
	Raw Noodles						Cooked Noodles					
	L*			b*			L*			b*		
	Day 0	Day 15	Day 30	Day 0	Day 15	Day 30	Day 0	Day 15	Day 30	Day 0	Day 15	Day 30
Whole egg	64.9^{Aa}	63.0^{Ab}	61.8^{Ab}	36.2^{Aa}	32.9^{Ab}	31.8^{Ab}	74.6^{Aa}	74.3^{Aa}	73.7^{Aa}	19.3^{Aa}	17.4^{Ab}	16.8^{Ab}
Pasta power	65.8^{ABa}	63.0^{Ab}	61.7^{Ab}	30.4^{Ba}	25.6^{Bb}	23.5^{Bc}	74.2^{Aa}	71.6^{Bb}	71.1^{Bb}	15.4^{Ba}	12.2^{Bb}	11.6^{Bb}
Soy flour	67.0^{Ba}	64.0^{Ab}	62.9^{Ab}	31.8^{Ba}	26.1^{Bb}	25.6^{Cb}	72.8^{Ba}	70.8^{Bb}	71.0^{Bb}	15.6^{Ba}	12.0^{Bb}	11.6^{Bb}

AB Means with different superscripts in columns indicate significant difference among treatments ($p < 0.05$).

abc Means with different superscripts in columns indicate significant difference among days ($p < 0.05$).

The Biopro:control blend exhibited a significantly higher hardness value at day 0 compared to all other treatments (Table 5.5). Whereas, Soy flour: control and Biozate1: control blends were significantly lower in hardness compared to all other blend treatments. Park and Baik (2004) reported that the hardness of noodles prepared without egg were approximately 380 g force. Vadlamani and Seib (1996) reported values of approximately 370 g-force. All the pasta in the presence study were at least 500 g. Baik et al. (1994) reported hardness values ranged from approximately 1350 g-force to 1919 g-force. These difference in values were attributed to variety differences and processing conditions.

The hardness of the Pasta power:control blend treatments was not significantly different from the control at day zero. All blend treatments were significantly different from the control at Day 30. The control, soy flour:control and Eggstend300:control blends did not change in hardness over time.

Before cooking at day 0, Eggstend 300:control treatment exhibited a significantly lower L value compared to the other treatments (Table 5.6). All other treatment were not significant from each other at day 0. The L value of the control, Eggstend300:control, and Biopro:control did not significantly change over time. Bejosano and Corke (1998) reported that the L value for the noodles were approximately 80.

Before cooking the b value of the control was significantly higher than the other treatments at day 0 and 30. Before cooking all treatments significantly decline in b value over time. Bejosano and Corke (1998) reported that the b value was approximately 11.

After cooking the L values of all treatments were higher than before cooking. Although, Biozate1:control exhibited a significantly lower L value compare to the other treatments. After cooking all b values were reduced compared to the before cooking

values. With Biozate1:control exhibited a significantly lower b value. The b values of all treatments except Biozate1:control significantly decreased. The b value of Biozate1:control did not significantly change over time.

Table 5.5. Means of cooking quality and hardness of 50% egg substitute treatments compared to control

	Cooking time (min)	Cooking loss (%)			Water uptake (%)			Hardness (g)		
		0	15	30	0	15	30	0	15	30
Whole egg	10.30	4.10^{Da}	4.10^{Ca}	4.2^{4Ba}	129.8Aa	128.3Aa	130.0Aa	714.3^{Ba}	682.7^{Ba}	687.0^{Ba}
Pasta power	10.30	3.86^{Da}	4.46^{Cb}	4.67^{Bb}	128.3Aa	126.1Aa	127.1Aa	650.0^{BCa}	605.7^{BCa}	520.7^{CDb}
Soy flour	10.30	4.57^{Ca}	5.39^{Bb}	5.71^{Ab}	126.2Aa	124.3Aa	124.8Aa	518.3^{Da}	453.0^{Eb}	457.7^{Dab}
Eggstend300	10.30	5.02^{Ba}	5.71^{ABb}	5.54^{Ab}	131.5Aa	123.9Ab	124.8Ab	603.3^{Ca}	560.0^{CDa}	545.7^{Ca}
Biozate1	10.30	5.50^{Aa}	5.92^{Ab}	5.68^{Ab}	140.7Ba	140.9Ba	139.3Ba	572.3^{CDa}	510.0^{DEb}	520.3^{CDab}
Bipro	11.00	4.26^{CDa}	4.35^{Ca}	4.35^{Ba}	126.6Aa	126.3Aa	126.2Aa	1054.0^{Aa}	949.7^{Ab}	919.3^{Ab}

AB Means with different superscripts in columns indicate significant difference among treatments ($p< 0.05$).
abc Means with different superscripts in columns indicate significant difference among days ($p < 0.05$)

Table 5.6. Comparison of color values of 50% egg alternatives to whole eggs before and after cooking over 30 days of storage at 4°C.

	Color											
	Before cooking						After cooking					
	L*			b*			L*			b*		
	Day 0	Day 15	Day 30	Day 0	Day 15	Day 30	Day 0	Day 15	Day 30	Day 0	Day 15	Day 30
Whole egg	64.9^{Aa}	63.0^{Aa}	61.8^{Aa}	36.2^{Aa}	32.9^{Ab}	31.8^{Ab}	74.6^{ABa}	74.3^{Aa}	73.7^{ABa}	19.3^{Aa}	17.4^{Ab}	16.8^{Ab}
Pasta power	64.8^{Aa}	61.4^{Ab}	61.7^{Aab}	33.9^{BCa}	28.3^{CDb}	25.7^{Dc}	74.2^{Ba}	74.6^{Aa}	74.4^{Aa}	18.1^{BCa}	15.1^{BCb}	13.6^{Bc}
Soy flour	64.4^{Aa}	62.7^{Aab}	61.0^{Ab}	34.9^{ABa}	30.8^{Bb}	28.0^{BCc}	73.8^{BCa}	72.7^{Bab}	72.7^{BCb}	17.3^{CDa}	14.3^{Cb}	13.6^{Bb}
Eggstend300	59.2^{Ba}	60.9^{Aa}	59.6^{Aa}	33.2^{Ca}	27.5^{Db}	25.6^{Dc}	74.7^{ABa}	74.2^{Aa}	73.8^{Aa}	16.6^{DEa}	11.7^{Db}	11.4^{Cb}
Biozate	63.7^{Aa}	60.7^{Ab}	60.0^{Ab}	33.0^{Ca}	29.6^{BCb}	29.3^{Bb}	72.8^{Ca}	72.0^{Bab}	71.7^{Cb}	15.4^{Ea}	14.3^{Ca}	14.4^{Ba}
Bipro	64.7^{Aa}	63.9^{Aa}	63.3^{Aa}	33.8^{BCa}	27.5^{Db}	28.2^{BCb}	75.6^{Aa}	74.7^{Aa}	74.6^{Aa}	18.7^{ABa}	16.2^{Bb}	13.6^{Bc}

AB Means with different superscripts in columns indicate significant difference among treatments ($p < 0.05$).
abc Means with different superscripts in columns indicate significant difference among days ($p < 0.05$).

Sensory Analysis

Sensory attributes evaluated by trained panel are shown in Table 5.7. The roughness and flavor of cooked noodles were not significantly affected by the type of egg substitutes at both 50 and 100% levels. However, the flavor scores tended to be marginally higher and roughness scores lower for noodles contained soy flour.

The color, stickiness and firmness of cooked noodles were significantly affected ($p < 0.05$) by the type of egg substitutes and their protein contents. Panelists reported that noodles containing Bipro were significantly firmer ($p< 0.05$) than other egg substituted noodles at both 50 and 100% levels. These results were comparable with the instrumental texture analysis of cooked noodles over 30 days of evaluation. Bipro contains the highest protein content which is responsible for the increase in the firmness. In contrast, noodles contained soy flour had slightly the lowest scores in firmness among treatments and was revealed by the instrumental texture analysis. Noodles contained pasta power, which mainly consists of wheat protein, had the highest stickiness scores at 100% egg replacement for cooked noodles whereas those contained 100% whole egg, and soy flour at 50% had lowest scores. Including whole eggs in noodles decreased the stickiness. The intensity of stickiness in the noodles contained whole eggs and egg substitutes at 50:50 ratio were lower than those contained only 100% egg substitutes. Noodles formulated with soy flour and whole eggs were exhibited a marginally higher color intensity than those noodles formulated with the other egg substitutes, whereas noodles contained 100% pasta power had the lowest color intensity. Instrumental analysis of the color of cooked refrigerated noodles revealed an increase in lightness in the noodles contained whole eggs.

Table 5.7. Comparison of sensory attributes of refrigerated pasta formulated with whole egg and egg alternatives using trained panel and a 9-point hedonic scale.

		Sensory Attribute				
		Color	**Roughness**	**Stickiness**	**Firmness**	**Flavor**
	Whole egg	2.9^{ab}	3.2^{a}	4.1^{b}	5.3^{b}	6.2^{a}
100% egg substitute	**Pasta power**	2.3^{d}	3.4^{a}	5.6^{a}	5.3^{b}	6.9^{a}
	Soy Flour	3.0^{a}	2.8^{a}	4.8^{ab}	4.9^{b}	7.3^{a}
50% egg substitute	**Pasta power**	2.6^{abcd}	3.7^{a}	4.3^{ab}	4.9^{b}	6.1^{a}
	Soy flour	2.9^{abc}	3.4^{a}	4.1^{b}	4.7^{b}	7.1^{a}
	Eggstend300	2.4^{cd}	2.9^{a}	4.9^{ab}	5.2^{b}	5.8^{a}
	Biozate1	2.5^{bcd}	3.2^{a}	5.2^{ab}	5.6^{ab}	6.6^{a}
	Bipro	2.7^{abcd}	3.1^{a}	4.4^{ab}	6.3^{a}	5.9^{a}

abcd Means with different superscripts in columns indicate significant difference among treatments ($p < 0.05$)

Significance of Results

Whole egg could not be totally replaced with any of the egg substitutes studied in the egg noodles without some loss of quality. However, partial replacement of eggs was competitive in regard to the physical and sensory properties evaluated.

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Chapter 6

Comparative Study of Egg White Protein and Egg Alternatives Used in an Angel Food Cake System

Commercial egg alternatives available for application in bakery products marketed as a considerable long-term cost savings. These egg alternatives are advertised to possess useful functional properties including: browning, cohesiveness, foaming gelling water binding and emulsifying attributes.

Foam.

This study investigated twelve egg alternatives and an egg white protein were evaluated and compared for foaming properties (Table 6.1). The suppliers advertise their products for use as an egg white protein replacer.

These egg alternatives were either purchased or donated.

Table 6.1. Ingredients and their sources used in the foam formulation.

Sample Name	*Company Name*
Collagen	**Great Lakes**
Cryogel-Gelatin	**PB Gelatins/Tessender lo Group**
Gelatin	**Rousselat**
Eggstend 300	**Parmalet**
BiPro (whey protein)	**Davisco**
Solugel Collagen Hydroysets	**PB Gelatins**
PeptanF-Collegen Hydrolysets (fish protein)	**Protein Products**
Propulose (pea protein)	**Parrheim Foods**
Remy Pro W 70 (rice protein concentrate)	**A & B Ingredients**
Soy Protein	**ADM**
Corn Zein	**Freeman Industry**
Casein	**Sigma**

Only the egg substitutes that exhibit an acceptable foam property performance level as deemed by the evaluators was designated for use in the angel food cake model system study. All egg substitutes were screened using selected criteria for use as a foaming agent as described in Chapter 2.

Materials and Methods.

Thirteen samples were investigated for foaming properties at 10 and 20 whipping time. However, only nine showed potential and were moved forward for further evaluation. These samples and their performance are shown in Table 6.2. and 6.3. Foam capacity and stability were measured using a modified method of Phillips et

al (1990). Three replication and three sub-samples per replications were performed on nine different treatments. Foam capacity and stability were measured after whipping/aerating a 150 mL of a 12% protein solution (w/v) for 10 or 20 min in a Kitchen Aid Mixer (Kitchen Aid, St. Joseph, MI) at approximately 100 watts. The drainage was measured every five minutes for thirty minutes using a funnel and graduated cylinder apparatus at room temperature. However, we included only the results for 10, 20, and 30 minutes because they clearly demonstrated the most significant change in drainage.

Statistics

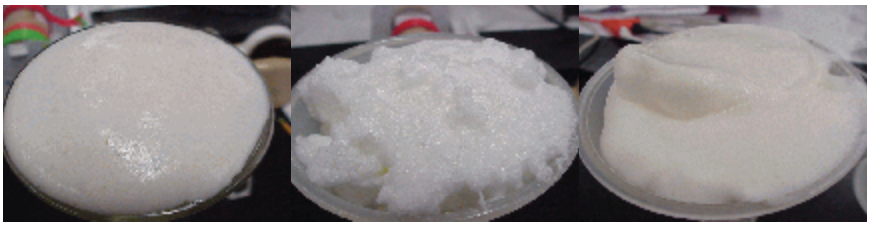
Three replications and three sub-samples per replication were performed on nine different treatments. Treatments were compared for their physical and sensory characteristics following a one-way complete randomized design. The analysis of variance and means comparison were conducted by the general linear model (Proc GLM) and Anova (Proc ANOVA) procedures with Statistical Analysis System software (version 8.2, SAS Institute, Inc., Cary, NC). Comparisons among treatments were analyzed by using Fisher's least significant difference (LSD), with a significance level at $P<0.05$.

Results

Figures 6.1 and 6.2 provide images of selected egg alternatives and their foam capacity and stability. Therefore, one may observe the range of foaming functionality that these selected egg alternatives possess.

A B C D E

Figure 6.1. Representative image comparing foams prepared with egg white and selected foaming products. A. Egg White B. Casein C. Wheat Isolate D. Parmalat EggStend 300 E. Davisco BiPRO



A B C

Figure 6.2. Representative images comparing foam stability of A. Parmalat EggStend 300, B. Egg White, and C. Davisco BiPRO


A


B


C

Figure 6.3. Representative comparison of foam capacity and foam stability of selected proteins: egg white (A), gelatin (B) and collagen (C).

Tables 6.2 and 6.3 exhibited differences in foam capacity and stability as a function of mixing time. This experiment was conducted to determine if egg alternatives needed a different mixing time to enhances their foaming properties compared to egg white protein. Analysis: BiPRO and Gelatin (Rousselot) foams exhibited similar foam density to egg whites (Table 6.2) Biozate had a much lower density. Cryogel, Collagen Joint Care, Eggstend, Solugel, and Arise 500 had a greater specific gravity. However, only Cryogel, Collagen Joint Care, and Arise 500 had longer foam stability compared to egg white foams. BiPro and Biozate had relatively similar foam stability at 30 min drainage. Eggstend 300 had both poor foam density and stability. Gelatin had similar foam density to egg white, but lesser drainage capacity**.**

Table 6.2 Comparison of the foam capacity and stability between egg white protein and egg alternatives after mixing for 10 minutes.

Treatment	Specific Gravity	Time (min)		
		10	20	30
		Drainage (mL)		
Egg White	0.078 ± 0.014	0.905 ± 1.124	2.19 ± 0.580	3.285 ± 0.163
Cryogel	0.299 ± 0.001	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Collagen Joint Care (Great Lakes Porcine Gelatin)	0.266 ± 0.050	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BiPro	0.088 ± 0.042	0.85 ± 1.203	2.465 ± 3.486	3.98 ± 4.310
Eggstend	0.155 ± 0.013	9.76 ± 1.500	14.09 ± 1.990	14.46 ± 1.470
Arise 500	0.117 ± 0.021	0.00 ± 0.00	0.065 ± 0.092	0.29 ± 4.10
Gelatin (Rousselot)	0.096 ± 0.005	4.84 ± 0.339	7.69 ± 0.410	8.8 ± 0.566
Biozate	0.039 ± 0.005	0.00 ± 0.00	2.044 ± 0.427	3.389 ± 0.155

Table 6.3. Foam capacity and stability when mixed for 20 minutes.

Treatment	Specific Gravity	Time (min)		
		10	20	30
		Drainage (mL)		
Egg White	0.093 ± 0.004	2.334 ± 0.566	4.40 ± 0.188	5.40 ± 0.188
Cryogel[a]	N/A	N/A	N/A	N/A
Collagen Joint Care Care (Great Lakes Porcine Gelatin)[a]	N/A	N/A	N/A	N/A
BiPRO	0.040 ± 0.001	0.000 ± 0.000	0.000 ± 0.000	1.967 ± 0.041
Eggstend	0.114 ± 0.009	13.350 ± 0.494	15.506 ± 0.502	15.883 ± 0.469
Arise 500	0.055 ± 0.001	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Gelatin (Rousselot)	0.108 ± 0.005	4.867 ± 0.208	8.4 ± 0.608	9.767 ± 0.643
Biozate	0.312 ± 0.002	0.00 ± 0.00	0.378 ± 0.402	1.90 ± 0.506

[a] **No foam formed; instead a gel like substance was formed.**

The: Cryogel and Collagen Joint Care did not form foams; instead they formed a gelatin like substance. BiPro, Arise 500, Gelatin (Rousselot), and Peptan F exhibited similar or better specific foam capacity than fresh egg white. However, only BiPro, Arise 500, and Biozate showed greater foam stability than fresh egg white.

Protein	10 min	20 min
Fresh Egg White		
Cryogel		
Collagen Joint Care (Great Lakes Porcine Gelatin)		
BiPro		
Eggstend		
Arise 500		
Gelatin (Rousselot)		
Biozate		

Figure 6.4 Depiction of egg white and egg alternative foams after 10 and 20 min of mixing

Significance of Foaming Data

Many of the egg alternatives were able to produce a stable foam (Figure 6.4). Although the specific gravity did vary form one protein source to the next. Based on the foaming data, the BiPro sample exhibited potential to make an acceptable angel food cake compared to the other egg alternatives evaluated.

Meringues

Preliminary data showed that not all egg alternatives that performed well in the foaming study could withstand the high temperatures (375F /30 min) required to baked an angle food cake. Prior to preparing all the foams for cake testing, a series of baked meringue were evaluated. Only the egg alternatives that successfully were able to deliver a baked meringue were considered for testing in the angel food cake experiments. Below are images that depicted the success of the egg alternatives in a baked meringue experiment. Only the Biopro egg alternative was able to maintain a meringue during baking. All other foams collapsed during the baking process. Representative samples are depicted in Figure 6.6.

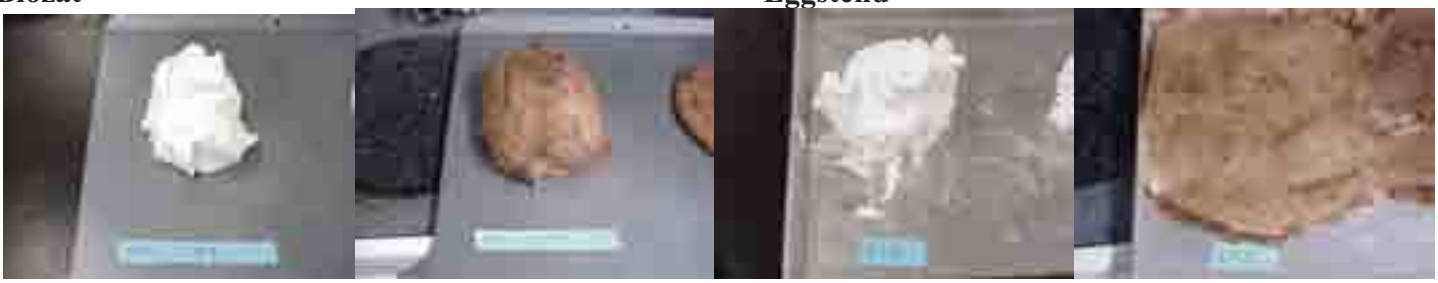
Angel Food Cake

Angel food cake was used as a system to compare and evaluate the functionality of the egg substitutes relative to the egg white protein. A commercial angel food cake formulation (Table 6.4) was modified for the study. The blended protein solutions will be whipped 1 min at speed setting 8 with an Ultra Power Mixer Model KSM90AC (Kitchen Aid Portable Appliances, St. Joseph, MI) equipped with a wire whisk attachment.

