ABSTRACT

JERVIS, MATTHEW GABRIEL. The Application of Qualitative and Quantitative Research to Evaluate Whole Wheat Bread and Sweet Whey Powder. (Under the direction of Dr. MaryAnne Drake).

Both qualitative and quantitative data collection methods hold great importance in the research of food products and consumer perception. Qualitative research can be used to understand consumer behavior and motivation, or to develop a hypothesis and relies on non-quantifiable data. Quantitative research can be used to test a hypothesis and involves a strictly objective measurement of variables of interest. Two studies were designed to explore the use of these two diverse data collection techniques.

The first study was designed to determine children's perceptions and attitudes towards whole grain sliced sandwich breads to identify ideal whole grain breads for children. Focus groups, emotional response surveys, appearance liking surveys, and an adaptive choice based conjoint survey were conducted with children (n=173). From focus groups, children had an overall positive attitude towards breads, but darker colored breads, and breads with toppings and crumb particulates were disliked. Quantitative utility values from conjoint survey analysis confirmed that across elementary, middle and high school aged children, children preferred bread with a light crumb (inside of the bread), a light crust, and no topping or added textures or visual cues in the crumb. A soft crust with no topping, and a soft crumb with no crumb particles or flake crumb particles were also preferred. Children had a generally negative feeling for breads with dark colored crumb and crust, but generally positive feelings for breads with light colored crumb and crust. Breads with white crumb were liked more than bread with dark crumb, regardless of crumb particles, crust or crust topping, and regardless of crumb color, no topping was preferred to flakes or oats as a

topping to the loaf or slice of bread. These results demonstrated that children like soft breads with light colored crumb and crust with no fillings or toppings. Successful whole grain breads for children must have the visual appeal of a white bread.

The second study was designed to understand the impact that point of bleaching had on the flavor and bleaching efficacy of various bleaching agents on sweet whey powder (SWP). Colored Cheddar whey was manufactured, fat separated and pasteurized. Subsequently, the whey (6.7% solids) was bleached, concentrated using reverse osmosis (RO) to 14% solids and then spray-dried, or whey was concentrated prior to bleaching and then spray dried. Bleaching treatments included: Control (CR) (no bleaching, 50°C, 60 min), hydrogen peroxide (HP) (250 mg/kg, 50°C, 60 min), benzoyl peroxide (BP) (50 mg/kg, 50°C, 60 min), lactoperoxidase (LP) (HP 20 mg/kg, 50°C, 30 min), and external peroxidase (EP) (2 dairy bleaching units (DBLU)/ml, 50°C, 30 min). The experiment was repeated in triplicate. Sensory properties and volatile compounds of SWP were evaluated by a trained panel and gas chromatography mass spectrometry, respectively. Bleaching efficacy (norbixin destruction) and benzoic acid levels were measured using high performance liquid chromatography. Differences in bleaching efficacy, sensory and volatile compound profiles and benzoic acid were observed with different bleaching agents ($p<0.05$), consistent with previous studies. Solids concentration impacted bleaching efficacy of HP ($p<0.05$) but not other bleaching agents. SWP from whey bleached with HP or LP following RO had increased cardboard and fatty flavors and higher concentrations of lipid oxidation compounds compared to SWP from whey bleached prior to RO. SWP bleached with BP after RO contained less benzoic acid than SWP from whey bleached before RO ($p<0.05$). Results indicated that solids concentration impacted bleaching efficacy of HP, and influenced off flavors and residual benzoic acid levels in SWP.

The Application of Qualitative and Quantitative Research to Evaluate Whole Wheat Bread and Sweet Whey Powder

by
Matthew Gabriel Jervis

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Food Science

Raleigh, North Carolina

2014

APPROVED BY:

_______________________________ _______________________________

Dr. Maryanne Drake
Committee Chair

Dr. Allen Foegeding

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Dr. Timothy Sander

DEDICATION

To Elliott and Ethan. All of this was for you.

BIOGRAPHY

Matthew Gabriel Jervis was born on April 27th, 1979 to Denise Jervis and Charles Jervis. Matthew was raised in suburban Philadelphia and enjoyed exploring the back roads and backwoods of Bucks County. Matthew attended Penn State University, and graduated with a Bachelors of Science in Education in 2001. Matthew became a teacher focusing on Math and Science education for middle and elementary schools. During this time, he married Suzanne Marie Jervis on June 14th, 2003.

After nine years of teaching at various grade levels and in various schools, Matthew decided it was time to move on and change career paths. After years of exposure to the field of food science from his wife, Matthew decided to pursue a Masters in Food Science degree, with the goal of becoming a food scientist. In 2011, Matthew spent one year concluding his teaching career while taking classes at night at North Caroline State University, and working on food research in his time outside of teaching. In 2012, Matthew transitioned to the role of full time student under the direction of Dr. MaryAnne Drake studying sensory science. The same year, Matthew and his wife were blessed with the birth of their twin boys. Matthew plans on pursuing work in the field of sensory science, and one day hiking the Appalachian Trail.

ACKNOWLEDGMENTS

First and foremost, I must extend my deepest appreciation to Dr. MaryAnne Drake for taking a chance on someone without a background in food science, and allowing me to prove myself in the field. My time in your lab has been in invaluable experience that I will carry with me always. Deepest thanks to Evan Miracle whose tireless work ethic and willingness to help the students in the lab was rivaled only by his enthusiasm and love for life. It's been a great honor to work with you and an even greater honor to call you a friend. Additionally, I would like to thank Dr. Foegeding and Dr. Sanders. I could not have asked for a more supportive committee. It is a true honor to have had the chance to work with you both as leaders in the field of food science and research.

To the Drake lab, you are an amazing group of people. Thank you for the support, camaraderie and the laughs. Sitting in 331 with some of the smartest people I've ever met has been equally enlightening and entertaining.

To James Dewees, Justin Vernon, and Chris Thile (and brothers), thank you for the support that you provided me as I wrote and researched. You're not aware of the level of encouragement and motivation that you provided me, but I don't think I could have done it without you.

And finally, to the love of my life – I could not have done this without you. From the initial push to quit my job and pursue a new career field, to the late nights trying to meet deadlines, to the past few weeks dealing with selling a house and raising the boys, you have been my loudest advocate, my biggest supporter and my greatest joy. Thank you. I love you, and I can't wait to see where this next chapter takes us.

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THE USE OF QUALITATIVE RESEARCH METHODS IN QUANTITATIVE SCIENCE: A REVIEW

JERVIS, M.G.[1], and DRAKE, M.A.[1,2]

[1] *Department of Food, Bioprocessing and Nutrition Sciences*

Southeast Dairy Foods Research Center

North Carolina State University

Raleigh, NC 27695

[2]Corresponding author. TEL: (919) 513-4598; FAX: (919) 515-7124; EMAIL: mdrake@ncsu.edu

RUNNING TITLE: QUALITATIVE RESEARCH METHODS IN QUANTITATIVE SCIENCE

ABSTRACT

Qualitative research in the field of food science strives to understand consumer behavior and motivation. Often, these methods are used to develop a hypothesis, which can be tested through quantitative research. Traditionally qualitative methods can provide excellent insight to consumer behavior, but the data collected can be difficult to organize and interpret. Focus groups are the most common qualitative research tool applied to understand consumer behavior and identify possible areas of focus for product development. However ethnography and means-end chain analysis can also be applied to understand consumer behavior and personal values. Many new qualitative techniques have been developed that attempt to mimic data normally collected in quantitative research. Grouping and projective mapping allow consumers to represent similarities and differences between products and produce maps that show how consumers perceive various attributes of these products. Each method has benefits and drawbacks, and each demands a particular data analysis methodology. Understanding these approaches is important in choosing a research method and proper interpretation of the collected data.

PRACTICAL APPLICATIONS

Qualitative research is often used as a way to develop and refine hypotheses in product development. They allow for quick, inexpensive probing of consumer demands in a natural and comfortable environment. However, qualitative research can also be used as a substitute for classical quantitative profiling methods or to powerfully augment quantitative methodology.

KEY WORDS

Qualitative, focus groups, projective mapping, napping, sorting

INTRODUCTION

Qualitative research plays a pivotal role in the progress of quantitative research. Qualitative data is collected from non-quantifiable or non-statistically derived sources. The qualitative approach seeks to examine responses in an uncontrolled, natural environment. Rather than relying on instrumental measurements, behaviors are observed by an investigator, and recorded through notes, video/audio recordings, and/or personal interaction. These observations are analyzed with consideration given to the environment of the observation, emotional responses that may be given, general themes discussed or observed, and implicitly intended meanings. In addition, variability in natural consumer language must be considered since similar responses can represent vastly different feelings in respondents. Qualitative data can help researchers understand complex emotional responses and can lead to understandings that may not be revealed in a quantitative study. In a broad sense, the goal of qualitative research is to understand why people react the way they do to a stimulus or experience (Maxwell, 2005; Harris *et al.* 2009). Qualitative methods can offer a higher degree of depth and detail than a quantitative method, at the cost of precision and applicability to a larger population. Given the open-ended nature of qualitative study, new ideas can be fully explored and discussed outside of the rigid framework that exists in quantitative studies. Since qualitative studies typically use purposive sampling, these new ideas cannot be applied to a larger population without further quantitative studies.

Often, in qualitative data collection, data is used to generate or refine a hypothesis. This is in stark contrast to quantitative methods in which a hypothesis has already been developed, and data is collected as a method to test that hypothesis. Methods of collecting qualitative data are varied and constantly evolving. Some methods, such as ethnography, are passive and involve observation of behavior in natural settings while the observed is unaware that they are being watched. Other methods are more involved and require careful planning, and execution, such as the focus group. Both of these methods allow for direct exposure to consumer derived language and can provide insight that would not be available through strictly quantitative methods. This review will examine some of the prominent qualitative data collection methods, as well as some new and novel methods with regard to their strengths, weaknesses, and applications in the field of food science.

QUALITATIVE APPROACHES

ETHNOGRAPHY

Ethnography involves observing peoples words, actions and behaviors, within the context of the various cultures that they are members of (Lindlof and Taylor, 2002). Each of us holds membership in multiple communities and cultures. These cultural identities can be very broad, such as one's national identity, or very narrow such as skim-milk consumers of a specific age group. It is important to consider each of these cultural memberships throughout data collection and analysis. While observing, it is important that the researcher is immersed and active in the community, but inconspicuous and unnoticed at the same time (Agar, 1996; Singer, 2009; Elliott and Jankel-Elliott, 2003). Collection of ethnographic data can help researchers understand social factors that affect purchasing behaviors and decisions (Jervis *et al.* 2012). In the context of sensory research, ethnography has been used to study consumer behavior in appropriate environments, with the goal of better understanding purchase intents.

Collection of ethnographic data has no set method, but generally involves an observer making general observations about the appropriate situation while recording behaviors of interest. In a recent study of latte-style coffee beverage purchasing patterns, Jervis *et al.* (2012) made observations while sitting in coffee restaurants, posing as a consumer. In that study, observations were made at different times throughout the day, at multiple coffee shops, and multiple branches of each in order to observe a general coffee-house environment, rather than focusing on one particular chain or time of day. Observations of coffee consumers were conducted using a checklist of 18 behaviors and attributes including gender, approximate age, coffee size, and additional purchases made. In addition, free-flow observations were made about the atmosphere such as the general conversational volume, music played and brightness, and general behavior of consumers in a location such as length of stay and typical activities that consumers engaged in. This data was analyzed for frequency of each behavior with consideration given for the general "feel" of each location. This allowed the researchers to tell the general story of each location. This data was used to develop a follow-up conjoint survey, and to interpret the results of that survey. The most influential factor in consumer choice of latte purchase was the culture that a coffee restaurant develops. This culture includes the general volume of the environment, the music playing, table size, general demographic makeup of consumers and baristas, Wi-Fi availability, and other similar factors.

Ethnography has also been used to study sugar consumption patterns in pregnant women (Graham *et al.* 2013). In this case, participants were recruited to complete questionnaires and interviews as opposed to observations in a natural environment. This was done to account for the relatively small population of pregnant women that may be observed without extensive periods of waiting, and the inability to easily identify pregnant women based on visual cues alone. Participants were asked questions about their food choices during pregnancy, but were not initially aware of the goal of studying sugar consumption. Interview and survey responses were recorded, and important words and concepts were identified. Categories of responses were created and recorded in a data matrix to compare and contrast sugar consumption patterns.

Ethnography is a powerful tool to analyze purchase choice. It can be conducted without specialized tools or software, and can identify influential factors that may not be identified using quantitative methods. The conclusions of an ethnographic study may be limited based on the general subjectivity of the method, and the limited role of the observer. Observations can be difficult and time-consuming. Further, the actual population or environment may not be readily accessible, limiting the use of ethnography. Despite these limitations, ethnography still holds great value and importance in the study of the consumer motivation and behavior, and is accessible with minimal training and resources.

MEANS END CHAIN

The Means-End Chain model (MEC) was originally developed for use in marketing and advertising research (Gutman, 1982) and attempts to understand the factors that guide consumer choice. MEC is founded on the assumption that consumers consume or utilize products based on product attributes (means) that provide physical and/or psychological benefits (consequences), and help to fulfill personal values or achieve desired states of being (ends). It is important to note, especially in the context of food and nutrition science, that these consequences may be immediate in terms of satiety or hedonism, or may be delayed in terms of nutritional delivery (Gutman, 1982; Costa *et al.* 2004; Santosa and Guinard, 2011). The multiple connections between the various *attributes* of a product, the *consequences* that result, and an individual's personal *values* (collectively referred to as ACV) form visual chains that represent the essence of MEC. As values increase in importance to the consumer, so do the attributes that lead to that value (Gutman, 1982). A consumer may have multiple chains for a product based on the various values a product may contribute to, and they may also have incomplete chains for a product if they are inexperienced with the product, or the product is considered basic (Lind, 2007). By understanding these chains, a better understanding of consumer decision-making processes, both conscious and unconscious, can be gained (Olson and Reynolds, 2001). Figure 1 shows an example MEC that represents a consumer's view of potato chips.

MEC data is collected through an interviewing technique known as laddering in which consumers are asked a series of probing questions aimed at eliciting their motivations behind their choices, and the linkages (ladders) between the product attributes, the consequences, and their values. A preliminary step in laddering involves the identification of specific product attributes by the consumer. This process can be in the form of a free-flowing conversation, or a checklist presented to the consumer in which they identify which attributes are important to them. These identified attributes form the groundwork for the interviewing procedure, and thus the actual MEC, so special care needs to be taken in this step (Costa *et al.* 2004).

After the elicitation procedure, the actual laddering interview begins. Interview questions used are typically a variation of the question, "why is this important to you…?" (de Ferran and Grunert, 2007). This method makes explicit the links between concrete product attributes and abstract motivators and values. The interviewer, depending on the product being studied and the number of subjects available, can employ either soft laddering or hard laddering techniques. Soft laddering encourages a natural and unrestrained flow to the conversation. The interview is later reviewed and the researcher constructs the links between ACVs. Alternatively, hard laddering requires the participant to manually and explicitly generate or verify the links between ACVs. Soft laddering tends to produce more MECs, and MECs of higher abstraction levels (consequences and values), which makes it ideal for complex purchase motivations. Soft laddering may also improve the probability of uncovering a relevant MEC with a high predictive ability due to the unstructured nature of the interview (Grunert and Grunert, 1995). Hard laddering is ideal for less motivationally complex situations, and when a larger sample size is needed as it is both easier and faster to administer and analyze. Hard laddering can provide more detailed and comprehensive results with less bias than soft laddering (Costa *et al.* 2004). Due to the rigid structure of the interview, hard laddering may result in participants reporting false associations, and lead to lower motivation levels. Both hard and soft laddering have benefits and drawbacks, but produce similar results (Russel *et al.* 2004). Often the choice of methods is based on the sample size needed. Soft laddering requires a substantial time commitment to review each interview, and extract the appropriate data. Hard laddering techniques are less time consuming, and computer software can automate the process. This makes hard laddering desirable when a large sample size is required, and a product is of low complexity. Regardless of the method chosen, the end products for each consumer are MECs that represent the linkages between ACVs.

Once MECs have been collected, participant data is aggregated in a coding process that classifies that various ACVs into broader categories to accurately reflect all relevant details while balancing accuracy and manageability. Finally, the links between these new broad categories are analyzed and aggregated into a single graphical representation known as a hierarchical value map (HVM) (Figure 2). A HVM is a tree diagram that represents ACVs and their connections (Fotopoulos *et al.* 2003). Typically, attributes are placed at the bottom of the structure, with notation of the frequency of each attribute. This frequency is often shown by increasing and decreasing the relative size of an attribute on the map. The consequences and values are positioned at the middle and top of the map respectively and all three are connected appropriately with notation of the frequency of connection. This allows for quick visual inspection and interpretation of the HVM and interpretation of consumer motivation. Figure 2 shows a simplified HVM representing consumer choice of high pressure processed juices in Norway (Olsen *et al.* 2011). This simplified HVM identifies four of the attributes considered. These attributes produce specific consequences of health and environmental benefits, which fulfill the value of benevolence. A third value of hedonism is directly fulfilled by the taste of the apple juice. A HVM showing a more complete view of consumer perception of orange juice is shown in figure 3 (Kitsawad and Guinard, 2014), and represents a specific cluster of consumers who are open to change, as opposed to a consumers who are more conservative in their purchasing behavior for orange juice.

In the realm of food product development and innovation, MEC can reveal information regarding the key benefits a consumer expects from a food, the features (both concrete and abstract) that consumers can use to understand the key benefits of the product, and the values and goals that consumers seek to attain through a product (Gutman, 1982; ter Hofstede *et al.* 1998; Costa *et al.* 2004). It can also be used to measure particular attributes that don't translate well to the quantitative realm. MEC has been used to study how consumers perceive wines produced from organic grapes (Fotopoulos *et al.* 2003), fair trade coffee (de Ferran and Grunert, 2007), yogurts and genetically modified foods (Boecker *et al.* 2008), and apple juices processed using different pasteurization methods (Olsen *et al.* 2011).

MEC would appear to be an ideal technique in the early stages of product development but it does have limitations and drawbacks. Most notably are the high time and labor requirements, which prevent the use of larger sample sizes. In addition, due to the subjective nature of MEC methods and analysis, the predictive quality of the data may be very limited (Costa, *et al.* 2004). MEC also has limited use at the product development stage because consumers have not had adequate time to build appropriate perceptions of new products and how the product fits into their lives and meets their needs/values. Despite these drawbacks, MEC can serve as an invaluable tool in identifying potential values that could lead to new avenues of development for existing products.

