THE SHIFT OF YOGURT ACID WHEY FROM WASTE PRODUCT TO VALUABLE INGREDIENT ACROSS VALUE ADDED FOOD PRODUCT CATEGORIES

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Food Science & Technology

by

Julie Camacho Flinois

May 2019

BIOGRAPHICAL SKETCH

Julie Camacho Flinois, daughter of Stephanie Porterie Flinois and Bruno Flinois, was raised in Neuilly Sur Seine, France. She attended Lycée Louis Pasteur (Highscool), followed by Université Paris VI Pierre et Marie Currie for Medical studies in France before moving to Canada. She received an Honors Bachelor's degree in Cognitive Science with minor in Interdisciplinary Life sciences and distinction from McGill University, QC, Canada in May 2017. She discovered the applications of science on the world of food she was always attracted to during her years in Montreal as she worked for a bakery offering vegan and gluten-free pastries. She then moved to Ithaca NY to work in the department of Food science under Dr. Olga I Padilla-Zakour at Cornell University.

During her studies, Julie gained experience working for a snack and beverage consulting company in Los Angeles CA, working mostly for PepsiCo and TATA as well as private clients. She is also a co-founder of Antithesis, student-run packaged-goods startup, with three of her colleagues from the Cornell Graduate school of Food science. She was the TA for the Sensory science class and won several awards including WNYIFT outstanding food science student (2018), Better process control school certificate, PMCA student outreach program participant, member of the finalist team (6^{th} place) of the IFTSA-Mars Product development competition, captain of the finalist team (3^{rd} place) of the Idaho Dairy Competition 2018 and the first place in the Research competition - product development section - at IFT18.

To my husband Alejandro Camacho:

For your indispensable support in accomplishing each step of this wonderful journey.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Olga Padilla-Zakour, for giving me the opportunity to learn about Food Science principles and about my own abilities in such a supportive environment. I realize now thanks to you how valuable a great mentor can be. I would also like to thank Dr. Robin Dando, my minor advisor, for sharing his expertise of Food Sensory science and for being exceptionally dependable.

I felt incredibly welcomed as part of the Cornell Community from day one. I am very appreciative for all of you who never hesitated to land a helping hand. Special thanks to Erin Atkins and Janette Robbins, for their inestimable help in keeping all administrative matters worry-free, to Kyle Kriner for his precious assistance in the lab and moral support, to Aaron for saving the day for me a few times and for delicious eggs, to Elizabeth Burman for her motherly guidance through grad-school life, and to Pedro Menchick for all his acid whey insights. A very special thanks to the Antithesis family, Jason Goodman who welcomed me before I even applied to the program, Ashton Yoon and Philip Kim; for being a part of my happiest hard-work memories and hopefully colleagues and friends for years to come.

All my gratitude to my family, Bruno, Stephanie, Clementine, Guillaume, Mariel, Juan, Daniela, Rodrigo, Paulina and Stephen, who are all in different industries and still patiently listened to me talk about the by-product of greek yogurt manufacturing and did not hesitate to try some of my concoctions.

Last but not least, to my incredible husband Alejandro who helps me discover the best version of myself every day, and without whom none of this would have been possible. For your encouragements, for your detriments and for my happiness, thank you.

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ABSTRACT

Introduction: Consumers are increasingly aware of the significance of the food choices they make, from a nutritional, environmental and social standpoint. The ingredient list, nutrition label, price of the items and other claims on food packaging are all important aspects of food choices that can be influenced by the use of novel ingredients.

Yogurt Acid Whey (YAW) is produced in surplus as a by-product of the booming Greek-style yogurt industry. Its chemical composition hinders its processability and its high biological oxygen demand (BOD) make its disposal in large quantities threatening to the environment. It is an abundant and cost-effective resource available near value added product manufacturers.

Compared to other by-products of the dairy industry integrated within the food system (buttermilk, skim milk, etc.), YAW nutrients are neither re-introduced for humans as a dairy product, nor as processed ingredients for the manufacture of other food products. Focused efforts are therefore warranted for the improvement of the management of the increasing volumes of YAW compared to buttermilk (causing no economic loss or environmental damage at current and expected production volumes).

Methods and results part 1: The YAW pilot-product formulated in the first part of this study (a dairy-based dip containing >60% YAW) performed as well as successful commercial samples in sensory studies, implying that YAW is a suitable ingredient to be used by manufacturers in significant proportions in commercial formulations. Additionally, the "Salsa con queso dipping sauce" made with YAW had a similar or better nutritional profile than the commercial controls.

Concluding on the viability of using YAW as a majority ingredient in sauces dressings and dips, a Ranch dressing formula was developed using buttermilk, which was then replaced with YAW at varied concentrations to assess the boundaries of its utilization and corresponding effects on nutrition and shelf-life, both of which were positive. We demonstrate that 15-17 ºBrix YAW leads to on-par consumer acceptability with buttermilk Ranch dressing. Yogurt Acid Whey was therefore shown to be a suitable ingredient in the sauces, dressings and dips category, provided selection of appropriate host products and minor processing adaptations.

Methods and results part 2: The suitability of acid whey uptake as a main ingredient in sauces and dip products advocates for further assessing the suitability of acid whey uptake in other product categories. The second part of this study aimed to extend the scope of application to understand the benefits and challenges of using YAW as an ingredient in the baked goods category. Baked products seem to be suitable as they often call for liquids (milk, buttermilk or water) that may be readily replaced by YAW. Using Pancakes (dairy-based, chemically leavened, sweet, high water content batter, surface baked) and Pizza crust (water-based, fermented /yeast leavened, savory, low water content dough, oven baked) as model products, we showed favorable use of YAW with a by-weight replacement of water, with shelf life benefits, cost reduction and minor flavor challenges.

Significance: The work performed in the context of this thesis leads to the conclusion that YAW in its minimally processed form is a suitable ingredient as major component in the formulation of products in several value-added food products categories. Formulating products using YAW is an ecological, industrially feasible and commercially viable initiative to support the sustainable growth of the Greek-style yogurt production.

CHAPTER 1A

FEASIBILITY OF THE USE OF YOGURT ACID WHEY AS A MAJOR INGREDIENT IN VALUE ADDED PRODUCTS: DAIRY-BASED DIPPING SAUCE

ABSTRACT

Introduction: The 20-fold increase in consumption of Greek yogurt in the past 10 years has resulted in the production of vast amounts of yogurt acid whey (YAW) as by-product. YAW composition (e.g. high acidity, biological oxygen demand, mineral content) presents considerable challenges for processing and disposal, whereas its flavor profile (e.g. high astringency, saltiness) makes its use as an ingredient more complex than sweet whey.

Method: A YAW based “Salsa con Queso dipping sauce” with over 50% YAW was formulated. The optimal formulation (60.9% YAW, pH 4.85±0.12, ºBrix 19.52±0.27, aw 0.979±0.001), was compared to four leading commercial products in the corresponding market segment (with mean attributes 5.1±1.0 pH, 21.9±8.8 ºBrix, 0.98±0.02 aw) using physical analysis and a consumer sensory test (n=97, JAR, 9-point hedonic, purchase intent, demographic). The melting properties and particle size of cheese were evaluated in water, YAW or YAW with trisodium citrate. All trials and analyses (pH, ºBrix, aw, colorimetry, viscosity) were triplicated for statistical analysis.

Results: Cochran’s Q and Post-Hoc tests on sensory data showed that liking and purchase intent for the YAW Salsa was on par with each commercial product ($p < 0.05$). Despite the astringency of the YAW, the pilot-product did not exhibit a higher perceived aftertaste than commercial products (fisher’s test, $p > 0.05$). Melting salts improved the lower cheese miscibility in YAW samples solving the potential physical separation concern.

Significance: YAW is a suitable ingredient as major component in the formulation of sustainable, healthier, commercially successful dipping sauces.

INTRODUCTION

Over the last decade, consumers have shown a growing interest in Greek-style yogurt, resulting in sales of greek yogurt going from under 5% of the total US yogurt market in the early 21st century, to close to 50% of the total yogurt market today (Watson, 2014; Erickson, 2017; Conick, 2015). These rising trends increase the relevance of studying the by-product of such a booming industry. The by-product of the production of Greek-style yogurt is Yogurt Acid Whey (YAW), which accounts for 2/3 of the milk used to make the final product (Kyle & Amamcharla, 2016) . The ten-fold increase in sales of Greek Yogurt translates to upwards of 1.5million metric tons of YAW produced in the US alone in 2015 (Erickson, 2017). Yogurt acid whey has high organic matter content (mostly lactose) and therefore high biological (> 35,000 ppm) and chemical (> 60,000 ppm) oxygen demand (Mawson, 1993, Smithers, 2008) mostly caused by the lactose content (Beszédes, László, Szabó, & Hodúr, 2010, W. S. Kisaalita, K. L. Oinder, K. V. Lo, 1990). All untreated acid whey disposal is prohibited through strict environmental regulations (Smithers, 2008), hence the need to find alternatives to YAW disposal.

During the production of dairy products derived from the coagulation of milk, the composition of the whey varies depending on the production process, including the process used to coagulate the milk. Rennet-coagulated products (e.g. hard cheeses) produce sweet whey: pH > 5.8, with high protein and limited mineral contents. Acid-coagulated products (e.g. cream cheese and greek yogurt) yield acid whey: pH < 5.0 (often as low as 3.5, Smithers, 2015), with a lower protein, and higher ash content.

Dairy products such as cheese or Greek yogurt, rely on the purposeful precipitation of casein. In order for casein to precipitate and separate from the rest of the milk's components (the whey, constituted of water and soluble fraction), either or both methods (rennet and acid) are used. Rennet coagulation causes a cleavage of k-casein (the "hairy appendices" of the micelles responsible for the electrostatic/steric repulsion between them and keeping them stable in suspension), causing micelles to aggregate due to hydrophobic interactions, forming the curd (Fox & McSweeney, 2003).

Acid coagulation (added or by fermentation) lowers the pH to 4.6 or below, reaching the isoelectrical point of k-casein, thus canceling the electrostatic repulsion and causing casein to coagulate. Additional heat treatment in the case of Greek yogurt also cause b-lactoglobulin to denature and unfold. It later attaches to the k-casein through disulfide bonds, staying in the curd portion when the whey is strained. Both processes being irreversible, attempting to re-suspend k-casein from cheese in the Greek yogurt whey would be troublesome as k-casein interacts together hydrophobically (Sfakianakis & Tzia, 2014)

In the production of Greek-style Yogurt, after the addition of acids to curdle the milk proteins, the processes most commonly used to concentrate the yogurt are centrifugal separation and ultrafiltration. These processes both separate the solid portion from the smaller compounds (small molecules like water and lactose, minerals and hydrogen ions) as by products. This process explains the lower pH, lower total solid content, higher levels of ash and lower levels of protein in acid compared to sweet whey (Lievore et al., 2013).

Contrary to sweet whey, which is widely used as an ingredient in its numerous processed forms (Bylund, 1995), the physicochemical characteristics of YAW pose scientific challenges that limit its processability (Smithers, 2015, Dec & Chojnowski, 2006), and therefore its utility. Although research groups across the world are working on the development of technologies to unlock the processing potential of YAW, most current uses are unlikely to expand sufficiently and cost-effectively to account for increasingly higher volumes of YAW. The land applications of YAW as fertilizers are tightly regulated by NY State Department of Environmental Conservation for environmental reasons and limited by nitrogen or phosphorus content (Ketterings, Czymmek, Gami, Godwin, & Ganoe, 2017). The use of YAW as animal feed is also limited by the high moisture content for practical reasons (T. Overton, personal communication, September 2018). The use of YAW as an energy source has been successful (Beszédes et al., 2010), although the steep investment required to adopt the technology has been cost prohibitive so far (Moser & Mattocks, 2000, Angenent, Schatz, Byers, Daly, & Gandy, 2014) leading to less than 0.5% of dairy farmers in NY State employing such technologies (Elliott, 2013).