Egg white **Collagen**

before **after** **before** **after**

Biozat **Eggstend**



before **after** **before** **after**

BioPro

before **after**

Figure 6.5 Depiction of meringues of egg white and egg alternatives before and after baking at 375 for 30 minutes.

Table 6.4 – Standard angel food cake formulation

	Amount	
Ingredient	(g)	% (flour basis)
Flour	110.0	100
Sugar	314.0	285
Dried Egg White/Protein	40.0	36.4
Monocalcium phosphate, monohydrate	1.5	1.4
NaCl	3.0	2.7
Water	295	268.0

Materials and Methods

Batter and Cake preparation

A Reed reel oven (Reed Oven Co., Kansas City, MO) was preheated to 375F (1C). During which time a pan of water was placed in the oven for conditioning. The pan of water was removed prior to checking the first test cake to ensure proper baking conditions for the experimental angel food cakes being baked and evaluated. About 18 hr before baking either the reconstitute egg white or BiPro in requisite amount of water was mixed with in a Kitchenaid mixer (Model K5-A, Hobart Corp. Troy, Ohio, Kitchenaid Div.) using a whip attachment on low for 5 min. The mixtures were covered and stored at 4º C over night. The following day either the egg white or BiPro solution was transferred to a to a Hobart A-100 12 quart mixer (Hobart Corp., Troy, OH). The other dry ingredients (sodium chloride, monocalcium phosphate, and one half of the sugar) were added. The dry ingredients were blended into the egg protein or egg alternative mixture using low speed for one minute or until a homogeneous solution was obtained. The bowl was then scraped. The mixture was blended on the highest mixer setting until the specific gravity of the mixture was between 0.14-0.13. The specific gravity was determined by the weight comparison method 10-14 (AACC, 1983). To determine specific gravity, fill tared 1/3rd cup measure with foam and determine weight. Divide foam weight by 78.9 (1/3rd cup water approximately 78.9 mL) to determine specific gravity. The batters will be weighed immediately after final whip
The cake flour was sifted and combined with the remaining sugar while mixing for at least 20 seconds on a low speed. Fold in remaining flour-sugar mixture by dipping the whip into the batter and rotating both bowl and whip ¼ turn. Shake off whip and repeat 10 times. The bottom of an angel food cake pan (10“ diameter) was with wax paper. Fill 10 in. aluminum pans with 650 g batter and bake for 55 min at 375º F. (or until the surface springs back when lightly touch). Cool in an inverted position on a wire rack for 40 minutes. Ring with spatula and tap out cake and measure for volume.

Texture Analysis

Cake firmness was determined with TA-XT2 Texture Analyzer (Texture Technologies Scarsdale, NY) equipped with a 25 kg load cell. The angel food cake sections will be compressed to 60% of the original height using a 20 mm cylindrical probe in the TPA mode (2-compression test) with a 15 s delay between compressions. Results were analyzed with the aid of a XTRAD computer program and presented as force vs time graph with a 15-g force threshold setting. The (8 in) angel food cake was longitudinally sliced to obtain two halves. The crust and crumb were evaluated for firmness. Individual halves were probed in five randomly selected locations around each half. This procedure was performed on three cakes per treatment. The firmness of each measurement was

recorded. Cakes were tested within 24 hr after baking. Measurements on the texture analyzer using the following setting: test mode: T.P.A., pre-test speed: 3 mm/second, test speed: 1.7 mm/second, post-test speed: 1.7 mm/second, distance: 6 mm, trigger: auto at 20g, acquisition rate: 200 pps.

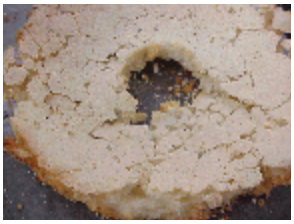


Figure 6.6 Representative image of an angel food cake formulated with an egg protein alternative treatment that did not make the screening because of unacceptable quality.

Table 6.5 Comparison of angel cake firmness of angel food cake formulated with egg white protein and whey protein isolate.

Treatments	**Crust firmness (g-force)**	**Crumb firmness (g-force)**
Control (egg white)	35.83±2.87^{B}	38.12±3.43^{B}
BioPro (whey protein isolate)	217.49±93.09^{A}	461.05±172.96^{A}

[1]Average ± standard deviation

^{AB}: Means followed by the same letters in the same column are not significantly different (P<0.05)

Table 6.6 Comparison of selected physical attributes of angel food cakes formulated with egg white protein or whey protein isolate.

	Color			**Height (cm)**	**Volume** (cm^3)
Treatments	L*	a*	b*		
Control	80.96±5.95 ^{A}	2.40±1.65^{B}	17.42±2.19^{B}	8.55±0.28^{A}	3193.23±131.55^{A}
BiPro	63.11±2.83^{B}	14.04±4.82	35.79±7.04^{A}	4.53±0.43^{B}	1411.45±212.55^{B}

[1]Average ± standard deviation

^{ABC}: Means followed by the same letters in the same column are not significantly different (P<0.05)

Egg protein **Whey protein isolate (Biopro)**

Figure 6.7. Representative images of angel food cakes prepared with egg white protein and whey protein isolate

The angel food cake formulated with whey protein isolate exhibited a significantly firmer crust and crumb compared to the egg white control.

The L value of the angel food cake formulated with egg white protein exhibited a significantly higher L value compared to the whey protein isolate (BioPro) Table 6.6. The control cake's height and volume were also significantly higher than the egg protein alternative.

Significance of the Results

The egg protein alternative did not perform as well as the control in the physical attributes evaluation. The angel food cake formulated with the egg alternative exhibited a firmer curs, lower volume and darker color compared to the control.

Sensory analysis

Cakes will be evaluated within 2 days after being baked using a complete block design to randomize the order of evaluation. After cooling and depanning, cakes will be cut into 1½-cm radial sections, placed in plastic freezer bags, sealed, and stored at 23EC until they are subjected to sensory analysis. Evaluations will be performed by 100 untrained sensory panel that are at least 18 years old. Panelists will be pre-screened for potential food allergies and on the basis of being an angel food cake consumer. Prior to starting the sensory

evaluation, all panelists will sign an informed consent statement. Sensory evaluation will be conducted in the Food Science Laboratory at Call Hall, Kansas State University. Panelists will be provided with an instruction/score sheet with specific instructions for evaluating the samples. Angel food cake samples will be offered to panelists on odorless plastic plates coded by three-digit random numbers at room temperature. Samples will be served to panelists monadically. The order of serving will be determined by random permutation. Questionnaires will be provided with samples. Panelists will be instructed to use unsalted crackers and distilled water to cleanse their palate before tasting the samples and any time during the test as needed. The panelists will evaluate angel food cake on a 9- point hedonic scale to determine degree of liking of the cake (9 = like extremely, 5 = neither like nor dislike, 1 = dislike extremely). The samples will be rated for aroma, taste, texture, and overall acceptability on the same scale. Analysis of variance (ANOVA) will be used to determine statistical significant differences between the two samples of angel food cake (IFT 1981).

Results

The control significantly out performed the angel food cake formulated with the egg alternative in all sensory categories evaluated (Table 6.7). Additionally, the consumers indicated that they are willing to purchase the control 2 to 1 over the angel food cake formulated with the egg protein alternative. The sensory data supported the physical data.

Table 6.7 Consumer Sensory of angel food cake formulated with egg white protein or whey protein isolate.

Sensory Attributes					
Treatments	Appearance	Texture/mouthfeel	Flavor/Taste	Acceptability	Willing to Purchase (%)
Control	7.14±1.37[A]	7.19±1.60[A]	6.99±1.54[A]	7.21±1.35[A]	80.2
BioPro	5.85±1.85[B]	5.54±2.00[B]	5.91±2.11[B]	5.61±1.95[B]	42.3

[1]Average ± standard deviation following a hedonic scale of 1-9 (1: Dislike extremely, 5: Neither like nor dislike, 9: Like extremely).

[AB]: Means followed by the same letters in the same column are not significantly different ($P<0.05$)

Table 6.8 Demographic Information for Angel Food Cake Consumer Sensory Study

Age	NUMBER	PERCENTAGE
18-25	47	44.76
26-30	16	15.24
31-35	2	1.90
36-40	5	4.76
41-45	6	5.71
46-50	9	8.57
51-55	6	5.71
56-60	5	4.76
61-70	8	7.62
71-80	1	0.95
Over 80		
Total	**105**	
Gender		
Male	38	36.19
Female	67	63.81
Total	**105**	
Education		
High school	7	6.67
Some college	43	40.95
B.S.	27	25.71
M.S.	16	15.24
PhD.	6	5.71
MD		
Other	6	5.71
Total	**105**	
How often do you eat cake?		
Every day	1	0.95
At least once a week	13	12.38
Once every 2 weeks	26	24.76
Once a month	59	56.19
Once a year	6	5.71
Never		
Total	**105**	
Food Allergies		
Yes		
No	105	100

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Chapter 7

Comparison of egg yolks and egg alternatives in French Vanilla Ice Cream

Fresh eggs are seldom used in ice cream except in rich ice cream, such as puddings. The cost of fresh eggs is generally such that they can be economically used only in ice cream retailing at higher than average prices.

Many ice cream makers use frozen egg yolks and powdered egg yolks because the egg yolk solids improve the whipping ability of the mix. Usually not more than .5% is needed for this purpose. Investigations have shown that egg yolks improve the rate of whipping more if they are sweetened with 10% sugar before being frozen.

The use of egg yolk solids produces the following beneficial effects: (1) Firmer ice cream at a given drawing temperature, (2) Increased whipping rate, (3) Less change in percentage overrun while unloading the freezer, (4) Improved appearance while ice cream is melting, (5) Slightly improved texture and (6) Increased food value

This study will investigate if commercial egg alternatives have the functionality necessary to replace egg yolk in French Vanilla ice cream using physical and sensory measurements as an evaluation means.

MATERIALS AND METHODS

The level of egg alternatives used to replace eggs were those suggested by the manufacturers of the egg alternatives. Table 7.1 shows the ingredients used in the control (egg yolks, M.G. Waldbaum Company, Wakefield NE) and each egg replacement sample.

The ingredients were measured to prepare 10 gallons batch of ice cream mix. Each batch was pasteurized at 165F/30min in a double-jacked stem kettle (Green MFG Co, Chicago IL). The mix was then cooled to 90F and homogenized (Creamery Pkg Manufacture, Chicago IL) at 1500 psi. The homogenized mix was temperature for 24 hr at 4C. Samples were collected for color and rheological analysis. After aging for 24 hr, a Vogt instant freezer (VS-85 Cherry-Burrell Corp, Cedar Rapids IA) was used to freeze the mixtures to -15^{o}C with a 100% overrun. The frozen ice cream was packaged into half gallon, pint and 6 oz paperboard containers. Once packaged, the containers were

immediately placed in a hardening room with circulating air at –40F. The samples were used for melting analysis, texture and sensory analysis.

Table 7.1. **Formulations of ice cream mixes.**

Treatment	Cream	Milk	Sugar	Nonfat dry milk	Stabilizer	Whole egg	Egg alternatives
Control Egg yolks	20	52	13.34		.26	3.22	
Eggstend 300 Whey-based	20	52	13.34	3	.46		3.22
FrigeX Modified corn starch	23	48	13.34	3	.46		3.22
Soy Soy protein	22	49.5	12.9	3085	0.46		3.22

FrigeX mixture contained the egg alternative (Frigx), water and N-Creamer

Viscosity Measurement

Apparent viscosity of the ice cream was determined using the Bohlin VOR rheometer (Bohlin Rheology, AB Lund Sweden). The ice cream mix samples were removed from refrigerated (4° C) temperatures and placed in a concentric cylinder with a 5° cone angle(Figure 7.1), and a torque element of 91.1 g-cm. The gap between the cone and plate was set at 0.150 mm. The rheometer was cooled to 4° C prior to the sample being placed onto the cup section of the geometry to simulate refrigeration temperatures. Samples were removed from 4° C storage and were allowed to in the geometry for at least 5 min to allow the samples to relax. The apparent viscosity was calculated within shear rates .925 s^{-1} to 92.5 s^{-1}. A shear rate of 9.26 s^{-1} was used for statistical analysis.

Figure 7.1 Depiction of the concentric cylinder geometry used to measure the apparent viscosity.

Color Measurement.

Ice cream mix samples were measured with a Hunter Lab Miniscan MS/S 4000S Spectrocolorimeter (Hunter Lab Inc. Reston, VA) calibrated with a white tile and light trap. The ice cream was measured according to the procedure described for translucent semi solid foods (Hunter Associates Laboratory, Inc 2004). The sample was placed into a 2.5 inch glass sample cup with a 10 mm black ring and white ceramic disk. Values of lightness (L), redness (a), and yellowness (b) were determined using illuminant C and a 10° viewing angle. Hue angle was calculated with the formula $\tan^{-1}$ (b/a).

MELTING Properties

A modified method according to Prindiville (2000) was used to evaluate the rate of melt. A number 7 wire mesh screen was placed on top of a analytical balance (0.0001 g). A 100 mL beaker was placed on the balance and below the mesh screen. The beaker was tarred. Approximately 80g ice cream was taken directly out of –18°C frozen storage and placed on to the number 7 mesh screen (Figure 7.2). The amount of sample collected into the 100 mL beaker at 21C at 5-minute intervals starting at 0 and continuing to 60 minutes was recorded. The data collected during the period of relatively constant draining was used to determine an overall rate of drainage for the ice cream.

Figure 7.2 Depiction of the set-up used to measure the French Vanilla ice cream treatments rate of melt

ICE CREAM TEXTURE ANALYSIS

Texture was determined with TA-XT2 Texture Analyzer (Texture Technologies Scarsdale, NY) using a 5 cm flat blade attachment. Prior to penetrating the sample the

blade was placed in –18C for 2 minutes. Ice cream samples were taken immediately from -18C storage to the TA platform. The pint container was slice in half to obtain a smooth surface. The hardness values were taken in three different locations equal distanced from each other and away from the walls of the pint container. All three measurements were taken within 45 s. The measurements on the texture analyzer using the following setting: test mode: compression, pre-test speed: 2.0 mm/second, test speed: 1.0 mm/second, post-test speed: 2.0 mm/second, distance: 6 mm, trigger: auto at 20g, acquisition rate: 200 pps.

Figure 7.3 Depiction of the set-up and measurement locations used to measure the French Vanilla ice cream treatments hardness.

Sensory Analysis

A total of 102 untrained panelists (72 female and 32 male) 18 – 80 years old participated in a consumer study. Panelists were prescreened for potential food allergies and on the basis of having consumed ice cream. Before starting the sensory evaluation, all panelists signed an informed consent statement.

Sensory evaluation was conducted in the Food Science Laboratory in Call Hall, Kansas State University. Each panelist evaluated four samples of French Vanilla ice cream at one session. One sample was the control in the study. Ice cream samples were removed from frozen storage (-17C) and immediately offered to panelists in odorless plastic cups coded by three-digit random numbers. Samples were served to panelists monadically. The order of serving was determined by random permutation. Questionnaires were provided with samples. The panelists were instructed to use unsalted crackers and distilled water to cleanse their palate before tasting the samples and any thim during the test as needed. The panelists evaluated the ice cream on a 9-point hedonic scale (Peryam and Girardot, 1952) to determine degree of liking for the ice cream products (9= like extremely, 5= neither like nor dislike, 1 = dislike extremely). The sample were rated for appearance, texture/mouthfeel, flavor/taste and overall

acceptability on the same scale (IFT 1981). Analysis of variance (ANOVA) was used to determine the statistical significant difference between the ice cream samples.

Statistical Analysis

Treatments were compared for their physical and sensory characteristics following a one-way complete randomized design. The analysis of variance and means comparison were conducted by the general linear model (Proc GLM) and Anova (Proc ANOVA) procedures with Statistical Analysis System software (version 8.2, SAS Institute, Inc., Cary, NC). Comparisons among treatments were analyzed by using Fisher's least significant difference (LSD), with a significance level at $P<0.05$.

Results

Viscosity Measurements

The mix apparent viscosity values were compared at approximately 10 s-1. Frige-X (starch) exhibited a significantly higher mix viscosity compared to all other treatments (Table 7.2). The apparent viscosity value was approximately 10 fold greater than the other treatments. Figure 7.4 depicts the shearing thinning properties of the ice cream mix treatments and the relative viscosity differences amongst treatments.

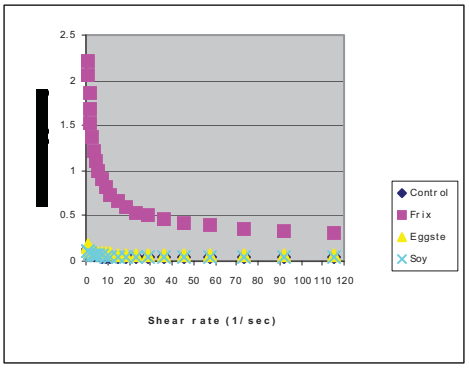

Figure 7.4 Comparison of the apparent viscosities of ice cream mixes formulated with egg and selected egg alternatives at 4C.

Color

The soy-based egg alternative exhibited a significantly lower L value compared to the other egg alternatives but was not significantly different from the control (Table 7.2). The control was significantly higher in b value compared to the other treatments.

Texture

EggStend and soy-based egg alternatives were significantly harder than the control and FrigeX treatments (Table 7.2).

Table 7.2 Comparison of the physical characteristics for French Vanilla ice cream formulated with either egg yolk or egg alternatives.

	Color			Viscosity	Hardness
Treatments	L*	a*	b*	(mPa.s)	(gram –force)
Control	88.11±0.18^{AB}	-1.02±0.10^{A}	12.92±0.10^{A}	58.33±3.83^{B}	4356.2±1027.49^{B}
Frig X	88.61±0.65^{A}	-1.57±0.14^{C}	7.22±0.89^{C}	852.5±51.23^{A}	3529.2±819.22^{B}
EggStend	88.55±0.36^{A}	-1.55±0.13^{C}	7.48±0.69^{C}	69.83±10.63^{B}	6638.1±1665.04^{A}
Soy Protein	88.01±0.34^{B}	-1.27±0.06^{B}	8.62±0.18^{B}	54.17±3.97^{B}	6440.7±1936.51^{A}

[1]Average ± standard deviation

^{ABC}: Means followed by the same letters in the same column are not significantly different ($P<0.05$)

Rate of Melt

The control was the first treatment to exhibited drip loss, which occurred after 5 min (Table 7.3). The egg alternatives did not exhibited any drip loss until 15 min. Firx X and Eggstend exhibited a significantly lower drip loss after 60 minutes.

Table 7.3 . Comparison of the percent melt for French Vanilla ice cream formulated with either egg yolk or egg alternatives from 0 to 60 min.