FOCUS GROUPS

Focus groups are a popular data collection technique that relies on group interaction to elicit personal and emotional responses towards a product or concept. In contrast to an individual interview, panelists participate in a group discussion while a moderator guides the discussion around pertinent research goals. Group discussion results both a comfort and a synergy that encourages participants to express, explore and clarify their perception of the subject, which often leads to insights that may not be reported or considered in other settings (Kitzinger, 1995). Focus groups also allow for the use of authentic, personal descriptions of products in a consumer's own words, as opposed to other methods where respondents are forced to respond using an established language. Pascall *et al.* (2009) reported that participants in a focus group are "caught up in the spirit of a group discussion" and can provide more information than a typical interview or survey by lowering participant inhibitions that may be natural in a one-on-one setting. This is due, in part, to the shared experience with others who can provide mutual support, affirmation and encourage a deeper level of participation (Kitzinger, 1995).

Focus groups are typically composed of a small number of demographically similar participants and a moderator (Kitzinger, 1995). Depending on the researcher, the ideal number of participants in a focus group varies. Stewart *et al.* (1994) recommend from three to eight participants while Krueger and Casey (2000) determined six to eight participants to be ideal. Others recommend using up to twelve participants (Barbour and Kitzinger, 1999). Clearly the subject of the focus group, and the demographic make up of the group will influence the appropriate size of a focus group. Morgan (1992) reviewed group sizing, and determined that smaller groups were appropriate for controversial topics, or topics that will generate a high level of discussion, while large groups are appropriate for neutral topics that will not generate as much discussion (Morgan, 1996). It is also recommended to hold smaller focus groups when working with children, or young adults. Jervis *et al.* (submitted) found a smaller group of 6-8 participants to be ideal when working with children ages 8-12 y, and Thompson *et al*. (2007) used groups of 2-5 participants with children ages 10-14 y. It is important that sessions are comfortable and conducive to open and honest discussion. To that end, seating participants in a circle helps to establish such a setting, and eliminates positions that may allow participants to avoid participation, or to take a dominant position in the group and overwhelm the conversation. Focus groups are also generally conducted in duplicate or triplicate with a similar group of respondents. A consistent set of results is ideal. Often, focus groups are repeated until results become redundant, ensuring the breadth of responses have been represented.

The dynamics of a focus group can encourage or hinder panelist participation. Thus, an experienced and professional moderator is important in a focus group in order to ensure equal participation and to make sure that the group discussion stays relevant to the intended purpose, while allowing a degree of freedom (Kitzinger, 1995; Edmunds, 1999). A moderator should be able to adapt to a wide range of subjects, participants and settings. They need to be good listeners and know when to speak up and when to allow the conversation to roll (Edmunds, 1999; Barbour and Kitzinger, 1999; Fern, 2001). There many varying styles of moderation that are employed and each has a particular benefit based on populations and subjects being studied (Fern, 2001).

Although focus groups were initially developed for use in marketing studies, they have been used extensively in food science. Pascall *et al.* (2009) conducted focus group research on tamper evident packaging devices. During the focus group, participants were asked about their knowledge of current tamper evident devices, their perceptions of these devices, personal experiences, willingness to pay more for tamper evident seals, and feedback about a prototype device that changes colors as evidence of the seal breaking or being tampered with. As a result of these focus groups, the researchers were able to determine that consumers are not as vigilant in checking tamper evident seals as they report to be, and that the prototype was seen as unnecessary, and in need of further explanation or clarification to be useful. Ramcharitar *et al.* (2005) used focus groups to determine consumer acceptability of muffins that contained varying levels of ground flaxseed. The researchers chose to use focus groups in order to get a view of consumer acceptance early in the development cycle and to allow for free expression of new and possibly novel ideas that could be used for further development.

Focus groups have been recently used to study consumer acceptability and behavior in regards to fish burgers (Di Monaco *et al.* 2009) in conjunction with a quantitative consumer acceptance test of fish burgers. Lee and Lee (2007) used focus groups in conjunction with conjoint analysis to understand consumer attitudes, opinions and concerns regarding breakfast cereal. Lutchmedial *et al.* (2004) conducted focus groups to ascertain early consumer reaction to prototype blends of soursop fruit yogurt at varying levels of added fruits. The information gained from these focus groups lead to a modification of the original fermentation process, and incubation times in order to produce a product that was consumer friendly before continuing on to chemical analysis. Childs *et al.* (2008) used focus groups to compile the opinions of consumers pertaining to meal replacement products with whey and/or soy proteins. The results of the focus groups were used to identify attributes and levels applied in a conjoint ballot. Focus groups were utilized in a similar experimental design by Childs and Drake (2009) to determine the perception of fat reduction in cheese. Childs and Drake (2010) later used focus groups to study how consumers perceived astringency in clear acidic whey protein beverages. More recently, Jervis *et al.* (submitted) used focus groups with children to determine how children perceived breads with varying attributes. Focus groups have also been applied to augment quantitative consumer studies with butter (Krause *et al.* 2007), chocolate milk (Thompson *et al.* 2007), beef from various processing technologies (De Barcellos *et al.* 2010), the use of whey protein and soy protein in meal replacement bars and drinks (Childs *et al., 2008),* and ginseng food products (Chung *et al.* 2011).

Analysis of focus group data is conducted in various ways depending on the type of data collected and the goals of the researcher. Ramcharitar *et al.* (2005) had participants give numerical responses to their various flaxseed-containing muffins and analyzed this data as quantitative. Other descriptive responses were recorded, coded and their frequencies were analyzed in order to make conclusions. Pascall *et al.* (2009) relied on simple frequency of responses to make general conclusions about tamper evident seals and determined general consumer perception based on these frequencies. Lee and Lee (2007) recorded and transcribed each focus group in their study of healthy breakfast cereals. These transcripts were edited for clarity and responses were compared between sessions in order to identify any trends in consumer perceptions.

Focus groups produce more data than individual interviews, in a shorter time and at a lower cost. The ability to collect a wide variety of data from a group in a short amount of time at a low cost allows for faster innovation and development to take place. Aldag & Tinsley (1994) sought to determine whether focus groups or individual interviews were more efficient. Participants either took part in a focus group or an individual interview that sought to determine what factors influence general food choices. Of the 53 individuals recruited, 28 participated in a series of interviews, while 25 participated in a series of focus groups. Focus groups generated 79 total factors influencing food choices, while interviews generated in 73 factors. After examining time requirements of each data collection method, it was determined that focus groups were able to produce more factors than interviews in less than half the time, and less than half the cost. In addition the focus groups were easier to conduct since the moderator in a focus group takes a more passive position. Focus groups have also been shown to generate more critical comments than interviews (Watts & Ebbutt, 1987). This is of utmost importance when researching consumer perceptions of new products. Focus groups are generally considered to be more difficult to prepare for and arrange as considerations had to be made for facilitating and coordinating more participants. In spite of this added difficulty in planning, focus groups allow for rapid insight to a product from a consumer point of view, and at a lower cost than traditional interviewing methods.

SORTING/GROUPING

Sorting is a popular data collection technique in the field of psychology that has recently become more popular in the field of sensory studies (Abdi *et al.* 2007). Lawless (1989) was among the first to apply this technique to sensory science while investigating odor quality. Soon after, this technique was applied to vanilla beans (Heymann, 1994), drinking water (Falahee & MacRae, 1997), cheese (Lawless *et al.* 1995), and beer (Chollet and Valentin, 2001). The premise behind sorting is simple. Participants are presented with a group of products – usually 10 to 15 – and are then asked to place the products into groups based on perceived similarity (Nestrud & Lawless 2010). Participants are allowed to create as many groups as they wish, and put as many products into a group as they wish, but each item can belong to only one group. Sorting tasks have produced reliable results with as little as 16 consumers (Lawless *et al.* 1995) but at least 20 is recommended in order to represent a wide spectrum of consumers (Santosa *et al.* 2010). Following the initial sorting activity, a follow-up step may be conducted in which the participant describing the groups, rates all of the products on a quantitative scale, or continues to divide each group into sub-groups. Each of these variants will be discussed in detail. After proper statistical analysis, a representative product space can be created that shows product relationships and can be used to interpret consumer responses and reveal underlying dimensions of the product (Chollet *et al.* 2011).

Typically sorting data is organized into a similarity matrix in which products are listed in both rows and columns in a table. The number of times individual products have been grouped together is tallied from all participants and recorded. This data is generally analyzed using multidimensional scaling (MDS), although multiple correspondence analysis

(MCA) and variations of MDS and MCA have been used (Abdi *et al.* 2007; Cadoret *et al.* 2009; Santosa *et al.* 2010). MDS produces a map that represents perceived similarities and differences between products as distances between points representing each product. Products that are closer together have been sorted together more often, while products that are furthest away were rarely sorted together. Figure 4 shows an example MDS map demonstrating consumer perception of cheeses (Lawless *et al,* 1995). This particular group was experienced with a variety of cheeses and had a deeper knowledge of cheese than the average consumer, hence the "experienced group" designation. Proximity to other cheeses represents perceived similarity/dissimilarity between them. This map may provide insight into the dimensions that consumers use to gauge similar products (Abdi, *et al.* 2007). Lawless (1995) reported that the only major problem with using MDS for analysis is that individual participant information is lost since their data is pooled with other participants in the creation of the similarity matrix. The loss of such data prevents the evaluation of agreement among assessors and the analysis of individual participants over multiple repetitions of the same procedure (Abdi *et al.* 2007). Again, various methods have been proposed that strive to eliminate this problem.

Lawless *et al.* (1995) applied the sorting procedure to examine consumer perception of 16 different cheese varieties. Using both a cheese-familiar and cheese-unfamiliar panel of 16 consumers, the cheeses were differentiated by taste, texture and appearance attributes. Cheeses in the same general family, (blue cheeses, white moldy cheeses etc.) appeared close together on the perceptual map. Feta, the only goat's cheese, tended towards the center of the map and wasn't associated with other cheese families or groups (Figures 4 & 5). Falahee and MacRae (1997) examined variation in 13 different samples of drinking waters with a panel of 20 untrained assessors over 5 replications. The waters included bottled, distilled and tap waters along with blends of the various waters. The assessors would sort the drinking waters into groups based on similarity, and also rank the samples in order of preference. The untrained panelists performed consistently across the 5 replications, and MDS data collected from the sorting procedure differentiated the various types of water including tap, distilled and bottled waters. Tang and Heymann (2002) used sorting in a study of 10 grape jellies. Data from the sort separated the jellies into 4 distinct groups, including segregation of the jellies based on sweetening system (artificial vs. sugar vs. high fructose corn syrup), grape flavor, and texture. Saint-Eve *et al.* (2004) examined the interactions of flavor on texture perception of yogurts using sorting. Assessors were able to identify major differences among the products, and separate the yogurts into distinct groups based on their textural and aromatic attributes. Using MDS on this data to produce a perceptual map showed that yogurts that were flavored with a single aroma compound were characterized as thick, while those with a mixture of aroma compounds were perceived as fluid.

Sorting has been proposed as an alternative to descriptive analysis (DA) when the time and money commitments for a trained sensory panel are prohibitive. Sorting does not require any quantitative rating, requires a minimal level of instruction, requires no training, produces little fatigue and boredom and can be conducted with a large number of samples in a relatively short timeframe (Cartier *et al.* 2006, Bijmolt and Wedel, 1995; Chollet *et al.* 2011; Courcoux, 2012).

Cartier *et al.* (2006) examined perceptions of breakfast cereals through the use of sorting as an alternative to DA in mapping sensory data. Participants were asked to group cereals based on texture and flavor. They were then asked to describe each group. Data revealed that DA and sorting produced similar results with slight variations between the two methods. Data from sorting identified one group of cereals as being cracking/crumbly/crunchy, cocoa, choclolate and vanilla. Group two consisted of nutty flavors such as hazelnut. Groups three and four were composed of vanilla/biscuit cereals, and crispy/airy/light texture with chocolate flavor respectively. The sorting method was faster than DA (27% faster as conducted, up to 55% estimated based on automatic data acquisition techniques) and did not require any training. Further, untrained panelists produced consistent data over time, which implies that replication may not be required although additional repetitions may show additional dimensions in a product and add confidence when using the data to make decisions. Chollet *et al.* (2011) used a modified sorting procedure to collect sensory data on a selection of 15 distinct beers, in addition to classical DA. Panelists were asked to sort the beers into groups, and as a follow up step, were asked to describe each group with an adjective and a qualifying word that indicated intensity. So a consumer may describe a group as “very hoppy” or “a little sweet”. The same consumers also quantified eight sensory characteristics on a line scale a month after the sorting task. The data from both methods divided the beers into four distinct groups. Two of the groups identified, stout beers and non-alcoholic beers, were identical between the two methods. The other two groups were similar, although slightly different. In the sorting task, a group of Gueuze beers (a Belgian beer that blends young and old beers and then undergoes a secondary fermentation) formed a group, and the higher alcohol level beers were grouped together with hoppy beers. By comparison, the DA data the hoppy beers were grouped together and the Gueuze beers were grouped together with the beers with a high degree of alcohol. The authors determined that despite similarities, the data from traditional DA was more precise and easier to interpret while the sorting task was better able to provide global information about the basic characteristics of the beers due to the freedom of panelists to describe the groups however they chose. The groupings that are derived also have the potential for product innovation. How products are grouped together makes explicit the attributes that consumers use to categorize and classify a product. By seeking out under-represented groups, potentials for new and innovative products may be revealed.

Taxonomic free sorting and hierarchical sorting have been proposed as alternatives to traditional sorting methods. In taxonomical free sorting (TFS), participants are asked to sort products into groups based on traditional sorting methods, but then asked to put together the groups that they consider the most similar. This agglomeration of groups continues until there are only two groups left. The combining of groups provides an additional layer of perception information, which can be interpreted to better reveal relationships amongst products (Courcoux *et al.* 2012). Products that were grouped together in the original sorting were considered similar. Data was recorded from the sorting tasks in a dissimilarity matrix. Products grouped in the primary sorting task were scored as a 0 (similar). The level at which groups were combined became the associated dissimilarity score. The dissimilarity matrix was then standardized to account for the different number of groups produced by individual participants. Finally, the data was averaged across all participants and subjected to nonmetric MDS. TFS provided better insights into the relationships between products than traditional sorting techniques, although TFS required more involved data collection and interpretation.

Hierarchical sorting is another form of sorting that seeks to improve traditional sorting methods. Participants perform an initial sorting of products, and then continue to divide the groups until the products in a group are considered homogenous, creating a hierarchical tree (Cadoret *et al.* 2011). This method was applied to examine consumer perceptions of 25 commercial extra virgin olive oils (Santosa *et al*. 2010). Data was analyzed using the DISTATIS method, a specialized method based on MDS which takes into account the individual responses of each participant, rather than analyzing pooled results. DISTATIS produces two distinct perceptual maps. First, a consensus map is produced that represents the products based on each participant's responses. Rather than dots representing products, the consensus map displays confidence ellipses around products, taking into account the individual responses. A second map is also produced that represents the individual assessors, which can be used to analyze consensus, or lack thereof within a group (Abdi *et al*. 2007; Chollet *et al.* 2011).

The data produced in sorting is not as accurate or as robust as data produced from DA but be used as an alternative to DA when time, money and personnel are limited. The data is acceptable as a rapid sensory mapping technique, which can be applied to screening prototypes or large groups of products. It also shows promise as a technique that can be used with children or lesser-educated adults, since it requires no training and little instruction. Sorting can also be used to obtain standardized data about a product that eliminates differences that may arise out of different language, dialect, education levels or socio-economic status since the actual language used is not as important as the actual groups that are produced.

PROJECTIVE MAPPING & NAPPING

Projective mapping (PM), is a qualitative data collection technique which is used to create a “projection” of a product as a way to better understand a product in relationship to another product, or to better understand consumers and their reactions to products (Risvik *et al.* 1994). PM was first used in food science by Risvik *et al.* (1994) as an attempt to connect consumer research data with sensory data. It can be used to reveal overall product differences, or can be used in conjunction with other descriptive techniques (sorting, flash profiling, DA etc.) to help determine which attributes are most important in differentiating products (Kennedy, *et al.* 2009). PM differs from grouping methods in that PM respondents don’t form strict groups. Rather, similarities and differences are represented by the distance between each product. Whereas in grouping, a product is either grouped with another product, or not grouped, in PM every objects distance is measured and analyzed. Thus even in clusters of products, slight differences can be represented.

In PM, individuals are presented with a large blank piece of un-scaled white paper (typically 60cm square, but any size can be used) and asked to place products on the space so that products that are similar are placed close together (although not necessarily grouped), and products that are dissimilar are placed farther apart (Risvik, *et al.* 1994; Nestrud & Lawless, 2010). As distance between products increases, so does their perceived dissimilarity. Participants are allowed to base the similarity on whatever attributes they choose. Like sorting methods, similarities and differences are examined, but PM adds a layer of data over typical sorting methods in that distance between every product is measured, allowing small differences between products to be detected, and allowing direct comparisons between each product. As products are placed on the provided space, a map of the products is created. The coordinates of each product is recorded and subject to data analysis. PM is a holistic approach to data collection in which product assessors consider a product as a whole, rather than assessing the sensorial attributes individually (Pagès *et al.* 2010). Typically, similar products are compared, such as various wines, or salty snack foods (Nestrud & Lawless, 2010).

PM has many advantages over other data collection techniques. It can show better differentiation between products than sorting (King *et al.* 1998), and is faster and less complex to the consumer than similarity testing and scaling (Risvik *et al.* 1997). PM does not require more than minimal training, when compared to a trained DA panel, but provides similar data in less time, while remaining just as consistent over replications. (Risvik *et al.* 1994). Need to address value in innovation vs sensory research.

PM is often used interchangeably with the term napping, but there are slight differences in the two approaches. Napping is actually a specialized form of PM that specifies the use of 60cm x 40 cm white paper as the mapping surface, whereas PM has no set size, although 60cm x 60cm is typical. Pagès (2003) noted that assessors rely on the x-axis more than the y-axis to differentiate products on a map, and so the x-coordinates have a larger influence than the y-coordinates. This is why a nappe (French for tablecloth) is specified to have rectangular orientation with a larger x-axis. Napping also specifies the use of multiple factor analysis (MFA), where traditional PM has more flexibility in data analysis. MFA is similar to PCA in that is produces a map that represents perceived similarities as distances between samples, but has the added benefit of taking into account individual respondent differences, rather than using only a group average. Napping was first proposed by Pagès (2003) in a study of 10 white wines. Two groups of trained wine professionals were asked to evaluate a series of wines. The first panel organized their samples on a map similarly to PM. The second panel evaluated the same wines using classical DA techniques. Since then, data collected from projective mapping and its variants has typically been analyzed using MFA (Nestrud & Lawless, 2010; Pagès and Husson, 2001).