The chemical composition of YAW (Menchik, Zuber, Zuber, & Moraru, 2018, Menchik, Zuber, Zuber, & Moraru, 2019), its physical attributes listed above, in addition to its sour and salty taste, limit its application as an ingredient in value added products. Still, YAW contains high levels of valuable nutrients such as minerals (e.g. calcium, potassium) (N. P. Wong, LaCroix, & McDonough, 1978) and lactose (Smithers, 2015, Wronkowska et al., 2015), which give it potential as an ingredient in the manufacture of value-added products in the food industry.

Avoiding complex and costly processing altogether (Smithers, 2015) and using YAW as an ingredient without segregating its constituents would be an economical solution to shift what used to be considered a 'waste' product into a cost-effective commodity in the food industry. However, several challenges must be overcome regarding the astringency, sourness, saltiness and sweet taste, as well as color. YAW's attributes require careful incorporation into the complex flavor and texture profile of a suitable host product. A maximum acceptable concentration of YAW may be identified for any individual product category. The miscibility of other dairy ingredients such as cheese must also be managed since YAW can be defined as their antipode. Melting salts, such as trisodium citrate, increase the solubility of colloidal calcium phosphate, the hydration of micelles, and the dissociation of casein from casein micelles (Pastorino, Hansen, & McMahon, 2003), and thus may improve cheese miscibility in YAW, for better mouthfeel and stability. Emulsion shelf life attributes may also be affected by the pH, lactose and minerals from the YAW.

The aim of this study was to assess the successful technical implementation and suitability of using YAW as an ingredient in a dairy-based dipping sauce, in a significant proportion to formulate commercial products.

MATERIALS AND METHODS

Ingredients: YAW (Byrne's dairy, NY) was collected and stored refrigerated (6ºC) for no more than a week before being pasteurized at 93ºC/181ºF for 3 min for shelf stability (Padilla-Zakour, 2009, p.407). Other ingredients and 4 commercial dipping sauces (anonymized in this thesis by letter codes P, T, B, N. Brand names will be disclosed upon request to the authors) were purchased from a national supermarket in Ithaca, New York. After 23 re-formulations collecting informal sensory feedback from panelists (focus group n=10, informal n=35 panel blind to study objectives) on Cornell campus, a formulation was selected as optimal.

Dipping sauce preparation: Starches and YAW were homogenized (Ultra-Turax, T25 basic IKA®, Werke) for 1 min (30 sec on 8000 RPM and 30 sec on 12000RPM) and heated (to 90ºC) whilst stirring continuously. Cheeses, tri-sodium citrate and YAW were stirred and left to sit (room temperature for 5min), homogenized (Ultra-Turax, T25 basic IKA®, Werke) for 1min (8000 RPM) and added to the starch mixture whilst stirring continuously. Spices, gums, vegetable oil, vinegar, YAW and vegetables (jalapeno, bell peppers, onions) were blended and added to the starch and cheese mix. The final product was brought to 83ºC (181ºF) for 3 min before being hot filled in jars and stored at refrigerated temperature (6ºC). Final product contained 60.9%/w YAW.

Sensory evaluation: In a Central Location Test (CLT), the cheddar-jalapeno dipping sauce was compared in a randomized blind sensory study (n=97) versus several commercial products. Demographic data was collected from the panelists, and sensory data was collected using the 9-point hedonic scale for overall, appearance, texture, color and flavor liking, Just About Right (JAR) scale, purchase intent and short open-ended questions. Analysis was performed at the Cornell Sensory Evaluation Facility, in individual booths, under standard lighting. All procedures were evaluated and approved by the Cornell University Institutional Review Board for Human Participants, with all subjects providing informed consent. Panelists were users of the category and recruited with normal senses of smell and taste and with no salient food allergies. Sensory data and sensory data statistical analyses were gathered using RedJade (Curion Insights, Redwood City, CA).

Phisico-chemical evaluation: The 5 dipping-sauce samples were compared on their chemical and physical aspects: nutritional profile (chronometer online software), pH (Orion 3 star pH Benchtop, Thermo Electron corporation, electrode Orion 8172BNWP ross sure-flow combination pH, Thermofisher scientific Inc., Waltham, MA), total soluble solids as ºBrix (pocket digital refractometer, 300053, Sper scientific, Phoenix, AZ), water activity (aw) (Aqua Lab Dew Point Water Activity Meter 4TE, Decagon, Pullman, WA), color components

(UltraScan VIS, HunterLab, VI) and viscosity (Broomfield DV-III ultra, programmable rheometer, Ametek, MA).

Cheese miscibility assay: In parallel to the product development study, a cheese miscibility assay was conducted, in order to compare the behavior of cheese in water and in YAW. A cheese blend (containing half shredded Cheddar and half shredded Montery Jack cheese) was stirred in water or YAW, homogenized at 16000RPM for 15 sec and 24000RPM for 15 sec, then heated on a hot plate (on the 200ºC setting for 15 min). A third mixture containing the same cheese blend and YAW was prepared with tri-sodium-citrate (Modernist Pantry, Kitchen Alchemy, 3%/w of cheese) and processed as above. The three final mixtures were then analyzed: pH, soluble solids as ºBrix, refraction or total soluble solids (Abbe refractometer, Leica Inc, Buffalo NY), water activity (aw) and particle size analysis (Masterizer 2000 and Hydro 2000G model AWA2000, Malvern instruments, Malvern, UK).

Statistical analysis: Throughout the study, samples were prepared in triplicates for instrumental testing, and measurements were performed in triplicates for each sample, leading to 9 individual observations of each variable for each condition. Statistical data analyses were performed using IBM SPSS Statistics (version 21). For hypothesis testing, a significance level of 0.05 was used.

RESULTS AND DISCUSSION

Acid Whey composition and variability

The physical composition of the Greek yogurt acid whey used in this study stemmed from a parallel study (Menchik et al. 2018-2019). This allowed for a comparison of the composition of acid whey from our source, Greek-yogurt-producing dairy farm in upstate New York, with other acid whey sources (Martínez-Hermosilla, Hulbert, & Liao, 2000, Lievore et al., 2013) and the Dairy Processing Handbook (Bylund, 1995), which showed to be considerably different for some parameters.

These differences in chemical composition (Table 1) of up to 20% of the compound's weight stem from variations in the milk (e.g. cow's diet, season), and the fact that acid whey may be a by-product of different types of dairy products (e.g. cottage cheese, Greek yogurt, quark) which may each be manufactured in slightly different ways in each plant. These differences may be valuable in increasing the specificity of product developed by dairy manufacturers upscaling their own production of acid whey, thus limiting the possibility of imitation of their formula. However, it might be an obstacle in the case of manufacturers developing products using the YAW produced by other manufacturing plants, because the composition of the ingredient may vary greatly from one source to the next, forcibly modifying the final product potentially significantly by a change of supply.

Table 1

Meta-analysis and comparison of the composition of acid whey depending on the dairy-product source.

	Units	Acid whey source	pH	Ash	Protein	Lipids	Dry mass /total solids	Moisture	Lactose
Menchik et al., 2018	% (w/w)	Greek style yogurt	4.21 –4.48	6.4 – 7.5	1.7 – 3.7	1.3	6.0 – 6.2	94.23	3.33 – 3.5
		Cottage cheese	4.35 – 4.41	3.3 – 4.2	1.7 – 5.1			93.08	1.99 – 3.13
Lievore et al., 2013	% (w/v)	Petit Suisse type cheese	4.37 (±0.14)	0.61 (±0.37)	0.84 (±0.55)	0.09 (±0.04)	5.57 (±57)	94.44 (±0.54)	4.18 (±0.84)
Martínez-Hermosilla et al., 2000	%	Cottage cheese	4.4	0.6	0.75	0.02	6.32		
Dairy processing handbook (Bylund, 1995)	%	generic	4.3 – 4.6	0.8	0.55	0.04	6.5	93.5	4.9
Gallardo-Escamilla, Kelly, & Delahunty, 2005	%	Quarg	4.36		0.78		6.3		
		Lactic acid Casein	4.48 – 4.61		0.68 – 0.70		5.9 – 6.9		
		Mozarella	4.61		0.29		6.1		

Table 1. Meta-analysis and comparison of the composition of acid whey depending on the dairy-product source.

Effect of YAW content on the physical attributes of a dairy-based sauce product.

To study the effects of using YAW in products containing cheese, a comparative study was performed. Analysis showed little to no effect on water activity compared to control, an expected decrease in pH and an increase in soluble solids (ºBrix) caused mostly by the lactose in the whey (Table 2). Other studies using acid whey as an ingredient (without focusing on its level of incorporation) showed results consistent with the results presented in this study. In fermented deer sausage production (Karwowska & Dolatowski, 2017), acid whey addition had no significant effect on water activity; however, contrary to the results presented here, there was also no difference in pH between the acid whey supplemented sausage and its control, probably due to the low percentage of YAW in their total formulation (5%/w).

Table 2

Physical attributes of cheese in water or cheese in YAW solutions after heat processing and homogenization.

	Water + cheese (0)	YAW + cheese (1)	YAW + cheese + tri-sodium citrate (2)
a_W	0.996 (± 0.001)	0.993 (± 0.001)	0.993 (± 0.001)
pH	5.51 (± 0.01)	5.09 (± 0.02)	5.28 (± 0.05)
Brix	3.7 (± 0.3)	9.2 (± 0.1)	9.6 (± 1.3)

Table 2. Physical attributes of cheese in water or cheese in YAW solutions after heat processing and homogenization.

The addition of YAW had a significant effect on cheese particle size (Figure 1). In order to control this, trisodium citrate was used (3%/w of cheese, Groups & Edition, 1993; Pastorino et al., 2003). Particle size was resultantly brought back to levels similar to the control (>60% under 1µm) with the use of tri-sodium citrate (Figure 1). Melting salts (e.g. sodium hexametaphosphate, trisodium citrate) are common ingredients amongst the commercial products of the category (2 out of 4 of the selected representatives in the second part of this study). The use of acid whey in a product containing cheese can thus be expected to increase the total soluble solids (ºBrix) by over 200% compared to water-based preparations and contribute to decreasing the pH below 5.5 while having little effect on water activity.

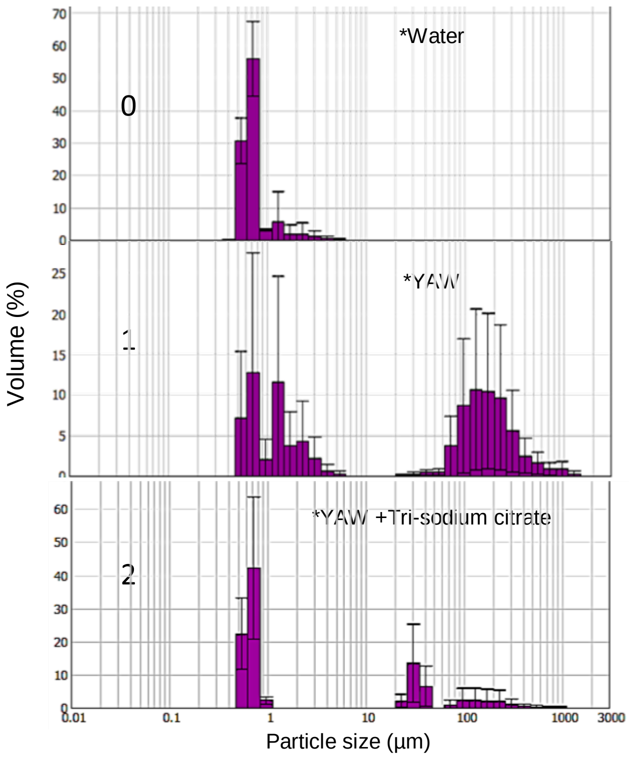

Figure 1. Particle size analysis of cheese blend homogenized in liquid* (mean ± 1 standard deviation error bar).