	Percent Rate of Melt over time (min)						
Treatment	0	5	10	15	20	25	30
Control	0.00	0.12±0.35	0.43±1.13	1.67±1.99^{A}	4.99±1.77^{A}	8.60±2.01^{A}	12.20±2.07^{B}
Frig X	0.00	0.00	0.00	0.08±0.18^{B}	0.72±0.98^{B}	4.22±3.08^{B}	11.70±1.62^{B}
EggStend	0.00	0.00	0.00	0.04±0.11^{B}	0.99±1.18^{B}	5.97±1.22^{B}	9.26±1.63^{C}
Soy	0.00	0.00	0.00	0.33±0.92^{B}	4.15±2.59^{A}	4.21±3.08^{A}	14.74±1.94^{A}

Treatment	35	40	45	50	55	60
Control	16.25±2.79^{B}	21.46±2.79^{B}	26.55±3.36^{B}	31.34±3.81^{A}	36.21±3.64^{A}	42.96±4.14^{A}
Frig X	15.81±1.66^{B}	20.52±2.84^{BC}	24.34±3.14^{BC}	27.51±3.70^{B}	30.67±3.74^{B}	32.61±3.59^{B}
EggStend	14.77±1.24^{B}	18.99±1.37^{C}	23.64±1.57^{C}	27.23±1.91^{B}	30.31±1.89^{B}	33.06±2.15^{B}
Soy	19.98±2.12^{A}	25.25±2.66^{A}	29.78±3.39^{A}	34.42±4.80^{A}	37.48±5.18^{A}	40.69±5.59^{A}

[1]Average in % ± standard deviation

^{ABC}: Means followed by the same letters in the same column are not significantly different ($P<0.05$)

Figure 7.5 Representative image of comparing the melting properties of French Vanilla ice cream formulated with either egg yolks or egg alternatives over 60 min at room temperature.

Sensory Analysis

There were no significant differences in appearance amongst the control, Frig-X or Eggstend treatments. The soy alternative exhibited a significantly lower appearance score compared to the other treatments. There were no significant difference in mouthfeel amongst the control, Frig-X or Eggstend treatments. The soy alternative exhibited a significantly lower mouthfeel score compared to the other treatments.
The control exhibited a significantly higher flavor score compared to the other treatments, whereas consumer scored soy-based egg alternative treatment as the ice cream with the least desirable flavor. The control and Eggstend treatments exhibited the highest acceptability scores, whereas consumer scored the stoy treatment as the ice cream that was the most unacceptable. Eight-one percent of the panelist would purchase the control compared to 36% for the soy-based egg alternative ice cream.

Table 7.4. Consumer Sensory Study comparing acceptability attributes for French Vanilla ice Cream formulated with egg yolk and egg alternatives.

Sensory Attributes					
Treatments	Appearance	Texture /Mouthfeel	Flavor/ Taste	Acceptability	Will to Purchase (%)
Control	7.12±1.37^{A}	7.20±1.42^{A}	7.44±1.31^{A}	7.35±1.28^{A}	81.7
FrigX	7.15±1.49^{A}	7.16±1.68^{A}	6.91±1.70^{B}	6.88±1.73^{B}	68.4
EggStend	6.82±1.41^{A}	6.93±1.42^{A}	6.92±1.63^{B}	6.91±1.44^{AB}	68.4
Soy	6.67±1.34^{B}	6.32±1.68^{B}	5.59±2.10^{C}	5.91±1.85^{B}	36.1

[1]Average ± standard deviation following a hedonic scale of 1-9 (1: Dislike extremely, 5: Neither like nor dislike, 9: Like extremely).

^{AB}: Means followed by the same letters in the same column are not significantly different ($P<0.05$)

Table 7.5 .Demographic Information for consumer study of French Vanilla ice cream formulated with egg yolk or egg alternatives.

AGE	NUMBER	PERCENTAGE
18-25	52	50.0
26-30	7	6.7
31-35	3	2.9
36-40	2	1.9
41-45	6	5.8
46-50	6	5.8
51-55	3	2.9
56-60	12	11.5
61-70	8	7.7
71-80	2	1.9
Over 80	3	2.9
Total	**104**	
GENDER		
Male	32	30.8
Female	72	69.2
Total	**104**	
EDUCATION		
High school	13	12.5
Some college	51	49.0
B.S.	15	14.4
M.S.	16	15.4
PhD.	6	5.8
MD		0.0
Other	3	2.9
Total	**104**	
HOW OFTEN DO YOU EAT ICE CREAM?		
Every day	4	3.9
At least once a week	57	55.9
Once every 2 weeks	23	22.5
Once a month	17	16.7
Once a year	1	1.0
Never		
Total	**102**	

A Comparison of Egg Solids in Selected Strains of Layer Hens: Examining the Impact of Hen Age, Egg Age, Storage Conditions and Forced Molt

Final Report Executive Summary

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Executive Summary

Feed consumption and feed conversion for white egg layers were not significantly affected by strain. The eggs per hen housed were influenced by the strain with a difference of 18.6 eggs from the highest producing stock to the lowest. This was not reflected in the percent hen day production between the strains, and therefore may in some cases be a result in the differences in mortality between the strains. All strains reach 50% production by 138 D of age, but the variation between the strains was as high as 8 days. Egg weight and subsequent egg size distribution was influence by the strain. There were no differences in the percent of large egg produced. The differences were related to a shift, predominantly related to small and medium sizes and the extra large percentages. Those strains with the heaviest eggs had the greatest percentage of extra large eggs. The percentage of Grade A eggs was not influence by strain. The percent of Grade B and loss eggs was different between strains. The egg income and feed expenses are significantly different between strains. The combination of high egg income and low feed costs resulted in as much as $1.08/hen difference. Each of the solids measurements were significantly impacted by strain of the hen, however, the changes in solids were not consistent between the different solid measurements. The interaction of strain and hen age on the percent of albumen solids shows that the strains' albumen secretion is different as the hens' age. Not all strains had continually decreasing albumen solids. The percent off albumen, yolk and whole eggs solids significantly changes as the hen ages. Albumen solids generally decreased as the hen aged. Yolk generally increased over the production cycle, however, there were a few period where yolk solids decreased. Whole egg solids increased though day 266 then plateaued at approximately 24.9%. The 21 day storage period resulted in a significant shift in the percent albumen and yolk solids. The albumen solids increased and the yolk solids decreased. Surprisingly, storage did not impact the whole egg solids. There was a significant interaction between hen age and storage temperature after 21 days of storage for yolk and whole egg solids, but not for albumen.

Even though the strain body weights were different after the random allocation to the molt treatments the average hen weights and weight losses for treatments were not different. The strain of hen did not impact the feed consumption during the 2nd cycle. The HH eggs were significantly increased in the molted hens over the non-molted hens. There was also a 8.3% reduction in mortality in the NF an FR molted hens. During the 2nd cycle, the strain had the greatest influence on egg weight. The strain of the hen did influence the albumen, yolk and whole egg solids during the 2nd cycle as is did in the 1st cycle. In general, the values were lower for the 2nd cycle than for the first. The yolk solids did not necessarily increase or decrease in response to corresponding changes in albumen solids. As with the 1st cycle, the age of the hen significantly influenced the percentage of albumen and yolk solids. Whole egg solids were stable throughout the 2nd cycle. Albumen solids were 0.5% higher in eggs from molted birds. Yolk and whole egg solids were not impacted by molting. The duration of the storage had a significant impact on all solids measurements. Albumen solids decreased throughout the 2nd cycle with stored eggs having highest solids. Yolk solids decreased during storage. However, as the

hen aged the differences between the fresh and store yolk solids diminished. Whole egg solids were not affected by a 4°C storage for 21 days, but did increase when storage temperature was increased to 20°C.

All production characteristics were significantly different between the brown egg layer strains except for mortality and age at 50% production. None of the egg quality characteristics were influenced by the strain of the hens. The brown whole egg solids were significantly impacted by the strain of the hen. Albumen and yolk solids were not different between the strains. However when broken down by age, strain did impact yolk solids. When all strains were group together, the age of laying hens does impact the percent albumen, yolk and whole egg solids. The 21 day storage period resulted in a significant shift in the percent albumen and yolk solids. Regardless of the temperature, storage resulted in increases in albumen and whole egg solids and decreases in yolk solids. The 20°C storage temperature for 21 days resulted in more pronounced shift in the percent solids for the albumen and yolk, but not in the whole egg solids. Hen age had a significant impact on albumen, yolk and whole egg solids when stored (both storage temperatures combined). There was no impact on albumen or whole egg solids by hen age when separating the two storage temperatures.

During the molt cycle, all the brown egg strains responded in a similar manner. However during the 2nd cycle the brown egg strains responded differently from one another. Mortality was not affected by strain. The molt program had no impact on the egg size distribution. Overall the molt program resulted in an improvement in egg quality. In the 2nd cycle the strain of hen significantly impacted egg solids however as the hen aged albumen, yolk and whole eggs solids decreased. During the middle of the 2nd cycle the percent of yolk solids fluctuated in eggs which had not been stored while the yolk solids of stored eggs remained relatively constant. Whole egg solids in the fresh eggs decreased throughout the 2nd production cycle while the whole egg solids in the stored eggs remained relatively constant. The albumen, yolk and whole egg solids responded differently as the hen age and storage temperature increased.

A Comparison of Egg Solids in Selected Strains of Layer Hens: Examining the Impact of Hen Age, Egg Age, Storage Conditions and Forced Molt

Final Report

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A Comparison of Egg Solids in Selected Strains of Layer Hens: Examining the Impact of Hen Age, Egg Age, Storage Conditions and Forced Molt

Introduction

Commercial strains of egg production layers have been selected primarily for high production of eggs with acceptable market weights whereas little, if any, emphasis has been directed towards egg composition (Jones et al., 2001). Additionally, improvements in the management, disease control, nutrition, and genetics of layers as well as advancements in processing technology over the last 40 years have undoubtedly changed egg quality and composition, yet few studies have documented this progress. There have been some studies (Cook and Briggs, 1977; Marion et. al., 1964; Jackson et al., 1986), which looked at breed, strain and age and their impact on egg composition. The general conclusion was the proportion of yolk tended to be greater and the proportion of albumen smaller in small eggs than in larger eggs. Other studies (Rodda et al., 1977.; May and Stadelman, 1960; Rose et al., 1966; Akbar et al., 1983; Hill et al., 1966) have reported that selected commercial strains weighed more and contained higher percentages of albumen, albumen solids and albumen protein. However, this variation among strains has often been related to variation in egg size.

Bird age has also been reported to have an effect on egg size and composition traits. Most of these trends can be reversed by forced molting, but the effects on egg size and composition resumes the typical decline in the 2nd Cycle. Eggs increase in weight over a production period. This increase is associated with development of both yolk and albumen constituents, although such changes occur disproportionately, with the percentage of yolk progressively while the percentage of albumen decreases. Izat (1983) and Cunningham et al., (1960) found that the percentage of albumen solids, albumen protein, and Haugh units decreased with age of bird. Both studies generally reported that as hens age the yolk quality traits generally improve, whereas the albumen traits worsen. However, Tharrington et al. (1999) reported no significant differences in between strains for albumen protein, solids, pH or yolk solids in eggs with significantly different weights. In fact, they reported genetic selection had produced larger eggs containing lower percentage of yolk while overall egg quality had been maintained or improve.

There seems to have been no comprehensive study looking at breaker eggs from current commercial stock over a laying cycle. What studies have been conducted look at only a few of the eggs characteristics or USDA physical quality. In a onetime snapshot of egg solids from the commercial strains participating in the 34th North Carolina Layer Performance and Management Test indicates that there are significant differences between the strains. See the results shown in the following table.

Egg solids percentages of strains in the 34th NCLP&MT at 105 Weeks of Age (preliminary data)

Strain	Whole Egg	Yolk	Albumen
White Egg Strains	(%)	(%)	(%)
B-300	24.2^{C}	50.8^{B}	9.8^{DE}
Bovans Exp	24.8^{C}	56.8^{A}	14.8^{A}
Bovans	29.9^{A}	57.2^{A}	13.0^{B}
Dekalb Sigma	30.7^{A}	57.6^{A}	7.5^{F}
DekalbExp	30.3^{A}	57.2^{A}	13.0^{B}
Hy-Line W-36	23.7^{C}	51.4^{B}	9.9^{D}
Hy-Line W-98	27.5^{B}	51.7^{B}	10.4^{C}
ISAWhite	24.7^{C}	50.9^{B}	9.3^{E}
ShaverWhite	27.5^{B}	56.9^{A}	15.0^{A}
Brown Egg Strains			
Bovans	23.1^{C}	51.8^{C}	9.9^{B}
Dekalb	28.0^{B}	57.6^{A}	15.2^{A}
Hy-Line	29.3^{A}	57.0^{B}	15.3^{A}

In the modern commercial environment, the breeders developing the layer strains for production of large egg sizes to enhance yield are working to continuously increase their productivity (Anderson, 2002). However, effects of such breeding efforts on the solids properties of eggs have not been studied. Eggs from layer strains bred for optimal albumen production may produce solids percentages that detrimentally affect yield of albumen. In addition, eggs may be more susceptible to breakage of the vitelline membrane with the subsequent contamination of albumen by yolk lipid. Because of poor yield or foaming power of the resulting product, economic advantage of such breeding programs may be negated.

A method to study these problems is to correlate strains of layer hens bred for the egg breaking industry to the quality, and egg solids of whole egg, albumen, and yolk. This research project allowed an evaluation of layer hen breeding characteristics production for yolk, albumen, or whole egg production properties of the eggs.

The objective of North Carolina State University's portion of the research was to analyze and then correlate profiles of egg solids (whole egg, yolk, and albumen) to the strain, production, alternative molting methods, and quality characteristics of eggs produced. The scientists at Auburn University examined the impact of storage temperature conditions and egg age on egg solids of whole egg, albumen, and yolk.

This project was unique in that it compared the solids composition of eggs from current layer strains over a complete two-year laying cycle which included a comparison of a non-molted, non-fasted molt, and fasted molt flock. These results will not only benefit the breaking operations, but could also benefit the geneticists by showing the relationship between egg composition and functionality between the current strains and the impact of molting methods on egg solids.

Objectives

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1) Provided eggs from twelve selected strains of laying hens with a potential for use in the egg breaking industry that were maintained under identical management and housing conditions.
2) Examined the impact of molt on egg solids.
3) Collected, analyzed, and then correlated albumen, yolk and whole egg solids composition, and quality for the 12 laying hens potentially used in the egg breaking industry.

Additionally, NCSU provided USDA quality and production measurement results for strains in this study. This information was collected as part of the standard experimental data collection practices associated with the 35th North Carolina Layer Performance and Management Test.

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1) Analyzed and then correlated albumen, yolk and whole egg solids composition from eggs stored at 2 storage temperatures (4º and 20º C) and egg age (21 day storage period), for the 12 strains of laying hens.
2) Post molt correlated albumen, yolk and whole egg solids composition from eggs stored at 2 storage temperatures (4º and 20º C) and egg age (21 day storage period), for the 12 strains laying hens and 3 molt treatments.

Experimental Design

The experimental design used for the production study was a completely randomized design using 12 strains, for a total of approximately 6048 hens. The production data was analyzed using the replicate means and the SAS®GLM procedure (SAS, 1996). Means of the main effects that were significantly different were separated using Least Square Means test.

The split-plot design used for the egg quality study utilized 13 hen ages as the repeated measure. The strain and subsequent molt treatment combinations were randomized within the house using the 12x3 factorial for strain and molt treatment as described above. Data was collected from the same strain treatment combinations throughout the experiment.

The egg quality was analyzed using the MIXED Procedure (SAS, 1996) for Split Plot designs with the between replicate factor being the strain*replicate and the within replicate factor being bird age. The error term for the whole plot was replicate (strain*replicate) and the sub plot used the residual error. The data was tested for distribution normality and homogeneity of the variance and when needed a prescribed transformation was utilized. The strain and replicate effects were separated with the use of the estimate statement, within the SAS MIXED Procedure (SAS, 1996), to estimate the linear function of the parameters. Means separation for the data that were significantly different were accomplished using the least square means, which were applied to the untransformed means for reporting when needed.

Methods

The strains that were utilized in this study were the following: Hy-Line Brown, Bovans Brown, Bovans Goldline, Dekalb White, Hy-Line W-36, Hy-Line W-98, Hy-Line CV-20, Bovans White Exp, Bovans White, Lohmann LSL-Lite, ISA Babcock B-300, and ISA White.

These strains were selected based upon their availability, and market share. The breaker market is looking for strains, which would produce eggs with a larger egg size.

The molt programs used in this study were conducted concurrently with a non-molted control. The treatments are described below:

1) Non-molted: Full Fed Control (NM): The replicates assigned to the full fed control group were maintained according to the standard management program as outlined previously. The laying house was partitioned such that the lighting program was consistent for maximum egg production.
2) Non-fasted: Non-anorexic molt program (NF): The hens were fed a diet, which was low protein, low energy, and had no supplemental Ca. At the end of the molt period (28 days) the hens were returned to a complete layer diet.
3) 13-day fast: Feed Restriction (FR): Post-fast and pre-egg production, hens received a diet containing 16% Crude Protein. When birds in the replicate being weighed reached target weight or 14 days off feed that rep. and sister reps. were returned to full feed. A body maintenance diet was fed until the hens reached 28 days after the initiation of the molt period. The hens were then returned to a complete layer diet.

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Egg Solids Procedures:
One flat (30 eggs)/strain*molt/sampling period was used to conduct tests related to albumen, yolk, and whole egg solids composition. The eggs were collected and stored at 4º C over night and broken out the following day.

Twenty-four eggs were randomly selected from one flat for each of the 12 strains. The albumen and yolk from twelve eggs were separated and pooled (4 eggs/pool) and the remaining twelve eggs were pooled in the same manner for whole eggs. Samples were then mixed for 30 seconds using a Stomacher Mixer to ensure homogeneity. Total solids measurements were conducted utilizing the method described by Curtis et al. (1986) in which approximately five gram samples were weighed into aluminum pans and dried in a forced air oven at 100ºC for 24 hours. Samples then were placed in a dessicator and brought to room temperature before final weights are taken. Whole eggs, albumen, and yolk solids analysis was made in triplicate from the pooled samples.

Standard Experimental Data Collection:

Egg Weights and Distribution
Egg weights were recorded at 28 day intervals beginning at 119 days of age. All eggs produced in the previous 24-hour period were weighed and sorted by sizes. Extra large, Large, Medium, Small and Pee Wee categories were defined as having minimum weights of 27, 23.5, 21, 18 and < 18 ounces/dozen (63.8,

55.2, 49.6, 42.5 and < 42.5 Grams/egg), respectively. Percentages of eggs within each size category, average egg weight, and average egg mass (hen-housed and hen-day) were calculated and summarized using blended size distribution.

Egg Quality

At 28 day intervals, egg weights were recorded for all eggs produced during the previous 24-hour period and were examined by candling light and graded according to U.S.D.A. standards for egg quality. Eggs were candled at the point of production with minimum handling prior to examination. Egg income was calculated at 28 day intervals using three year regional average prices for farm value eggs based on egg production and quality evaluation.

Feed Consumption and Conversion

The weight of all feed provided was recorded by each experimental replicate. At 14 days of age, and every 14 days thereafter in the brood-grown house and every 28 days in the layer house, feed was weighed back by replicate group in both houses for the calculation of feed consumption. Feed intake, feed/dozen eggs, and feed per unit of egg mass were calculated using these data. Feed cost was based on the average regional price and was calculated at 28day intervals and summarized for each production cycle.

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Egg Solids Procedures:

Two flats of eggs were collected from the 12 different strains (by molt treatment) of breaker eggs from the North Carolina Layer Management and Performance Test conducted at the North Carolina Department of Agriculture Piedmont Research Station. After collection the eggs were transported to Auburn University. Samples were collected starting in May 2003 and subsequent samples were collected every other month for a 24-month period and the molting period. Upon arrival at Auburn University the one flat per strain was placed in its respective storage temperature (4° and 20°C) and stored for 21 days. After 21 days one flat per strain was used to conduct tests related to albumen, yolk, and whole egg solids composition.