Kennedy and Heymann (2009) used projective mapping of milk and dark chocolates in conjunction with DA. Panelists sampled and sorted chocolates on a 60cm x 60cm white paper using PM methods. When panelists finished their sorting on their paper, the location of each sample was recorded as x- and y- coordinates. The same panelists were then trained as a DA panel over a two-week period. The trained panel evaluated the same chocolate samples for aroma, taste, hardness and grittiness on unstructured line scales. PM data was analyzed using MFA, and the DA data was analyzed using principal component analysis (PCA). Both data sets were then combined. Both PM and DA were able to differentiate the bitter from the sweet chocolates with further differentiation of the chocolates using terms such as fruity, cocoa, spicy and other descriptors. Data from PM and DA showed a high level of correlation among the data sets (RV>0.8).

King *et al.* (1998) used PM to analyze 18 snack bars with consumers in conjunction with sorting. One group of consumers evaluated the bars using PM, while a separate group of consumers evaluated the same bars through sorting. PM and sorting were both analyzed using MDS. Both methods were able to differentiate the bars based on their use as a meal replacement bar or a snack bar. PM was able to also differentiate based on chocolate content, which implies that PM may be able to reveal information that sorting may not. Barcenas *et al.* (2004) used PM in a study of 8 cheeses produced from ewes' milk. Assessors identified three distinct groupings of cheeses across three replications, each of which represented a different length of ripening. Both trained and untrained panelists assessed and organized the cheeses following standard PM procedures. The trained assessors performed better than untrained consumers, but both groups produced similar configurations.

Albert *et al.* (2011) used PM to study hot foods with complex textures. Untrained assessors sampled 9 samples of fish nuggets with varying batters and cooking methods. Samples were all cooked to proper internal temperature and held under an infrared lamp to maintain heat after cooking. PM data was analyzed using MFA. Assessors were able to differentiate the samples by texture attributes and batter type. In addition to PM, assessors used DA to analyze the fish nuggets. DA results were more accurate in describing the fish nuggets, but PM required less time and produced a map that correlated well with the DA data. Nestrud and Lawless (2008) used PM to study perception of citrus juices using 14 culinary professionals chosen for their experience in flavor evaluation, and 16 citrus juice consumers chosen for their lack of experience in flavor evaluation. Assessors were presented with 13 samples of citrus fruit juices that represented a wide variety of flavors. Following the mapping task, assessors were asked to rate each juice for sweetness, sourness, bitterness and other relevant attributes. Analysis of the PM and scaling data for the consumer group revealed a high level of agreement between the methods, but a lower level of agreement in the culinary professionals group, which may be attributed to their developed sensoria acuity.

Pagès *et al.* (2010) recently proposed an approach referred to as sorted napping that combines napping and sorting. Sorted napping involves a panelist creating their nappe, and then circling products to make groups based on whatever criteria they choose. The panelists then wrote names or descriptors for each group and each product. In this study, panelists evaluated eight samples of fruit smoothies in duplicate made from various fruit combinations. The map of the various smoothies was able to differentiate between general fruit composition of the smoothies. The grouping and word association information was able to identify specific sensory attributes such as thick and sweet, and associate these terms with the smoothies and smoothie groups.

Many other variations on PM have been utilized recently. In 2008, Perrin *et al.* studied wines and combined napping with ultra-flash profiling (UFP). Immediately following the mapping activity, assessors described each wine by appropriate terms directly on their map. They then added appropriate quantifiers and scaled that descriptor for each product. In addition to this modified nappe, DA, traditional napping, and free profiling were performed and comparisons made between the methods. Each of the methods examined was able to differentiate the wines similarly, and the addition of the UFP data to napping revealed which criteria were important for judges in discrimination. Napping with UFP could not replace DA though as a quantitative measure, but could be used when a trained panel is not available or when accurate descriptions are not necessary (Perrin *et al.* 2008). Partial napping (PN) was first suggested by Pagès (2003) and recently examined by Delholm *et al.* (2012) in a study different types of liver pâté. PN involves identifying relevant sensory modalities for a product (appearance, flavor, aroma…) and napping specific sensory modalities separately. PN data was highly correlated with data collected from traditional DA, and faster since it required little training, and shorter sessions. Louw *et al.* (2013) examined brandies with two panel groups of 10-12 consumers using both PM and PN. PN provided better results while remaining reliable, reproducible and repeatable for smaller sample sets which are preferable in high alcohol content beverages due to high fatigue levels. Drake et al. (2009) used a combination of home usage test, group discussion, and PM with 12 cottage cheese consumers, a technique called QMA (qualitative multivariate analysis) to identify drivers of liking for cottage cheeses. These results were comparable to those obtained from a traditional preference mapping study with DA and a 100 consumer CLT.

It is recommended that PM be limited to 10-20 samples as fatigue and adaptation can distort results (Schifferstein, 1996; Tang and Heymann, 2002). It should also be noted that by itself, PM does not actually characterize a product, which would need to be done through or in conjunction with DA and/or instrumental data (Pagès 2003; 2005).

CONCLUSIONS

Qualitative research methods offer insight to consumer motivations and thinking in a way that quantitative methods cannot, with a greater degree of flexibility. These methods require little to no training on the part of the assessor, and can reveal product dimensions that quantitative methods cannot through open ended techniques such as focus groups and means-end chain analysis. Although not a substitute for quantitative methods, qualitative methods can be used to enhance quantitative studies and with time or financial limitations, can be used as a substitute. Methods such as focus groups, ethnography and means-end chain can be used to better understand consumer desires and can provide data that can be used to refine an existing product, or produce a new product to meet those consumer needs. Other methods like grouping, sorting and projective mapping can be analyzed by using multidimensional scaling to produce perceptive maps. These powerful tools show perceived similarities and differences between products and the appropriate magnitude. These methods can serve as a faster and less expensive substitution for classical profiling, a preliminary approach to clarify or augment quantitative consumer tests, or can be used in the beginning stages of product development, to guide developers. Traditional qualitative research methods such as the focus group have proven their worth in scientific research. Novel approaches such as projective mapping have great potential in understanding consumer perceptions, and simplifying future research methods.

ACKNOWLEDGEMENTS

Funding provided in part by the Dairy Research Institute (DRI) (Rosemont, IL). The use of tradenames does not imply endorsement or lack of endorsement by those not mentioned.

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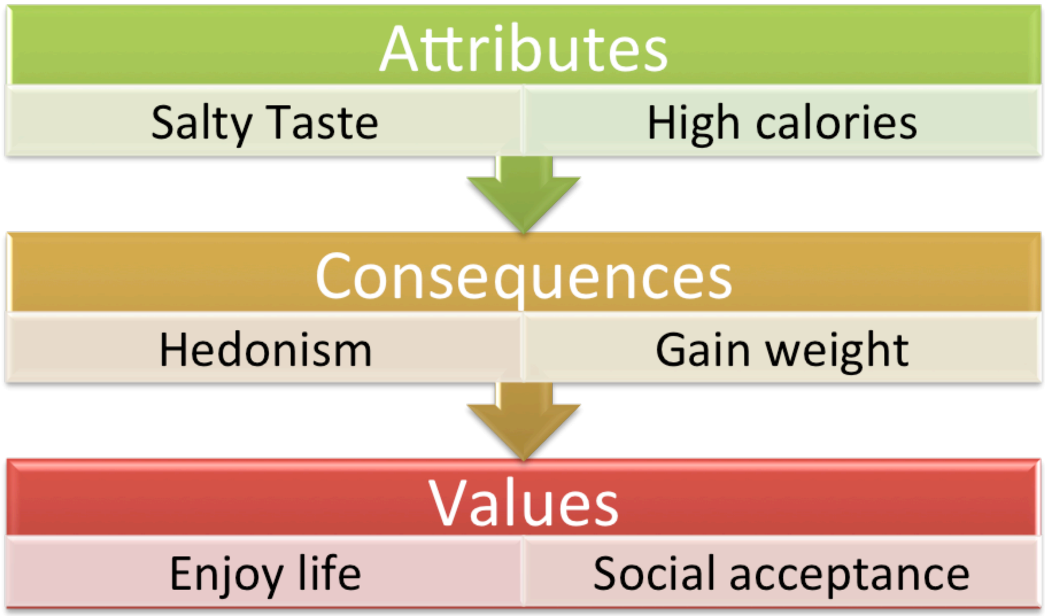

Figure 1: Example Means-End Chain for Potato Chips

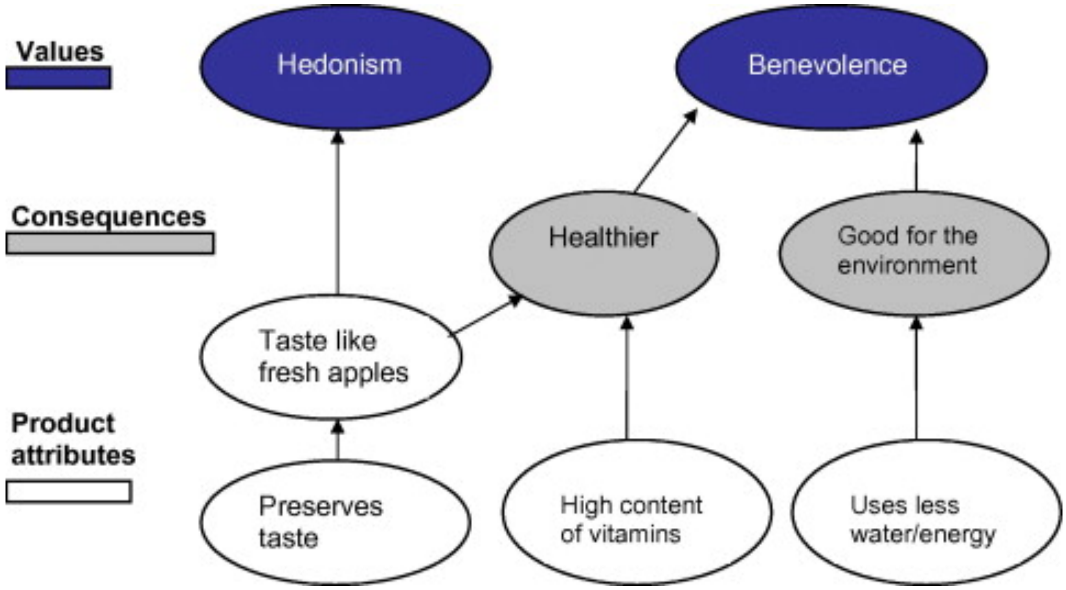

Figure 2: Simplified Hierarchical Value Map of consumer choice of high pressure processed juices in Norway (Taken from Olsen *et al.* 2011)

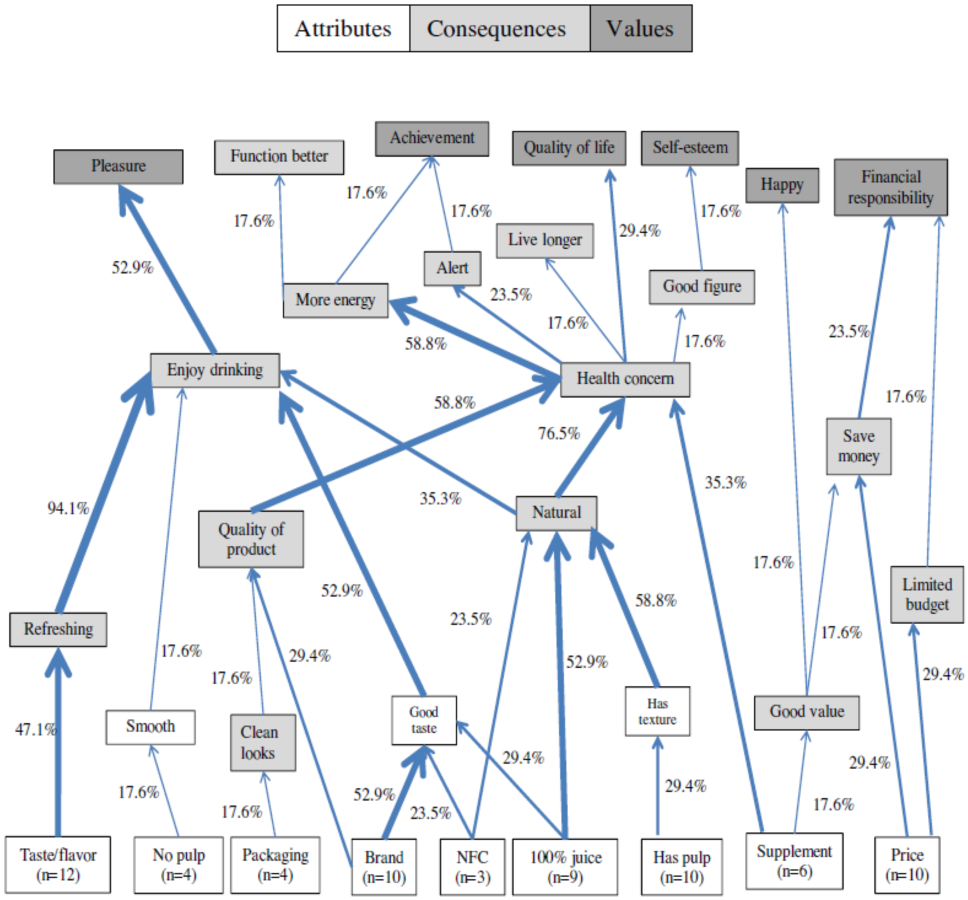

Figure 3: Hierarchical Value Map of consumer choice of high pressure processed juice (Taken from Kitsawad and Guinard, 2014)

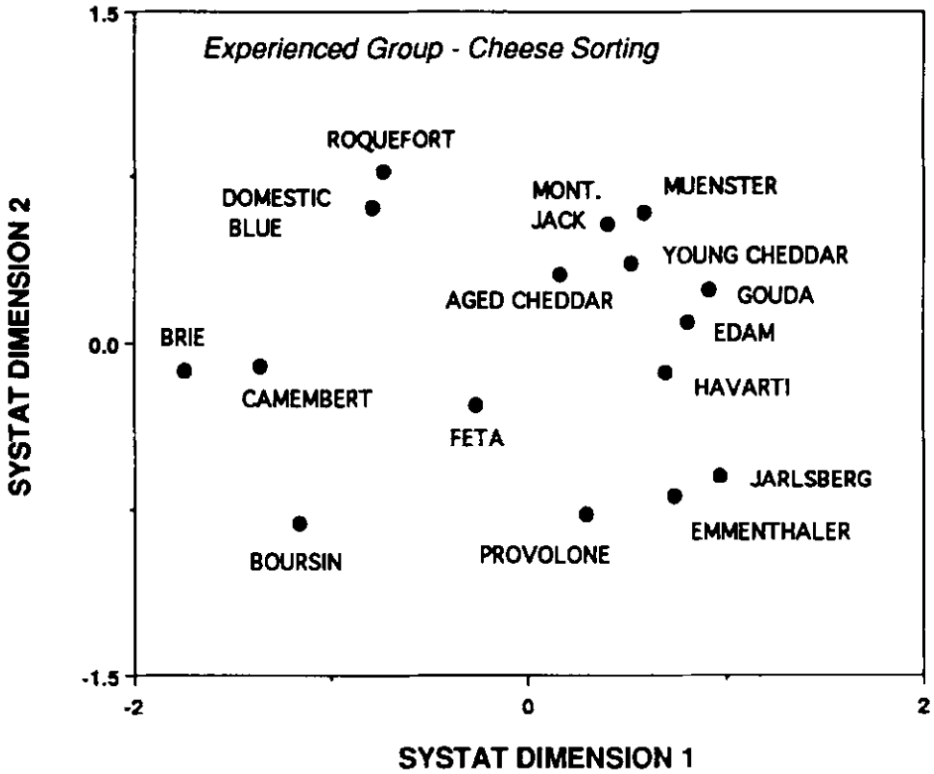

Figure 4: Two-dimensional MDS from cheese name sorting among consumers experienced with European cheeses (Taken from Lawless *et al.* 1995).

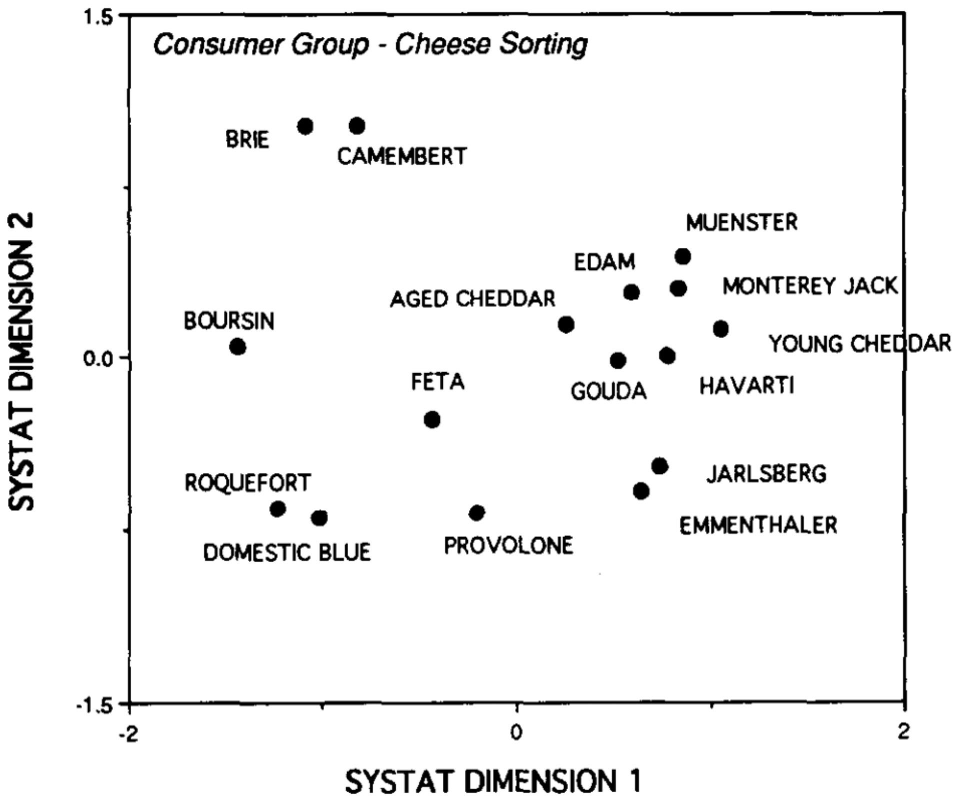

Figure 5: Two-dimensional MDS from cheese name sorting among consumers not experienced with European cheeses (Taken from Lawless *et al.* 1995).