Developing a healthier dipping-sauce product with >50% YAW

To better understand the feasibility of using YAW in sauces, dips and dressings, a model product was developed to represent a broad commercial spectrum: a dip, containing dairy (cheese), with a non-astringent flavor profile. This cheddar and jalapeno dipping sauce was developed to target the segment of products marketed under the terms “Salsa con queso, medium”. This category was selected versus others such “cheese sauce”, “cream cheese dip” or “pimiento cheese” following several arguments. First, products labeled as “salsa con queso” typically contain more ingredients, allowing for more flexibility with ingredient substitutions, such as the inclusion of YAW. Additionally, “salsa con queso” typically has a richer flavor profile than other dipping sauce categories (cheese, salsa-vegetables, spices…), increasing the potential for masking YAW’s flavor profile. Since flavors are super-additive in the brain (Small & Prescott, 2005), the complex flavor profile of “salsa con queso” was hoped to be most susceptible of masking the potential aftertaste of YAW. Finally, “salsa con queso” is the highest consumed of similar dipping sauce categories.

Four commercial products representative of this category were chosen using those identified as "best seller" and "top customer rating" on major national retail sites (Amazon.com and Walmart.com). The YAW product was then developed aiming to target the average physical and chemical attributes of the 4 commercial products used as market representatives. To better understand the benefits and challenges of using acid whey as an ingredient, no artificial colors or flavors were used, although they were present in some of the commercial products. The formula of a pilot-product was developed, containing similar ingredients (vegetable oil, cheese blends and cheese powders, starches, gums, vegetables/peppers, condiments and spices) as the four market-representative products, but in different proportions to accommodate for >50% YAW. This pilot-product was developed to fit the non-astringent product market "Medium Cheddar Jalapeno Dip" and to be physically and sensorially on-par with commercial representatives of this market category, but with superior nutritional profile (Table 3).

Table 3
Nutrition facts for average commercial product in the category "medium salsa con queso" and pilot-product medium salsa con queso developed with >60% acid whey.

Product	Calories /serving	Total fat g/serving	Sat. fat g/serving	Trans fat g/serving	Sodium mg/serving	Total Carb. g/serving	Protein g/serving	Calcium %RDI/serving	Potassium %RDI/serving
YAW product	44	2.3	0.7	0.7	278.8	3.9	1.9	7%	1.4%
Average Market product	64 (± 25)	3.9 (± 2.1)	1.0 (± 0.4)	1.0 (± 0.4)	300 (± 106)	3.7 (± 1.0)	1.0 (± 1.4)	4.5% (± 3.8)	0%

Table 3. Nutrition facts for average commercial product in the category "medium salsa con queso" and pilot-product medium salsa con queso developed with 50% acid whey.

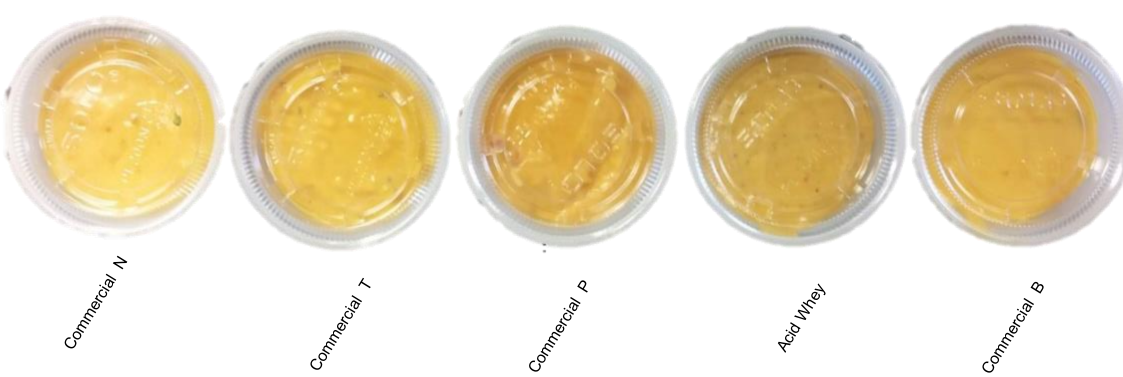

Figure 2. Samples presented to 97 panelists for sensory consumer/hedonic analysis.

The developed dip was successful in meeting the typical physical attributes of the products in this category. The total soluble solids content (approximated as ºBrix), acidity (pH), water activity (aw) and viscosity at refrigerated (4-7ºC) and room temperature (28-22ºC) were all within one standard deviation of the average of the representative products in the market category (see Figure 3). The absence of artificial color and lower fat content were responsible for a darker color (Figure 2) and thicker texture (Figure 3).

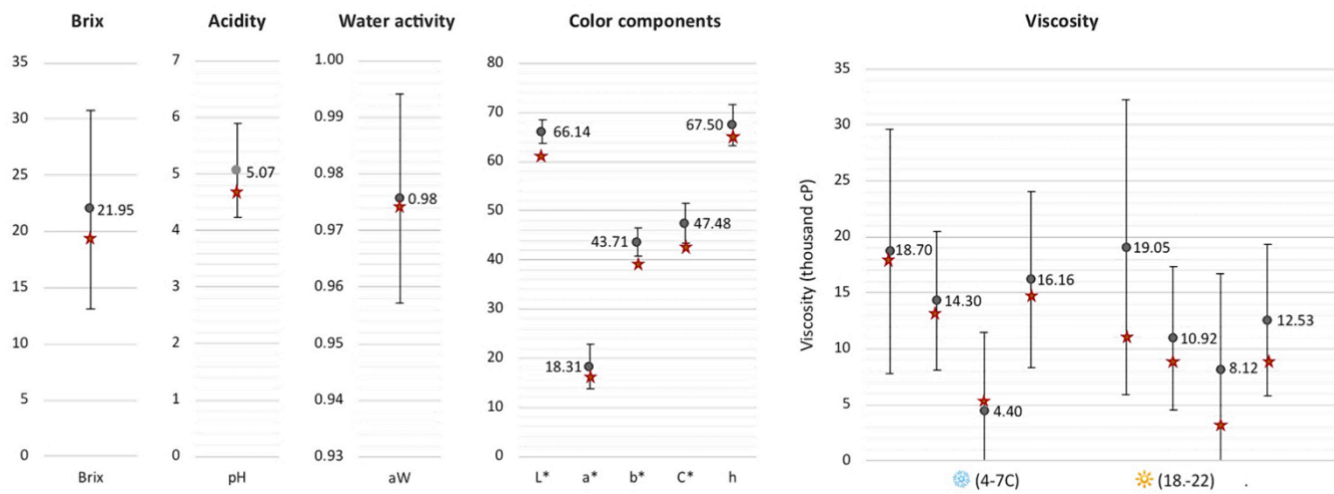

Figure 3. Comparison of physical and chemical properties of *YAW Salsa con queso* (★) with market products (n=4, whiskers represent standard deviation triplicate measurements from triplicate samples of the four products:

The color components of the pilot product were the only attributes outside of 1 standard deviation from the commercial products: the darkness (lower L* and C*) was considered to be an acceptable difference to commercial representatives in the absence of artificial color. The premise that acid whey can be used at >50%/weight of a healthier dip or sauce product requires avoiding the use of artificial color or flavor ingredients as they would be in a commercial setting. The overall liking of the product may have thus been impacted by the lower score on the appearance liking: 5.2 for the YAW product, 6.0 (± 0.5) for the commercial products (Figure 4). Karwowska & Dolatowski (2017) also found an effect of acid whey on lightness (L*) and redness (a*) in their meat product, probably due to the effect of acid whey on the browning of heme.

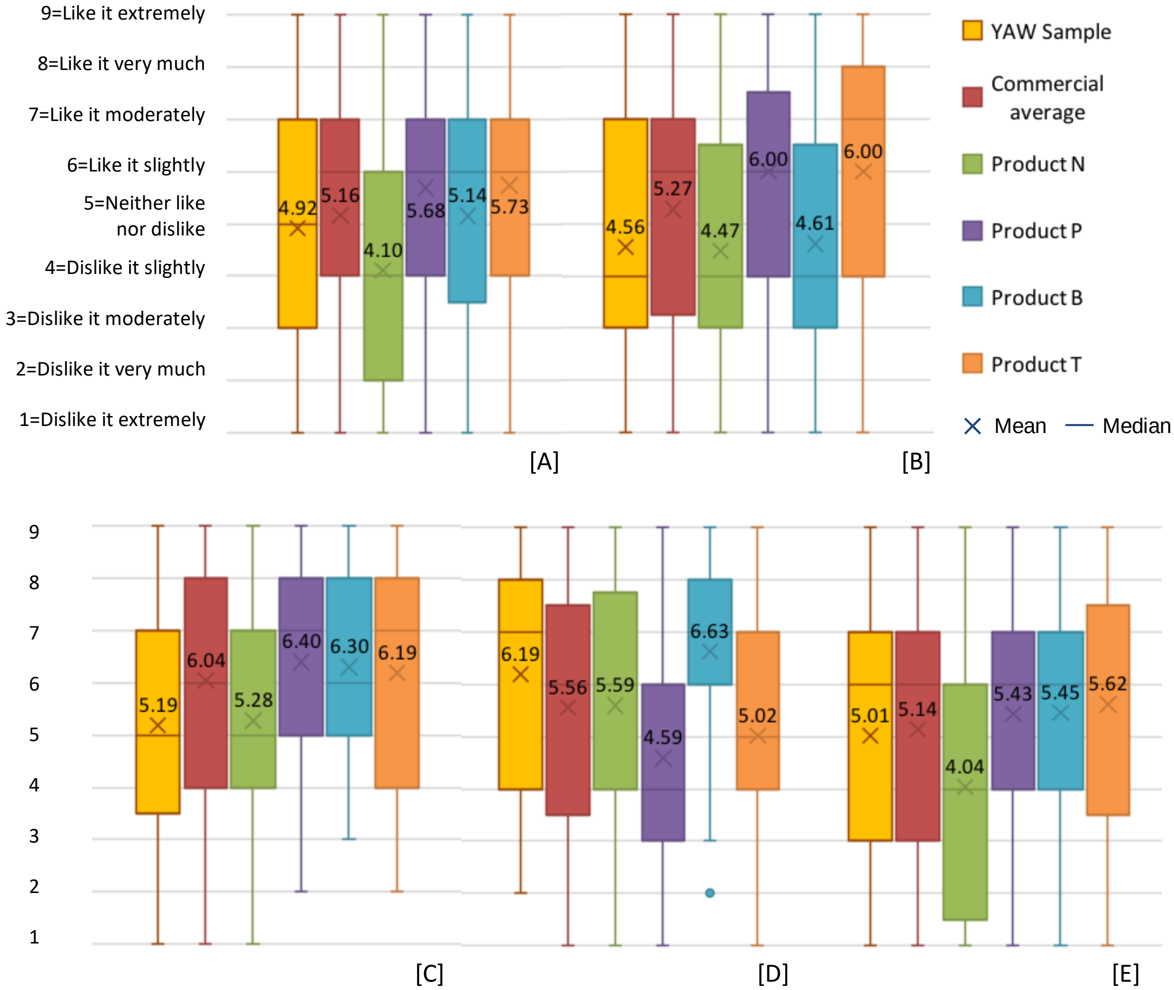

Figure 4. Comparison of sensory rating distribution of panelists (n=96) on 9-point hedonic scale of YAW sample and average of commercial controls, and individual commercial products. Overall liking [A], Appearance liking Color [B], Appearance liking Texture [C], Flavor liking [D], Texture liking [E].