Twenty-four eggs were randomly selected from one flat/storage temperature for each of the 12 strains. The albumen and yolk from twelve eggs was separated and pooled (4 eggs/pool) and the remaining twelve eggs were pooled in the same manner for whole eggs. Samples were then mixed for 30 seconds using a Hamilton Beach Drink Mixer to ensure homogeneity. Total solids measurements were conducted utilizing the method described by Curtis et al. (1986) in which approximately five gram samples were weighed into aluminum pans and dried in a forced air oven at 100ºC for 24 hours. Samples then were placed in desiccators and brought to room temperature before final weights were taken. Whole eggs, albumen, and yolk solids analysis were made in triplicate from the pooled samples.

Results and Discussions

White Egg Strains: First Production Cycle (119-462 days of age)

Production Characteristics:

Strain: Feed consumption and feed conversion were not significantly affected by strain (Table 1). The eggs per hen housed (HH) were influenced ($P<0.05$) by the strain with a difference of 18.6 eggs from the highest producing stock to the lowest. The LSL-Lite had the highest number of eggs 287.7 and the Dekalb White had the lowest

number of eggs at 266.1. This was not reflected in the percent hen day production (HD) between the strains. This may be the result of the differences (P<0.05) in mortality between the strains during this same time frame. However, this is not the case with all the strains since the LSL-Lite had the highest level of production with an intermediate mortality. All of the strains reached 50% production by 138 D of age, but the variation (P<0.05) between the strains was as high as 8 days. The W-98 reached 50% production at 130 D of age which was lower than all remaining strains.

Egg Size Distribution:

Strain: Egg weights and subsequent egg size distribution was influenced by the strain (Table 2). The strains with the highest (P<0.05) egg weights were the W-98 and ISA White at 61.2 and 61.0 g, respectively. Unlike in the past the initial body weight did not have an impact on egg weights as illustrated by the body weights of the W-98 and ISA White with 17 wk body weights of 1.38 and 1.18 kg, respectively. The lowest egg weights were associated with the W-36 hen's eggs weighing 57.1 g during the first cycle, which had a 17 wk body weight of 1.27 kg (Table 15). There were no differences in the percent of large eggs produced between the strains. The differences were related to a shift, predominantly related to small and medium sizes and the extra large percentages. Those strains with the heaviest eggs had the greatest percentage of extra large eggs.

Egg Quality and Income:

Strain: The percent A grade eggs produced was not influenced by the strain of the hens (Table 3). The percent B grade and loss eggs were different (P<0.05) between the strains. These differences appear to be influenced by the distribution between the under grade categories and not related to the variation in the A grade classification. The egg income and feed expenses shown in Table 3 are significantly (P<0.05) different between the strains. With the income and expenses fluctuating in both directions for any given strain the difference between these may be of greater importance (gross income). The combination of high egg income and low feed costs resulted in as much as $1.08/hen difference between the B-300 and LSL-Lite with gross incomes of $7.30 and $8.38, respectively.

Albumen, Yolk, and Whole Egg Solids:

Strain: Each of the solids measurements were significantly (P<0.05) impacted by the strain of the hen (Table 4), however, the changes in solids were not consistent between the different solids measures. The CV-20 had the highest albumen solids in the first cycle at 12.92% while the LSL-Lite had the lowest at 12.05% whereas the yolk solids percentages were no different between these two strains with 48.03% and 48.00% yolk solids, respectively. The whole egg solids were highest (P<0.05) in the B-300 at 24.68% solids while the Dekalb White and LSL-Lite had the lowest whole egg solids of 23.79 and 23.81%, respectively.

The interaction (P< 0.0001) of strain and hen age on the percentage of albumen solids, in Figure 1, shows that the strains' albumen secretion is different as the hens' age. This figure shows that the CV-20 has high albumen solids through 322 d whereas the B-300 has lower albumen solids at 154 d then the solids increase significantly then remain high through 322 d before they begin to drop. The other strains typically had decreasing albumen solids through 434 d the 1st cycle. The LSL-Lite had the poorest albumen solids throughout the 1st cycle. The strain by hen age interaction (P< 0.01) in Figure 2 shows that whole egg solids increase as the hen's age through 322 d then whole egg solids plateau through the remainder of the 1st cycle. The W-36 and B-300 hens had significantly higher solids from 182-210 d of age. In subsequent periods 322 and 378 d, the B-300 and W-36 increased respectively while the remaining strains remained relatively constant.

Hen Age: The age of laying hens resulted in the percent of albumen, yolk, and whole egg solids significantly (P<0.05) changing during the production cycle (Table 5). Albumen solids decreased by 1.1% from 119 through 434 D of age at 13.12 and 12.02%, respectively. Yolk solids increased (P<0.05) at 182 to 210 D to 50.14% then

decreased in the next sampling age to 47.99%. Through the remaining sampling ages 238 through 434 D the percent yolk solids increased. Whole egg solids continuously increased ($P<0.05$) through 266 D then plateaued in the remaining periods at approximately 24.9% solids.

Storage: A twenty one day storage period resulted in a significant ($P<0.05$) shift in the percent albumen and yolk solids (Table 6). The albumen solids increased by 0.18% and the yolk solids decreased by 2.8%. Surprisingly, this did not impact the whole egg solids. The high storage temperature of 20°C resulted in a similar shift in the percent solids for the albumen and yolk as was seen in the stored eggs. In this case albumen solids increased by 0.42% and yolk solids decreased by 1.77% when stored at 20°C. The interaction of hen age, storage temperature with 21 d of storage was significant for yolk and whole egg solids.

There was hen age by egg age interaction ($P< 0.0001$) for albumen solids. This interaction shows the shift in percent albumen solids after storage for 21 days to a level lower than the egg stored for 0 days when the hens were 294-322 d of age. The same interaction ($P< 0.0001$) for percent yolk solids is shown in Figure 4. The interaction occurred at 182-210 d of age. This corresponds to an incident of Osteomalacia that resulted from a drop in Ca absorption due to the physical form of the Ca in the diet.

Table 7, shows the interaction of hen age, storage temperature, and egg age on solids. There was no effect on albumen solids. However both yolk and whole egg solids were affected ($P< 0.05$) as shown in Table 7 and illustrated in Figures 5 and 6. Yolk solids decreased when they were stored for 21 days at 4°C (Figure 5) and those eggs stored at 20°C had even lower yolk solids. The exception to this was 182-210 d of age where the hens experienced a documented case of osteomalacia. Whole egg solids increased significantly from 119 through 266 d of age (Figure 6). Unlike the yolk solids the whole egg solids increased slightly when they were stored for 21 days at 4°C and the eggs stored at 20°C had even higher solids. Here again the exception to this was 182-210 d of age where the hens experienced a documented case of osteomalacia and from 294 through 322 d of age. This trend was also present in the brown egg strains. One theory for the increasing whole egg solids in contrast to the lower yolk solids is a change in the proportion of albumen to yolk in the egg. This could be the result of yolk size variation changing the proportions as the hens' age or the changes in albumen volume during storage.

Brown Egg Strains: First Production Cycle (119-462 days of age)

Production Characteristics:

Strain: All of the production characteristics were significantly ($P< 0.05$) different between the strains except for mortality and age at 50% production. Feed consumption was similar for the Bovans Brown and Goldline and both were higher than the Hy-Line Brown (Table 8). However, feed conversion was the same for the Bovans Goldline and the Hy-line Brown with the Bovans Brown having the lowest ($P< 0.05$) feed conversion at 0.47 g egg/g feed versus the .049 g egg/g feed for the other strains. The eggs per hen housed were influenced ($P<0.05$) by the strain with HH Eggs reduced only in the Bovans Brown strain, but, the %HD production was not different between any of the strains. This may be the result of the slight differences in mortality between the strains during this same time frame. Daily egg mass was highest ($P< 0.05$) for the Bovans Brown and Goldline which produced 1.1 and 1.9 g of egg more per day than the Hy-Line Brown.

Egg Size Distribution:

Strain: Egg weights were the highest ($P< 0.05$) for the Bovans Brown and Goldline at 61.0 and 60.8 g/egg as compared to the eggs from the Hy-Line Brown at 59.5 g (Table 9). This egg size shifted the distribution by strain from medium eggs to extra large eggs. The strains with the highest ($P<0.05$) egg weights were the Bovans Brown and Goldline resulting in the lowest ($P< 0.05$) percent Medium eggs and the highest ($P< 0.05$) percent extra large.

Egg Quality and Income:

Strain: None of the egg quality characteristics were influenced by the strain of the hens (Table 10). The egg income was not significantly different between the strains, however, due to the lower feed consumption of the Hy-Line Brown that strain had the lowest ($P< 0.05$) feed expenses. With these values fluctuating in both directions for any given strain the difference between these may be of greater importance (gross Income). The combination of egg income and feed costs resulted in the Bovans Brown with the lowest gross income of $7.76/hen while the Hy-Line Brown and the Bovans Goldline had gross incomes of $8.34 and $8.24, respectively.

Albumen, Yolk, and Whole Egg Solids:

Strain: The whole egg solids were significantly ($P<0.05$) impacted by the strain of the hen (Table 11). The differences in the whole egg solids between the strains shows that the Bovans Brown has the highest solids at 23.55% and the Hy-Line Brown has the lowest at 23.14%, while the Bovans Goldline was intermediate. Albumen and yolk solids were not different between the strains.

The interaction ($P< 0.01$) of strain and hen age on the percent yolk solids, in Figure 7, shows that the strains yolk solids vary as the hens' age. This figure shows that during the period 182 through 210 d of age the yolk solids increased with the Bovans Goldine hens producing eggs with the highest yolk solids. This is the same period as an osteomalacia diagnosis in the hens. This appears to indicate that the intake of specific nutrients could contribute to yolk solid levels in eggs. The Hy-Line Brown had reduced yolk solids at 294 through 322 d of age. After these periods the yolk solids returned to levels of approximately 48.5% yolk solids. The strain by hen age interaction ($P< 0.05$) in Figure 8 shows that whole egg solids increase as the hens age through 266 d then whole egg solids declined from 294 through 322 d of age. In the subsequent periods all of the strains increased slightly then remained relatively constant through the end of the first cycle.

Hen Age: The age of laying hens does impact the percent of albumen, yolk, and whole egg solids significantly ($P<0.05$) changing during the 1st production cycle (Table 12). Albumen solids decrease by 1.32% from 119 through 434 d of age at 13.32 to 12.00%, respectively. Yolk solids increased ($P<0.05$) at 182 to 210 d to 50.34% then decreased at the next sampling age to 47.99%. Through the remaining sampling ages 238 through 434 d the percent yolk solids increased. Whole egg solids continuously increased ($P<0.05$) through 266 d then decreased to 22.74% from 294 through 322 d. The whole egg solids increased and plateaued in the remaining periods at approximately 24.2% solids.

Storage: A twenty one day storage period resulted in a significant ($P<0.05$) shift in the percent albumen and yolk solids (Table 13). The albumen solids increased by 0.33%, yolk solids decreased by 2.14%, and correspondingly whole egg solids increased by 0.68%. Regardless of the temperature storage resulted in increases in albumen and whole egg solids and decreases in yolk solids. The high storage temperature of 20°C resulted in more pronounced shift in the percent solids for the albumen and yolk as was seen in the stored eggs, but not in whole egg solids. In this case albumen solids increased by 0.35% and yolk solids decreased by 1.41% when stored at 20°C. The interaction of hen age, storage temperature with 21 d of storage was significant for yolk and whole egg solids.

There was a hen age by egg age interaction ($P< 0.001$) for albumen solids (Figure 9). This interaction shows the shift in percent albumen solids after the hens were 232 d of age, with storage for 21 days having a higher solids % level than the egg stored for 0 days. After 294 d the albumen solids were relatively constant for the 0 and 21 d storage. The same interaction ($P< 0.0001$) for percent yolk solids is shown in Figure 10. The yolk solids varied by as much as 4.5% throughout the 1st cycle. However, the greatest differences at 21 d of storage occurred at 182-210 d of age. This corresponds to an incident of Osteomalacia that resulted from a drop in Ca absorption due to the physical form of the Ca in the diet. Figure 11, shows that interaction of hen age and egg age focused on the whole

egg solids 294 to 322 d of age. Whole egg solids decreased in the 0 d storage group then increased in the latter periods of the 1st cycle to where the 0 and 21 d old whole egg solids were the same.

Table 14, shows the interaction of hen age, storage temperature, and egg age on percent solids. There was no interaction effect on albumen or whole egg solids. However, yolk solids were affected ($P< 0.05$) as shown in Table 14 and illustrated in Figure 12. Yolk solids decreased when they were stored for 21 days at 4°C except for the hens at 294 to 322 d of age. In this age range the yolk solids increased, then subsequently, those eggs stored at 20°C had lower yolk solids at all of the hen ages. In the Brown egg layers there was no consistent whole egg solids increase or decrease throughout the 1st cycle.

White Egg Strains: Molt Cycle (462-491 days of age)

Body Weights and Weight Loss:

Strain: The strains are unique ($P< 0.05$) in their growth and development as indicated by the 17 wk body weights of the hens (Table 15). The range in 17 wk body weights was 1.18 kg for the ISA White to 1.35 for the W-98 with all other strains being intermediate in weight. Subsequently, the 66 wk body weights 1.68 kg for the Dekalb White versus the 1.97 kg weight for the W-98.

Molt Treatment: Even though the strain body weights were different after the random allocation to the molt treatments the average hen weights and weight losses for treatments were no different. As expected the weight losses between the different treatments during the molt cycle were significant ($P<0.05$) with the Non-Molted (NM) having the least weight loss at 3.2%, and the Non-Fasted (NF) and 13 d Fast; Feed Restricted (FR) having the greatest weight loss at 21.0% and 32.1%, respectively. The NF and FR molting programs resulted in lighter weight hens at 491 d of age than the NM control.

Production Characteristics:

Strain: There was a significant ($P< 0.05$) Strain by Molt Treatment interaction shown in Table 16. The interaction appears to be associated with the B-300 strain which had the highest feed consumption in the NM group and one of the lowest feed consumptions in the FR group.

Molt Treatment: As expected the NM hens had the highest feed consumption averaging 10.7 kg/100 hens/d while the NF and FR hens had an average consumption of 7.5 and 4.6 kg/100 hens/d. The reduced feed consumption in the two molt treatments resulted in fewer ($P< 0.05$) HH Eggs which indicates that the molted hens achieved 0% production regardless of the molting method. The HD% was therefore reduced in the two molted groups. Mortality was not affected by the molt treatment.

Egg Size Distribution:

There were insufficient eggs from all treatments to conduct an assessment and comparison of egg size distribution.

Egg Quality and Income:

There were insufficient eggs from all treatments to conduct an assessment and comparison of egg quality.

Strain: The egg income and feed costs were consistent across all strain and molt treatment combinations.

Molt Treatment: During the molt cycle the NM hens had the greatest ($P< 0.05$) egg income with an overall average of $1.17 and highest ($P< 0.05$) feed cost with an average of $0.60 (Table 16). The NF and FR hens had

average egg incomes of $0.25 and $0.19 while average feed costs were $0.28 and $0.15, respectively. The NF molting program resulted in a negative income of $0.03/hen.

Albumen, Yolk, and Whole Egg Solids:

Strain: Albumen and yolk solids were similar to the solids percentages seen near the end of the 1st cycle. Albumen solids were highest ($P<0.05$) in the W-36, CV-20, and B-300 (Table 17). This is a small portion of the eggs produced since the hens were ceasing production and going through a significant physiological change. The LSL-Lite had the lowest albumen solids at 11% of any of the strains. The same trends among the strains were present in the yolk solids.

The interaction of strain and molt treatment indicates that the strains responded differently to the molt treatments. Figure 13, shows that the W-98, B-300, and ISA White responded negatively to the FR molt program. Indicating that the eggs produced during the molt period had reduced yolk solids using the FR program in these strains. The remaining strains responded in a similar manner.

Molt Treatment: Albumen and whole egg solids were not affected by the molt treatment during the molt cycle. The hens molted using the FR method had the lowest ($P<0.05$) yolk solids than the NM hens or NF alternative molt program (Table 18).

Brown Egg Strains: Molt Cycle (462-491 days of age)

Body Weights and Weight Loss:

Strain: The strains are unique ($P< 0.05$) in their growth and development as indicated by the 17 wk body weights of the hens (Table 19). The Bovans Brown had 17 wk body weight of 1.56 kg while the Hy-Line Brown's weight was 1.46 kg the Bovans Goldline was intermediate in weight at 1.50 kg. Subsequently, by 66 wk body weights the brown strains were similar in weight. The treatment body weights were similar after the random allocation of the strains to the molt treatments.

Molt Treatment: As expected the weight losses between the different treatments during the molt cycle were significant ($P<0.05$) with the Non-Molted (NM) having the least weight loss at 3.8%, and the Non-Fasted (NF) and 13 d Fast; Feed Restricted (FR) having the greatest weight losses at 17.4% and 27.9%, respectively. The NF and FR molting programs resulted in lighter ($P< 0.05$) weight hens at 491 d of age than the NM control by 0.29 kg.

Production Characteristics:

Strain: During the molt cycle all of the Brown Egg Strains responded in a similar manner with no significant differences between them.

Molt Treatment: The effect of the molting program had similar effects as seen in the white egg layers with the NM hens having the highest feed consumption, egg production, egg income and feed costs (Table 20). There was a significant ($P< 0.05$) strain effect on feed consumption with the Bovans Brown and Goldline being higher than the Hy-Line Brown. The NM group had the highest ($P<0.05$) feed consumption followed by the NF group and the FR group having the lowest at 11.1, 8.8, and 5.1 kg/100 ♀/d, respectively. In brown egg layers the mortality was higher in the NF and FR molted hens than the NM controls.

Egg Size Distribution:

There were insufficient eggs from all treatments to conduct an assessment and comparison of egg size distribution.

Egg Quality and Income:

There were insufficient eggs from all treatments to conduct an assessment and comparison of egg quality.

Strain: The egg income was highest in the Hy-Line Brown and Bovans Goldline while the Goldline had the highest feed cost (Table 20).

Molt Treatment: The gross income was highest in the NM control hens in the molt period at $0.54/hen while the NF and FR molt groups had gross incomes of $0.01 and $0.00, respectively.

Albumen, Yolk, and Whole Egg Solids:

Strain: During the molt period none of the solids were affected by the strain of the hen (Table 21).

Molt Treatment: The molting method had no significant impact on albumen or yolk solids (Table 22). Only the whole egg solids were higher ($P<0.05$) during the molting period for the FR molted brown egg hens.

White Egg Strains: Second Production Cycle (491-798 days of age)

Production Characteristics:

Strain: The strain of the hen did not impact the feed consumption or conversion during the 2nd Cycle (Table 23). The interaction of the strain with the molt treatment showed that the feed consumption for the different strains was influenced by the molt treatments. As shown in Table 23, the NM hens typically had lower feed consumption except for the Dekalb White and B-300 strains. The LSL-Lite had significantly higher ($P<0.05$) feed consumption in the hens molted by the NF method. Among the other strains the NF and FR molt treatment feed consumptions were not significantly different. The feed conversions were significantly improved ($P<0.05$) in the FR group in the W-36, W-98, LSL-Lite and ISA White strains. HH eggs were affected by strain of the hen. The CV-20 had the highest egg numbers at 185.8 eggs and the Dekalb White had the lowest at 144.5 eggs. This did not translate in the same manner to HD% when the mortality was factored into the calculation with the B-300 hens having the highest HD production in the two molted groups. The daily egg mass relationships are similar to those seen in the feed conversion.

Molt treatment: The HH eggs were significantly increased in the molted hens over the non-molted hens. The difference between the NM vs. NF and NM vs. FR were 28 and 35.3 eggs, respectively. The other surprising difference is the 8.3 % reduction in mortality in the NF and FR molted hens. This indicates a definite positive response to molting by the hens. This corresponds to the reviews done on fasting and caloric restriction that showed in these instances a reduction in diseases and cancers in the restricted groups.