CHAPTER 2: DETERMINING CHILDREN'S PERCEPTIONS, OPINIONS, AND ATTITUDES FOR SLICED SANDWICH BREADS

DETERMINING CHILDREN'S PERCEPTIONS, OPINIONS, AND ATTITUDES FOR SLICED SANDWICH BREADS

JERVIS, M.G.[1,] JERVIS, S.M.[1], GUTHRIE, B.[2], and DRAKE, M.A.[1,3]

[1] *Department of Food, Bioprocessing and Nutrition Sciences*

North Carolina State University

Raleigh, NC 27695

[2]*Cargill Global Food Research*

Wayzata, MN 55391

[3]Corresponding author. TEL: (919) 513-4598; FAX: (919) 515-7124; EMAIL: mdrake@ncsu.edu

RUNNING TITLE: Children's perceptions for breads

ABSTRACT

The objective of this study was to determine the ideal whole grain bread product for children (8-17y). Focus groups (3 focus groups, n=23), emotional response and appearance liking surveys (n=172), and an adaptive choice based conjoint survey (n=173) were conducted with children. Across elementary, middle and high school aged children, children preferred bread with a light crumb (inside of the bread), a light crust, and no topping or added textures or visual cues in the crumb. Children had generally negative feelings for breads with dark colored crumb and crust, but had generally positive feelings for breads with light colored crumb and crust. Breads with white crumb were liked more than bread with dark crumb, regardless of crumb particles, crust or crust topping. Crust color had no impact on overall appearance liking score. These results demonstrate that regardless of age, children like soft breads with light colored crumb and crust with no fillings or toppings.

PRACTICAL APPLICATIONS

Increased consumption of whole grain breads is an effective technique in decreasing obesity in American children. Aside from reduction of obesity, health benefits of increased whole grain intake include reductions in cardiovascular disease, type II diabetes and certain cancers. Although these health concerns are not usually concerns with children, eating habits developed in childhood can carry over to adulthood. Children's likings of bread products have an inverse relationship with whole grain vs. refined grain content. This study demonstrated that development of a whole grain bread product that is desirable to children in both visual appearance and taste is an important step towards increased whole grain consumption by children and a decrease in obesity rates in children.

KEY WORDS

Children, Whole Grain Sandwich Bread, Adaptive Choice Based Conjoint, Emotions

INTRODUCTION

In data collected from the years 2005-2008, 16.2% of US children ages 2-19 y were classified as obese based on their weight and the weight of their peers (USDHHS, 2013). The obesity rate in children increased nearly 22% from 2000-2010 (USDHHS, 2013). Both government and commercial initiatives have been implemented in an effort to reduce the obesity of rates of children and adults, and improve general health (Kraak *et al.* 2009; Adachi-Meija *et al.* 2011). The Healthy People 2020 initiative organized by the US government includes a targeted 10% reduction in obesity rates to 14.6% as the goal for the year 2020 (USDHHS, 2013).

One promising intervention designed to combat rising childhood obesity rates is increasing consumption of whole grain products – specifically whole grain sliced sandwich breads. Children consume only about one third of the amount recommended of whole grains (Sadeghi, 2008). Increased consumption of whole grains has been linked to lowered rates of obesity, cancers, cardiovascular disease and diabetes (Slavin *et al.* 2001). Recent studies that include whole wheat bread substitutions for refined grain bread products decreased the levels of obesity in children (Marcus *et al.* 2009). As such, increased consumption of whole grain bread products by children is a desirable outcome in terms of health. One reason that whole grains are not consumed as frequently as refined grain products is the inverse relationship of whole grain content of a bread product to liking scores. Delk and Vickers (2007) found that in elementary school children, liking of bread rolls decreased as whole grain content of bread increased. In addition to taste liking, the appearance of bread is an important attribute that requires careful study. Appearance of a food product is a main driver of food choices for children (Leon et al, 1999; Marshall *et al.* 2006). With these facts in mind, an important step towards increased whole grain consumption by children would be to produce a whole grain bread product that retains some of the visual characteristics of white, refined flour breads in order to remain visually appealing.

Conjoint analysis is a reliable method of measuring children's food preferences and the importance of the varying attributes of a food product. In order to conduct conjoint analysis on products that may not be commercially available, the use of pictures or models in place of actual product is required. Recently, Olsen *et al.* (2012) demonstrated that using conjoint analysis with pictures of buns and juice yielded results consistent with visual hedonic preference measures and product choices in children. Guthrie *et al.* (2000) conducted a study with 3-5 year olds and reported that tasting a food resulted in the most reliable results (r=0.81), followed closely by judging based on pictures on a computer screen (r=0.75). Jarmillo *et al.* (2006), Calfas *et al.* (1991), and Vereecken *et al.* (2010) all demonstrated that testing food preferences of children using images in place of actual product was a reliable method as long as children were familiar with the foods.

The relationship between foods and the emotions that they elicit is a recently researched concept. It is particularly important as a way to distinguish between foods with similar liking scores. Recent work has shown that emotions analysis can be conducted with the actual food product or with images of a food (Cardello *et al.* 2012). Richins (1997) showed that an emotions questionnaire was reliable when surveying across a large number of products. The reliability of emotional responses to food was verified by Cardello *et al.* (2012), and was consistent with prior studies that verified the reliability of emotional responses to products other than food (Chrea *et al.* 2009, Richins, 1997). Emotional responses of children to images of food have yet to be researched in depth. The importance of children as consumers and decision makers in food purchase and consumption warrants further research into the emotional responses of children when presented with a visual stimulus of a food product.

The goal of this study was to use determine the perceptions and attitudes of children towards a range of different bread composite pictures that represented possible whole grain bread products that could be mass produced. Focus groups were conducted initially in order to develop an appropriate lexicon of emotions and responses of children towards various foods. An emotions and liking survey was used to assess children's emotional responses towards various sandwich breads. Finally, adaptive choice based conjoint (ACBC) was applied to determine what drives liking of bread in children and to create an ideal whole wheat bread with visual appeal. Pairing the results of a conjoint study of sliced sandwich breads, which can identify the attributes of a sandwich bread that children find important, and the emotional responses of children towards various bread products can help manufacturers produce a whole grain bread product that children will feel comfortable with and enjoy eating.

METHODS

This study involved three main components. First, children participated in focus groups in order to develop an appropriate lexicon to be used in the emotions, picture liking, and conjoint surveys. Following the focus groups, children completed a computer based emotional response survey in which they were shown 36 composite bread images. Emotional responses and overall liking of each bread picture were evaluated. After completion of the ACBC survey, an age and language appropriate adaptive choice based conjoint (ACBC) survey was developed and conducted to determine the utilities of various composite whole and refined grain breads and their individual attributes.

Participants

All testing was conducted in compliance with NCSU IRB regulations (protocol 2937) Parents of children ages 8-17 y were contacted using an online database of >5000 consumers from the greater Raleigh/Durham/Chapel Hill, NC area maintained by the Sensory Service Center of North Caroline State University. To quality for any of the testing, their children had to be regular consumers of sliced sandwich breads. Twenty four children, ages 8-13 y, were recruited to participate in one of three focus groups. Children were assigned to one of the 3 focus groups to allow for an even distribution of ages and genders. These participants were also invited to participate in the conjoint and emotions surveys in the second part of this study. An additional 200 children, ages 8-17 y, were recruited through the same online database to participate in the emotions and conjoint surveys. The emotions survey and conjoint survey were conducted in the same session, with an optional rest period for children in between surveys. Participants were compensated with a $60 gift card. A total of 172 children participated in the emotions survey adaptive choice based conjoint surveys. The same respondents were used for both surveys to allow direct comparison of utility scores and emotional responses.

Focus Groups

A total of three 60 minute focus groups were conducted. Each focus group was comprised of 6-8 children ranging from 8-13 y. These focus groups were conducted on the campus of North Carolina State University and were led by a trained focus group moderator. Focus groups were audio and video recorded for later reference. Parents of participating children viewed the focus group through a closed circuit television system from an adjacent room. In the focus groups, children were first instructed in the use of appropriate emotional language and then practiced the use of emotion words to describe how various pictures made them feel. At first, the pictures that children responded to were of high interest situations (a clown, a roller coaster, a beach). After children were comfortable responding to images with emotions, they were shown pictures of various foods that were chosen to elicit a strong response from children. The foods shown were: apple, bacon, broccoli, chocolate chip cookie, frosted doughnut, hamburger, strawberry ice cream cone, sliced peaches, sliced pineapple and a salad. After each picture, children were asked "How does this food make you feel?" and "How would you feel if your family served you this food for lunch/dinner?" After children were shown pictures of these foods, they were presented with pictures of a variety of breads and asked the same emotional response questions. Bread images were chosen to represent a wide variety of breads and bread attributes including different colors, shapes, toppings and fillings. Finally, children were given laminated pictures (approximately 3"x5") of various foods and asked to group the pictures based on their emotional responses to the foods. They were asked to give each group an emotional name. After the focus groups, emotion responses were tallied, consolidated in order to reduce redundancy, and categorized as positive, neutral or negative. The highest frequency words were chosen to use in the conjoint and emotions surveys.

Picture Generation

Pictures representing selected, bread attributes and their respective levels were created using methods developed by Jervis *et al.* (submitted). Composite bread pictures were created using the same procedures. These levels and composite breads are shown in Figures 1 and 2 and fully detailed in Table 1.

Emotion and Liking Surveys

A check all that apply (CATA) emotions and liking survey was created using SSI Web (Sawtooth Software version 8.0.22, Orem, UT). Children were asked if they attended elementary, middle or high school, and then presented with an explanation of the composite bread pictures prior to beginning the survey (Figures 3, 4). All 36 composite pictures were presented to each respondent in a monadic sequential randomized design (Figure 2). For each picture presented, children were asked to choose from a block of emotional responses how that picture made them feel, and/or how they would feel if they were served a sandwich with that bread. King and Meiselman (2008) developed the EsSense Profile as a method of measuring emotional responses. This method includes 39 emotional responses developed for testing with adults. Due to the age group and reading abilities of the respondents to be tested, we proposed that a smaller bank of emotional responses would be appropriate. Children could choose from the following emotional responses based upon the words generated by the focus group participants: confused/bewildered/iffy, disappointed, disgusted, excited, happy, interested, satisfied, strange/awkward/weird, surprised, uninterested, upset, and other. The

12 emotions words were presented in alphabetical order (King *et al.* 2010). If the respondent chose, other, they were able to enter their emotional response. The emotional responses presented in the CATA section were chosen from focus group responses and were appropriate to the entire age range of respondents. These responses also reflected positive, neutral and negative responses. Desmot and Shiffereson (2008) determined that food experiences were mainly associated with positive emotions. As such, the EsSense Profile includes primarily positive emotional responses, and only three negative. Due to our smaller number of emotional responses used, we felt it important to reflect different levels and aspects of negative responses. Children were then asked to evaluate their overall liking of the appearance of the composite bread product picture using a modified version of the Peryam-Kroll hedonic scale for children (Kroll, 1990), where 1=super bad and 7=super good. Children took approximately 10-15 minutes to complete this survey. After evaluating all 36 pictures, children were presented with a screen with an affirmation message assuring them that they were doing well, and allowed to take a 5 minute break before proceeding to the conjoint survey.

Adaptive Choice Based Conjoint

An ACBC survey was created using SSI Web (Sawtooth Software version 8.0.22, Orem, UT). Levels of crust, crumb, crust topping and crumb particles are represented in Figure 1. Non-picture attributes were also identified for this study. These attributes included crust texture (hard or soft), middle of bread/crumb texture (moist, soft, chewy, smooth, squishy, grainy, dense or firm), label claim ("tastes great," "whole grain," "tastes like mom made it," "high fiber," "soft," "all natural," or "no artificial ingredients or preservatives"). Levels for all attributes were derived from Jervis *et al.* (submitted).

The ACBC study began with a build your own (BYO) activity where children were presented with each level of each attribute and asked to build the best bread possible. Following the BYO section, children were presented with ten screening tasks in which three product concepts were presented. Each product concept was created based on the responses to the BYO activity. Two or three attributes were permitted to vary from the BYO levels chosen for each product concept. For each product concept, one level for each attribute was displayed for each attribute, and pictures used to represent the crust and middle of the bread (crumb) to create a composite bread product. Children responded to each product concept by choosing from the responses "I'd eat it" or "I would not eat it." Throughout the survey, five questions were presented in which participants chose any unacceptable levels, and four questions were presented where children chose must have levels (Orme, 2010; Jervis *et al.* 2012,). Following the screening task, participants were presented with a tournament activity in which a maximum of 20 product concepts were used with a minimum of three concepts for each choice task (Orme, 2010; Jervis *et al.* 2012). At the conclusion of the survey, participants were thanked and received a $60 gift card.

Statistical Analysis

Focus group emotional responses were analyzed using chi-square (XLSTAT). Emotional responses were analyzed using principal component analysis using XLSTAT Addinsoft version 2010.5.02 (New York, NY). Overall appearance liking scores from the emotions and liking survey across and between school levels were analyzed using a two-way analysis of variance (ANOVA) with Fisher's least significant difference (LSD) as the post hoc test (XLSTAT).

Individual utility scores from the conjoint were extracted using Hierarchical Bayesian estimation (HB). The utility scores were rescaled using a zero-centered differences method (Orme, 2010; Jervis *et al.* 2012). The zero-centered scores are used in order to facilitate comparisons and to standardize all of utility scores within any given attribute. The zero-centered utility scores were then analyzed across school age using two-way ANOVA using Fisher's LSD as the post hoc test (XLSTAT). Importance scores were determined by first calculating the range of utility scores for each attribute. The range was then divided by the total utility range and multiplied by 100 (Orme, 2010). Importance scores across school age were compared using two-way ANOVA and Fisher's LSD as the post hoc test (XLSTAT). All statistical analysis was carried out at a 95% significance level.

RESULTS & DISCUSSION

Focus Groups

A total of 254 emotion responses were recorded during the three focus groups. Responses were examined and words with identical or very similar meanings were condensed in order to reduce redundancy. This resulted in 51 unique responses. These responses were then categorized as positive, negative or neutral responses. The top 20 responses are shown in Table 2 along with their classification. Of all the responses given, 89 were positive, 59 neutral and 105 negative. Of the 11 responses chosen, 4 were classified as positive, 4 as neutral and 3 as negative. A fourth choice of "other" was also provided. The

11 most used responses ($p<0.05$) were chosen as emotions terms to be used in the emotions survey. These words were chosen in order to provide adequate variety for each classification, without overwhelming children with choices that may lead to confusion or frustration.

Reactions to unfamiliar bread, and breads with toppings and/or fillings were often met with skepticism and strong reactions, both physical and verbal, from the children. Familiar white and whole wheat breads were met with a generally positive but subdued response. These results are consistent with work by Olsen *et al.* (2012) in which children showed clear preferences for white breads in a conjoint study. One bread was reported to look "sweet" by 14 of the 23 children. This assumption was attributed by the children to an orange carrot colored crumb. This bread was met with positive reactions despite the crumb particles and unfamiliar appearance. These children were willing to overlook their neophobia of new and/or unfamiliar breads if they anticipated sweet tasting bread. Children based their perception of taste for unfamiliar breads from both past experiences and visual cues.

Emotions Survey

Relationships between breads and emotional responses were analyzed using principal component analysis (PCA). Emotional responses were recorded using a check all that apply (CATA) format. The PCA of breads and emotional responses explained 92% of the variability within the set, with 86.7% loading on principal component (PC) 1 (figure 5). Generally positive emotional responses (surprised, interested, happy, satisfied, excited) loaded strongly on the negative axis of PC1, while generally negative emotional responses (confused/bewildered/iffy, strange/weird/awkward, disgusted, uninterested, disappointed, upset) loaded strongly on the positive axis of PC1. Bread #16 (white crumb, dark crust, no crumb particles, no crust topping) and bread # 3 (white crumb, light crust, no crumb particles, no crumb toppings) were the most highly associated with positive emotional responses. The two breads were composed of a white crumb, no crumb particles and no crust topping. Bread 16 had a light crust, and bread 13 had a dark crust. Children had the strongest positive emotional responses to breads that were uniform and were free of added flakes, seeds or oats. This result is consistent with the results of the focus groups, in which children had positive responses to uniform appearance of sliced bread.

Gastón *et al.* (2010) recently used PCA to analyze CATA data in a study of chocolate milk desserts. In it, 18 terms were presented in a CATA block, which represented sensorial attributes relating to the sample. Significant differences were found in the frequency of word choices, and consumer perceptions were able to be differentiated using PCA. Use of a CATA survey is advantageous in that is a natural and simple exercise for consumers as opposed to scaled evaluations, and still allows for responses to be differentiated and analyzed. This method was chosen for our study as it was important to ensure that the response tasks were simple and natural for children who have a lower mental stamina compared to an adult, yet still allow for quantitative analysis.

Crumb color had the greatest impact on children's emotional response. White crumb (breads 1-18) was strongly associated with positive emotional responses and dark crumb (breads 18-36) was more strongly associated with negative emotional responses. This observation for crumb color was also affected by crumb particles and crust topping. Children overall had more positive responses to dark colored crumb breads if they appeared uniform in composition as opposed to a lighter color bread that was not uniform. Breads 25 (brown crumb, dark crust, flake crumb particles, no crust topping) and 31 (dark crumb, dark crust, no crumb particles, no crust filling) were seen more positively than breads 2 (white crumb, dark crust, seed crumb particles, oat-like crust topping), 11 (white crumb, light crust, flake crumb particles, oat-like crust topping) and 8 (white crumb, dark crust, flake crumb particles, oat-like crust topping). These dark crumb breads shared the attributes of having no crust topping, and no or flake crumb particles. These white crumb breads had oat-like crust topping, which was more negatively viewed than the other crust toppings. Breads with crumb particles and crust toppings were seen more negatively than breads with no particles and no topping. Seeds as a crumb particle and oat-like crust topping were the most negative levels in their respective attributes for both white crumb and brown crumb breads. Children had a more positive response to sliced sandwich bread that appeared uniform than one that did not regardless of crumb color however the preference was for a lighter color crumb. In order to create sliced sandwich bread that contains whole grains and is still appealing to children, the bread must appear uniform in crust and crumb and any particles added to the crumb or crust need to blend visually. Recent work by Delk and Vickers (2007) showed that using blends of refined and whole-wheat flour in breads could be used to increase consumption and acceptability of whole wheat bread products by children. They proposed that a series of 14 threshold steps, gradually increasing whole grain flour content, would be necessary to increase whole-wheat percentages in a bread roll from 0 to 91%.