The developed dip was also successful in meeting the typical sensory profile for the targeted product category (Figure 4). For instance, panelists gave it a rating of 3.4 (± 1.1) for spiciness and 3.0 (± 1.2) for salsa flavor, for an average of 3.5 (± 1.2) and 3.2 (± 1.2) respectively for the 4 commercial products (T-test between YAW sample and the average of commercial samples shows no significant difference: p= 0.32 and 0.21 respectively), thus confirming the pertinence of the selected YAW formulation for the purpose of this study.

Overall flavor liking was similar between the YAW dip and 3 commercial samples, and significantly better than the fourth (ANOVA, $p < 0.001$, Post Hoc HSD =0.90). The purchase intent (Figure 5) of the YAW sample was 2.4, not statistically different from three commercial samples, and again higher than one (N) of the four market products (average of 2.5 ± 0.4) (Cochran's Q test, $p < 0.001$, Post Hoc HSD = 0.45). Despite the astringency of YAW, the proportion of panelists reporting the presence of an aftertaste (Yes/No) was not significantly higher than the average of commercial samples (Fisher's test, $p = 0.16$). A pairwise comparison showed that one commercial sample (N) had significantly more aftertaste than each of the other and another (T) had significantly less aftertaste than each of the other ($\chi 2$ test $p < 0.001$, cross-tabulation standard adjusted residuals: +3.2 and -2.2 respectively).

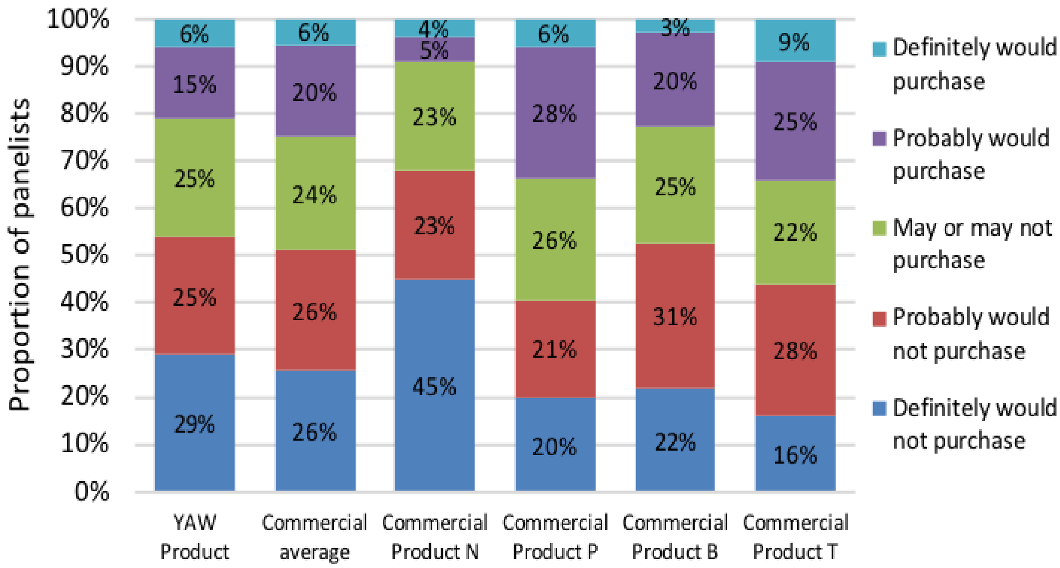

Figure 5. Purchase intent (n=97) of YAW "Salsa con queso dipping sauce" and 4 commercial control products.

The pilot-product scored 3rd on visual texture liking (5.6), not significantly different from products P, T and B (commercial products: 5.6 ± 1.0). Flavor liking was similar to 3 of the 4 commercial products (the product N scoring significantly lower) (Figure 4).

Although the pilot product contains less sodium per serving than commercial products, it was rated as second highest in "saltiness" (4.2 compared to 4.1 ± .2 for commercial products). Sourness ratings (4.3) were not different from the commercial products on average (4.4 ± 0.6), although one commercial product (N) had a significantly higher sourness (5.3), whereas the other three (P, T, B) were rated from 4 to 4.1.

CONCLUSIONS

Based on the attributes of the pilot-product (i.e. Salsa con queso), healthier products with a flavor profile differing from YAW (non-astringent, non-tartaric, non-sour) and containing over 60% acid whey can have on-par acceptability to consumers within their market segment. These products may contain less sodium, less fat and more minerals (potassium and calcium) compared to their corresponding controls. Working with YAW presents challenges due to its lingering native flavor, however this can be overcome in product formulations without any increase in aftertaste (astringency or otherwise) compared to controls.

The effects of acid whey on other dairy ingredients (cheese) and on the physical properties (aw, pH, º Brix) of sauces, dressings and dips, permit successful product development with little adjustment to the formulation. Addition of melting salts, such as tri-sodium citrate, may be useful in the case of products requiring dispersed cheese at room temperature, contributing to a smooth mouthfeel.

Future work will involve the study of replacement of specific dairy ingredients (e.g. buttermilk) by YAW in the product category of sauces dressings and dips, and the appropriate YAW proportion and concentration for best results. Attention will be drawn to formulation and processing adjustments required for successful implementation.

ACKNOWLEDGEMENTS

Research was supported by the NYS Department of Environmental Conservation "A comprehensive strategy for the value-added utilization of acid whey streams” and Terre d’enfant (Art de Vivre high-end and eco-friendly for children) sustainability fund. Recognition to Kyle Kriner for his technical assistance and Byrne Dairy for the acid whey.

AUTHOR CONTRIBUTIONS

J. Camacho Flinois designed the study, collected test data, interpreted the results and drafted the manuscript.

R. Dando contributed to study design, data analysis and manuscript editing.

O. I. Padilla-Zakour contributed to study design, data analysis and manuscript editing.

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CHAPTER 1B

IMPLEMENTATION OF YOGURT ACID WHEY AS AN INGREIENT IN VALUE ADDED PRODUCTS: RANCH DRESSING CASE STUDY

ABSTRACT

Introduction: Greek-style yogurt has expanded from 5% to 50% of the US yogurt market in the past decade, accompanied by a corresponding increase in production of its by-product: yogurt acid whey (YAW). YAW qualities (e.g. low pH, mineral content, astringency, saltiness) present challenges for processing, disposal or ingredient use.

Methods A shelf stable "Ranch dressing" was formulated by replacing buttermilk in the control with YAW and concentrated YAW (6.3 to 25.2 ºBrix). Added salt, gums and acids were adjusted. The effects of buttermilk substitution on stability were studied on pasteurized samples (8 months at RT). A consumer sensory study (n = 96) was conducted utilizing hedonic and Just About Right (JAR) scales. Purchase intent and demographic data were also collected. A focus group (n = 7) evaluated the sensorial attributes of the samples after 6 months. The experiment was performed in triplicate and all instrumental analyses (pH, soluble solids as ºBrix, aw, refraction index, color) were conducted in triplicates for statistical analysis.

Results: Increasing the gum content in YAW samples resulted in equivalent texture liking compared to control. Matching the control's NaCl concentration resulted in undesirable higher saltiness. The pH of 18.9 ºBrix YAW Ranch sample without lactic acid was under 4.6, with no effect on flavor liking. Increasing concentrations of YAW decreased L* and aw, and increased the refractive index and hue. YAW samples presented minimal changes over 8 months of storage and had better water retention than controls. We conclude that 15-17 ºBrix YAW is the optimal replacement for buttermilk in a dressing.

Significance: The formulation of dressings may be accomplished successfully, sustainably and cost-effectively, with minor processing adjustment, by substituting buttermilk with YAW.

INTRODUCTION

Products derived from the coagulation of milk are responsible for the co-production of liquid whey. Eighty to 90% of the milk entering dairy manufacturing facilities is turned into whey, accounting for about 50% of the nutrients originally in the milk (Božanić, Barukčić, & Lisak, 2014; Bylund, 1995; Nergiz & Sec, 1998; Wronkowska et al., 2015). The composition of this whey varies depending on the end product, and the manufacturer's production process. Hard cheeses (rennet-coagulated products like Cheddar) result in sweet whey, with a relatively high pH (> 5.8), high protein and limited mineral contents. Fresh cheese and strained yogurts (acid-coagulated products like Ricotta and Greek yogurt) produce acid whey, with a much lower pH (3.5 - 5), with lower protein and higher ash content.

The high biological oxygen demand of whey (Marwaha & Kennedy, 1988; Tsakali, Petrotos, & Allessandro, 2010) makes its disposal in natural water streams or municipal waters threatening to the environment. Its acidity and nutrient content upsets the natural equilibrium of stagnating waters, leading to algae blooms and loss of aquatic life (Carvalho, Prazeres, & Rivas, 2013; Kavaz & Öztoprak, 2017). This explains why whey disposal is tightly regulated (Smithers, 2008) and high scale dairy producers must find alternatives to its disposal.

Because of the threat to soil and water streams, land application of whey as fertilizers is also tightly regulated by the NY State Department of Environmental Conservation (Ketterings et al., 2017) and animal feed usage is unlikely to account for the increasingly higher volumes of whey being produced. Although successful, the use of acid whey as an energy source through bio-digestion requires millions of dollars of infrastructure (Angenent et al., 2014; Mawson, 1993; Smithers, 2015) leading to poor development across NY farms (Elliott, 2013).

In the case of sweet whey, innovative processing techniques have been developed for the extraction of lactose and protein to be upscaled as value-added ingredients (Bylund, 1995; Smithers, 2008). In the case of YAW, its demanding physicochemical characteristics, mainly low pH and lack of protein, have posed significant challenges that constraint its spray-drying and limit application for concentration and nutrient extraction (Smithers, 2015, Dec & Chojnowski, 2006). The complexity of YAW disposal has made it a costly process (Smithers, 2015).

These limitations have caused YAW to be directed mostly towards non-food uses, and valuable nutrients of acid whey remain predominantly outside of the human consumption channel (Bylund, 1995). The ever growing sales of Greek-style yogurt over the last 10 years have resulted in it representing over 50% of the total US yogurt market today compared to less than 5% at the beginning of the century (Watson, 2014; Erickson, 2017; Conick, 2015). In parallel, Greek-style yogurt acid whey is accounting for more and more of the whey by-product produced, and an increasing share of the global food loss. Thus, the upscaling of YAW and its reintroduction into the food supply chain would have a notable impact on the reduction of global food waste. The shift of YAW from costly waste to a valuable ingredient would be a financial achievement for the dairy industry, as well as an indispensable permanent solution to the dairy pollution problem (Kavaz & Öztoprak, 2017; Smithers, 2015).