Egg Size Distribution:

Strain: The strain has the greatest influence on egg weight with the W-98 having the heaviest ($P<0.05$) egg weight at 69.1g and the W-36 and B-300 with the lightest weight eggs at 65.1g (Table 24). The remaining strains are intermediate. The differences in egg weights were illustrated in changes within the distribution of eggs from the smaller egg sizes of mediums and large to the extra large classification. The W-98 produces 89.1% extra large eggs while the W-36 and B-300 produces 69.4 and 65.1%, respectively. These strains then have a correspondingly decrease or increase in the medium and large egg weights. In the egg products sector this shift to the larger egg sizes may increase the through put of the breaking machines however, the shell strength may be compromised in the later stages of the production cycle.

Molt Treatment: The molt treatment only had an impact on the percentage of medium eggs (Table 24). The NM control hens had the highest percentage of medium eggs. The two molt treatments were no different. This is indicative of the effect of molting on egg size.

Egg Quality and Income:

Strain: The strain of the layer did not impact the percentage of Grade A eggs or the percentage of loss eggs (Table 25). The interaction of strain and molt treatment influenced the percentage of Grade A eggs produced. The interaction centers around the Bovans White strain where the NM control hens produced a greater percentage of Grade A than the hens in the NF or FR molt groups. All of the remaining strains showed improved percentages of Grade A after the molt regardless of the molt program. The various strains did respond differently to the NF and FR molt programs. In 8 of the 9 strains there were no differences between the quality and the molting method, but the B-300 produced 3.7% more Grade A eggs when the NF molt program was used. The Dekalb White, W-98, and LSL-Lite had the most % Grade B eggs at 7.2, 6.7, and 6.5 %, respectively.

The egg income was influenced by the strain of the laying hen (Table 25). The CV-20, W-36 and Bovans White Exp had the highest ($P<0.05$) egg incomes of $10.90, $10.74, and $10.28 with the Dekalb White having the lowest at $8.04. Feed costs were closely associated with the egg income.

Molt Treatment: The post-molt egg quality for the NF and Fr treatment groups was similar within all the strains except the B-300. The NF hens in this strain had 3.7% more Grade A eggs than the same strain molted using the FR method. Molting by either method resulted in fewer Grade B and Cracked eggs than in the NM control group (Table 25).

The egg income was greater ($P<0.05$) for the hens which had been molted with the FR molted hens having the highest overall income at $10.63. Feed costs were lowest ($P<0.05$) for the NM hens at $5.19, with both the NF and FR hens having similar feed costs at $6.02 and $5.96, respectively. The gross income was improved for the hens that were molted by either method except for the case of the Bovans White where the NM and NF groups had similar incomes. The gross income for the FR molted hens in all cases had the greatest gross income for all the strains except the Bovans White Exp wherein both the NF and FR groups in this strain had the same gross income of $4.46/hen.

Albumen, Yolk, and Whole Egg Solids:

Strain: The strain of the laying hen continued to influence ($P<0.05$) the albumen, yolk, and whole egg solids in the eggs they produce in the 2nd cycle (Table 26). Albumen solids were highest in the eggs from the W-98 at 12.28% while the Dekalb White eggs had the lowest albumen solids of 11.47%. Yolk solids did not necessarily increase or decrease in response to corresponding changes in albumen solids. The B-300 has the highest Yolk solids at 48.45% and also had one of the higher albumen solids and the LSL-Lite had the lowest yolk solids at 47.77%. Whole egg solids were highest in the eggs from W-36 at 25.23% and the lowest were from the LSL-Lite at 24.10%.

The interaction of strain and hen age as shown in Figure 14, illustrates how the various strains differ as they progress through the 2nd production cycle. Beginning at 491 d of age the Bovans White, B-300, and ISA White eggs had the highest ($P<0.0001$) percent albumen by 771 d of age the W-98 was clearly had the highest % albumen solids. Yolk solids changed differently during the course of a 21 day storage period for the different strains (Figure 15). In all cases the yolk solids decreased as the eggs aged, with the yolk solids in the LSL-Lite decreasing the greatest amount of 4.52%. The B-300 ad the highest ($P< 0.0001$) whole egg solids immediately post-molt as shown in Figure 16 while the W-36 maintained a higher level of whole egg solids through 50% of the sampling periods in the 2nd cycle. Figure 17, shows that the whole egg solids from the different strains eggs typically increased during storage. Two strains the Bovans White and the LSL-Lite did not increase in the same manner as the rest of the strains. The molt

treatment by strain interaction shown in Figure 21, shows that the whole egg solids produced by the strains in the different treatment groups were similar in their relation to one another. The interaction is associated with the response of the strains to the NF and FR molt programs, such as the W-98, which had higher whole egg solids using the FR program while the LSL-Lite and ISA White had higher whole egg solids when the NF program was used.

Hen Age: The age of laying hens resulted in the percentage of albumen, and yolk solids significantly ($P<0.05$) changing during the production cycle (Table 27). Albumen solids decrease by 1.09% from 491 through 798 d of age at 12.33 and 11.24%, respectively. Yolk solids were relatively stable from 491 through 630 d then decreased ($P< 0.05$) in the next sampling age to 47.73%. At 715 d of age yolk solids increased sharply to 48.86% solids then decreased in the last sampling period. Whole egg solids were stable throughout the 2nd cycle.

Molt Treatment: The main effect of the molt treatment resulted in an increase ($P<0.05$) in the albumen solids by approximately 0.5% over the NM group (Table 28). Yolk and whole egg solids were not influenced by the molt treatment. There were significant interactions between the hen's age and the molt treatment. The NF and FR molt programs resulted in eggs with increased ($P< 0.0001$) percent albumen solids from 491 through 715 d of age (Figure 18). From 715 through 798 there were no differences between the albumen solids in eggs from the three treatment groups. Figure 19, shows that the act of molting layers has a significant impact on yolk solids, late in the 2nd cycle starting at 715 d of age. Molting improved yolk solids however, the NF program resulted in the greatest percentage of yolk solids at 715 d while the FR program had the greatest % yolk solids at 771 d. Whole egg solids were similar in each of the treatment groups during the early and mid 2nd cycle (Figure 20). The whole egg solids were improved ($P< 0.001$) in the eggs produced by the NF and FR hens by 0.64 and 0.44%, respectively over the NM group.

Storage: The duration of the storage had significant ($P< 0.05$) influence on all of the solids measured (Table 29). Albumen and whole egg solids increased after a 21 d storage period by 0.38 and 0.45%, respectively. Conversely, the yolk solids decreased by 3.54% in the same time period. Storage temperature of 4° C resulted in the preservation of the albumen and whole egg solids after a 21 d storage. The yolk solids in the 4° C storage group decreased ($P< 0.05$) by 3.36% more during the 21 d storage period than the no storage group. When the storage temperature was increased to 20° C during the storage period the albumen and whole egg solids increased by 0.82 and 0.93%, respectively from the no storage group while the yolk solids decreased by 3.72%. Albumen solids decreased throughout the 2nd cycle with the eggs stored for 21 d having the highest ($P<0.0001$) solids from 547 through 798 d of age (Figure 22). Yolk solids decrease ($P< 0.0001$) during storage as shown in Figure 23, then as the hens age the difference between the fresh egg yolk solids and after storage diminished. In Figure 24, whole egg solids were shown to be higher in stored eggs than in fresh eggs and at 715 d through 798 d of age whole egg solids were significantly higher in the stored eggs.

Table 30, displays the interaction of hen age by storage temperature interaction, which are further illustrated in Figures 25 to 27. Albumen solids decreased by the end of a 4° C, 21 day storage in the 2nd cycle; however this was not the case for the eggs stored at 20° C. As the hens age, the 4° C, 21 day storage effect was lost and the albumen solids increase in the eggs stored at 20° C (Figure 25). Yolk solids decreased during the course of egg storage regardless of the storage temperature (Figure 26). The whole egg solids were not affected by a 4° C, 21 day storage from 491 through 742 d of age and were increased in the eggs stored at 20° C (Figure 27).

Brown Egg Strains: Second Production Cycle (492- 798 days of age)

<u>Production Characteristics:</u>

Strain: In the 2nd cycle, the brown egg strains responded differently from one to another. The Bovans Brown and Goldline had the highest ($P< 0.05$) feed consumption as illustrated in Table 31. This resulted in poorer ($P<0.05$) feed conversion in the Bovans Brown of 0.35g egg/g feed as compared to the Hy-Line Brown and Bovans Goldline at 0.38 and 0.40 g egg/g feed, respectively. The HH eggs were highest in the Hy-Line Brown but the HD percentage

was only reduced in the Bovans Brown, which resulted in a reduced egg mass produced daily. Mortality was not affected by strain.

Molt Treatment: The NF and FR molting programs resulted in improved feed conversion, HH eggs, HD production, daily egg mass, and mortality (Table 31). In the brown strains the FR program resulted in the greatest improvement in the production traits over the NM control. The performance of the NF molted hens was intermediate.

Egg Size Distribution:

Strain: The egg weights were the heaviest ($P< 0.05$) for the Bovans Brown and Goldline at 67.7 and 67.8 g, respectively while the egg weight for the Hy-Line Brown was 66.5 (Table 32). This difference in egg weight translated in a significant shift in the egg size distribution from large to extra large for the Bovans Strains.

Molt Treatment: The molt programs had no effect on the egg size distribution. There was a strain by molt treatment interaction which was associated with the production of Medium eggs in the Bovans Goldline hens. The hens in the NF group had 1.3% more Medium eggs than the FR group.

Egg Quality and Income:

Strain: The strain of the hen had no effect on the USDA egg quality (Table 33). The egg income was highest for the Hy-Line Brown strain with an average egg income of $10.03 while the Bovans Brown and Goldline had egg incomes of $8.26 and $9.11, respectively. This resulted in a higher ($P< 0.05$) gross income for the Hy-Line Brown of $3.64/hen with the lowest gross income for the Bovans Brown of $2.15 and the Goldline being intermediate at $2.85.

Molt Treatment: Over all the molt program resulted in an improvement in egg quality (Table 33). The percent Grade A eggs for the NM, NF, and FR molt programs were 85.9, 88.3 and 90.5%, respectively. The shift in egg size is inversely related to the percent Grade B for the same molt treatments. There was no effect of molt treatment on cracks or loss eggs. The egg income and feed costs were increased ($P< 0.05$) due to molting. This resulted in the NF molted hens with a $0.74/hen gross income increase over the NM group and the FR molted hens having a $1.75/hen increase in gross income.

Albumen, Yolk, and Whole Egg Solids:

Strain: In the 2nd cycle the strain of the hen significantly ($P< 0.05$) affected all of the egg solids. The Hy-Line Brown had the highest albumen solids at 11.77% while the Bovans Gold line had the lowest at 11.51%, conversely the Goldline had the highest yolk solids at 48.48% and the Hy-Line Brown had the lowest at 48.11%. In both of these cases the Bovans Brown was intermediate. The interaction of strain and hen age in Figure 28, shows that the Bovans Goldline had the highest percent yolk solids from 491-574 and 715-742 d of age while in the other period they were similar or lower than the other strains. The Bovans Brown had the highest whole egg solids at 23.56 while the Hy-Line Brown and Bovans Goldline were at 23.24 and 23.23%, respectively.

Hen Age: The hen age was a factor dictating the albumen, yolk, and whole egg solids components (Table 35). In the 2nd cycle as the hens aged the solids components decreased. In all cases the solids decreased rapidly from 491 to 574 d of age plateaued in the middle of the production cycle then dropped again after 715 d of age. Figure 29, illustrates the hen and egg age interaction indicating that from 603 through 798 d of age storing the eggs increases the percent albumen in the eggs. During the middle of the 2nd cycle the percent yolk solids fluctuated in the eggs which had not been stored while the yolk solids in the stored eggs remained relatively constant (Figure 30). Whole

egg solids in the fresh eggs decreased throughout the production cycle while the whole egg solids in the stored eggs remained relatively constant throughout the 2nd cycle (Figure 31).

Molt Treatment: The molt programs resulted in significant shifts in the percent albumen and whole egg solids (Table 36). The NF and FR molt programs resulted in an increase in albumen solids over the NM control. The whole egg solids decreased in the NF and FR group's eggs.

Yolk solids were highest in the Bovans Gold line, NM group but were not different in the other strain molt treatment combinations (Figure 32). The whole egg solids from Hy-Line and Bovans Brown hens had eggs with similar solids content while those from the Bovans Goldline were highest in the NF program and lowest in the FR program (Figure 33). As the hens aged the yolk solids from the NF group's eggs were higher than the FR group's eggs from 603-742 d of age while the yolk solids from eggs in the FR group increased after 715 d of age (Figure 34).

Storage: Twenty one days of storage resulted in increases in albumen and whole egg solids percentages, and lower yolk solids percentages post-molt (Table 37). Storage also impacts yolk solids from some strains more than others with the Bovans Gold line having eggs with the highest yolk solids in fresh eggs shown in Figure 35, while eggs were similar in yolk solids for all strains after the eggs had been stored for 21 d. Storage temperature illustrates the dramatic differences in albumen, yolk, and whole egg solids between day 0 and 21 days of storage in the 20E C (68° F) represented accelerated aging. Albumen solids were not affected when stored at 4° C, but were significantly ($P< 0.05$) increased when stored at 20° C. Overall yolk solids percentages declined during storage and at different rates depending on the storage temperature. Yolk solids in eggs from the brown egg strains declined 2.51% when stored at 4° C (39.2 F) and 2.85% when stored at 20° C (68 F). Whole egg solids increased by 0.2% when the eggs were stored at 4° C for 21 d, and by 1.22% when stored at 20° C for 21 d. The whole egg solids response in the eggs from the brown egg strains resulted in a significant ($P< 0.05$) storage temperature by strain interaction shown in Figure 36. The whole egg solids from the eggs from the Bovans Goldline did not increase when stored at 4° C but increased sharply when stored at 20° C.

The albumen, yolk, and whole egg solids responded differently as the hen age and storage temperature increased. In all cases the 20° C storage temperature increased the percent albumen and whole egg solids while the yolk solids decreased (Table 38). When eggs were stored at 4° C the change in the component egg solids was more dependent upon the age of the hen, however, even this was not a consistent trend. These trends can be visualized in Figures 37 to 39. Albumen (Figure 37) and whole egg (Figure 39) solids in general increase as the eggs were stored. The major differences in these two solids components were associated with the hen's age. Albumen solids in fresh eggs decreased as the hen's age and storage periods equalized the solids except in the late stages of the 2nd cycle. The whole egg solids remained relatively constant throughout the 2nd cycle. Yolk solids responded opposite to the albumen and whole egg solids (Figure 38). Yolk solids decrease when the egg is stored for 21 days. As the hens age the yolk solids after storage are greater than after storage in the younger hens.

Correlation analysis: Correlation analyses were run to determine if there were significant and consistent relationships between the main effects and various factors measured in this study. Upon completion of this analysis it was found that although there were transient relationships between the different factors measured throughout this study, none of them were consistent or predictably recurring. This indicates that the main effects responded independently and in this instance were not predictive in nature. Time or hen age appear to be important as a means of determining what will happen to the eggs being produced.

Conclusions

The performance criteria of the hens in this study are consistent with previous reports examining the strain performance and other comparable research. The brown egg strains' performance was not appreciably

enhanced by the molting process. This study supported the general conclusion from previous studies that the proportion of yolk tended to be greater and the proportion of albumen smaller as egg size increased. It also supported the previous findings that strain significantly influenced egg size.

Previous research shows that albumen solids tend to decrease as the bird ages. This was generally the case in both the 1st and 2nd cycles in this study. Each of the solids measurements were significantly impacted by strain of the hen, however, the changes in solids were not consistent between the different solid measurements. The interaction of strain and hen age on the percent of albumen solids shows that the strains' albumen secretion is different as the hens' age. Not all strains had continually decreasing albumen solids. Therefore, strain selection for consistency in albumen solids may be one way of improving functionality consistency in albumen. Molting of the laying hen by either method increased the solids in albumen, yolk, and whole egg solids in the 2nd cycle over the non-molted group

As would be expected, the 21 day storage period resulted in a significant shift in the percent albumen and yolk solids. The albumen solids increased and the yolk solids decreased. As the eggs age and moisture is lost, it would be expect for the solids in the albumen to increase. Likewise, as the yolk ages it allows moisture from the albumen to seep into the yolk which would lead to less solids content. Storage did not impact the whole egg solids. Therefore, it appears there more of the moisture was shifting into the yolk rather than being lost through the shell. Part of this effect may also be explained by the changing proportion of albumen to yolk and how this would affect the whole egg solids. This loss was more evident in the 20°C storage temperature than in the 4°C storage temperature. During the 2nd cycle albumen solids were significantly more impacted by storage than during the 1st cycle. In brown shell eggs whole egg solids were also more significantly impacted due to storage during the 2nd cycle. This raises the question is there greater moisture loss through the shell post-molt than pre-molt relating to the shell porosity and thickness.

Overall strain and hen age greatly influence the solids in the various egg component parts. These factors could have even further reaching impacts on egg functionality and microbial integrity.

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TABLE 1. EFFECT OF WHITE EGG STRAIN ON PRODUCTION PARAMETERS OF HENS (119-462 DAYS)

Breeder (Strain)	Feed Cons	Feed Conversion	Eggs Per Bird Housed	Egg Production	Egg Mass	Mortality	Age at 50% Production
	(kg/100 ♀/d)	(g egg/g feed)	(HH Eggs)	(HD%)	(g/HD)	(%)	(Days)
Dekalb White	10.1	0.50	266.1^{C}	85.0	50.4	16.0^{A}	138^{A}
Hy-Line W-36	9.4	0.49	274.0^{B}	81.2	46.7	2.3^{G}	138^{A}
Hy-Line W-98	10.4	0.49	273.8^{B}	83.7	51.3	7.7^{DEF}	130^{E}
Hy-Line CV-20	9.4	0.51	273.4^{B}	82.4	48.0	4.7^{FG}	137^{A}
Bovans White Exp	10.1	0.49	284.4^{A}	85.9	50.0	5.9^{EFG}	135^{CD}
Bovans White	10.4	0.49	280.8^{A}	88.4	51.6	14.3^{AB}	135^{D}
Lohmann LSL-Lite	10.2	0.50	284.7^{A}	87.9	51.5	9.5^{CDE}	136^{BC}
ISA Babcock B-300	10.6	0.47	268.7^{BC}	84.2	50.2	12.3^{ABC}	138^{A}
ISA White	9.9	0.51	266.6^{C}	82.8	50.9	11.0^{BCD}	136^{B}

^{ABCDEFG} - Different letters denote significant differences ($P<0.05$), comparisons made among strain average values.

TABLE 2. EFFECT OF WHITE EGG STRAIN ON EGG WEIGHT AND EGG SIZE DISTRIBUTION OF HENS (119-462 DAYS)

Breeder (Strain)	Egg Weight	Pee Wee	Small	Medium	Large	Extra Large
	(g/egg)	(%)	(%)	(%)	(%)	(%)
Dekalb White	58.8^{B}	1.3^{BC}	6.5^{CD}	20.4^{B}	52.3	19.5^{BC}
Hy-Line W-36	57.1^{D}	2.1^{A}	10.9^{A}	22.6^{A}	49.7	14.6^{D}
Hy-Line W-98	61.2^{A}	0.2^{E}	4.8^{EF}	16.6^{C}	43.4	34.8^{A}
Hy-Line CV-20	57.9^{C}	1.8^{A}	8.7^{B}	21.6^{AB}	49.3	18.6^{BC}
Bovans White Exp	57.9^{C}	1.1^{BC}	7.3^{C}	22.8^{A}	52.6	16.0^{CD}
Bovans White	58.1^{C}	0.8^{CD}	7.2^{C}	23.0^{A}	52.5	16.2^{CD}
Lohmann LSL-Lite	58.1^{C}	1.3^{B}	6.5^{CD}	21.5^{AB}	53.8	16.7^{CD}
ISA Babcock B-300	59.2^{B}	1.1^{BC}	5.9^{DE}	19.5^{B}	52.3	21.0^{B}
ISA White	61.0^{A}	0.5^{DE}	4.2^{F}	15.4^{C}	47.7	32.0^{A}

^{ABCDEF} - Different letters denote significant differences ($P<0.05$), comparisons made among strain average values.