Liking Scores

Liking scores were consistent with results from emotions testing (Table 3). Breads with stronger positive emotional responses were liked more than breads associated with a stronger negative emotional response. Breads 16 and 13 scored highest in liking ($p<0.05$). These breads had white crumb, no crumb particles and no crust topping. Breads 21, 33, 29, 27, 26, 36, 23, 20, 35 and 32 received the lowest liking scores ($p<0.05$). These breads had dark crumb, both light and dark crust, flake or oat-like crust topping, and a variety of crumb filling in no particular order. These results suggests that crumb particulate is not as important of an attribute in dark crumb breads as in white crumb breads because a particulate in a dark crumb bread is more difficult to see than in a light crumb bread. In breads with white crumb, no topping was preferred ($p<0.05$) in all but one circumstance. Bread 7 (white crumb, dark crust, flake crumb particles, no crust topping) scored at parity with breads 18, 17, 15 and 14 – each of which had either flakes or oats for crust topping. Following these breads, flakes as a crust topping were liked more so than an oat-like crust topping. In breads with dark crumb, crumb particulate, and crust color did not impact liking scores and can been seen in all levels throughout the most and least liked dark crumb breads. Crust toppings did affect liking scores similar to white crumb breads. No toppings were preferred to oat toppings ($p<0.05$). Flakes as a crust topping were liked more than oats and liked less than no topping. These findings agree with responses from the emotions survey, and are consistent with previous findings by Olsen *et al.* (2012) who found that images of white buns were far more popular among children than darker buns, and that the fewer toppings and fillings a bun had, the more popular it was.

Conjoint Survey

Importance scores reflect the importance of each attribute in the decision making process of the respondents. Crumb picture was the most important attribute for children (Table 4). This result is consistent with the findings from the emotions survey in which children had strong positive emotional reactions to white crumb breads and strong negative emotional reactions to dark crumb breads, and visual liking scores in which white crumb breads received higher liking scores than dark crumb breads. The next most important attribute was crust, followed by flavor/taste, crumb texture, label claim and finally, crust texture. It is important to note that the two most important attributes were visual attributes. There was no difference in attribute importance scores between grade levels ($p<0.05$) for crumb, crust appearance, crumb appearance, crumb texture and label claim. Middle school children placed equal importance ($p<0.05$) on crust appearance and flavor/taste. This shows that middle school children were considering all attributes in their decision and not relying solely on visual cues. This is important to note due to concerns that respondents may overly rely on image importance and not place enough importance on the non-visual attributes in their decision making (Jervis *et al.* submitted). Elementary school children placed equal importance ($p<0.05$) on label claim and crust texture, although these two attributes were the lowest across all school age groups.

A comparison of utility scores for visual assessment of crumb is shown in Table 5. A white, uniform crumb had the highest utility followed by white with flakes and then white with seeds. There is an overall agreement that a white crumb is the most attractive crumb in sliced sandwich breads in children 8–17 y ($p<0.05$). For elementary and high school children, white crumb and white crumb with flakes were ranked at parity for their respective school-age groups ($p<0.05$). A dark crumb with flakes, and dark with no particulate were at parity, and dark with seeds was the least desirable. Comparing utility score distributions across school age, middle school children ranked the three dark crumb attributes as equally desirable. A higher degree of separation between visual evaluation of crust levels was observed compared to crumb picture levels. Despite overall statistical separation between crusts with toppings, individual school-age groups showed variability in their preferences and tolerances for crusts with toppings. This may be attributed to the combination of color of the actual crust, and the appearance of the toppings included. Light crust with no topping and dark crust with no topping scored at parity across children of all ages. Middle school children placed more utility on a light crust with no topping over a dark crust with no topping. Crusts with topping were significantly less desirable across both light and dark crusts. Light crust with flakes was preferred to light crust with oats. Dark crusts with toppings were least desirable, but unlike white crusts, oats were preferred to flakes as a topping. This may be due to the oats disguising the dark crust and making it appear lighter overall. Elementary and middle school children scored white crust with flakes and white crust with oats at parity. They also ranked light crust with oats and dark crust with oats at parity, and dark crust with oats and dark crust with flakes at parity. Middle school children ranked the light crust with toppings at parity, and the dark crusts with toppings also at parity. High school students ranked white crust with oats and dark crust with oats at parity, and both dark crusts at parity. Overall, there was a clear preference for breads with no topping among school age children. Jervis *et al.* (submitted) reported adults preferences for the same crust and crumb pictured attributes to be higher for crusts with topping and crumbs with particulates of seeds followed by flakes. This is in antithesis to what is reported here for children demonstrating the need for sliced bread products that are focused towards children's preferences.

Utility score distribution of flavor/taste claim was the most important non-visual attribute for children (Table 5). Across all school groups, the most attractive claim was that of no flavor/taste. If there is to be a flavor/taste attribute on the bread package, buttery was the most attractive followed by sweet or toasted, wheaty, mild, yeasty or earthy, with nutty being the least desirable ($p<0.05$). For the crumb texture attribute, a soft crumb was the most attractive level, followed by smooth. High school children ranked soft and smooth at parity, but elementary and middle school children showed a preference for soft. The next most attractive crust texture was moist, followed by chewy, squishy, firm or grainy (at parity) and grainy or dense (at parity). The most attractive label claim was that of bread that "tastes great" followed by bread that "tastes like mom made it", at parity with bread that was "soft". Elementary school children ranked the "tastes great" label claim higher than any other school-age group ($p<0.05$). The remaining label claims were all health-conscious label claims. These label claims were less attractive to children than taste and texture label claims. The most attractive of these label claims was all-natural, followed by whole grain and then high fiber and no artificial ingredients or preservatives which scored at parity for the least attractive label claim. Children are less product driven by health composition label claims than with label claims involving taste and texture. This follows with the individual attribute importance scores that ranked flavor/taste above all other non-visual attributes. All age groups reported a soft crust texture to be more desirable than a hard crust texture.

CONCLUSIONS

Children desire bread that that is light in crust and crumb color, with no toppings and no crumb particles. Children showed a positive emotional response to lighter breads with no toppings or fillings in the focus group and in the emotions survey. Liking scores were generally higher in these breads and conjoint analysis showed that visual attributes were more important than non-visual cues. Of the visual attributes, white was preferred to dark in crust and crumb. In order to produce a whole grain sliced sandwich bread that is sensorially appealing to school-aged children, efforts should be made to ensure that crumb and crust color are light and free of toppings or fillings. Children do not find flavor claims appealing but prefer a mild/low flavor bread that tastes great. Overall children desire sliced sandwich bread that is light in color, uniform, soft, and mild in flavor. Formulating sliced sandwich bread with whole grains that meets these criteria is difficult due to the sensory attributes of whole grain products. Adding whole grains in such a way as to not be as noticeable to children visually and texturally will be key to making acceptable sliced whole grain sandwich bread.

ACKNOWLEDGEMENTS

Funding provided in part by Cargill, Inc. The use of tradenames does not imply endorsement nor lack of endorsements by those not mentioned. Horizon Milling, LLC and the assistance of Gang Guo are gratefully acknowledged.

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Figure 1. Pictures of Crust and Crumb for Emotions and Liking Surveys and ACBC Survey.

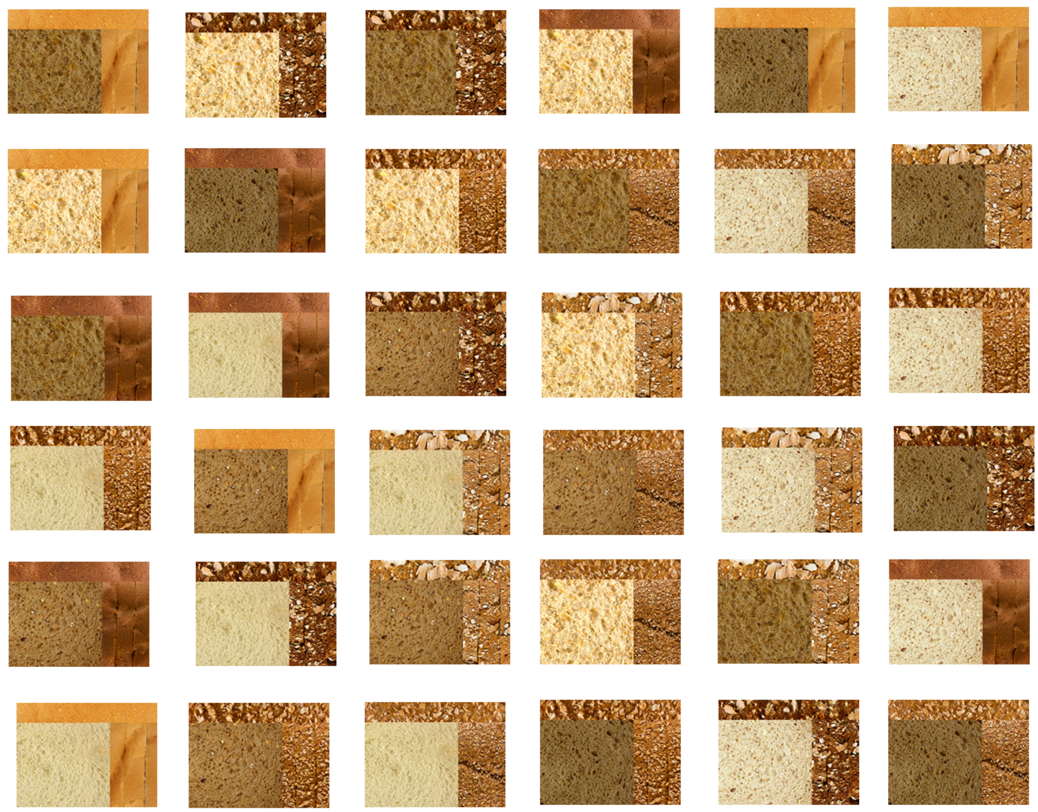

Figure 2. Thirty-six Composite Pictures for Emotions and Liking Survey

Table 1 – All Bread Composites and their Attributes and Levels

Bread Number	Crumb Color	Crumb Particles	Crust Color	Crust Topping
1	White	Seeds	Dark	None
2	White	Seeds	Dark	Oat-Like
3	White	Seeds	Dark	Flake-Like
4	White	Seeds	Light	None
5	White	Seeds	Light	Oat-Like
6	White	Seeds	Light	Flake-Like
7	White	Flakes	Dark	None
8	White	Flakes	Dark	Oat-Like
9	White	Flakes	Dark	Flake-Like
10	White	Flakes	Light	None
11	White	Flakes	Light	Oat-Like
12	White	Flakes	Light	Flake-Like
13	White	None	Dark	None
14	White	None	Dark	Oat-Like
15	White	None	Dark	Flake-Like
16	White	None	Light	None
17	White	None	Light	Oat-Like
18	White	None	Light	Flake-Like
19	Brown	Seeds	Dark	None
20	Brown	Seeds	Dark	Oat-Like
21	Brown	Seeds	Dark	Flake-Like
22	Brown	Seeds	Light	None
23	Brown	Seeds	Light	Oat-Like
24	Brown	Seeds	Light	Flake-Like
25	Brown	Flakes	Dark	None
26	Brown	Flakes	Dark	Oat-Like
27	Brown	Flakes	Dark	Flake-Like
28	Brown	Flakes	Light	None
29	Brown	Flakes	Light	Oat-Like
30	Brown	Flakes	Light	Flake-Like
31	Brown	None	Dark	None
32	Brown	None	Dark	Oat-Like
33	Brown	None	Dark	Flake-Like
34	Brown	None	Light	None
35	Brown	None	Light	Oat-Like
36	Brown	None	Light	Flake-Like

Table 2: Top Focus Group Emotional Responses

Words used in emotional survey	*Disgusted*	*13.36% a*	*Negative*
	Happy	*9.31% ab*	*Positive*
	Excited	*6.88% bc*	*Positive*
	Bewildered/Confused/Iffy	*6.88% bc*	*Neutral*
	Weird/Strange/Awkward	*6.88% bcd*	*Negative*
	Upset	*4.86% bcde*	*Negative*
	Uninterested	*3.64% cdef*	*Neutral*
	Interested	*3.64% cdef*	*Positive*
	Satisfied	*3.24% cdef*	*Positive*
	Surprised	*3.24% cdef*	*Neutral*
	OK	*3.24% cdef*	*Neutral*
Words not used in emotional survey	Sad	2.83% def	Negative
	Scared	2.83% def	Negative
	Nauseated	2.83% def	Negative
	Crazy	2.43% ef	Neutral
	Good	2.43% ef	Positive
	Creepy/Creeped Out	2.02% ef	Negative
	Chipper	2.02% ef	Positive
	Cheap	2.02% ef	Neutral
	Awesome	1.62% f	Positive

Different letters within column are different ($p<0.05$)

Table 3: Appearance Liking Scores

Bread	Crumb:	Filling	Crust:	Toppings:	Liking Score Mean
16	White	None	Light	None	**5.84 a**
13	White	None	Dark	None	**5.62 a**
4	White	Seeds	Light	None	**5.27 b**
10	White	Flakes	Light	None	**5.01 bc**
1	White	Seeds	Dark	None	**4.82 cd**
18	White	None	Light	Flakes	**4.57 de**
7	White	Flakes	Dark	None	**4.51 e**
17	White	None	Light	Oats	**4.46 e**
15	White	None	Dark	Flakes	**4.44 e**
14	White	None	Dark	Oats	**4.34 ef**
6	White	Seeds	Light	Flakes	**4.12 fg**
3	White	Seeds	Dark	Flakes	**4.05 fgh**
12	White	Flakes	Light	Flakes	**3.98 ghi**
9	White	Flakes	Dark	Flakes	**3.97 ghi**
5	White	Seeds	Light	Oats	**3.94 ghi**
25	Dark	Flakes	Dark	None	**3.91 ghij**
2	White	Seeds	Dark	Oats	**3.80 hijk**
28	Dark	Flakes	Light	None	**3.78 hijk**
31	Dark	None	Dark	None	**3.71 ijkl**
11	White	Flakes	Light	Oats	**3.63 jklm**
22	Dark	Seeds	Light	None	**3.60 lkm**
19	Dark	Seeds	Dark	None	**3.53 klmn**
8	White	Flakes	Dark	Oats	**3.52 klmn**
30	Dark	Flakes	Light	Flakes	**3.48 lmno**
34	Dark	None	Light	None	**3.44 lmnop**
24	Dark	Seeds	Light	Flakes	**3.40 mnopq**
21	Dark	Seeds	Dark	Flakes	**3.39 mnopqr**
33	Dark	None	Dark	Flakes	**3.39 mnopqr**
29	Dark	Flakes	Light	Oats	**3.34 mnopqr**
27	Dark	Flakes	Dark	Flakes	**3.30 mnopqr**
26	Dark	Flakes	Dark	Oats	**3.29 nopqr**
36	Dark	None	Light	Flakes	**3.24 nopqr**
23	Dark	Seeds	Light	Oats	**3.22 opqr**
20	Dark	Seeds	Dark	Oats	**3.15 pqr**
35	Dark	None	Light	Oats	**3.13 qr**
32	Dark	None	Dark	Oats	**3.09 r**

Different letters within a column are different ($p<0.05$)
Questions answered on a 7 point feeling scale where 1=super bad, 4=maybe good or maybe bad, and 7=super good