The acidic and salty taste of YAW have been a barrier to its unprocessed use as an ingredient in value added food products, although a few experimental uses with no or minimal processing (Lievore et al., 2015; Wronkowska et al., 2015) and our results in the earlier part of the study proved promising (Chapter 1A). Further work on the extent to which liquid YAW can be used as an ingredient is thus essential, both in terms of the maximum acceptable concentration that can be applied to different product categories, as well as any required processing adjustments. Such data can act as the back bone to the implementation of YAW as an ingredient in the manufacture of high scale value-added food product.

MATERIALS AND METHODS

Ingredients: In order to assess the feasibility of replacing buttermilk with YAW in salad dressings, a pilot-product with a deliberately astringent flavor profile (Ranch dressing) was selected, thought to be likely to accommodate the flavor of YAW (Gallardo-Escamilla, Kelly, & Delahunty, 2005a; Mcgugan, Larmond, & Emmons, 1972). A control Ranch dressing was developed using buttermilk (Byrne's dairy, NY), mayonnaise (Hellman's, Unilever, Lisle IL), and a prepared mix of ingredients for flavor and texture (less than 2% of: MSG, salt, spices, dried parsley, sugar, white distilled vinegar, lactic acid, thyme, xanthan and guar gums). All ingredients were purchased from a national supermarket in Ithaca, New York. Four versions were prepared with 48%, 65%, 74% and 79% YAW respectively, in addition to the control. To achieve these YAW contents, 48%/w YAW was added in each recipe (replacing the 48%/w of buttermilk in the control formulation), with increasing soluble solids concentration (6.3, 12.6, 18.9 and 25.2 ºBrix).

Ranch dressing preparation: Ingredients were weighed (Table 4) and thoroughly mixed until visual-homogenization of fat and water components. Heat treatment was applied to the final Ranch dressing: 181ºF for 3min in a water-bath followed by hot filling in 32oz glass canning jars (Ball, Broomfield, CO) to achieve shelf stability (Padilla-Zakour, 2009, p .407). YAW (6.5 ºBrix, pH 4.45) was collected (Byrne's Dairy, NY), stored refrigerated (6°C) for no more than a week, pasteurized (93ºC/181ºF for 3 min) and concentrated using a freeze dryer (Harvestright freeze dryer, North Salt Lake, Utah). Additional formulations replaced the buttermilk in the control recipe with YAW at 4 different levels: 6.3 ºBrix (lowest native concentration observed in a period of 4 months from the facility), 12.6 (2X) 18.9 ºBrix (3X) and 25.2 (4X). No lactic acid was added (lactic acid is naturally present in YAW) and the amount of gums was increased inversely-proportionally to the YAW concentration.

Consumer acceptance: The 5 dressings (control, YAW1, YAW2, YAW3 and YAW4) were compared in a consumer sensory study (n = 96). One ounce of each samples was served at room temperature in a 2oz plastic cup, with a spoon, in a monadic sequential manner. Panelists had access to unsalted crackers and water for palate cleansing. Sensory data was collected using 9-point hedonic scales, JAR scales, purchase intent and short open-ended questions (Lawless & Heymann, 2010). All procedures were evaluated and approved by the Cornell University Institutional Review Board for Human Participants, with all subjects providing informed consent. Panelists were users of the category, recruited with normal senses of smell and taste, with no salient food allergies, and received financial compensation for their participation in the study. Sensory data were gathered using RedJade (Curion Insights, Redwood City, CA).

Physico-chemical evaluation: A shelf life study was also conducted at room temperature over 8 months: Day 1, Week 2, Week 5, Week 9, Week 15, Week 23 (5 months) and Week 36 (8 months). Each time, color was measured on the L*a*b* scale (Chroma Meter CR-400/410, Konica Minolta, Chiyoda, Tokyo, Japan), and water retention was analyzed as an indirect measure of the stability of the emulsion. The water retention of all the samples was measured following an adaptation of the water-holding-capacity procedure (Sodini, 2005). Three aliquots of 1.6 mL of each triplicated sample (n = 9) were centrifuged with a microfuge at 3000RPM/503RCFxg on "continuous" for 10min (Scientific model V, VWR International, Radnor, PA), at room temperature. The amount of whey expelled during centrifugation was measured visually (ImageJ Version 1.51 (100) 2015) as a proportion of the total volume (percentage of the water-based filtrate to the fat-containing supernatant). On the first two stages of the shelf life study, soluble solids as ºBrix (pocket digital refractometer, 300053, Sper scientific, Phoenix, AZ) and pH (Orion 3-star pH Benchtop, Thermo Electron corporation, electrode Orion 8172BNWP ross sure-flow combination pH, Thermofisher Scientific Inc., Waltham, MA) were also measured. Data presented for L*a*b* and water retention is the average of all time-point measurements as not effect of time was detected (2-way ANOVA $p>0.05$).

Shelf life focus group: At 23 weeks, the samples were given to panelists (n = 7) in a focus group setting following focus group methodology references from Liamputtong (2015). The panelists were blind to the samples (control, YAW1, YAW2, YAW3 and YAW4 at 5 months) and to the purpose of the study. Inclusion criteria comprised general good health, good understanding of the English language, and the absence of any egg or dairy allergy. The group was balanced for age and gender (4 women, 3 men) and rated their Ranch-flavor dressing consumption frequency from sometimes to extremely often. Subjects were asked not to wear perfume and not to eat or drink (except water) 1 h prior to the test session. Subjects received financial compensation for participation in the study. Panelists were guided through the tasting of samples and asked to discuss their impression of the individual samples first, followed by pairwise comparison with the control. Panelists were also asked to rank the samples on a linear scale from "like" to "dislike", and to agree on words characterizing each of the 5 samples from a prompted list of flavor, texture, odor and visual appearance.

Statistical analysis: Throughout the instrumental study, samples were prepared in triplicates, and measurements were performed in triplicates for each sample, leading to 9 individual observations of each variable for each condition. Statistical data analyses were performed using IBM SPSS Statistics (version 21). Sensory data were analyzed using RedJade. For hypothesis testing, a significance level of 0.05 was used.

TABLE 4

Formulation of control and experimental Ranch-style dressings

	Control	YAW1	YAW2	YAW3	YAW4
Buttermilk	48.15%	-	-	-	-
YAW (6.3 Brix)	-	48.03%	-	-	-
YAW (12.6 Brix)	-	-	48.06%	-	-
YAW (18.9 Brix)	-	-	-	48.06%	-
YAW (25.2 Brix)	-	-	-	-	48.06%
Mayonnaise	48.15%	48.03%	48.06%	48.09%	48.11%
Gums (xanthan and guar gum)	0.05%	0.10%	0.09%	0.08%	0.07%
Sodium Chloride	0.58%	0.77%	0.72%	0.67%	0.63%
Sugar	0.19%	0.19%	0.19%	0.19%	0.19%
MSG	0.96%	0.96%	0.96%	0.96%	0.96%
Lactic acid	0.19%	0.19%	0.19%	0.19%	0.19%
Vinegar	0.19%	0.19%	0.19%	0.19%	0.19%
Spices (parsley flakes, garlic powder, onion powder, black pepper, ground thyme)	1.54%	1.54%	1.54%	1.54%	1.54%
Total	100.00%	100.00%	100.00%	100.00%	100.00%

Table 4. Formulations of control and experimental Ranch-style dressings.

RESULTS AND DISCUSSION

Consumer's response to a Ranch dressing replacing buttermilk with YAW

For most sensory attributes evaluated in this study, overall flavor liking was poorest at the lowest (YAW1) and highest (YAW4) YAW concentration, hinting at the existence of an optimal level for buttermilk replacement (Figure 6). Aside from this point however, YAW replacement resulted in no decrease in overall or flavor liking up to a level of 18.9 ºBrix in the dressings. The texture of the YAW samples was actually liked more at higher levels of YAW although this could possibly be attributed to an accompanying decrease in concentration of gums in the formulation. A reduction in appearance liking was noted by panelists, suggesting some attention would have to be paid to ameliorating color changes induced by YAW during heat processing.

Even though all samples were standardized for sodium content, the control Ranch dressing displayed the highest "Just about right" score frequency (65% JAR) and smallest standard deviation (± 0.71). All YAW samples received lower frequency of "Just about right" scores (YAW1: 59%; YAW2: 61%; YAW3: 51%; YAW4: 51%), skewing "too salty". This highlights the possibility that YAW-supplementation may assist in developing sodium reduced dressings that are still perceived as pleasingly salty by consumers.

The product with a sourness level most often deemed JAR was YAW2, followed by YAW1, control, YAW3 and YAW4 placing last (Figure 7B). The only sample with a significant increase in mean perceived sourness from control was YAW4 (Cochran's Q test $p = 0.001$, post Hoc HSD: 0.35).

All YAW samples had a higher proportion of panelists who chose "way too much" or "moderately too much" (YAW1 10%; YAW2:12%; YAW3: 16%; YAW4:19%) than the control (9%) for the intensity of herbs and spices despite all formulations having the same proportion of herbs and spices (Figure 7C). The proportion of panelists perceiving too much herb-and-spice intensity increases proportionally to the amount of YAW in the samples, despite the standard amounts used in all samples. YAW may enhance the flavor of the herbs and spices within our formulation somewhat, and thus could allow for a decrease in herbs and spices as a silent change in commercial products, with associated cost benefits.