TABLE 3. EFFECT OF WHITE EGG STRAIN ON EGG QUALITY, INCOME AND FEED COSTS OF HENS (119-462 DAYS)

Breeder (Strain)	Grade A	Grade B	Cracks	Loss	Egg Income	Feed Costs	Gross Income
	(%)	(%)	(%)	(%)	($/hen)	($/hen)	($/hen)
Dekalb White	97.2	1.4^{ABC}	1.1	0.3^{A}	14.98^{D}	7.33^{C}	7.65^{CD}
Hy-Line W-36	97.7	0.9^{CD}	1.3	0.1^{B}	15.00^{D}	7.40^{BC}	7.60^{DE}
Hy-Line W-98	97.2	1.3^{BC}	1.3	0.1^{B}	15.83^{AB}	7.90^{A}	7.93^{BC}
Hy-Line CV-20	98.0	0.7^{D}	1.1	0.1^{B}	15.23^{CD}	7.31^{C}	7.92^{BCD}
Bovans White Exp	97.4	1.2^{C}	1.3	0.1^{B}	15.90^{A}	7.77^{A}	8.13^{AB}
Bovans White	97.1	1.8^{A}	1.1	0.1^{B}	15.67^{AB}	7.66^{AB}	8.02^{B}
Lohmann LSL-Lite	97.8	1.1^{CD}	1.0	0.1^{B}	16.03^{A}	7.65^{AB}	8.38^{A}
ISA Babcock B-300	96.9	1.7^{AB}	1.1	0.3^{A}	15.15^{CD}	7.85^{A}	7.30^{E}
ISA White	97.6	1.2^{CD}	1.0	0.2^{AB}	15.45^{BC}	7.41^{BC}	8.04^{B}

^{ABCD} - Different letters denote significant differences (P<0.05), comparisons made among strain average values.

TABLE 4. EFFECT OF WHITE EGG STRAIN ON PERCENTAGE OF ALBUMEN,YOLK, AND WHOLE EGG SOLIDS FROM HENS (119-462 DAYS)

Breeder (Strain)	Albumen	Yolk	Whole Egg
	----------%----------		
Dekalb White	12.37^{C}	48.27^{BCD}	23.79^{D}
Hy-Line W-36	12.86^{A}	48.43^{BC}	24.58^{AB}
Hy-Line W-98	12.74^{AB}	48.50^{AB}	23.95^{CD}
Hy-Line CV-20	12.92^{A}	48.03^{CD}	24.28^{BC}
Bovans White Exp	12.76^{AB}	48.69^{A}	24.31^{B}
Bovans White	12.40^{C}	48.70^{A}	24.19^{BC}
Lohmann LSL-Lite	12.05^{D}	48.00^{D}	23.81^{D}
Babcock B-300	12.78^{A}	48.87^{A}	24.68^{A}
ISA White	12.59^{B}	48.57^{AB}	23.83^{D}
Pooled Se	±0.06	±0.15	±0.12

^{ABCD} Numbers in columns with different superscript are significantly different ($P<0.05$)

TABLE 5. EFFECT OF HEN AGE ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM WHITE EGG STRAIN HENS (119-462 DAYS)

Hen Age (Days)	Albumen	Yolk	Whole Egg
	----------%----------		
119-154	13.12^{A}	47.03^{D}	22.10^{D}
182-210	12.97^{B}	50.14^{A}	23.99^{C}
238-266	12.79^{C}	47.99^{C}	24.29^{B}
294-322	12.58^{D}	48.36^{B}	24.93^{A}
350-378	12.17^{E}	48.65^{B}	24.76^{A}
406-434	12.02^{F}	48.53^{B}	24.90^{A}
Pooled Se	±0.05	±0.12	±0.09

^{ABCDEF} Numbers in columns with different superscript are significantly different (P<0.05)

TABLE 6. EFFECT OF A 21 DAY STORAGE AND STORAGE TEMPERATURE OF 4 OR 20 C ON PERCENT SOLIDS IN EGGS FROM WHITE EGG STRAINS (119-462 DAYS).

Storage (Days)	Albumen	Yolk	Whole Egg
	----------%----------		
0	12.52^{B}	49.85^{A}	24.09
21	12.70^{A}	47.05^{B}	24.23
Pooled Se	±0.03	±0.07	±0.06
Storage Temp (C°)			
4 (No Storage)	12.52^{B}	49.85^{A}	24.09
4	12.49^{B}	47.94^{B}	24.21
20	12.91^{A}	46.17^{C}	24.25
Pooled Se	±0.04	±0.08	±0.07

^{ABC} Numbers in columns with different superscript are significantly different ($P<0.05$)

TABLE 7. INTERACTION OF HEN AGE, TEMPERATURE, AND 21 DAY STORAGE PERIOD ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM WHITE EGG STRAIN HENS (119-462 DAYS)

Hen Age (Days)	Temp	Storage	Albumen	Yolk	Whole Egg
	(C°)	(days)	----------%----------		
119-154	4	0	13.10	48.22^{D}	22.17^{I}
	4	21	13.03	47.04^{F}	22.06^{IJ}
	20	21	13.26	44.67^{I}	21.99^{J}
182-210	4	0	12.80	50.83^{A}	23.88^{H}
	4	21	13.02	48.91^{C}	24.36^{F}
	20	21	13.26	49.97^{B}	23.85^{H}
238-266	4	0	12.64	49.71^{B}	24.14^{G}
	4	21	12.69	47.76^{E}	24.27^{FG}
	20	21	13.19	44.81^{I}	24.60^{E}
294-322	4	0	12.70	49.94^{B}	25.04^{BC}
	4	21	12.26	48.29^{D}	24.73^{DE}
	20	21	12.67	45.27^{H}	24.90^{CD}
350-378	4	0	12.15	50.41^{A}	24.57^{E}
	4	21	11.97	47.57^{E}	25.04^{BC}
	20	21	12.42	46.19^{G}	24.85^{D}
406-434	4	0	11.74	49.97^{B}	24.74^{D}
	4	21	11.96	48.11^{D}	24.81^{D}
	20	21	12.63	46.08^{G}	25.30^{A}
Pooled Se			±0.09	±0.20	±0.09

^{ABCDEFGHI} Numbers in columns with different superscript are significantly different ($P<0.05$)

TABLE 8. EFFECT OF BROWN EGG STRAIN ON PERFORMANCE OF HENS (119-462 DAYS)

Breeder (Strain)	Feed Cons	Feed Conversion	Eggs Per Bird Housed	Egg Production	Egg Mass	Mortality	Age at 50% Production
	(kg/100♀/d)	(g egg/g feed)	(HH Eggs)	(HD%)	(g/HD)	(%)	(Days)
Hy-Line Brown	10.4[B]	0.49[A]	283.2[A]	85.9[A]	51.3[B]	6.6	132
Bovans Brown	11.2[A]	0.47[B]	276.6[B]	85.6[A]	52.4[A]	10.8	131
Bovans Goldline	10.9[A]	0.49[A]	285.3[A]	87.2[A]	53.2[A]	8.8	132

[AB] - Different letters denote significant differences (P<0.05), comparisons made among strain average values.

TABLE 9. EFFECT OF BROWN EGG STRAIN ON EGG WEIGHT AND EGG SIZE DISTRIBUTION OF HENS (119-462 DAYS)

Breeder (Strain)	Egg Weight	Pee Wee	Small	Medium	Large	Extra Large
	(g/egg)	(%)	(%)	(%)	(%)	(%)
Hy-Line Brown	59.5[B]	0.3	4.1	21.1[A]	51.3	23.1[B]
Bovans Brown	61.0[A]	0.2	2.9	16.5[B]	48.8	31.2[A]
Bovans Goldline	60.8[A]	0.2	3.6	17.3[B]	47.6	30.9[A]

[AB] - Different letters denote significant differences (P<0.05), comparisons made among strain average values.

TABLE 10. EFFECT OF BROWN EGG STRAIN ON EGG QUALITY, INCOME AND FEED COSTS OF HENS (119-462 DAYS)

Breeder (Strain)	Grade A	Grade B	Cracks	Loss	Egg Income	Feed Costs	Gross Income
	(%)	(%)	(%)	(%)	($/hen)	($/hen)	($/hen)
Hy-Line Brown	97.6	1.2	1.0	0.1	16.25	7.91[B]	8.34[A]
Bovans Brown	97.0	1.4	1.6	0.0	16.06	8.30[A]	7.76[B]
Bovans Goldline	96.9	1.9	1.1	0.0	16.46	8.23[A]	8.23[A]

[AB] - Different letters denote significant differences (P<0.05), comparisons made among strain average values.

TABLE 11. EFFECT OF BROWN EGG STRAIN ON PERCENTAGE OF ALBUMEN,YOLK, AND WHOLE EGG SOLIDS FROM HENS (119-462 DAYS)

Breeder (Strain)	Albumen	Yolk	Whole Egg
	----------%----------		
Hy-Line Brown	12.63	48.04	23.14^{B}
Bovans Brown	12.69	48.39	23.55^{A}
Bovans Goldline	12.60	48.56	23.37^{AB}
Pooled Se	±0.06	±0.21	±0.10

^{AB} Numbers in columns with different superscript are significantly different (P<0.05)

TABLE 12. EFFECT OF HEN AGE ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM BROWN EGG STRAIN HENS (119-462 DAYS)

Hen Age (Days)	Albumen	Yolk	Whole Egg
	----------%----------		
119-154	13.32^{A}	47.27^{C}	22.00^{D}
182-210	13.20^{A}	50.34^{A}	23.37^{B}
238-266	12.88^{B}	48.16^{B}	23.58^{B}
294-322	12.34^{C}	46.75^{C}	22.74^{C}
350-378	12.10^{D}	48.83^{B}	24.25^{A}
406-434	12.00^{D}	48.61^{B}	24.17^{A}
Pooled Se	±0.08	±0.30	±0.14

^{ABCDEF} Numbers in columns with different superscript are significantly different (P<0.05)

TABLE 13. EFFECT OF A 21 DAY STORAGE AND STORAGE TEMPERATURE OF 4 OR 20 C ON PERCENT SOLIDS IN EGGS FROM BROWN EGG STRAINS (119-462 DAYS).

Storage (Days)	Albumen	Yolk	Whole Egg
	----------%----------		
0	12.47^{B}	49.40^{A}	23.01^{B}
21	12.80^{A}	47.26^{B}	23.69^{A}
Pooled Se	±0.04	±0.17	±0.08
Storage Temp (C°)			
4 (No Storage)	12.47^{C}	49.40^{A}	23.01
4	12.63^{B}	47.96^{B}	23.70
20	12.98^{A}	46.55^{C}	23.68
Pooled Se	±0.05	±0.20	±0.10

^{ABC} Numbers in columns with different superscript are significantly different (P<0.05)

TABLE 14. INTERACTION OF HEN AGE, TEMPERATURE, AND 21 DAY STORAGE PERIOD ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM BROWN EGG STRAIN HENS (119-462 DAYS)

Hen Age (Days)	Temp	Storage	Albumen	Yolk	Whole Egg
	(C°)	(days)	----------%----------		
119-154	4	0	13.24	48.61^{C}	21.87
	4	21	13.42	47.77^{D}	22.15
	20	21	13.38	44.11^{F}	22.10
182-210	4	0	13.17	50.87^{A}	23.41
	4	21	12.93	49.84^{B}	23.16
	20	21	13.55	49.80^{B}	23.52
238-266	4	0	12.37	49.84^{B}	23.27
	4	21	13.09	47.37^{D}	23.84
	20	21	13.68	45.59^{E}	23.95
294-322	4	0	12.22	46.30^{DE}	21.23
	4	21	12.20	47.71^{D}	24.24
	20	21	12.71	46.70^{DE}	24.26
350-378	4	0	11.92	50.61^{AB}	24.13
	4	21	12.15	47.05^{DE}	24.67
	20	21	12.41	47.05^{DE}	24.06
406-434	4	0	11.94	50.15^{AB}	24.17
	4	21	12.00	48.04^{C}	24.16
	20	21	12.12	46.09^{E}	24.18
Pooled Se			±0.13	±0.49	±0.23

^{ABCDEF} Numbers in columns with different superscript are significantly different ($P<0.05$)

TABLE 15. FFECT OF WHITE EGG STRAIN AND SYNCHRONIZED MOLT TREATMENT ON HENS (462-491 DAYS)

Breeder (Strain)	Molt Program	17 Wk Body Wt	66 Wk Body Wt	1st Cycle Wt Gain	Lowest Body Weight	Molt Weight Loss	70 Wk Body Wt
		(kg)	(kg)	(%)	(kg)	(%)	(kg)
Dekalb	NM	1.23	1.72	41.9	1.64	4.4	1.65
White	NF	1.18	1.66	41.0	1.36	17.8	1.37
	FR	1.16	1.65	44.7	1.09	33.8	1.27
	Average	1.19^{EF}	1.68^{D}	42.5^{ABC}	1.37^{C}	18.7	1.43^{C}
Hy-Line	NM	1.26	1.72	39.0	1.69	1.5	1.70
W-36	NF	1.26	1.75	39.8	1.35	22.6	1.35
	FR	1.30	1.75	35.8	1.21	30.9	1.37
	Average	$1.27^{B\,C}$	1.74^{BC}	38.2^{BCD}	1.42^{BC}	18.3	1.47^{BC}
Hy-Line	NM	1.34	1.92	45.8	1.76	7.9	1.75
W-98	NF	1.36	1.98	48.6	1.55	21.5	1.55
	FR	1.35	2.01	48.1	1.40	30.5	1.51
	Average	1.35^{A}	1.97^{A}	47.5^{A}	1.57^{A}	20.0	1.61^{A}
Hy-Line	NM	1.23	1.65	36.8	1.60	2.6	1.60
CV-20	NF	1.27	1.71	35.4	1.30	23.8	1.30
	FR	1.25	1.73	37.9	1.18	32.1	1.34
	Average	1.25^{BCD}	1.70^{CD}	36.7^{CD}	1.36^{C}	19.5	1.41^{C}
Bovans	NM	1.28	1.74	36.2	1.76	-1.0	1.70
White Exp	NF	1.26	1.68	33.3	1.35	19.5	1.35
	FR	1.28	1.74	36.4	1.18	32.0	1.34
	Average	1.28^{B}	1.72^{BCD}	35.3^{D}	1.43^{B}	16.8	1.46^{BC}
Bovans	NM	1.23	1.73	41.3	1.66	4.0	1.66
White	NF	1.26	1.74	37.2	1.34	22.8	1.33
	FR	1.23	1.74	41.2	1.15	33.8	1.28
	Average	1.24^{CD}	1.74^{BC}	39.9^{BCD}	1.38^{BC}	20.2	1.42^{C}
Lohmann	NM	1.19	1.68	42.4	1.65	1.9	1.67
LSL-Lite	NF	1.23	1.71	43.0	1.37	20.0	1.31
	FR	1.24	1.69	35.0	1.15	32.2	1.25
	Average	1.22^{DE}	1.70^{CD}	40.1^{BCD}	1.39^{BC}	18.0	1.41^{C}
ISA Babcock	NM	1.28	1.78	37.2	1.71	3.7	1.71
B-300	NF	1.23	1.79	40.4	1.41	21.0	1.40
	FR	1.27	1.73	39.8	1.21	30.2	1.38
	Average	1.26^{BCD}	1.76^{B}	39.1^{BCD}	1.44^{B}	18.3	1.50^{B}
ISA	NM	1.20	1.67	39.4	1.61	3.6	1.61
White	NF	1.19	1.77	46.9	1.41	19.9	1.38
	FR	1.14	1.66	46.4	1.10	33.5	1.25
	Average	1.18^{F}	1.70^{CD}	44.2^{AB}	1.38^{BC}	19.0	1.41^{C}
All Strains	NM	1.25	1.73	40.0	1.67^{X}	3.2^{Z}	1.68^{Y}
	NF	1.25	1.75	40.6	1.38^{Y}	21.0^{Y}	1.37^{Z}
	FR	1.25	1.74	40.6	1.18^{Z}	32.1^{X}	1.33^{Z}

^{ABCD} Different letters denote significant differences ($P < 0.05$), comparisons made among strain average values.
^{XYZ} - Different letters denote significant differences ($P < 0.05$), comparisons made among molt program average values.
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 16. EFFECT OF WHITE EGG STRAIN AND SYNCHRONIZED MOLT PROGRAM ON PERFORMANCE OF HENS DURING THE MOLT PERIOD (462-491 DAYS)*

Breeder (Strain)	Molt Program	Feed Cons	Eggs Per Bird Housed	Egg Prod.	Mortality	Egg Income	Feed Costs	Gross Income
		(kg/100 ♀/d)	(HH eggs)	(HD%)	(%)	($/hen)	($/hen)	($/hen)
Dekalb	NM	10.9^{b}	17.6^{e}	80.9^{b}	2.4	1.01^{d}	0.52^{d}	0.49
White	NF	7.2^{ef}	3.8^{fgh}	16.9^{efg}	6.0	0.23^{efg}	0.24^{g}	-0.01
	FR	4.5^{ikl}	3.0^{gh}	13.9^{fghi}	6.5	0.18^{fg}	0.12^{i}	0.06
	Average	7.5	8.1	37.2	5.0^{A}	0.47	0.29	0.18^{B}
Hy-Line	NM	10.0^{b}	19.4^{bcd}	72.4^{d}	0.9	1.18^{bc}	0.60^{bc}	0.58
W-36	NF	6.9^{fg}	4.5^{f}	16.6^{efgh}	0.9	0.28^{e}	0.30^{ef}	-0.02
	FR	4.3^{ikl}	3.5^{fgh}	12.5^{i}	0.8	0.21^{efg}	0.17^{hi}	0.04
	Average	7.1	9.1	33.8	0.9^{DEF}	0.56	0.36	0.20^{AB}
Hy-Line	NM	10.9^{b}	19.2^{bcd}	75.7^{cd}	1.4	1.16^{bc}	0.64^{ab}	0.52
W-98	NF	8.2^{cd}	4.6^{f}	17.9^{e}	1.6	0.28^{e}	0.33^{e}	-0.05
	FR	4.2^{kl}	3.2^{gh}	13.1^{hi}	2.4	0.20^{fg}	0.13^{i}	0.07
	Average	7.7	9.0	35.5	1.8^{DEF}	0.55	0.37	0.18^{B}
Hy-Line	NM	10.3^{b}	20.2^{bc}	76.7^{c}	1.1	1.22^{ab}	0.61^{bc}	0.61
CV-20	NF	6.2^{gh}	4.6^{f}	16.9^{efg}	0.8	0.28^{e}	0.25^{fg}	0.03
	FR	3.8^{l}	3.1^{gh}	11.8^{i}	0.4	0.19^{fg}	0.14^{i}	0.05
	Average	6.8	9.3	35.1	0.8^{EF}	0.56	0.33	0.23^{A}
Bovans	NM	10.7^{b}	20.4^{b}	78.2^{bc}	0.5	1.23^{ab}	0.63^{abc}	0.60
White Exp	NF	8.0^{cde}	4.6^{f}	17.6^{e}	0.5	0.28^{e}	0.33^{e}	-0.05
	FR	4.1^{kl}	3.2^{gh}	12.4^{i}	1.4	0.20^{fg}	0.15^{i}	0.05
	Average	7.6	9.4	36.1	0.8^{F}	0.57	0.37	0.20^{A}
Bovans	NM	10.8^{b}	19.9^{bc}	85.3^{a}	3.0	1.17^{bc}	0.57^{cd}	0.60
White	NF	7.6^{def}	3.9^{fgh}	18.1^{e}	5.0	0.24^{efg}	0.23^{gh}	0.01
	FR	5.5^{hi}	3.1^{gh}	13.2^{hi}	4.2	0.19^{fg}	0.17^{hi}	0.02
	Average	7.9	9.0	38.9	4.1^{AB}	0.53	0.33	0.20^{A}
Lohmann	NM	10.9^{b}	21.7^{a}	85.4^{a}	2.4	1.31^{a}	0.62^{bc}	0.69
LSL-Lite	NF	7.7^{def}	4.1^{fg}	17.1^{ef}	2.8	0.25^{ef}	0.27^{fg}	-0.02
	FR	4.4^{ikl}	3.0^{gh}	12.4^{i}	1.0	0.18^{fg}	0.14^{i}	0.04
	Average	7.6	9.6	38.3	2.1^{CDE}	0.58	0.34	0.24^{A}
ISA Babcock	NM	12.0^{a}	19.0^{cd}	77.2^{bc}	2.6	1.11^{c}	0.69^{a}	0.42
B-300	NF	8.6^{c}	3.1^{gh}	13.8^{fghi}	3.3	0.19^{fg}	0.29^{efg}	-0.10
	FR	5.2^{ij}	2.9^{h}	12.2^{i}	4.0	0.17^{g}	0.17^{hi}	0.00
	Average	8.6	8.3	34.4	3.3^{BC}	0.49	0.39	0.10^{C}
ISA	NM	10.1^{b}	18.2^{de}	76.6^{c}	2.1	1.11^{c}	0.51^{d}	0.60
White	NF	7.2^{ef}	3.3^{gh}	13.6^{ghi}	1.9	0.20^{fg}	0.26^{fg}	-0.06
	FR	5.0^{ijk}	3.0^{gh}	11.9^{i}	2.5	0.18^{fg}	0.16^{i}	0.02
	Average	7.4	8.1	34.1	2.2^{CD}	0.50	0.31	0.19^{B}
Average	NM	10.7	19.5	78.7	1.8	1.17	0.60	0.57^{A}
	NF	7.5	4.1	16.5	2.5	0.25	0.28	-0.03^{C}
	FR	4.6	3.1	12.6	2.6	0.19	0.15	0.04^{B}

^{ABC} - Different letters denote significant differences (P< 0.05), comparisons made among strain average values.