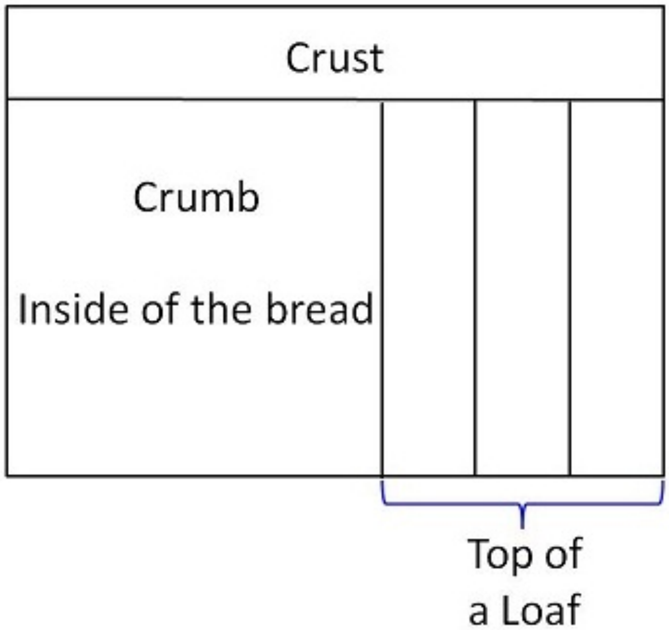

Figure 3 – Explanation Image Used in Emotions Survey

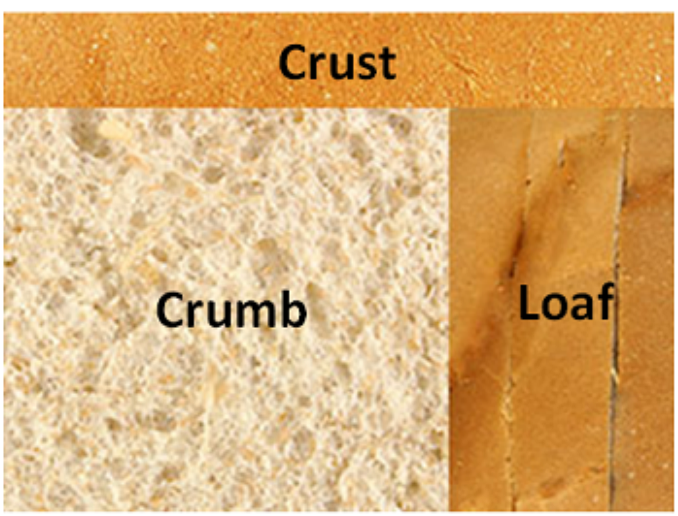

Figure 4 – Example Image Used in Emotions Survey

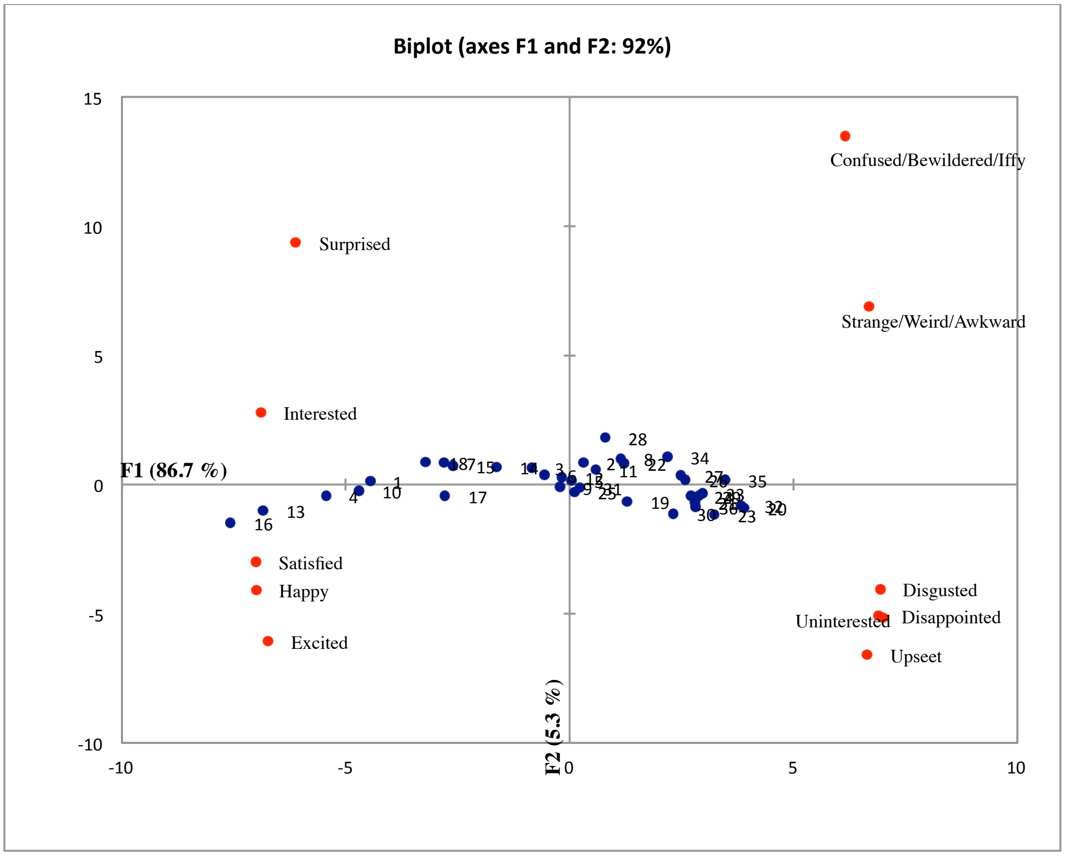

Figure 5: Principal Component Biplot of Breads and Emotional Responses

Table 4: Attribute importance from conjoint analysis

Attribute	Overall	Elementary	Middle	High
Middle of the Bread	24.93 a	25.22 a	23.75 a	25.80 a
Crust	21.88 b	21.20 b	22.08 a	22.37 b
Flavor/Taste	18.86 c	18.37 c	19.59 b	18.60 c
Middle of the Bread Texture	15.12 d	15.31 d	15.60 c	14.44 d
Description	11.16 e	11.05 e	11.44 d	10.98 e
Crust Texture	8.06 f	8.84 e	7.55 e	7.78 f

Different letters within a column and within an attribute are different ($p<0.05$)

Table 5: Zero-centered utility values for attributes and levels of each segment from conjoint analysis

	Overall	Elementary	Middle	High
White crust	51.43 b	37.72 c	64.01 a	54.32 ab
Dark crust	44.37 bc	36.50 c	46.23 bc	52.13 ab
White crust with flakes	-9.14 d	-7.37 d	-13.07 de	-6.90 d
White crust with oats	-19.17 e	-15.44 de	-19.34 ef	-23.67 efgh
Dark crust with oats	-28.57 fgh	-19.96 efg	-33.11 ghi	-34.22 hi
Dark crust with flakes	-38.91 i	-31.45 fghi	-44.72 i	-41.66 i
White	64.49 ab	57.79 abc	70.53 a	66.04 ab
White with flakes	50.31 c	48.39 c	49.79 c	53.32 bc
White with seeds	8.67 d	8.25 d	13.78 d	3.38 d
Dark with flakes	-35.59 ef	-30.60 e	-39.81 efg	-37.05 ef
Dark	-37.60 ef	-37.84 ef	-42.63 efgh	-31.60 e
Dark with seeds	-50.28 gh	-45.99 fgh	-51.66 gh	-54.09 h
Soft	22.07 a	21.37 a	22.30 a	22.69 a
Hard	-22.07 b	-21.37 b	-22.30 b	-22.69 b
Soft	31.74 a	32.72 a	32.40 a	29.77 ab
Smooth	22.64 b	21.10 bc	21.67 bc	25.68 ab
Moist	12.20 d	13.83 cd	13.05 cd	9.19 de
Chewy	5.78 e	8.28 de	5.47 e	2.99 e
Squishy	-10.71 gh	-15.97 hij	-3.90 fg	-11.86 ghi
Firm	-17.41 ij	-17.30 hij	-19.83 ijk	-14.81 hij
Grainy	-20.70 jk	-19.16 ijk	-23.37 jk	-19.59 ijk
Dense	-23.54 k	-23.51 jk	-25.50 k	-21.37 jk
Tastes great	25.82 b	31.50 a	24.01 b	20.75 b
Tastes like mom made it	8.45 c	8.57 c	9.52 c	7.07 cd
Soft	5.10 cd	3.52 cde	8.73 c	2.94 cde
All natural	0.06 ef	-1.28 efg	0.15 def	1.65 def
Whole grain	-7.80 hi	-7.21 ghi	-11.50 ij	-4.35 fgh
High fiber	-14.33 jk	-15.60 jk	-16.10 k	-10.72 hij
No artificial ingredients or	-17.29 k	-19.50 k	-14.82 jk	-17.36 k
None	93.94 a	86.35 b	93.71 ab	103.72 a
Buttery	40.20 c	39.67 c	42.77 c	37.93 c
Sweet	21.70 d	23.07 d	20.23 de	21.66 de
Toasted	16.71 de	19.73 de	18.51 de	10.89 ef
Wheaty	4.14 fg	2.84 fgh	3.58 fgh	6.40 fg
Mild	-5.19 h	-3.18 gh	-5.59 hi	-7.27 hij
Yeasty	-16.69 jk	-17.61 jk	-16.40 ijk	-15.85 ijk
Earthy	-21.23 k	-22.15 k	-23.15 k	-17.90 jk
Nutty	-39.64 l	-42.36 l	-39.96 l	-35.86 l

CHAPTER 3: THE INFLUENCE OF SOLIDS CONCENTRATION AND BLEACHING AGENT ON BLEACHING EFFICACY AND FLAVOR OF SWEET WHEY POWDER

THE INFLUENCE OF SOLIDS CONCENTRATION AND BLEACHING AGENT ON BLEACHING EFFICACY AND FLAVOR OF SWEET WHEY POWDER

JERVIS, M.G.[1] and DRAKE, M.A.[1,3]

[1] *Department of Food, Bioprocessing and Nutrition Sciences*

Southeast Dairy Foods Research Center

North Carolina State University

Raleigh, NC 27695

[3]Corresponding author. TEL: (919) 513-4598; FAX: (919) 515-7124; EMAIL: mdrake@ncsu.edu

RUNNING TITLE: Influence of solids concentration …

ABSTRACT

Recent studies have demonstrated the impact of bleaching and bleaching agent on flavor and functional properties of whey protein ingredients. Solids concentration at bleaching significantly impacted bleaching efficacy and flavor effects of different bleaching agents. It is not known if these parameters influence quality of sweet whey powder (SWP). The purpose of this study was to determine the effects of solids concentration and bleaching agent on the flavor and bleaching efficacy of SWP. Colored Cheddar whey was manufactured, fat separated and pasteurized. Subsequently, the whey (6.7% solids) was bleached, concentrated using reverse osmosis (RO) to 14% solids and then spray-dried, or whey was concentrated prior to bleaching and then spray dried. Bleaching treatments included: Control (C) (no bleaching, 50°C, 60 min), hydrogen peroxide (HP) (250 mg/kg, 50°C, 60 min), benzoyl peroxide (BP) (50 mg/kg, 50°C, 60 min), lactoperoxidase (LP) (HP 20 mg/kg, 50°C, 30 min), and external peroxidase (EP) (MaxiBright™, 2 dairy bleaching units(DBLU)/ml, 50°C, 30 min). The experiment was repeated in triplicate. Sensory properties and volatile compounds of SWP were evaluated by a trained panel and gas chromatography mass spectrometry, respectively. Bleaching efficacy (norbixin destruction) and benzoic acid were measured using high performance liquid chromatography. Differences in bleaching efficacy, sensory and volatile compound profiles and benzoic acid were observed with different bleaching agents ($p<0.05$), consistent with previous studies. Solids concentration impacted bleaching efficacy of HP ($p<0.05$) but not other bleaching agents. SWP from whey bleached with HP or LP following RO had increased cardboard and fatty flavors and higher concentrations of lipid oxidation compounds compared to SWP from whey bleached prior to RO. SWP bleached with BP after RO contained less benzoic acid than SWP from whey bleached before RO ($p<0.05$). These results indicate that solids concentration impacted bleaching efficacy of HP and influenced off flavors associated with specific bleaching agents in SWP.

KEY WORDS: Sweet whey, reverse osmosis, bleaching

INTRODUCTION

Liquid whey has become a precursor to high value protein ingredients, due in part to functional and nutritional properties of dried whey ingredients. Most dried whey ingredients are manufactured from fluid sweet whey. Sweet whey, in contrast to acid whey, refers to whey that is collected from a cheese manufacture process that uses starter cultures and rennet, including Cheddar cheese, Mozzarella, Gouda, and Swiss cheeses and generally has a pH of 5.8-6.6 (Varnum and Sutherland 1994). Cheddar cheese is colored using the carotenoid annatto which is primarily composed of norbixin (Kang et al., 2010). Of the added annatto, a portion of the norbixin (ca 10%) remains in the liquid sweet whey, imparting a yellow color (Smith et al., 2014). Dried whey ingredients that are both colorless and flavorless are desired to avoid unwanted color and flavor transfer to final food products. To obtain a colorless product, bleaching is a required step in whey ingredient manufacture. The point of bleaching in whey production varies among manufacturers, but can occur at any point in the manufacturing process. Processing steps in manufacture of WPC34, WPC80 and WPI, including bleaching, impart off-flavors, which carry over to food/beverage applications (Croissant et al., 2009; Drake et al., 2009; Evans et al., 2010; Wright et al., 2009; Listiyani et al., 2011; Jervis et al., 2012), so care should be taken to maximize final product quality.

Benzoyl peroxide (BP) and hydrogen peroxide (HP) are the two approved chemical bleaching agents used in the US for bleaching of liquid whey and whey retentate. The use of BP for bleaching has declined in recent years due to concerns of some countries regarding benzoic acid residues. BP has been banned for use in China and Japan over these concerns, but remains an approved chemical bleaching agent, and chemical bleaching with HP or BP remain cost effective methods for bleaching. Recent studies have determined that while bleaching with HP and BP are effective in reducing norbixin in liquid whey, this processing step negatively influences the flavor of liquid whey and dried whey proteins WPC80, WPC70, and WPC34 (Croissant et al., 2009; Jervis et al., 2012; Listiyani et al., 2011). The non-specific oxidation processes that reduce norbixin increase lipid oxidation products which are the primary source of off-flavors in dried whey products (Whitson et al., 2010). Bleaching liquid whey or concentrated whey with HP produces higher levels of lipid oxidation and subsequent off flavors than BP (Croissant et al., 2009; Fox et al., 2013; Listiyani et al., 2011; Jervis et al., 2012). At optimal conditions in fluid whey, BP is a better bleaching agent than HP. In contrast, in 80% protein liquid retentate, HP destroyed more norbixin than BP (Fox et al., 2013). Li et al. (2012) examined the effects of bleaching at varying solids levels with HP at 250 mg/kg and reported bleaching 80% whey protein retentate produced greater bleaching efficacy than 34% whey protein retentate at equivalent solids, indicating that solids composition directly impacted bleaching efficacy of HP.

Concerns over chemical bleaching agents have led to research into alternative bleaching methods. Enzymatic bleaching with the lactoperoxidase system (LP) is one such alternative bleaching method. LP is the second most abundant enzyme found naturally in bovine milk and requires thiocyanate (SCN^-, generally sufficient in milk) and a small concentration of HP to be active (Seifu et al., 2005, Campbell et al., 2012). Bleaching fluid whey with LP (HP 20 mg/kg) was more effective in norbixin destruction than chemical bleaching with HP (HP 250 mg/kg) (LP > 99% norbixin destruction at both 50°C and 35°C vs. HP 46% at 50°C or 32% at 35°C) (Campbell et al., 2012). The use of an external peroxidase (EP) has recently been approved by the FDA as an additional enzymatic bleaching agent for whey. EP facilitates enzymatic bleaching of whey similar to the LP system, but can account for variability in lactoperoxidase levels that may result from varying feeding regimes and processing steps (Seifu et al., 2005; Campbell and Drake, 2014). EP does not require thiocyanate for bleaching to occur and has also been shown to be an effective bleaching agent for fluid whey at cold temperatures (Campbell and Drake, 2013).

Reverse osmosis (RO) is a pressure filtration process used in the dairy industry, which passes liquids through a semi-permeable membrane to remove water, concentrating each of the remaining components while retaining the same relative concentrations (Madaeni and Mansourpanah, 2004; Suárez et al., 1992). RO is desirable as a pre-concentration step before spray drying in order to reduce energy costs in spray drying, and as a way to reduce transportation volume and reduce shipping costs (Hiddink, et al., 1980). RO operates at ambient temperatures, which reduces impact on the functional properties of the whey protein, and also lowers energy requirements in comparison to other concentration methods such as evaporation (Smith, 1981, Hiddink et al., 1980). RO or evaporation can be used in manufacture of sweet whey powder (SWP). The effect of bleaching fluid whey at various solids concentration levels is not yet fully understood in regards to the potential impact on both bleaching efficacy and flavor, and no published studies to our knowledge have evaluated the impact of bleaching on sensory and chemical properties of SWP. The objective of this study was to examine the impact of bleaching of colored liquid whey at varying concentrations of total solids on the sensory and chemical properties of SWP.

MATERIALS AND METHODS

Experimental Design

Liquid sweet whey (pH 6.3) was manufactured from a standard Cheddar cheese manufacture process. Sweet whey was pasteurized and then fat separated. At this point, the whey was separated into two batches. The first batch was further divided into 5 sample groups based on bleaching method. These samples included one control, and whey samples bleached using HP, BP, LP and EP at native total solids concentrations (approximately 6.7%). All five of the wheys were then concentrated to approximately 14% total solids using RO and spray dried. The second batch was concentrated to 14% total solids, and then separated into 5 sample groups. These sample groups were then bleached at the higher total solids concentration using the same 5 bleaching methods. Following bleaching and concentration, all sweet whey samples were cooled to 4°C and stored overnight. The following day, all samples were spray dried. This experiment was replicated in triplicate.

Sweet Whey Manufacture, Bleaching & Concentration

Cheddar whey was manufactured from HTST (17 s at 72°C) pasteurized whole milk (approximately 1400 kg) following the methods of Campbell and Drake (2013). The whey and curds were separated at pH 6.3 and a sieve was used to remove any remaining fines. Whey was then processed using a hot bowl cream separator (model KD-6QQ, MilkTech, Inc., Plantation, FL) in order to reduce fat content. The fluid whey was then HTST pasteurized following the same parameters previously discussed. Percentage of total solids of the whey was analyzed using the Smart System 5 moisture-solids analyzer (CEM, Matthews, NC). Fluid whey was then cooled to 50°C and divided into two batches, weighing approximately 625 and 125 kg respectively.

Batch 1 (625 kg) was separated into 5 aliquots for bleaching, each approximately 125 kg. These 5 aliquots were bleached at native total solids concentration. All bleaching took place at 50°C. This temperature was chosen based on recent research that demonstrated that this temperature resulted in optimal bleaching performance for HP and BP bleaching (Fox et al., 2013). HP (35% HP, FCC grade, Columbus Chemical Industries Inc., Columbus WI) was added at 250 mg/kg to one aliquot and held for 60 min. This concentration was selected because it represents the mid-range concentration of HP use for bleaching of whey (US FDA, 2009). BP (Oxylite Type XX Benzoyl Peroxide 32% by weight, Nelson Jameson, Marshfield, WI) was added to the second aliquot at a concentration of 50 mg/kg and held for 60 min. This concentration represents a moderate concentration that is within the range covered by Good Manufacturing Procedures. The LP system was activated in the third aliquot by addition of 20 mg/kg HP and held for 30 min (Campbell et al., 2012). The fourth aliquot was bleached with the addition of EP (MaxiBright, DSM Food Specialties, Delft, Netherlands) at a concentration of 2 Dairy Bleaching Units (DBLU) and 20 mg/kg HP for 30 minutes (Campbell and Drake, 2013; Campbell et al., 2012). A fifth aliquot was held at 50°C for 60 min, but remained unbleached (control). These aliquots were cooled to 4°C and held until concentrated using RO and spray dried the next day. Peroxide test strips were used in order to determine if any HP remained in the HP, LP and EP aliquots after bleaching. In order to eliminate any remaining HP and stop peroxidase activity, catalase (FoodPro CAT, Danisco, New Century, NJ) was added at a rate of 20 mg/kg.

Batch 2 of liquid whey (125 kg) was concentrated to approximately 14% total solids concentration immediately following pasteurization and cooled without bleaching. Whey was transferred to a holding tank and pumped using a centrifugal pump to the RO system at 4°C. The RO system was equipped with a high pressure pump (model A96084762P10324US193, Grundfos Pumps Corporation, Olathe, KS) and two 4" outer diameter reverse osmosis thin-film composite filter column membranes (model RO-SYN2-4040, Snyder Filtration, Vacaville, CA). The system was run at approximately 1310 KPA. This system produced two feeds. The permeate was the water removed from the whey and the retentate was the partially concentrated whey, which was cycled back into the holding tank to undergo further concentration. Total solids levels were monitored using the Smart System 5 moisture-solids analyzer (CEM, Matthews, NC) to determine if further concentration was necessary. Once the desired 14% total solids concentration was reached, the concentrated whey was cooled and held at 4°C (batch 1 treatments). Total concentration time was approximately one h per sample. The remaining volume of concentrated whey was then divided into 5 equally sized containers (approximately 2 L each) and bleached using the parameters outlined previously. All samples were spray dried the following day (model Lab 1, Anhydro Inc., Soeberg, Denmark). Inlet temperature was 175 °C and outlet temperature was 80°C. Total spray drying time was 1 h per sample. Sweet whey powders (SWP) were stored in Mylar bags and held at -80°C until analyses (initiated within 1 wk).