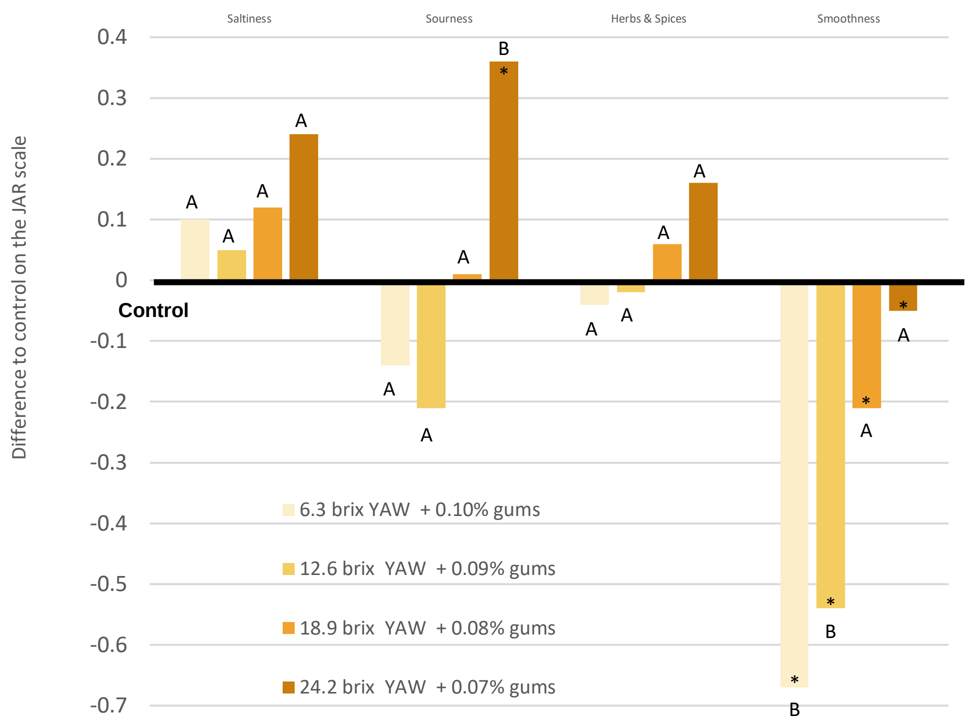
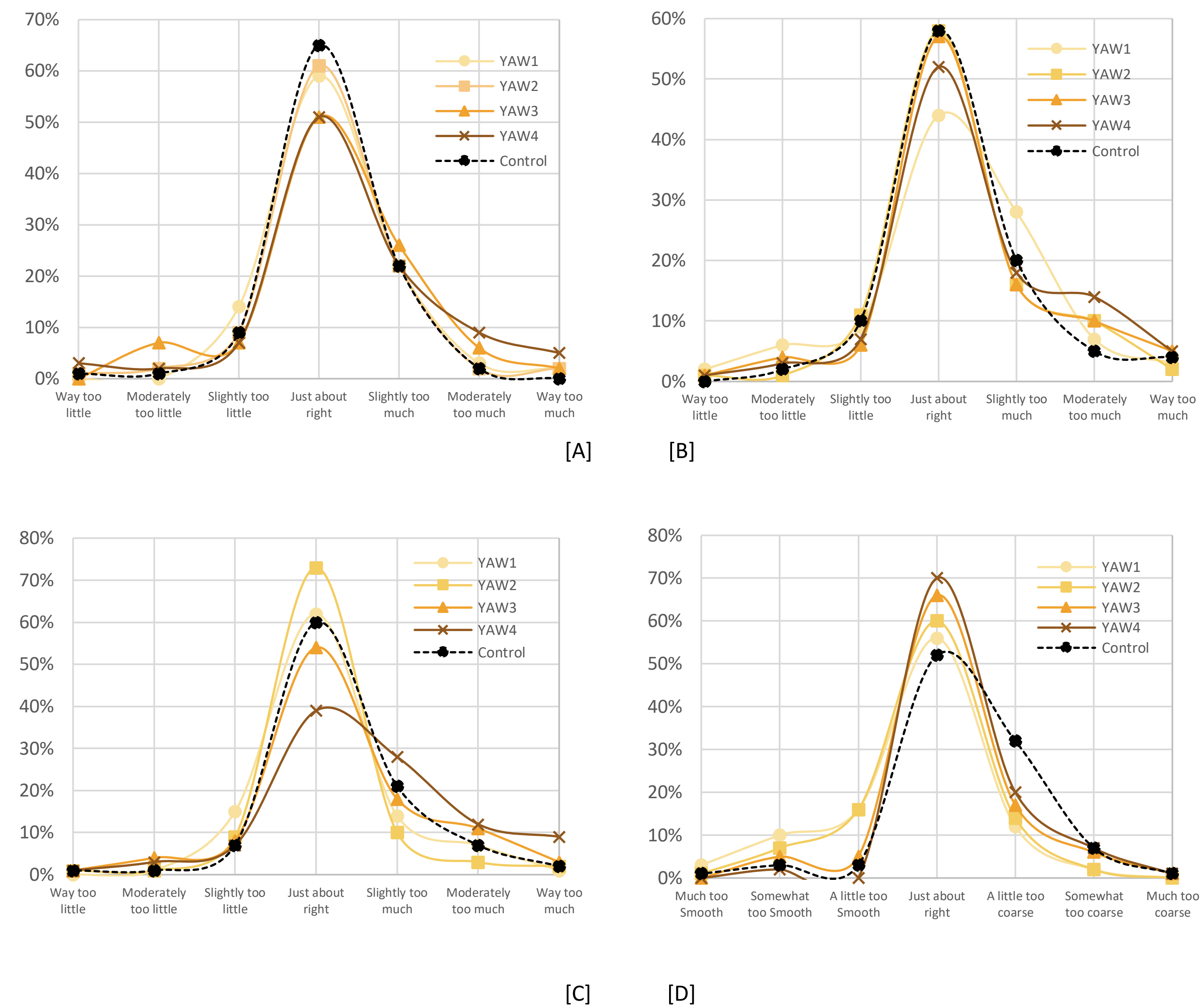


Figure 6. Flavor and texture liking scores of Ranch dressings at different YAW concentrations compared to control

Letters represent categories where the average score is (B) or not (A) statistically significantly different from control based on Cochran's q test followed by post-hoc comparison using Tukey HSD. Asterisks (*) represent categories where the distribution of scores is statistically significantly different from control based on ANOVA test followed by post-hoc comparison using Tukey HSD.

The amount of gums was increased in the YAW sample formulations to imitate the mouthfeel and thickness of the buttermilk in the control Ranch dressing. The thickness score distribution of YAW 3 was most similar to that of the control, with a mean of 4.0 (± 0.8) compared to 4.2 (± 0.7) for the control. It is therefore possible to recreate JAR thickness of Ranch dressing with an increase in gum content. The control Ranch dressing was the sample with the most "Too lumpy/grainy/coarse" ratings (Figure 7D).



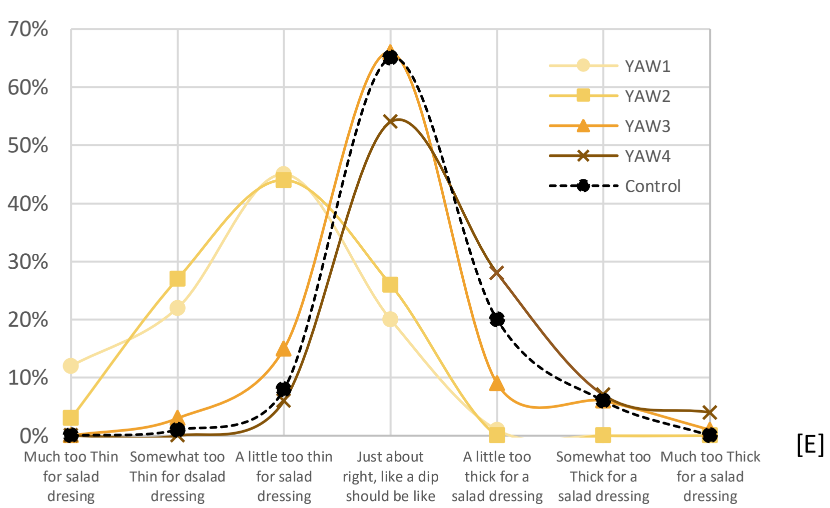


Figure 7. Percentage of panelists for each Saltiness rating [A] sourness rating [B] herbs/spices intensity [C] smoothness/mouthfeel [D] and thickness rating [E] distribution of Ranch dressings on the 7-point JAR scale.

The increase in mean JAR score for smoothness (Figure 7D) as well as the decrease in standard deviation were very positively correlated (proportional) with the increase in proportion of YAW (Pearson correlation r score of *YAW concentration*average smoothness JAR score* = 0.987), and was inversely correlated with the amount of gums (Pearson correlation r score of *gum content*average smoothness JAR score* = -0.987) since higher levels of YAW had proportionally lower gum concentrations. The control was the only sample for which the textural attribute "gritty" was selected by panelists during the focus group study. Based on the product's nutritional information (Figure 8), yogurt acid whey allows for increased smoothness despite lower fat content. There were no differences in texture liking between the control product and YAW3, suggesting that YAW plus gum can provide satisfactory texture liking despite the absence of buttermilk solids/fat in the final product.

Nutrition Facts [A]

Serving size	**2 tbsp (30g)**
Amount Per Serving	
Calories	**100**
	% Daily Value*
Total Fat 11g	**14%**
Saturated Fat 1.5g	**8%**
Trans Fat 0g	
Polyunsaturated Fat 6g	
Monounsaturated Fat 2.5g	
Cholesterol 5mg	**2%**
Sodium 170mg	**7%**
Total Carbohydrate 1g	**0%**
Dietary Fiber 0g	**0%**
Total Sugars < 1g	
Includes 0g Added Sugars	**0%**
Sugar Alcohol 0g	
Protein 0g	**0%**
Vitamin D 0mcg	0%
Calcium 22mg	2%
Iron 0mg	0%
Potassium 34mg	0%

*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Nutrition Facts [B]

Serving size	**2 tbsp (30g)**
Amount Per Serving	
Calories	**110**
	% Daily Value*
Total Fat 11g	**14%**
Saturated Fat 2g	**10%**
Trans Fat 0g	
Polyunsaturated Fat 6g	
Monounsaturated Fat 2.5g	
Cholesterol 10mg	**3%**
Sodium 180mg	**8%**
Total Carbohydrate 1g	**0%**
Dietary Fiber 0g	**0%**
Total Sugars < 1g	
Includes 0g Added Sugars	**0%**
Sugar Alcohol 0g	
Protein 0g	**0%**
Vitamin D 0mcg	0%
Calcium 21mg	2%
Iron 0mg	0%
Potassium 31mg	0%

*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Figure 8. Nutrition facts for Ranch dressing made with 17°Brix YAW [A] or buttermilk [B].

Sensory data suggest that the ideal acid whey Ranch dressing would be made with 15-17 ºBrix YAW. At that level, calories, sodium and protein are the only nutritional parameters impacted sufficiently (>5 kcal or 0.5g / serving) to be noticeable on the US FDA 2016 Nutrition Facts (FDA, 2016) (Figure 8A). Specifically, we would observe a 5-8% decrease in calories and sodium, up to 20% decrease in sugar, 12% increase in calcium and 8% increase in potassium. The only nutritional deficiency versus the control would be a 0.5g/serving decrease in protein, which, as discussed, is separated from the acid whey and retained in Greek-style yogurt.

YAW samples had significantly lower scores than the control for two attributes. The first attribute was the color liking (Figure 10D). These results can be explained by the higher darkness (lower lightness: L*) and higher yellow color (b*) of the YAW samples (Figure 9). Heat processing variables (time, temperature and stirring frequency) were kept standard for all 5 samples. However, the high lactose content of the YAW samples may have accelerated browning through the Maillard reaction at the point of contact with the heat source. To solve that issue, Ranch dressings made with acid whey should be processed appropriately, with a lower temperature, higher time, and more constant stirring to avoid drying at the contact with the heat source, and therefore avoid browning.

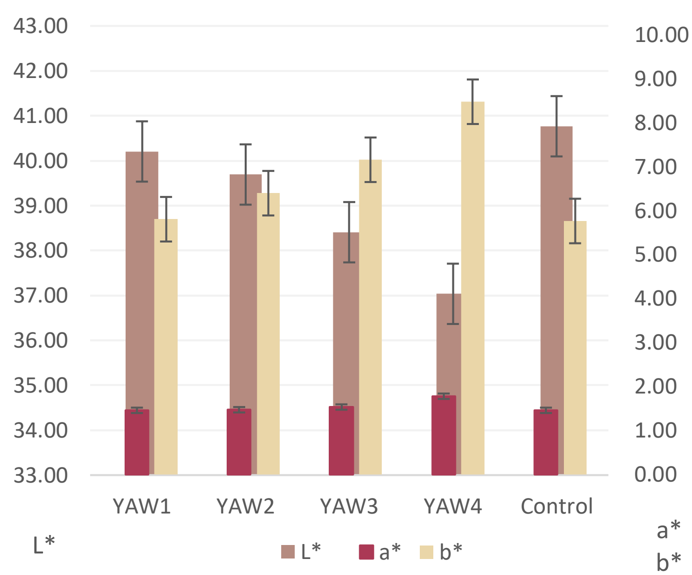


Figure 9. Average color components (L*a*b*) of Ranch dressing (with YAW or buttermilk) over an 8-months shelf life at room temperature (triplicate measurements of triplicate samples measured at 6 time points: n=54).

Error bars: standard error

Very few studies have been published on the incorporation of YAW in value added food products. In one application for fermented deer sausage production (Karwowska & Dolatowski, 2017), it was found that acid whey addition decreased lightness (L*) and redness (a*), probably due to the effect of acid whey on the browning of heme. Incorporation of YAW may have an impact on the color attributes of a final product, caused by either interaction with other ingredients or the reaction of YAW components to processing conditions.