^{abcdefgh} - Different letters denote significant strain*molt treatment interactions (P< 0.05).

NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

*There was insufficient egg size and quality data for the molt period. This information will be included in the second cycle tables.

TABLE 17. EFFECT OF WHITE EGG STRAIN ON PERCENTAGE OF ALBUMEN,YOLK, AND WHOLE EGG SOLIDS FROM HENS (462-491 DAYS)

Breeder (Strain)	Albumen	Yolk	Whole Egg
	----------%----------		
Dekalb White	11.32^{CD}	50.69^{AB}	23.86
Hy-Line W-36	11.99^{A}	50.72^{A}	25.50
Hy-Line W-98	11.93^{AB}	50.97^{A}	24.79
Hy-Line CV-20	12.12^{A}	49.03^{CD}	25.13
Bovans White Exp	11.76^{B}	50.70^{AB}	25.27
Bovans White	11.57^{BC}	49.82^{BC}	25.37
Lohmann LSL-Lite	11.00^{D}	48.70^{D}	24.20
Babcock B-300	12.16^{A}	50.26^{AB}	24.99
ISA White	11.74^{BC}	49.19^{CD}	24.76
Pooled Se	±0.13	±0.31	±0.38

^{ABCD} Numbers in columns with different superscript are significantly different (P<0.05)

TABLE 18. EFFECT OF MOLT TREATMENT ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM WHITE EGG STRAIN HENS (491-798 DAYS)

Molt Treatment	Albumen	Yolk	Whole Egg
	----------%----------		
NM	11.63	50.22^{A}	24.87
NF	11.68	50.17^{A}	24.82
FR	11.87	49.62^{B}	24.93
Pooled Se	±0.08	±0.18	±0.22

^{AB} Numbers in columns with different superscript are significantly different (P<0.05)
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 19. EFFECT OF BROWN EGG STRAIN AND SYNCHRONIZED MOLT TREATMENT ON HENS (462-491 DAYS)

Breeder (Strain)	Molt Program	17 Wk Body Wt	66 Wk Body Wt	1st Cycle Wt Gain	Lowest Body Weight	Molt Weight Loss	70 Wk Body Wt
		(kg)	(kg)	(%)	(kg)	(%)	(kg)
Hy-Line	NM	1.41	2.07	47.8	1.99^{a}	3.8	1.99
Brown	NF	1.49	2.02	37.4	1.70^{bc}	15.9	1.71
	FR	1.47	2.16	45.3	1.56^{d}	27.9	1.75
	Average	1.46^{B}	2.08	43.5	1.75	15.9	1.82
Bovans	NM	1.53	2.08	36.0	1.97^{a}	5.3	1.97
Brown	NF	1.55	2.07	34.8	1.72^{b}	16.7	1.77
	FR	1.59	1.95	24.0	1.43^{e}	25.6	1.69
	Average	1.56^{A}	2.03	31.6	1.71	15.9	1.81
Bovans	NM	1.53	2.05	38.3	2.00^{a}	2.4	2.02
Goldline	NF	1.47	2.03	40.1	1.63^{cd}	19.5	1.63
	FR	1.51	2.08	40.3	1.45^{e}	30.3	1.66
	Average	1.50^{AB}	2.05	39.6	1.69	17.4	1.77
All Strains	NM	1.49	2.07	40.7	1.99	3.8^{Z}	1.99^{Y}
	NF	1.50	2.04	37.4	1.68	17.4^{Y}	1.70^{Z}
	FR	1.52	2.06	36.6	1.48	27.9^{X}	1.70^{Z}

^{abcde} - Different letters denote significant strain*molt treatment interactions ($P < 0.05$).
^{AB} - Different letters denote significant differences ($P < 0.05$), comparisons made among strain average values.
^{XYZ} - Different letters denote significant differences ($P < 0.05$), comparisons made among molt program average values.
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 20. EFFECT OF BROWN EGG STRAIN AND SYNCHRONIZED MOLT PROGRAM ON PERFORMANCE OF HENS IN THE 35th NCLP&MT DURING THE MOLT PERIOD (462-491 DAYS)*

Breeder (Strain)	Molt Program	Feed Cons	Eggs Per Bird Housed	Egg Produc-tion	Mortality	Egg Income	Feed Costs	Gross Income
		(kg/100 ♀/d)	(HH eggs)	(HD%)	(%)	($/hen)	($/hen)	($/hen)
Hy-Line	NM	10.5	20.8	79.0	0.7	1.22	0.62	0.60
Brown	NF	8.2	5.9	23.8	1.5	0.37	0.31	0.06
	FR	4.8	3.2	12.3	1.4	0.19	0.18	0.01
	Average	7.8^{B}	10.0	38.4	1.2	0.59^{A}	0.37^{B}	0.22^{A}
Bovans	NM	11.5	17.6	73.8	0.9	1.08	0.61	0.47
Brown	NF	8.9	5.6	22.9	4.3	0.34	0.36	-0.02
	FR	5.3	2.8	11.7	3.6	0.17	0.18	-0.01
	Average	8.5^{A}	8.6	36.1	2.9	0.53^{B}	0.38^{B}	0.15^{B}
Bovans	NM	11.4	20.4	78.5	1.1	1.23	0.69	0.54
Goldline	NF	9.2	5.9	23.9	3.8	0.36	0.37	-0.01
	FR	5.2	2.8	11.9	2.9	0.17	0.17	0.00
	Average	8.6^{A}	9.7	38.1	2.6	0.58^{A}	0.41^{A}	0.17^{B}
All Strains	NM	11.1^{X}	19.6^{X}	77.1^{X}	0.9^{Z}	1.18^{X}	0.64^{X}	0.54^{X}
	NF	8.8^{Y}	5.8^{Y}	23.5^{Y}	3.2^{Y}	0.36^{Y}	0.35^{Y}	0.01^{Y}
	FR	5.1^{Z}	3.0^{Z}	12.0^{Z}	2.6^{Y}	0.18^{Z}	0.18^{Z}	0.00^{Y}

^{AB} - Different letters denote significant differences (P< 0.05), comparisons made among strain average values.
^{XYZ} - Different letters denote significant differences (P< 0.05), comparisons made among molt program average values.
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.
*There was insufficient egg size and quality data for the molt period. This information will be included in the second cycle tables.

TABLE 21. EFFECT OF BROWN EGG STRAIN ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM HENS (462-491 DAYS)

Breeder (Strain)	Albumen	Yolk	Whole Egg
	----------%----------		
Hy-Line Brown	11.67	51.17	23.98
Bovans Brown	11.64	50.98	23.31
Bovans Goldline	11.29	51.13	24.44
Pooled Se	±0.20	±0.19	±0.16

TABLE 22. EFFECT OF MOLT TREATMENT ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM BROWN EGG STRAIN HENS (462-491 DAYS)

Molt Treatment	Albumen	Yolk	Whole Egg
	----------%----------		
NM	11.24	51.44	23.86^{B}
NF	11.70	50.93	23.84^{B}
FR	11.67	50.91	25.02^{A}
Pooled Se	±0.20	±0.19	±0.16

^{AB} Numbers in columns with different superscript are significantly different ($P< 0.05$)
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 23. EFFECT OF WHITE EGG STRAIN AND SYNCHRONIZED MOLT TREATMENT ON PRODUCTION PARAMETERS OF HENS (491-798 DAYS)

Breeder (Strain)	Molt Program	Feed Cons	Feed Conv.	Eggs Per Bird Housed	Egg Produc-tion	Egg Mass	Mortality
		(kg/100 ♀/d)	(g egg/g feed)	(HH eggs)	(HD%)	(g/HD)	(%)
Dekalb	NM	11.0^{abcde}	0.36^{ij}	124.9	60.0^{gh}	39.1^{f}	23.5
White	NF	10.3^{efgh}	0.46^{bcde}	157.3	71.3^{bcde}	47.2^{bc}	13.1
	FR	10.7^{abcde}	0.44^{bcdef}	144.5	71.8^{abcde}	47.4^{bc}	17.3
	Average	10.6	0.42	142.2^{F}	67.7	44.5	18.0^{AB}
Hy-Line	NM	9.7^{h}	0.41^{fgh}	158.6	60.0^{gh}	39.3^{f}	16.1
W-36	NF	10.4^{cdefg}	0.43^{def}	186.2	69.3^{cdef}	45.1^{cd}	12.1
	FR	9.8^{gh}	0.48^{ab}	206.7	72.8^{abcd}	47.0^{bc}	6.3
	Average	10.0	0.44	183.9^{AB}	67.4	43.8	11.5^{DE}
Hy-Line	NM	10.5^{cdefg}	0.36^{ij}	137.3	53.9^{i}	36.9^{f}	17.0
W-98	NF	11.3^{a}	0.42^{f}	181.8	67.3^{ef}	46.9^{bc}	6.5
	FR	11.1^{abc}	0.46^{bcde}	184.6	74.3^{ab}	50.7^{a}	8.5
	Average	10.9	0.41	167.9^{CD}	65.1	44.9	10.7^{DE}
Hy-Line	NM	9.8^{gh}	0.41^{fg}	164.7	61.3^{gh}	40.1^{ef}	13.3
CV-20	NF	9.8^{gh}	0.47^{abc}	197.1	70.9^{bcde}	46.4^{bcd}	5.9
	FR	10.0^{fgh}	0.47^{abc}	195.7	72.3^{abcd}	47.4^{bc}	6.4
	Average	9.9	0.45	185.8^{A}	68.2	44.6	8.5^{E}
Bovans	NM	10.4^{defgh}	0.37^{hi}	156.0	59.0^{hi}	38.4^{f}	21.1
White Exp	NF	10.8^{abcde}	0.44^{cdef}	186.8	71.5^{abcde}	47.4^{bc}	10.9
	FR	10.5^{cdefg}	0.44^{cdef}	181.0	69.2^{cdef}	45.8^{cd}	10.9
	Average	10.6	0.42	174.6^{ABC}	66.5	43.9	14.3^{BCD}
Bovans	NM	10.7^{abcde}	0.37^{hij}	140.4	61.1^{gh}	39.3^{f}	23.2
White	NF	11.0^{abcd}	0.44^{cdef}	144.3	71.6^{abcde}	47.8^{abc}	17.8
	FR	10.7^{abcde}	0.44^{bcdef}	163.5	71.3^{bcde}	47.4^{bc}	17.4
	Average	10.8	0.42	149.4^{EF}	68.0	44.8	19.5^{A}
Lohmann	NM	10.4^{defgh}	0.38^{ghi}	149.6	58.7^{hi}	38.3^{f}	17.6
LSL-Lite	NF	11.2^{ab}	0.43^{def}	176.6	72.6^{abcd}	47.8^{abc}	9.5
	FR	10.3^{efgh}	0.47^{abc}	187.9	74.0^{abc}	48.4^{abc}	8.8
	Average	10.6	0.43	171.3^{C}	68.4	44.9	12.0^{CDE}
ISA Babcock	NM	11.4^{a}	0.33^{j}	133.1	57.7^{hi}	37.5^{f}	23.6
B-300	NF	10.7^{abcde}	0.46^{abcd}	167.0	75.8^{ab}	49.3^{ab}	12.3
	FR	10.8^{abcde}	0.46^{bcde}	178.1	75.9^{ab}	49.2^{ab}	11.4
	Average	10.9	0.42	159.4^{DE}	69.8	45.3	15.8^{ABC}
ISA	NM	10.3^{efgh}	0.42^{ef}	153.1	64.8^{fg}	43.3^{de}	15.5
White	NF	10.6^{bcdef}	0.44^{cdef}	172.0	68.8^{def}	46.5^{bcd}	8.3
	FR	10.3^{efgh}	0.50^{a}	192.7	75.7^{ab}	51.0^{a}	8.9
	Average	10.4	0.45	172.6^{BC}	69.8	46.9	10.9^{DE}
All Strains	NM	10.4	0.38	146.4^{Z}	59.6	39.1	19.0^{Y}
	NF	10.7	0.44	174.4^{Y}	71.0	47.2	10.7^{Z}
	FR	10.5	0.46	181.7^{X}	73.0	48.3	10.7^{Z}

^{ABCDEF} - Different letters denote significant differences (P< 0.05), comparisons made among strain average values.
^{XYZ} - Different letters denote significant differences (P< 0.05), comparisons made among molt program average values.
^{abcdefghij} - Different letters denote significant strain*molt program interactions (P< 0.05).
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 24. EFFECT OF WHITE EGG STRAIN AND SYNCHRONIZED MOLT TREATMENT ON EGG WEIGHT AND EGG SIZE DISTRIBUTION OF HENS (491-798 DAYS)

Breeder (Strain)	Molt Program	Egg Weight	Pee Wee	Small	Medium	Large	Extra Large
		(g/egg)	(%)	(%)	(%)	(%)	(%)
Dekalb	NM	65.1	0.3[a]	0.1	3.1	32.7	63.5
White	NF	66.3	0.0[b]	0.0	1.4	28.5	69.4
	FR	66.0	0.0[b]	0.2	0.9	29.9	68.6
	Average	65.8[CD]	0.1	0.1	1.8[A]	30.4[AB]	67.2[CD]
Hy-Line	NM	65.7	0.0[b]	0.0	0.9	28.6	70.0
W-36	NF	65.2	0.0[b]	0.0	0.6	30.2	69.2
	FR	64.6	0.0[b]	0.0	0.7	30.3	69.0
	Average	65.1[D]	0.0	0.0	0.7[BC]	29.7[AB]	69.4[CD]
Hy-Line	NM	68.9	0.0[b]	0.0	0.3	11.0	88.8
W-98	NF	69.8	0.0[b]	0.0	0.0	8.5	91.0
	FR	68.5	0.0[b]	0.0	0.1	12.0	87.5
	Average	69.1[A]	0.0	0.0	0.1[C]	10.5[D]	89.1[A]
Hy-Line	NM	65.5	0.0[b]	0.0	0.7	31.0	67.8
CV-20	NF	65.4	0.0[b]	0.0	0.8	29.1	69.8
	FR	65.5	0.0[b]	0.0	0.7	28.4	70.8
	Average	65.5[CD]	0.0	0.0	0.7[BC]	29.5[AB]	69.5[CD]
Bovans	NM	65.4	0.0[b]	0.0	0.8	30.3	68.7
White Exp	NF	66.4	0.0[b]	0.0	0.3	25.0	74.2
	FR	66.2	0.0[b]	0.0	0.8	25.5	73.7
	Average	66.0[C]	0.0	0.0	0.7[BC]	26.9[B]	72.2[C]
Bovans	NM	64.7	0.0[b]	0.2	2.2	36.6	60.5
White	NF	66.8	0.0[b]	0.0	0.5	24.4	74.4
	FR	66.6	0.0[b]	0.0	1.0	26.3	72.5
	Average	66.0[C]	0.0	0.1	1.2[AB]	29.1[AB]	69.1[CD]
Lohmann	NM	65.7	0.0[b]	0.2	1.1	28.1	69.8
LSL-Lite	NF	65.8	0.0[b]	0.0	1.1	28.0	70.6
	FR	65.7	0.0[b]	0.0	0.7	32.8	66.2
	Average	65.7[CD]	0.0	0.1	1.0[ABC]	29.6[AB]	68.9[CD]
ISA Babcock	NM	65.0	0.0[b]	0.0	2.8	29.4	67.8
B-300	NF	65.2	0.0[b]	0.0	1.2	32.4	66.0
	FR	65.0	0.0[b]	0.0	1.2	36.7	61.5
	Average	65.1[D]	0.0	0.0	1.7[A]	32.8[A]	65.1[D]
ISA	NM	66.9	0.0[b]	0.0	0.6	23.7	74.5
White	NF	67.5	0.0[b]	0.0	0.2	20.0	79.4
	FR	67.4	0.0[b]	0.0	0.2	20.6	78.8
	Average	67.3[B]	0.0	0.0	0.3[C]	21.4[C]	77.6[B]
All Strains	NM	65.9	0.0	0.1	1.4[Y]	27.9	70.1
	NF	66.5	0.0	0.0	0.7[Z]	25.1	73.8
	FR	66.2	0.0	0.0	0.7[Z]	26.9	72.1

[ABCD] - Different letters denote significant differences (P< 0.05), comparisons made among strain average values.
[XYZ] - Different letters denote significant differences (P< 0.05), comparisons made among molt program average values.
[ab] - Different letters denote significant strain*molt program interactions (P< 0.05).
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 25. EFFECT OF WHITE EGG STRAIN AND SYNCHRONIZED MOLT TREATMENT ON EGG QUALITY, INCOME AND FEED COSTS OF HENS (491-798 DAYS)