Composition analysis

SWP powders were analyzed for moisture using vacuum oven drying for 5 h. (Wehr and Frank, 2004; method 15.111). Fat content was determined by ether extraction (AOAC, 2000; method 989.05; 33.2.26). Protein was determined by the Kjeldahl method (AOAC, 2000, method 991.20; 33.2.11). Mineral analysis (Sulfur, Phosphorous, Potassium, Calcium, Magnesium, Iron, Copper, Zinc, Sodium) was performed by the NCSU Soil Science Analytical Services Laboratory (Raleigh, NC) using a standard dry ash method with an inductively coupled plasma optical emission spectroscopy (Lloyd et al., 2009). All samples were measured in duplicate.

Color analysis and Norbixin extraction and analysis

Hunter L*, a*, b* values were measured in both dry powder form (10 g) and liquid form (10 mL of 10% [wt/vol] solution). Samples were placed into the bottom of a 60 x 15-mm polystyrene Petri dish (Becton Dickinson, Franklin Lakes, NJ). Color was measured using a Minolta Chroma-Meter (model CR-410; Konica Minolta Sensing Americas Inc., Ramsey, NJ). Each sample was measured in duplicate. Before values were measured, a factory-supplied calibration plate was used to calibrate the instrument. Using the Hunter L*, a*, b* scale, L* is the lightness of the color, a* is the position between red and green, and b* is the position between yellow and blue.

Norbixin was extracted and quantified from liquid wheys to measure the percent norbixin destruction. Extraction of norbixin was conducted and quantified by high performance liquid chromatography (HPLC) using a method described by Campbell et al. (2014). The supernatant was removed and placed into vials for HPLC quantification. In order to minimize norbixin isomerization and degradation (Mercadante, 2008), premium full-spectrum F885 flat sheet filters were used to cover all lights (Ergomart, Dallas, TX). Norbixin was quantified using HPLC (Waters 1525 Binary Pump, Waters, Milford, MA) as described by Campbell et al. (2014). Norbixin destruction was calculated on a percentage basis by comparison of the peak area and retention time of norbixin in bleached samples with the peak area found in control samples. The maxima used for retention of norbixin was 482 nm (Campbell et al., 2014).

Descriptive Sensory Analysis

SWP were rehydrated (10% (w/v)) in deionized water and evaluated in duplicate by 8 trained panelists, each with more than 150 h of experience with descriptive analysis of dried dairy ingredient aroma and flavor, using the Spectrum descriptive analysis method (Drake and Civille, 2003; Meilgaard et al., 2007). Aroma and flavor attributes of reconstituted SWP were evaluated using a 0 to 15 point universal scale and an established lexicon for dried dairy ingredients (Drake, et al., 2003; 2009; Wright et al., 2009). Descriptive sensory analysis was conducted in compliance with the North Carolina State University Institutional Review Board for Human Subjects approval. Reconstituted SWP were dispensed (30 mL) into 3-digit coded 60 mL lidded soufflé cups (Solo Cup Co., Champaign, IL). Samples were prepared with overhead lights off to avoid light exposure. The samples were then tempered to 20°C and served at this temperature. Samples were evaluated at room temperature by each panelist in duplicate. Sensory data were collected using Compusense five (release 5.2; Compusense Inc., Guleph, ON, Canada).

Volatile compound analysis

Volatile compounds of interest in liquid whey were extracted by solid-phase microextraction (SPME) using selective ion monitoring. These compounds were chosen based on prior research and relevance to flavor of whey, bleaching of whey, or both

(Croissant et al., 2009; Campbell et al., 2012; Jervis et al., 2012; Kang et al., 2012; Listiyani et al, 2012; Campbell and Drake, 2013). These compounds were then separated and identified by gas chromatography-mass spectrometry (GC-MS) using the method of Campbell and Drake (2013). Samples were prepared with 10% (wt/vol) sodium chloride (Fisher Scientific, Fairlawn, NJ) and 5 μL of an internal standard solution (2-methyl-3-heptanone in methanol at 81 mg/kg; Sigma-Aldrich, Milwaukee, WI). Samples were injected using a CombiPAL auto-sampler (CTC Analytics AG, Zwinger, Switzerland) which was attached to an Agilent 6890N GC with 5975 inert MSD (Phenomenex Inc, Torrance, CA) equipped with a ZB-5ms column of 30 m, 0.25 mm I.D., and 0.25 μL film thickness (Agilent Technologies Inc., Santa Clara, CA).

The GC method specified an initial temperature of 40°C for 3 min with a ramp rate of 10°C/min to 90°C, followed by a ramp rate of 5°C/min to 200°C, a 10 minute hold time, and a final ramp rate of 20°C/min to 250°C, held for 5 min. Compounds of interest were identified using the NIST 2005 library of spectra (www.nist.gov) and comparison of spectra of authentic standards injected under identical conditions. Relative abundance for each compound was calculated using the calculated recovery of the internal standard concentration to determine relative concentrations of each compound. Retention indices were calculated using an alkane series.

Benzoic acid extractions and measurement

Residual benzoic acid (BA) was extracted and quantified following a method developed by Listiyani et al. (2011). In brief, 2.5g of each SWP was added to a centrifuge tube (VWR International), to which 15 mL of HPLC-grade water was added, vortexed and diluted again with 20 mL of additional HPLC grade water. 5 mL of 1*M* zinc acetate solution (Mallinckrodt Baker Inc., Phillipsburg, NJ) and 5 mL of 0.25 *M* potassium hexacyanoferrate (II) trihydrate (Alfa Aesar, Ward Hill, MA) in water solution were added to the sample in order to precipitate fat and protein. This solution was then diluted do 50 mL and shaken to ensure proper dissolution of the zinc acetate and potassium hexacyanoferrte (II) trihydrate. Samples were then vacuum filtered through a 0.45 μm polyethersulfone (PES) membrane (VWR International). The filtrate was collected and diluted 1:1 with HPLC mobile phase and placed intoa 1.5 mL HPLC vial (Alltech Associates Inc., Deerfield, IL).

BA was quantified using an HPLC system equipped with a binary pump (Waters 1525 Binary Pump, Waters), autosampler (Waters 2707 Autosampler, Waters), and fitted with a Phenomenex HyperClone ODS (C18) 120A column (4.0 x 250 mm, 5μm) with a c18 security guard (4.0 x 2.0mm; Phenomenex Inc.). Column oven temperature was set to maintain a temperature of 30°C. A mobile phase of 4% (vol/vol) methanol (Mallinckrodt Baker Inc.) and 96% (vol/vol) ammonium acetate buffer (0.02 *M*; Sigma Aldrich Corp.) was used with a flow rate of 1.0 mL/min. 20μL was injected from each sample. The UV detector was set at 230-nm wavelength. A standard curve for BA was constructed at for the concentrations of 0.5, 1, 3, 5, 10, 25, and 50 mg/kg. To create this standard, BA (EMD Chemicals) was added to mobile phase solutions at the appropriate concentrations, and analyzed on the same HPLC system. The extracted samples were injected in duplicate. Additionally, a control sample of unbleached whey was spiked with BA standard (10 mg/kg), extracted and injected, and used to calculate BA recovery. BA concentrations were calculated based on the standard curve, recovery rate, and dilution factors.

Statistical Analysis

Data were analyzed using two-way (bleach type x solids) ANOVA using a general linear model with Fishers least significant difference for means separation (XLSTAT, Version 2013.05.05; Addinsoft Inc., New York, NY). Both main effects and interaction effects were analyzed. Principal component analysis (XLSTAT) was conducted to visualize differences among treatments.

RESULTS & DISCUSSION

Composition Analysis

No compositional differences were detected among the SWP ($p>0.05$). Moisture content was 1.18% ± 0.32%, fat content was 0.65% ± 0.08%, and protein content was 12.7% ± 0.2%. These values are similar to values reported in other studies of sweet whey powders (Glass and Hedrick, 1976; Mavropoulou and Kosikowski 1972; Sithole et al., 2005). Similarly, no differences were detected in mineral concentrations ($p>0.05$) except for iron content, which was lower ($p<0.05$) when whey was bleached with HP at 14% solids when compared to SWP from whey bleached with HP at 6.7% solids (Table 2). Mineral values were also consistent with previous sweet whey powder studies (Glass and Hedrick, 1976; Mavropoulou and Kosikowski, 1972; Sithole et al., 2005).

Color analysis and Norbixin extraction and analysis

Significant differences in Hunter L*, a*, b* values ($p<0.05$) were observed in both SWP and in rehydrated SWP (10% w/v) (Table 3). In both SWP and rehydrated SWP (10% w/v), BP and BP14 had significantly lower b* values indicating decreased yellow color compared to control and other bleaching treatments (Table 3). All bleaching treatments, regardless of point of bleaching, were significantly lower in b* compared to control with the exception of HP which was not different from control ($p>0.05$). Previous work has also reported higher yellowness in WPC80 and SPC80 from colored and uncolored whey bleached with HP compared to BP (Jervis et al., 2012; Campbell et al., 2013).

An interaction between point of bleaching (6.7% vs. 14% total solids concentration) and bleaching agent was observed for norbixin destruction ($p<0.05$). Percent norbixin destruction was not different with point of bleaching for BP, LP or EP ($p>0.05$) (Figure 1). In contrast, HP bleaching before RO resulted in lower norbixin destruction than bleaching with HP at higher solids (HP14) ($p<0.05$). The decreased bleaching efficacy of HP in fluid whey compared to following RO is in agreement with chroma-meter measurements indicating that HP was more yellow than HP14. These results are consistent with results reported by Fox et al. (2013) who reported that HP (250 mg/kg) bleaching of liquid whey (6.7% total solids) at 50°C destroyed less norbixin than bleaching with the same parameters of liquid whey retentate (12% total solids; 80% protein [w/w]) manufactured by ultrafiltration (UF). Li et al. (2013) reported increased bleaching efficacy ($p<0.05$) with HP (250 mg/kg) when bleaching liquid WPC80 or liquid WPC34 than fluid whey, confirming the role of composition on bleaching: increased solids increased HP bleaching efficacy. With the exception of HP, point of bleaching in the current study did not impact bleaching efficacy. Fox et al. (2013) hypothesized that increased HP bleaching efficiency at higher solids was due to a combination of chemical HP bleaching as well as some bleaching with concentrated native LP. The native LP is permanently oxidized by the excess HP (Campbell et al., 2012), but sufficient concentrations are present at higher solids to result in some bleaching prior to inactivation.

Descriptive Sensory Analysis

Sensory profiles of rehydrated SWP bleached before and after RO were distinct (10% w/v) (Table 4, Figure 2). Point of bleaching had no effect on the sensory profiles of BP and EP, however point of bleaching did impact the flavor profiles of HP and LP ($p<0.05$) (Table 4). SWP from HP14 was higher in cardboard flavor, while SWP from LP14 was significantly higher in cardboard and fatty flavors which are both off flavors associated with lipid oxidation products (Evans et al., 2009; Wright et al., 2009; Whitson et al., 2010, 2011).

Volatile compound analysis

Point of bleaching had a significant impact on lipid oxidation and protein degradation compounds (Table 5, Figure 3). Bleaching after RO increased volatile formation for SWP from HP, BP, LP, and EP ($p<0.05$), although not in a consistent manner. In HP, LP and EP bleached SWP, higher levels of lipid oxidation and protein degradation compounds including dimethyl sulfide, hexanal, heptanal, and octanal were found when bleached at 14% when compared to SWP from bleaching at 6.7% ($p<0.05$). Most notable of the differences was hexanal, which tripled in HP14 and LP14 compared to HP and LP respectively, and nearly doubled in EP14 compared to EP. Unbleached SWP contained lower relative abundances of most volatiles than the bleached SWP. Campbell and Drake (2013) found similar results with fluid whey, fluid whey retentate and powdered WPC80 bleached with HP (250 mg/kg), LP (20 mg/kg HP) and EP (2 DBLU). HP and LP bleached treatments were higher in hexanal, which is a key indicator of lipid oxidation. In the same study, it was also noted that fluid whey retentates were higher in aldehydes than fluid whey, regardless of bleach treatment.

Listiyani et al. (2011) and Croissant et al. (2009) also examined the impact of bleaching with HP and BP and determined that BP produced lower levels of lipid oxidation products (aldehydes, ketones, etc.). Point of bleaching impacted BP treatments in that bleaching at 14% total solids resulted in a decrease in hexanal, heptanal, 2-pentylfuran, and 2-E-octenal, and an increase in DMS, DMDS, and decanal when compared to treatments bleached at 6.7% total solids ($p<0.05$). The effect of both increases and decreases in select compounds was only observed with BP. Overall, point of bleaching resulted in HP14, LP14, and EP14 SWP being associated with lipid oxidation and protein degradation compounds compared to their HP, LP, and EP counterparts. Volatile compound results were consistent with sensory profiles in that point of bleaching significantly affected the flavor of HP and LP bleached SWP by increasing off-flavor production.

SWP from HP14 was higher in lipid oxidation and protein degradation compounds compared to HP SWP (Table 5). SWP from HP14 also had a lower iron concentration compared to HP. Jervis and Drake (2013) hypothesized that iron facilitated the formation of hydroxyl radicals from HP, which then facilitated bleaching and other reactions such as lipid oxidation and protein degradation. Reverse osmosis will concentrate all minerals present in whey, including iron. The increased concentration of iron when HP was introduced (HP14) may have resulted in increased iron facilitated HP mechanisms as outlined in Jervis and Drake (2013) which would account for the higher lipid oxidation and protein degradation compounds, as well as the lower iron content in the HP14 treatment. Jervis et al. (2012)

reported lower iron concentrations for WPC80 bleached with HP than WPC80 bleached with BP or not bleached. This effect was observed with and without annatto color. The HP treatments were also higher in lipid oxidation and protein degradation compounds (Jervis et al. 2012), consistent with the current study with SWP.

Benzoic acid extractions and measurement

Benzoic acid (BA) levels detected in HP, LP and EP bleached SWP, as well as the unbleached control, were similar to previously reported literature with WPC34 (Listiyani et al., 2011) (Figure 4). In the current study, SWP bleached with BP at 14% total solids had lower residual BA compared with bleaching with BP at 6.7% total solids ($p<0.05$) (Figure 4). In both cases, whey was dosed with 50 mg/kg of BP based on total weight of the sample. One sample was bleached pre RO and the other was bleached post RO. The sample bleached post RO was already concentrated and retained its initial BP and BA levels. The RO process removes water, thereby increasing the relative concentrations of all remaining solids, including BP and by extension BA.

Approximately 700 mg/kg residual benzoic acid was expected from the sample bleached at 6.7% solids, based on a weight of BP of 2742 mg added to 3.92 kg of total solids in 56.7 kg of liquid whey. Instead, 417 mg/kg of residual BA was recovered from SWP, an approximate 60% recovery rate. Approximately 350 mg/kg of benzoic acid was expected from whey bleached at 14% solids, based on 125.5 mg BP added to 0.36 kg total solids in 2.5 kg of bleached concentrated liquid whey. Approximately 132 mg/kg of residual BA was detected in SWP, or 38% recovery. Little published research has addressed the impact of various BP bleaching conditions (concentration, point of bleaching) on residual BA in spray dried whey ingredients. Previously, Listiyani et al. (2011) noted that residual BA was lower in BP bleached WPC34 compared to WPC80, and they then demonstrated that BA was recovered in permeate, demonstrating that some BA was lost during UF and subsequent diafiltration (DF). However, those processes were not present in SWP manufacture in the current study, and solids concentration differences do not fully account for the consistent differences in residual BA between SWP from BP bleached fluid whey compared to that from BP bleached higher solids RO retentate. It is possible that BA may become bound to fat or protein during the bleaching process. Benzoic acid binding to proteins found in bovine milk has been reported (Wedzicha and Ahmed, 1993; Moriguchi et al, 1968). Liquid whey bleached at 14% solids contained a higher concentration of protein and fat to BP ratio than whey bleached at 6.7% solids. If BA was interacted or bound to protein or fat, this increased ratio which might account for an increased level of BA binding and a decreased BA recovery. Additional studies would be necessary to further clarify this issue. Regardless, the current study demonstrates that for SWP manufacture (no UF or DF), bleaching at higher solids concentration decreases residual BA while maintaining comparable BP bleaching efficacy.

CONCLUSIONS

Point of bleaching significantly affected the bleaching efficacy and resulting flavor formation of sweet whey powder. Bleaching after reverse osmosis to 14% solids increased the bleaching efficacy of HP, and negatively impacted off-flavor formation from HP, LP, and EP. Point of bleaching also significantly affected residual benzoic acid levels when bleaching with BP with decreased levels of benzoic acid when whey was bleached after RO. Increased solids by RO or evaporation potentially benefit the dairy industry in the processing of SWP by lowering costs associated with processing and spray drying, however if the whey is to be bleached, it is better to bleach prior to solids concentration in order to avoid increased off-flavor production. If bleaching with BP is to be utilized, bleaching after RO will result in less benzoic acid residue.

ACKNOWLEDGEMENTS

Funding provided in part by the Dairy Research Institute (DRI) (formerly Dairy Management Inc. (DMI)) (Rosemont, IL) and by DSM (Delft, Netherlands). The whey manufacturers across the United States and Canada who provided samples are gratefully acknowledged. The use of tradenames does not imply endorsement nor lack of endorsement by those not mentioned.