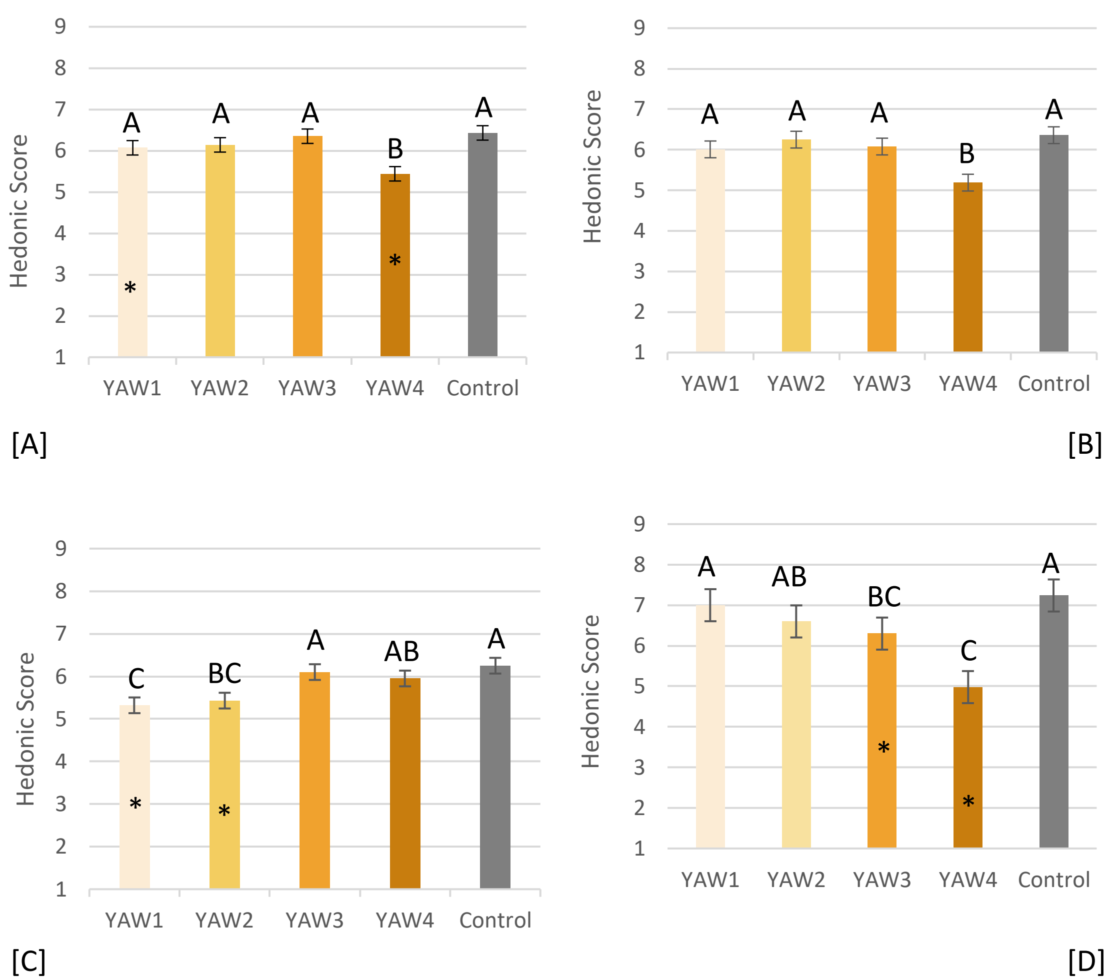


Figure 10. Overall liking, [A], Overall flavor liking [B], Texture liking [C], Color appearance liking [D] distribution of Ranch dressings on the 9-point hedonic scale (n=97).

Letters represent statistically significantly different mean scores based on Cochran's q test followed by post-hoc comparison using Tukey HSD. * represent statistically different distribution of scores within the variable. Error bars: standard error

Despite no difference in overall liking (Figure 10A), YAW samples scored 2.9 on average (from 2.76 for YAW4 to 3.08 for YAW 3) compared to 3.3 for the control, on a 5-point purchase intent scale, ranging from "Definitely would not purchase" to "Definitely would purchase". This lower score was likely driven by the lower visual appeal of the YAW products. This rating, based on sensory cues alone, might also be caused by the familiarity of panelists with classic buttermilk Ranch dressing, which could be overcome with brand fidelity to an acid whey product, and by the nutritional and sustainability claims made on the packaging. Finally, further optimization of YAW content, suggested in this study to be around 15-17 ºBrix, would further improve appeal.

Effect of YAW on shelf life at RT

The pH of all 4 samples was stable under 4.6 along shelf life, as expected. The only added source of acid in the YAW samples was white vinegar, used in small proportion for flavor only, and equal to the control. The YAW, with the lactic acid it contains, is thus responsible for the pH of the samples and allows the preparation of acid shelf stable products without the addition of lactic acid (Figure 11). The elimination of lactic acid would contribute to a cleaner label, desirable for today's consumers.

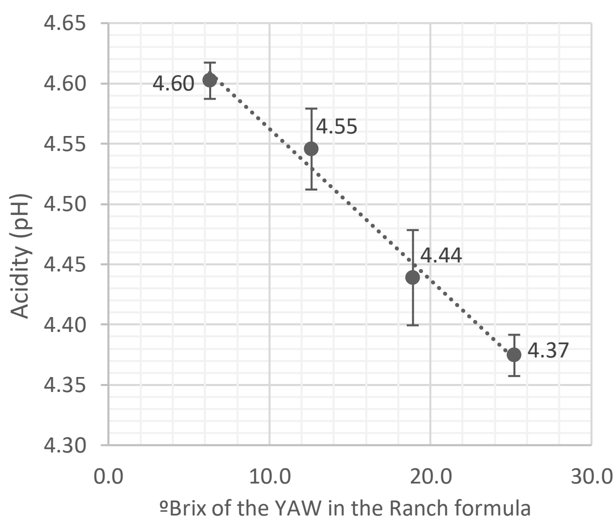


Figure 11. pH of Ranch dressings without added lactic acid depending on the concentration of the YAW in the sample (48%/wt) measured after 8 months (same results as one day after production).

The stability of the emulsion was improved by YAW as can be seen in Figure 12. After centrifugation, there was less separation of water and herbs from the compared to the control for all YAW samples throughout the shelf life study. Water retention score was significantly improved from the control in YAW3 and YAW4 at certain time points as well as on average over time (Figure 12A).

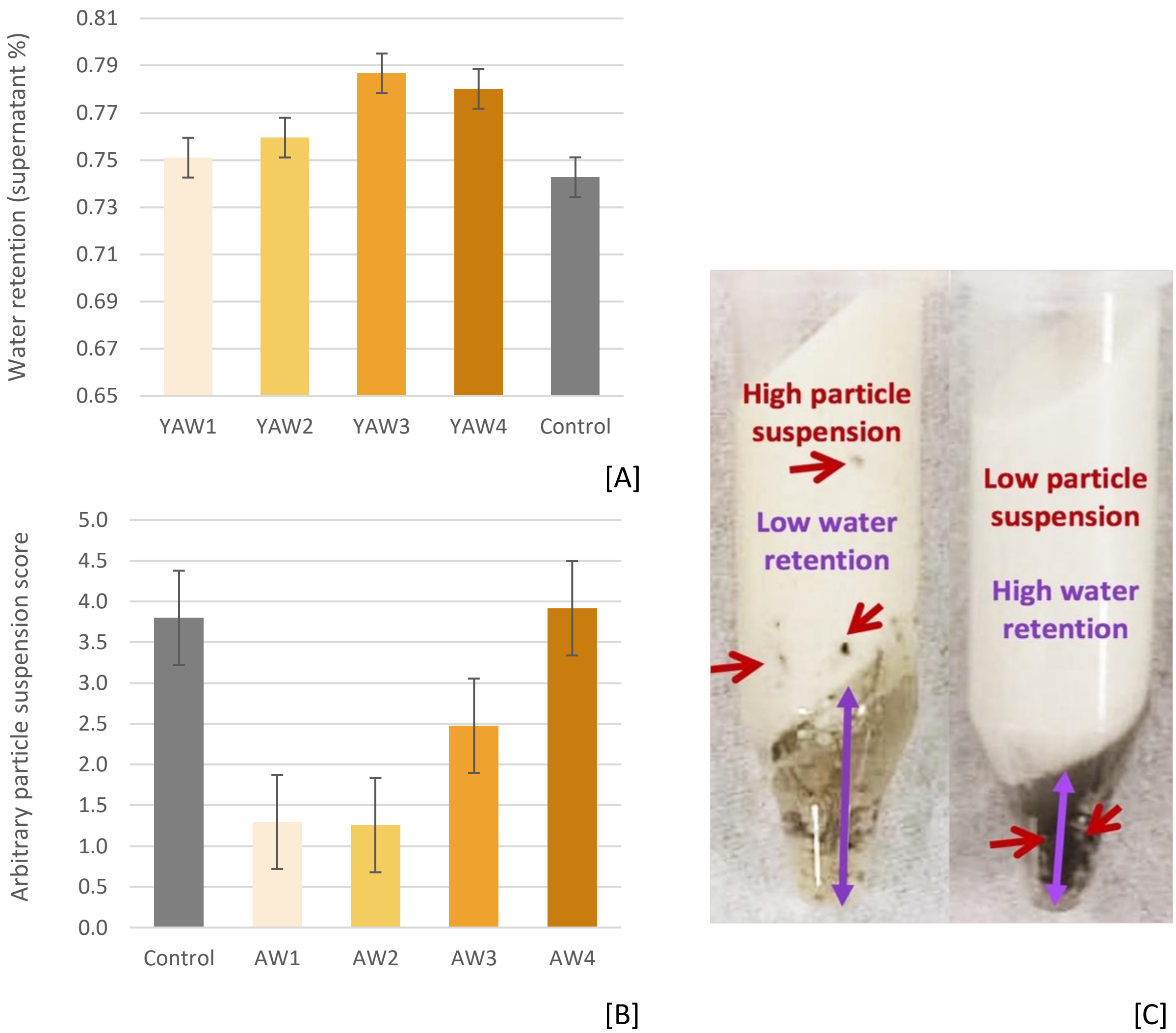


Figure 12. Emulsion stability: Average difference between the proportion of water separation (100%-retention) of control and YAW samples after centrifugation over 8 months [A], Particle suspension (arbitrary score) of control and YAW samples graded in duplicate by two panelists (blind to the study) 3 times over 5 months (n =12) after centrifugation. [B] Picture of samples of the centrifuged Ranch dressing [C] Error bars: standard error

Depending on the sample, the herbs either stayed suspended in the fat portion, or were separated into the aqueous layer, thus increasing the volume of the water phase (Figure 12C). As a result, the water retention measurements were artificially increased (Figure 12B). Particle suspension was therefore measured to assess its impact on the water retention measurements. Particle suspension seemed not to be correlated with the YAW content but correlated to the viscosity of the samples (high-concentration YAW and control being the thickest samples with the highest particle suspension, and YAW 1 and 2 being the thinnest samples with the lowest particle suspension). Despite the herb volume being accounted for, YAW samples showed better water retention; however, the significance of water retention improvement brought by YAW are underestimated by the previous measurement method (Sodini et al., 2005).