Breeder (Strain)	Molt Program	Grade A	Grade B	Cracks	Loss	Egg Income	Feed Costs	Gross Income
		(%)	(%)	(%)	(%)	($/hen)	($/hen)	($/hen)
Dekalb	NM	82.4^{f}	9.3	6.4	2.0	6.84	4.60	2.24^{kl}
White	NF	88.7^{bcde}	5.8	4.1	1.4	9.03	5.24	3.79^{efghi}
	FR	87.7^{de}	6.6	4.4	1.3	8.26	4.98	3.28^{hij}
	Average	86.3	7.2^{A}	4.9	1.6	8.04^{E}	4.94^{F}	3.10
Hy-Line	NM	88.2^{cde}	6.1	4.1	1.8	9.08	5.28	3.80^{efghi}
W-36	NF	91.1^{abcd}	4.3	3.2	1.4	10.96	6.44	4.53^{bcdef}
	FR	91.6^{abc}	4.2	2.8	1.5	12.19	6.40	5.79^{a}
	Average	90.3	4.8^{B}	3.3	1.5	10.74^{A}	6.04^{AB}	4.70
Hy-Line	NM	82.5^{f}	9.8	5.9	1.8	7.62	5.42	2.20^{l}
W-98	NF	88.6^{cde}	6.4	3.5	1.5	10.50	6.96	3.54^{ghi}
	FR	91.6^{abc}	4.0	3.2	1.2	10.91	6.30	4.61^{bcde}
	Average	87.5	6.7^{A}	4.2	1.5	9.68^{BC}	6.23^{A}	3.45
Hy-Line	NM	89.9^{abcd}	5.0	4.4	0.7	9.58	5.38	4.20^{efgh}
CV-20	NF	90.4^{abcd}	5.0	3.7	1.0	11.54	6.23	5.31^{abc}
	FR	92.2^{ab}	3.7	2.9	1.3	11.60	6.23	5.37^{ab}
	Average	90.8	4.5^{B}	3.7	1.0	10.90^{A}	5.95^{ABC}	4.96
Bovans	NM	90.0^{abcd}	5.1	4.0	0.9	9.13	5.52	3.61^{fghi}
White Exp	NF	90.7^{abcd}	5.0	3.4	0.9	10.96	6.50	4.46^{cdef}
	FR	92.3^{ab}	4.5	2.5	0.7	10.76	6.30	4.46^{cdef}
	Average	91.0	4.9^{B}	3.3	0.8	10.28^{AB}	6.11^{AB}	4.17
Bovans	NM	90.6^{abcd}	6.7	2.5	0.2	8.17	4.97	3.20^{ijk}
White	NF	88.2^{cde}	6.1	4.8	0.9	8.29	5.10	3.19^{ijk}
	FR	90.4^{abcd}	5.1	3.3	1.3	9.54	5.64	3.90^{efghi}
	Average	89.7	6.0^{AB}	3.5	0.8	8.67^{DE}	5.24^{EF}	3.43
Lohmann	NM	85.8^{ef}	6.6	6.0	1.6	8.41	5.32	3.09^{ijkl}
LSL-Lite	NF	88.2^{cde}	6.0	5.1	0.7	10.19	6.21	3.98^{efghi}
	FR	89.0^{abcde}	6.8	3.4	0.7	10.86	5.97	4.89^{bcd}
	Average	87.7	6.5^{A}	4.8	1.0	9.82^{BC}	5.83^{BCD}	3.99
ISA Babcock	NM	88.3^{cde}	5.8	4.9	0.8	7.69	5.28	2.41^{jkl}
B-300	NF	92.6^{a}	3.0	3.3	1.2	9.87	5.51	4.36^{defg}
	FR	88.9^{bcde}	5.0	4.4	1.1	10.21	5.89	4.32^{defg}
	Average	89.9	4.6^{B}	4.2	1.0	9.26^{CD}	5.56^{DE}	3.70
ISA	NM	85.7^{ef}	6.8	6.1	1.4	8.61	4.94	3.67^{efghi}
White	NF	90.1^{abcd}	5.5	3.0	1.4	10.02	6.03	3.99^{efghi}
	FR	90.4^{abcd}	5.0	3.8	0.9	11.31	5.96	5.35^{abc}
	Average	88.7	5.8^{AB}	4.3	1.2	9.98^{B}	5.65^{CD}	4.33
All Strains	NM	87.0	6.8^{Y}	4.9^{Y}	1.2	8.35^{Z}	5.19^{Z}	3.16^{Z}
	NF	89.8	5.2^{Z}	3.8^{Z}	1.2	10.15^{Y}	6.02^{Y}	4.13^{Y}
	FR	90.4	5.0^{Z}	3.4^{Z}	1.1	10.63^{X}	5.96^{Y}	4.67^{X}

^{ABCDE} - Different letters denote significant differences (P< 0.05), comparisons made among strain average values.
^{XYZ} - Different letters denote significant differences (P< 0.05), comparisons made among molt program average values.
^{abcdefghijkl} - Different letters denote significant strain*molt program interactions (P< 0.05).
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 26. EFFECT OF WHITE EGG STRAIN ON PERCENTAGE OF ALBUMEN,YOLK, AND WHOLE EGG SOLIDS FROM HENS (491-798 DAYS)

Breeder (Strain)	Albumen	Yolk	Whole Egg
	----------%----------		
Dekalb White	11.47^{E}	48.15^{AB}	24.28^{CD}
Hy-Line W-36	11.90^{C}	48.33^{A}	25.23^{A}
Hy-Line W-98	12.28^{A}	47.83^{B}	24.15^{D}
Hy-Line CV-20	11.91^{C}	48.20^{AB}	24.84^{B}
Bovans White Exp	11.64^{D}	48.23^{A}	24.94^{B}
Bovans White	11.63^{D}	48.25^{A}	24.55^{C}
Lohmann LSL-Lite	11.48^{E}	47.77^{B}	24.10^{D}
Babcock B-300	12.06^{B}	48.45^{A}	24.99^{B}
ISA White	11.74^{D}	48.30^{A}	24.41^{C}
Pooled Se	±0.05	±0.14	±0.07

^{ABCDE} Numbers in columns with different superscript are significantly different ($P<0.05$)

TABLE 27. EFFECT OF HEN AGE ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM WHITE EGG STRAIN HENS (491-798 DAYS)

Hen Age (Days)	Albumen	Yolk	Whole Egg
	----------%----------		
491-518	12.33^{A}	48.31^{B}	24.62
547-574	12.18^{B}	48.04^{B}	24.61
603-630	11.88^{C}	48.09^{BC}	24.69
659-686	11.72^{D}	47.73^{D}	24.65
715-742	11.37^{E}	48.86^{A}	24.63
771-798	11.24^{F}	47.99^{CD}	24.47
Pooled Se	±0.04	±0.24	±0.06

^{ABCDEF}Numbers in columns with different superscript are significantly different ($P<0.05$)

TABLE 28. EFFECT OF MOLT TREATMENT ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM WHITE EGG STRAIN HENS (491-798 DAYS)

Molt Treatment	Albumen	Yolk	Whole Egg
	----------%----------		
NM	11.45[B]	48.09	24.62
NF	11.95[A]	48.25	24.66
FR	11.96[A]	48.16	24.56
Pooled Se	±0.05	±0.08	±0.04

[AB] Numbers in columns with different superscript are significantly different (P<0.05)
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 29. EFFECT OF A 21 DAY STORAGE AND STORAGE TEMPERATURE OF 4 OR 20 C ON PERCENT SOLIDS IN EGGS FROM WHITE EGG STRAINS (491-798 DAYS).

Storage (Days)	Albumen	Yolk	Whole Egg
	----------%----------		
0	11.60[B]	49.94[A]	24.39[B]
21	11.98[A]	46.40[B]	24.84[A]
Pooled Se	±0.02	±0.06	±0.03
Storage Temp (C°)			
4 (No Storage)	11.60[B]	49.94[A]	24.39[B]
4	11.54[B]	46.58[B]	24.36[B]
20	12.42[A]	46.22[C]	25.32[A]
Pooled Se	±0.03	±0.07	±0.04

[ABC] Numbers in columns with different superscript are significantly different (P<0.05)

TABLE 30. EFFECT OF HEN AGE, TEMPERATURE, AND 21 DAY STORAGE PERIOD ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM WHITE EGG STRAIN HENS (491-798 DAYS)

Hen Age (Days)	Temp	Storage	Albumen	Yolk	Whole Egg
	(C°)	(days)	----------%----------		
491-518	4	0	12.43^{B}	50.22^{B}	24.61^{D}
	4	21	12.02^{C}	46.82^{F}	24.43^{DE}
	20	21	12.45^{B}	45.95^{GH}	24.84^{C}
547-574	4	0	12.01^{C}	50.39^{AB}	24.52^{D}
	4	21	11.96^{C}	46.45^{F}	24.46^{D}
	20	21	12.75^{A}	44.93^{I}	24.95^{C}
603-630	4	0	11.66^{D}	50.14^{B}	24.49^{D}
	4	21	11.70^{D}	45.92^{H}	24.52^{D}
	20	21	12.52^{B}	46.15^{G}	25.29^{B}
659-686	4	0	11.45^{E}	49.35^{C}	24.43^{DE}
	4	21	11.52^{E}	45.99^{GH}	24.19^{F}
	20	21	12.48^{B}	46.22^{G}	25.55^{B}
715-742	4	0	11.05^{F}	50.74^{A}	24.23^{E}
	4	21	11.00^{F}	47.41^{E}	24.14^{E}
	20	21	12.39^{B}	46.55^{FG}	25.92^{A}
771-798	4	0	11.01^{F}	48.76^{D}	24.05^{G}
	4	21	11.04^{F}	46.87^{F}	24.38^{EF}
	20	21	11.92^{C}	47.54^{E}	25.40^{B}
Pooled Se			±0.06	±0.18	±0.09

^{ABCDEFGHI} Numbers in columns with different superscript are significantly different ($P < 0.05$)

TABLE 31. EFFECT OF BROWN EGG STRAIN AND SYNCHRONIZED MOLT TREATMENT ON PRODUCTION PARAMETERS OF HENS (491-798 DAYS)

Breeder (Strain)	Molt Program	Feed Cons	Feed Conver-sion	Eggs Per Bird Housed	Egg Produc-tion	Egg Mass	Mortality
		(kg/100 ♀/d)	(g egg/g feed)	(HH eggs)	(HD%)	(g/HD)	(%)
Hy-Line	NM	10.5	0.37	157.7	58.3	38.4	11.9
Brown	NF	10.9	0.41	167.8	65.5	43.9	8.6
	FR	10.9	0.43	193.8	71.5	47.0	6.1
	Average	10.8^{B}	0.40^{A}	173.1^{A}	65.1^{A}	43.1^{A}	8.8
Bovans	NM	11.1	0.29	109.2	47.8	32.1	19.8
Brown	NF	11.6	0.36	156.6	62.3	42.0	11.6
	FR	11.5	0.39	164.5	67.5	45.3	8.3
	Average	11.4^{A}	0.35^{B}	143.4^{C}	59.2^{B}	39.9^{B}	13.2
Bovans	NM	10.9	0.33	129.6	51.5	35.0	22.7
Goldline	NF	11.5	0.39	167.4	65.8	44.1	10.7
	FR	11.2	0.43	178.0	71.5	48.4	4.1
	Average	11.2^{AB}	0.38^{A}	158.3^{B}	62.9^{A}	42.5^{A}	12.5
All Strains	NM	10.8	0.33^{Z}	132.2^{Z}	52.5^{Z}	35.2^{Z}	18.1^{X}
	NF	11.3	0.39^{Y}	164.0^{Y}	64.5^{Y}	43.4^{Y}	10.3^{Y}
	FR	11.2	0.42^{X}	178.7^{X}	70.1^{X}	46.9^{X}	6.1^{Z}

^{AB} - Different letters denote significant differences ($P< 0.05$), comparisons made among strain average values.
^{XYZ} - Different letters denote significant differences ($P< 0.05$), comparisons made among molt program average values.
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 32. EFFECT OF BROWN EGG STRAIN AND SYNCHRONIZED MOLT TREATMENT ON EGG WEIGHT AND EGG SIZE DISTRIBUTION OF HENS (491-798 DAYS)

Breeder (Strain)	Molt Program	Egg Weight	Pee Wee	Small	Medium	Large	Extra Large
		(g/egg)	(%)	(%)	(%)	(%)	(%)
Hy-Line	NM	66.2	0.0	0.1	1.5^{ab}	26.3	72.0
Brown	NF	67.3	0.0	0.0	0.4^{b}	23.9	75.5
	FR	65.9	0.0	0.0	1.3^{ab}	30.2	68.2
	Average	66.5^{B}	0.0	0.0	1.1	26.8^{A}	71.9^{B}
Bovans	NM	67.8	0.0	0.0	0.4^{ab}	20.3	78.2
Brown	NF	68.0	0.0	0.0	0.5^{ab}	16.9	82.5
	FR	67.3	0.1	0.1	1.3^{ab}	21.9	76.3
	Average	67.7^{A}	0.0	0.0	0.7	19.7^{B}	79.0^{A}
Bovans	NM	68.6	0.0	0.0	1.1^{ab}	20.1	78.4
Goldline	NF	67.2	0.1	0.1	1.6^{a}	20.0	78.0
	FR	67.7	0.0	0.0	0.3^{b}	22.3	76.9
	Average	67.8^{A}	0.0	0.0	1.0	20.8^{B}	77.8^{A}
All Strains	NM	67.5	0.0	0.0	1.0	22.2	76.2
	NF	67.5	0.0	0.0	0.8	20.3	78.6
	FR	66.9	0.0	0.0	1.0	24.8	73.8

^{AB} - Different letters denote significant differences ($P< 0.05$), comparisons made among molt program average values.
^{ab} - Different letters denote significant strain*molt program interactions ($P< 0.05$).
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 33. EFFECT OF BROWN EGG STRAIN AND SYNCHRONIZED MOLT TREATMENT ON EGG QUALITY, INCOME AND FEED COSTS OF HENS (491-791 DAYS)

Breeder (Strain)	Molt Program	Grade A	Grade B	Cracks	Loss	Egg Income	Feed Costs	Gross Income
		(%)	(%)	(%)	(%)	($/hen)	($/hen)	($/hen)
Hy-Line	NM	86.9	9.1	3.7	0.3	9.03	5.81	3.22
Brown	NF	88.8	7.6	3.4	0.2	9.73	6.47	3.26
	FR	90.2	5.4	3.9	0.5	11.34	6.88	4.46
	Average	88.6	7.4	3.7	0.4	10.03^{A}	6.39	3.64^{A}
Bovans	NM	84.3	9.7	5.4	0.6	6.13	5.00	1.13
Brown	NF	87.5	8.8	3.0	0.7	9.01	6.77	2.23
	FR	91.3	5.7	2.1	1.0	9.64	6.55	3.09
	Average	87.7	8.1	3.5	0.8	8.26^{C}	6.11	2.15^{C}
Bovans	NM	86.5	8.8	3.1	0.2	7.33	5.49	1.84
Goldline	NF	88.6	8.2	2.6	0.7	9.64	6.76	2.88
	FR	89.9	6.6	3.1	0.4	10.37	6.52	3.85
	Average	88.3	7.9	2.9	0.4	9.11^{B}	6.26	2.85^{B}
All Strains	NM	85.9^{Z}	9.2^{Y}	4.1	0.3	7.50^{Z}	5.43^{Z}	2.05^{Z}
	NF	88.3^{YZ}	8.2^{Y}	3.0	0.5	9.46^{Y}	6.67^{Y}	2.79^{Y}
	FR	90.5^{Y}	5.9^{Z}	3.0	0.6	10.45^{X}	6.65^{Y}	3.80^{X}

^{ABC} - Different letters denote significant differences ($P< 0.05$), comparisons made among strain average values.
^{XYZ} - Different letters denote significant differences ($P< 0.05$), comparisons made among molt program average values.
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 34. EFFECT OF BROWN EGG STRAIN ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM HENS (491-798 DAYS)

Breeder (Strain)	Albumen	Yolk	Whole Egg
	----------%----------		
Hy-Line Brown	11.77^{A}	48.11^{B}	23.24^{B}
Bovans Brown	11.65^{B}	48.22^{B}	23.56^{A}
Bovans Goldline	11.51^{C}	48.48^{A}	23.23^{B}
Pooled Se	±0.04	±0.27	±0.06

^{ABC}Numbers in columns with different superscript are significantly different (P<0.05)

TABLE 35. EFFECT OF HEN AGE ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM BROWN EGG STRAIN HENS (491-798 DAYS)

Hen Age (Days)	Albumen	Yolk	Whole Egg
	----------%----------		
491-518	12.05^{A}	48.86^{A}	23.75^{A}
547-574	11.96^{A}	48.05^{B}	23.43^{B}
603-630	11.74^{B}	48.25^{B}	23.36^{B}
659-686	11.67^{B}	48.02^{B}	23.48^{B}
715-742	11.30^{C}	48.29^{B}	22.98^{C}
771-798	11.15^{C}	48.15^{B}	23.04^{C}
Pooled Se	±0.06	±0.11	±0.09

^{ABCD} Numbers in columns with different superscript are significantly different (P< 0.05

TABLE 36. EFFECT OF MOLT TREATMENT ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM BROWN EGG STRAIN HENS (491-798 DAYS)

Molt Treatment	Albumen	Yolk	Whole Egg
	----------%----------		
NM	11.55[B]	48.36	23.44[A]
NF	11.71[A]	48.31	23.38[AB]
FR	11.67[A]	48.36	23.21[B]
Pooled Se	±0.04	±0.10	±0.06

[AB] Numbers in columns with different superscript are significantly different (P< 0.05)
NM = Non-molted; NF = Non-fasted molt; FR = 13-day fast.

TABLE 37. EFFECT OF A 21 DAY STORAGE AND STORAGE TEMPERATURE OF 4 OR 20 C ON PERCENT SOLIDS IN EGGS FROM BROWN EGG STRAINS (491-798 DAYS).

Storage (Days)	Albumen	Yolk	Whole Egg
	----------%----------		
0	11.42[B]	49.61[A]	22.99[B]
21	11.87[A]	46.93[B]	23.70[A]
Pooled Se	±0.04	±0.06	±0.08
Storage Temp (C°)			
4 (No Storage)	11.42[B]	49.61[A]	22.99[C]
4	11.47[B]	47.10[B]	23.19[B]
20	12.26[A]	46.76[C]	24.21[A]
Pooled Se	±0.04	±0.07	±0.06

[ABC] Numbers in columns with different superscript are significantly different (P< 0.05)

TABLE 38. EFFECT OF HEN AGE, TEMPERATURE, AND 21 DAY STORAGE PERIOD ON PERCENTAGE OF ALBUMEN, YOLK, AND WHOLE EGG SOLIDS FROM BROWN EGG STRAIN HENS (491-798 DAYS)

Hen Age (Days)	Temp	Storage	Albumen	Yolk	Whole Egg
	(C°)	(days)	----------%----------		
491-518	4	0	12.05^{CD}	50.68^{A}	23.69^{CD}
	4	21	11.89^{D}	47.31^{E}	23.43^{D}
	20	21	12.18^{C}	46.75^{F}	24.18^{BC}
547-574	4	0	11.85^{D}	49.36^{CD}	23.28^{DE}
	4	21	11.67^{EF}	47.16^{E}	23.31^{DE}
	20	21	12.46^{A}	46.31^{B}	23.87^{C}
603-630	4	0	11.49^{F}	49.92^{B}	22.98^{F}
	4	21	11.62^{E}	46.49^{F}	23.32^{DE}
	20	21	12.35^{B}	46.67^{F}	24.19^{B}
659-686	4	0	11.42^{G}	49.08^{D}	23.04^{EF}
	4	21	11.49^{FG}	46.75^{F}	23.11^{EF}
	20	21	12.34^{B}	47.15^{E}	24.74^{A}
715-742	4	0	10.91^{I}	49.63^{BC}	22.42^{G}
	4	21	10.98^{I}	47.50^{E}	22.81^{FG}
	20	21	12.40^{AB}	46.41^{F}	24.29^{B}
771-798	4	0	10.79^{I}	48.99^{D}	22.51^{G}
	4	21	11.18^{H}	47.37^{E}	23.16^{E}
	20	21	11.80^{DE}	47.27^{E}	23.98^{C}
Pooled Se			±0.09	±0.18	±0.15

^{ABCDEFGHI} Numbers in columns with different superscript are significantly different ($P< 0.05$)