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TABLES & FIGURES

Table 1: Descriptions of sweet whey powder (SWP) treatments

Treatment	Description
CR	Control before RO
CR14	Control after RO
HP	Hydrogen peroxide before RO
HP14	Hydrogen peroxide after RO
BP	Benzoyl peroxide before RO
BP14	Benzoyl peroxide after RO
LP	Lactoperoxidase before RO
LP14	Lactoperoxidase after RO
EP	External peroxidase before RO
EP14	External peroxidase after RO

- RO = reverse osmosis to 14% solids
- Hydrogen peroxide (250 mg/kg)
- Benzoyl Peroxide (50 mg/kg)
- Lactoperoxidase (hydrogen peroxide 20 mg/kg)
- External peroxidase (2 DBLU and hydrogen peroxide 20 mg/kg)

Table 2 Mean mineral compositions of sweet whey powders (SWP)

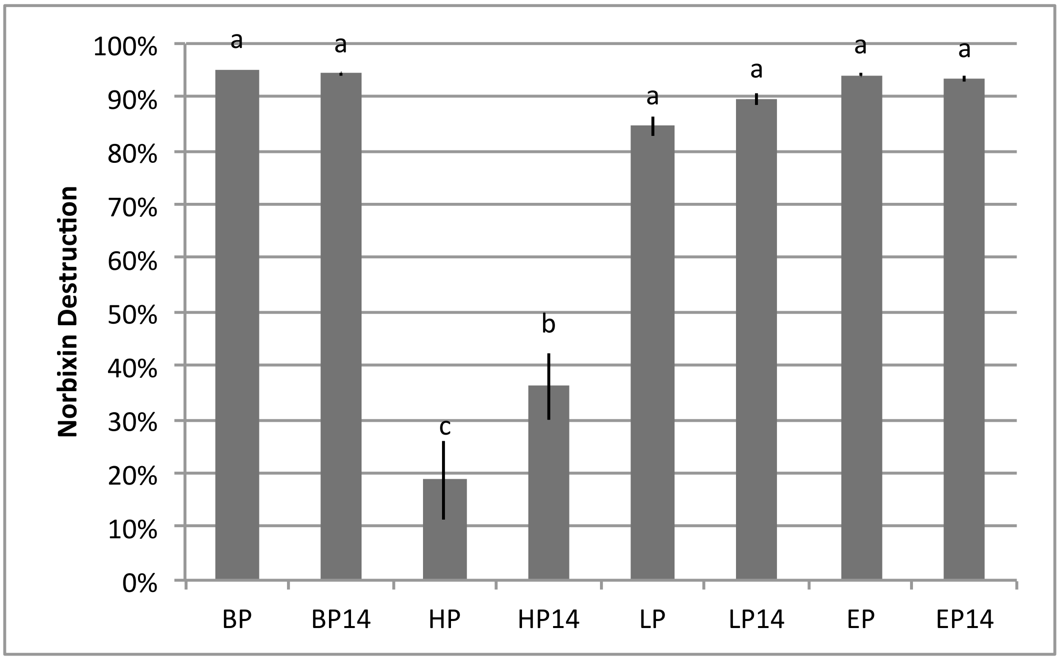
TRT	S	P	K	Ca	Mg	Na	Fe	Cu	Zn
	-wt%-	-wt%-	-wt%-	-wt%-	-wt%-	-mk/Kg-	-mk/Kg-	-mk/Kg-	-mk/Kg-
CR	0.19 a	.057 a	2.27 a	0.57 a	0.12 a	6650 a	2.44 a	2.93 a	1.37 a
CR14	0.19 a	.058 a	2.30 a	0.57 a	0.12 a	6670 a	2.52 a	3.01 a	1.34 a
HP	0.19 a	.058 a	2.30 a	0.57 a	0.12 a	6680 a	2.34 a	2.90 a	1.35 a
HP14	0.19 a	.058 a	2.28 a	0.57 a	0.12 a	6690 a	2.04 b	3.14 a	1.30 a
BP	0.19 a	.057 a	2.26 a	0.57 a	0.12 a	6690 a	2.51 a	2.98 a	1.43 a
BP14	0.19 a	.057 a	2.26 a	0.56 a	0.12 a	6640 a	2.33 a	3.23 a	1.40 a
LP	0.19 a	.057 a	2.27 a	0.56 a	0.12 a	6630 a	2.53 a	2.83 a	1.41 a
LP14	0.19 a	.057 a	2.29 a	0.57 a	0.12 a	6650 a	2.45 a	2.97 a	1.50 a
EP	0.19 a	.057 a	2.27 a	0.57 a	0.12 a	6620 a	2.67 a	3.15 a	1.34 a
EP14	0.19 a	.057 a	2.28 a	0.56 a	0.12 a	6670 a	2.33 a	3.12 a	1.47 a

- Means in a column followed by a different letter are significantly different ($p<0.05$)
- %wt represent the percentage of the indicated compound (w/w)
- <eans from duplicate measurements from three trials
- Treatment descriptions found in Table 1

Table 3. Mean color (L*, a*, and b* values) of spray dried rehydrated sweet whey powder (SWP) bleached before or after reverse osmosis (14% solids).

TRT	Powder			Liquid (10% rehydrated w/vol)		
	L* Value	a* Value	b* Value	L* Value	a* Value	b* Value
CR	95.1 d	-0.9 a	10.8 a	75.2 c	-1.8 a	12.8 a
CR14	95.1 d	-1.1 a	10.9 a	75.3 c	-1.7 a	12.9 a
BP	96.3 a	-2.3 b	7.6 c	77.8 a	-2.3 a	8.4 d
BP14	96.4 a	-2.5 b	7.4 c	77.7 a	-2.3 a	8.6 d
HP	95.4 bcd	-1.9 b	10.0 ab	76.3 b	-1.9 a	11.0 ab
HP14	95.3 cd	-1.9 b	9.1 b	76.4 b	-1.8 a	10.1 bc
LP	95.8 bc	-2.2 b	9.4 b	77.2 ab	-2.2 a	9..4 cd
LP14	95.3 cd	-2.1 b	9.0 b	76.1 b	-2.1 a	10.0 bc
EP	95.6 bc	-2.3 b	9.3 b	77.1 b	-2.3 a	9.3 cd
EP14	95.3 cd	-2.2 b	9.1 b	76.5 b	-2.2 b	10.1 bc

- Means in the same column not sharing a common superscript letter are different ($p<0.05$)
- Treatment designations found in table 1



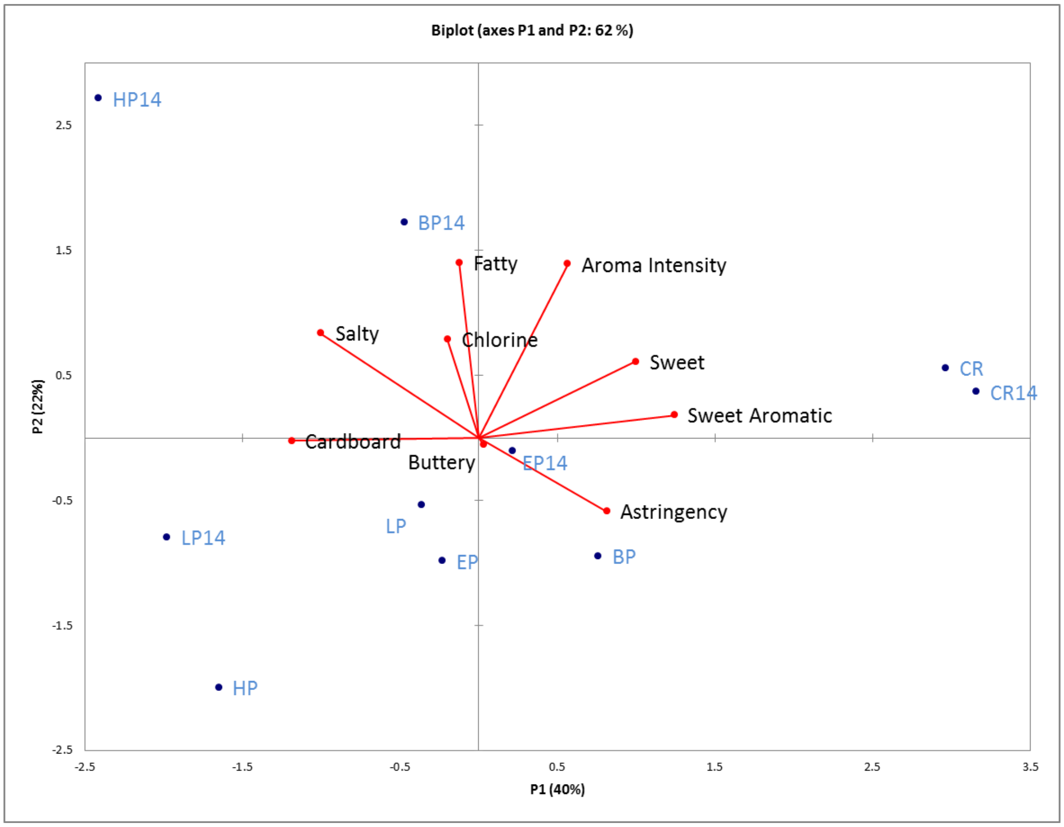
- Different letters indicate significant differences ($p<0.05$)
- Treatment designations found in Table 1

Figure 1. Mean percent norbixin destruction of sweet whey powders (SWP) from whey bleached before or after reverse osmosis (14% solids).

Table 4. Mean sensory profiles of sweet whey powders (SWP) bleached before or after reverse osmosis (14% solids).

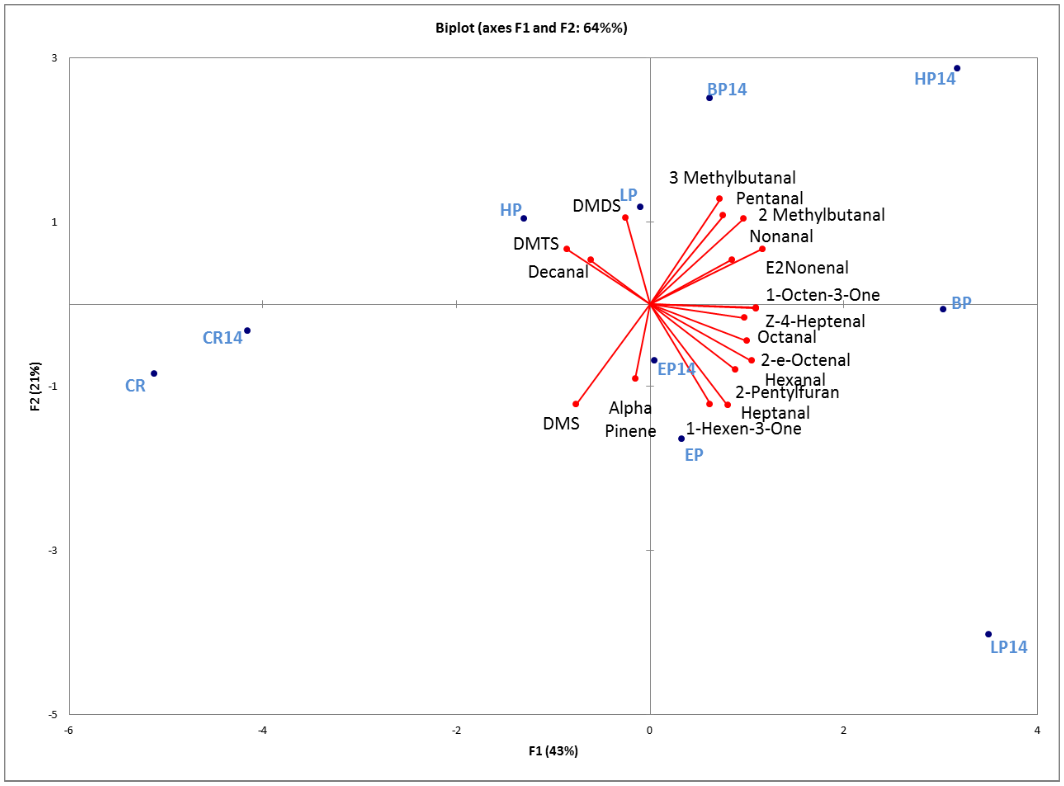
TRT	Aroma Intensity	Sweet Aromatic	Cardboard	Fatty	Sweet	Salty	Chlorine/ Chemical	Buttery
CR	2.3 a	1.9 a	1.1 d	ND	2.5 a	1.5 a	ND	0.5 a
CR14	2.2 ab	1.8 ab	1.0 d	ND	2.6 a	1.5 a	ND	0.5 a
BP	2.1 ab	1.2 abc	1.5 c	ND	2.5 a	1.6 a	0.6 a	ND
BP14	2.0 abc	1.2 abc	1.6 c	ND	2.5 a	1.7 a	0.6 a	ND
HP	1.6 d	0.7 bc	2.2 b	0.5 a	2.4 a	1.6 a	ND	ND
HP14	1.9 bcd	0.5 c	2.8 a	0.8 a	2.0 a	1.4 a	ND	ND
LP	1.8 cd	0.8 bc	2.1 b	ND	2.5 a	1.6 a	ND	ND
LP14	1.9 bcd	0.6 c	2.8 a	0.6 a	2.3 a	1.6 a	ND	ND
EP	1.6 d	1.1 abc	2.1 b	ND	2.4 a	1.6 a	ND	ND
EP14	1.9 bcd	1.1 abc	2.3 b	ND	2.5 a	1.6 a	ND	ND

- Means in a column followed by a different letter are significantly different ($p<0.05$)
- ND Not Detected
- Treatment descriptions found in Table 1



PC1 and PC2 = Principal components 1 and 2

Figure 2. Principal component biplot of sensory profiles of sweet whey powders (SWP) bleached before or after reverse osmosis (14% solids).



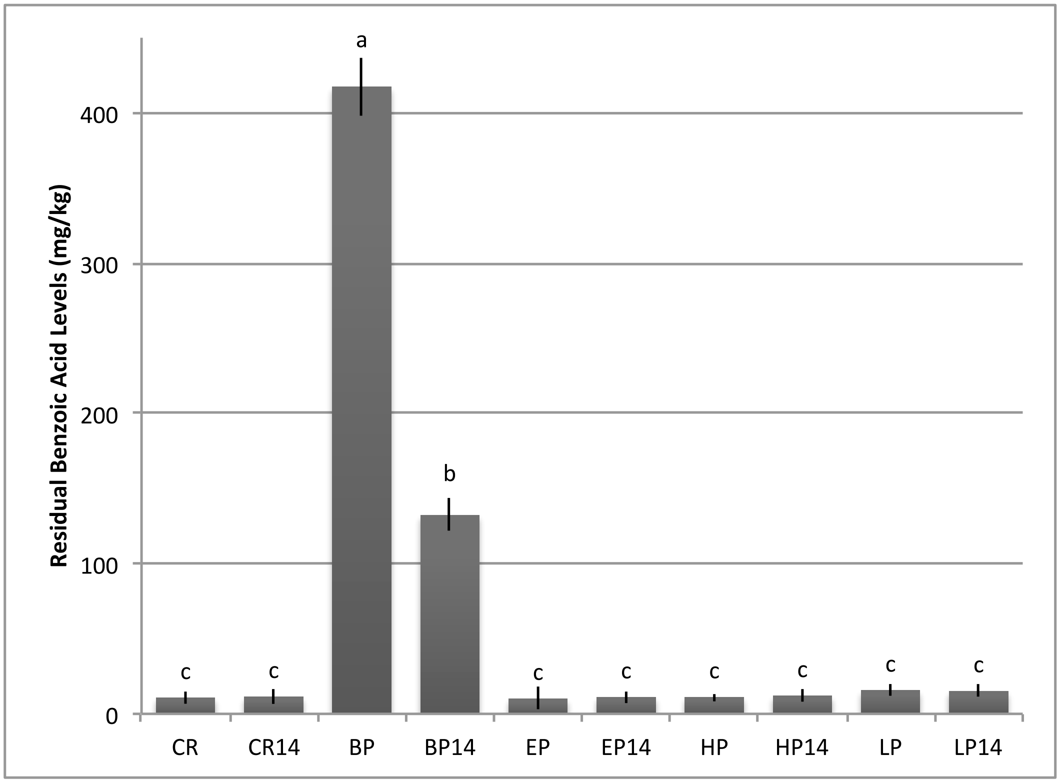
PC1 and PC2 = Principal components 1 and 2

Figure 3. Principal component biplot of volatile compound analysis (GC-MS) of sweet whey powders (SWP) bleached before or after reverse osmosis (14% solids).

Table 5. Selected volatile compounds of sweet whey powders (SWP) bleached before or after reverse osmosis (14% solids).

TRT	CR	BP	BP14	CR14	HP	HP14	LP	LP14	EP	EP14
DMS	0.106 bcd	0.067 d	0.140 abc	0.129 bc	0.076 d	0.076 d	0.065 d	0.141 abc	0.156 ab	0.096 cd
2 Methylbutanal	0.590 d	1.531 bc	1.947 ab	0.696 d	1.713 abc	2.431 a	1.495 bc	1.585 abc	0.910 cd	1.319 bcd
3 Methylbutanal	2.944 c	3.801 abc	3.837 abc	3.196 c	3.010 c	4.581 a	3.549 abc	2.973 c	3.478 bc	3.226 c
Pentanal	3.07	3.81	3.54	2.75	3.10	4.70	4.21	3.06	3.62	3.33
1-Hexen-3-One	0.017 b	0.016 b	0.020 b	0.012 b	0.010 b	0.019 b	0.017 b	0.077 a	0.014 b	0.021 b
DMDS	0.006	0.004	0.009	0.007	0.005	0.007	0.005	0.005	0.004	0.005
Hexanal	0.308 f	1.786 c	0.878 ef	0.503 f	0.871 ef	2.388 b	1.045 de	3.775 a	1.597 cd	2.657 b
Heptanal	0.173 d	0.396 b	0.213 d	0.164 d	0.199 d	0.360 b	0.133 d	1.09 a	0.326 bc	0.236 cd
Alpha Pinene	0.255 a	0.096 bc	0.043 c	0.195 ab	0.121 bc	0.097 bc	0.143 b	0.181 ab	0.132 bc	0.163 ab
2-Pentylfuran	0.193	3.501	1.267	0.166	0.256	0.605	1.405	2.473	2.653	1.578
Z-4-Heptenal	2.934 d	7.335 bc	7.458 bc	2.812 d	7.514 bc	8.114 ab	7.638 bc	8.791 a	8.996 a	8.192 ab
DMTS	0.031	0.014	0.025	0.036	0.038	0.027	0.033	0.02	0.016	0.029
1-Octen-3-One	2.93 c	7.33 b	7.45 b	3.34 c	7.51 b	8.11 ab	7.63 b	8.79 a	8.99 a	8.19 ab
Octanal	0.301	0.403	0.365	0.353	0.376	0.417	0.347	0.452	0.307	0.389
2-e-Octenal	0.561	0.912	0.624	0.73	0.729	0.855	0.744	0.876	0.766	0.849
Nonanal	1.90d	3.06 ab	3.18 a	2.13 d	2.68 bc	3.31 a	2.49 c	2.93 ab	2.50 c	2.68 bc
E2Nonenal	0.118	0.158	0.155	0.129	0.132	0.145	0.146	0.15	0.117	0.117
Decanal	0.367	0.228	0.426	0.422	0.537	0.305	0.319	0.247	0.248	0.563

- Means in a column followed by a different letter are significantly different ($p<0.05$)



*Different letters indicate significant differences (p<0.05)

Figure 4. Residual benzoic acid (mg/kg) of sweet whey powders (SWP) bleached before or after reverse osmosis (14% solids).