The focus group (n=7) was conducted after 5 months of shelf life indicated that all samples were considered acceptable. Panelists pointed out the darker color of the high-concentration YAW samples and the thinner texture of the lower-concentration YAW samples, but they did not make a distinction (positive or negative) between YAW samples and control regarding odor or flavor.

Marketing and consumers

The discussion portion of the focus group brought to light that consumers were welcoming of acid whey as an ingredient if the labeling can communicate the contribution to sustainability. Careful ingredient description, the possible involvement of sustainability certifications as well as the inclusion of a romance panel on the packaging could reassure, as well as educate consumers about acid whey (labeled as "whey", FDA, 2018). The branding, labeling and marketing of product using re-purposed waste ingredients can be perceived as a barrier to consumer acceptance.

On the other hand, consumer awareness about the overwhelming amount of food wasted along the value chain may increase interest in products aiming at reducing food waste through a careful choice of re-purposed ingredients. Consumer studies show that food recovery through reassessment of waste to Value-Added Surplus Products (VASP) (Bhatt et al., 2018) seems like a valuable strategy manufacturers can adopt and consumers will embrace.

The preferred term for consumer acceptance, and therefore most appropriate label for what used to be considered "waste", seems to be "upcycled", which augmented consumer's perception of environmental friendliness similarly to "organic" labeling (Bhatt et al., 2018).

CONCLUSIONS

Based on the sensorial and physical properties of the pilot products developed (Ranch dressings), 65-75%/wt in the total formulation of acid whey at native concentration of 6.3 ºBrix (equivalent to 48% acid whey after concentration to 15-17 ºBrix) is the acceptable range to formulate dressings with an astringent flavor profile like Ranch dressing. YAW concentration to 15-17 ºBrix is necessary to mimic buttermilk and avoid undesirably high water-content. In acid (pH<4.6) shelf stable products containing YAW, lactic acid may be omitted thanks to the intrinsic acidity of YAW, thus shortening the ingredient list.

The effects of acid whey on physical attributes (e.g. water retention) permit successful product development with minor processing adjustments. Thermal pasteurization conditions need to be optimized to avoid Maillard browning caused by the lactose in the case of products for which a light appearance is desirable.

Physical analysis and a focus group sensory test showed no negative effect on shelf life (8 months at room temperature) of replacing buttermilk by any concentration (from 6.3 to 25.2 ºBrix) of acid whey. There is a benefit on emulsion stability at higher levels of YAW concentration (48%/wt of YAW at 18.9 and 25.2 ºBrix).

The development of value-added products using YAW represents a key component to ensure the sustainability of Greek yogurt operations.

ACKNOWLEDGEMENTS

Research was supported by the NYS Department of Environmental Conservation "A comprehensive strategy for the value-added utilization of acid whey streams" and Terre d'enfant (Art de Vivre high-end and eco-friendly for children) sustainability fund. Recognition to Kyle Kriner for his technical assistance and Byrne Dairy for the acid whey.

AUTHOR CONTRIBUTIONS

J. Camacho Flinois designed the study, collected test data, interpreted the results and drafted the manuscript.

R. Dando contributed to study design, data analysis and manuscript editing.

O. I. Padilla-Zakour contributed to study design, data analysis and manuscript editing.

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CHAPTER 2

BENEFITS AND LIMITATIONS OF YOGURT ACID WHEY AS AN INGREDIENT IN VALUE ADDED PRODUCTS: PIZZA CRUST AND PANCAKES AS MODELS FOR THE BAKED GOODS INDUSTRY

ABSTRACT

Introduction: The increased production of Greek-style yogurt in the past decade has induced the need for the reintroduction of the nutrients of its by-product, yogurt acid whey (YAW), into the food system to combat food waste and aid sustainability. The processing and treatment of acid whey can be costly and complex. Upscaling YAW as an ingredient in food products with minimal re-processing is a cost-effective way to bypass the need for further processing.

Method: To span a broad spectrum of baked products (sweet and savory, biologically and chemically leavened, dairy or water based, oven or surface baked, batter or dough, etc.) pilot commercial pizza crust and pancake formulations were developed. Dimensions and physico-chemical properties of produced samples were measured at production and over shelf life at room temperature (23ºC). Consumer sensory testing (n=120 and n=108 respectively, JAR, 9-point hedonic, purchase intent, demographics) were conducted for both products.

All trials and analyses (ºBrix, aw, color attributes, viscosity, dimension measurements, texture analysis) were conducted in triplicate for statistical analysis.

Results: Cochran's Q and Post-Hoc tests on sensory data showed that liking for at least one experimental YAW sample for each of the pizza and pancake formulations were on par with their respective commercial control. Adding sustainability claims brought back the purchase intent on par with the controls. Replacement of water by weight of YAW was more appropriate than by water content of the YAW. Sourness was the main undesirable trait of YAW samples based on penalty analysis. The use of YAW improved the shelf life of baked goods based on their respective failure mechanisms (textural properties and mold growth).

Significance: YAW is a suitable ingredient in the formulation of sustainable, healthy, safe and commercially successful baked products that have a tolerance or can benefit from a sour flavor profile.

INTRODUCTION

Water is a major ingredient used in the processing of baked products. Through its chemical interactions (hydration, dispersion, dissolution, gelatinization, suspension, emulsion, etc. Cauvain & Young, 2008) with other ingredients (proteins, starches and fats) water has many effects on the physical properties of final products. Water may be added directly, but is also sometimes added as part of a dairy ingredient like milk or buttermilk (up to 91% water content), or to rehydrate powdered dairy ingredients (Cauvain & Young, 2008). Those liquids' properties such as hardness (mineral content, specifically calcium and magnesium), pH and microbial load have important effects on the textural, sensorial and shelf life attributes of the final products.

Acid whey is a by-product of the manufacture of strained Greek-style yogurt and cream cheese. Like sweet whey (originating from the manufacture of hard cheeses) it is produced in large amounts (>200,000 metric tons a year (Erickson, 2017; Macwan, Dabhi, Parmar, & Aparnathi, 2016; Smithers, 2015)) due to the increasing popularity of its parent product, Greek-style yogurt (Elliott, 2013). Yogurt acid whey (YAW), which contains around 95% of water, has a dry mass consisting mostly of lactose and galactose (about 4%) leading to a high biological oxygen demand (BOD) (Macwan et al., 2016; Marwaha & Kennedy, 1988; Tsakali et al., 2010), raising serious environmental concerns (Marwaha & Kennedy, 1988) and making it challenging for processors to dispose of (IDEM (Indiana department of environmental Management); Smithers, 2015). Unlike sweet whey, the starting material for whey protein isolates and concentrates (WPIs, WPCs) found in many manufactured food products, YAW has not yet reached that level of development. Drying (spray-drying) and membrane separation (microfiltration and ultrafiltration) commonly used for sweet whey, are hindered in the case of YAW by its high acidity and mineral content (Macwan et al., 2016), thus its main current uses are in its raw form as fertilizer and for cattle feed (Angenent et al., 2014; Ketterings et al., 2017; Mawson, 1993). Manufacturers are seeking technological advances to unlock the potential of acid whey (Smithers, 2008), by reintroducing the nutrients it contains into the value-added food chain, or convert them into available energy. Such technological advances include fractional concentration to extract valuable ingredients and the generalization of biofuel production (Beszédes et al., 2010; Kyle & Amamcharla, 2016; Mawson, 1993). The discrepancy between the rapid growth of sales of Greek-style yogurt and the availability of such technological advances in the processing of YAW call for effective alternative uses in the meantime.

The high water-content and chemical properties of YAW make it an ideal candidate in the baked goods industry, often calling for water and dairy ingredients in large amounts. As a cost-effective resource, it provides a dairy flavor, and potential flavor enhancing effects (Citation Ranch paper). Its inherent acidity and astringency can be advantageous in products benefiting from such features (cheesecake or citrus flavored products, buttermilk cream cheese containing products, etc.).

As an acidic product with pH ranging from 4.21 to 4.48 (Menchik P., Zuber T., Zuber A. and Moraru CI., 2019), YAW may be used as a clean-label alternative or complement to added preservatives, in the case of products in which acid flavors are preferred by consumers (Stanley P. Cauvain & Young, 2008a). The organic acids contained in YAW (lactic acid 0.65%, citric acid 0.18%, glutaric acid 0.06%) may have antifungal effects (El-kadi, 2015) increasing product shelf life. The acidity of YAW may contribute to the flavor of fermented doughs and batters. Interactions of the protons in YAW with chemical leavening agents (containing sodium bicarbonate) may lead to faster release of carbon dioxide gas (Stanley P Cauvain & Young, 2008) leading to an increase in product yield for short baking time products like pancakes.

Sodium chloride (table salt) is a recurrent ingredient in baked goods as it strongly effects flavor (S.P. Cauvain, 2007). The high mineral content of YAW, mainly potassium (>150mg/100g), calcium (>120mg/100g) and phosphorus (>60mg/100g), may help reduce sodium content while maintaining pleasant organoleptic properties (Citation Ranch paper), which may be attractive to hypertensive and health-conscious consumers (C. L. Wong et al., 2013). Mineral salts such as calcium and magnesium are helpful to reinforce the gluten network and are not present in YAW in such high concentrations (>180mg/L) as to rigidify the gluten structure excessively.

The sugars contained in YAW, mainly lactose (>3%) and galactose (>0.6%) are useful to the baking industry as they can provide a sweet flavor and a softer dough (Stanley P. Cauvain & Young, 2008b). They are also known to have an effect on increased Maillard browning (Ashoor & Zent, 1984), a capacity to lower Equilibrium Relative Humidity (ERH) and may also encourage fermentation (Stanley P. Cauvain & Young, 2008b). These effects may complement those of added sucrose, lowering the use of added sugars in baked products. The water activity of a 16.7% sucrose solution is 0.998 (BC Centre for Disease Control, 2013), that of a 16.7% lactose solution is 0.988 (Miracco, Alzamora, Chirife, & Fontan, 1981) showing a higher water-binding potential of lactose compared to sucrose. The decrease of added sucrose, replaced by YAW intrinsic lactose for sweetness, may therefore lead to lower water activity of the final YAW products.

The combined effect of non-sodium minerals and non-sucrose sugars to bind water lower the amount of water available to support the growth of microorganisms without resulting in a high sodium high sugar-added product.

Containing between 1.7 and 3.7 g/L of protein (Menchik et al. 2019), YAW may help increase product total protein content when compared to the equivalent product manufactured with water while reducing costs for products formulated with dairy powders and modified whey ingredients rehydrated with water.

In order to assess the feasibility of using YAW in the manufacturing of baked goods, two model products, American-style pancakes and pizza (ready-to-eat and par-baked pizza crust), were chosen. These two products are widely consumed and suitable to span the baked goods category: sweet and savory products, yeast leavened (fermented) and chemically leavened products, baked goods made primarily with water or dairy as the liquid phase, oven-baked and surface-baked products, batter (~150 baker's% of water) and dough (~60 baker's% of water). Both products traditionally contain dairy ingredients and/or modified whey ingredients and thus no new allergen would be introduced from using YAW. We can therefore postulate that YAW could be a suitable major ingredient (top 3 by weight, at the traditional level of water or liquid dairy) in the formulation and manufacture of a variety of baked goods.

MATERIALS AND METHODS

Ingredients: YAW (Byrne's dairy, NY) was collected and stored refrigerated (5ºC) for no more than a week before being heated to 93ºC/181ºF for 3 min for pasteurization (Padilla-Zakour, 2009)). Flour (11.7% and 12.7% protein, King Arthur Flour, Norwich, VT), sodium chloride (Morton Salt, Chicago, IL), soybean oil (Wal-Mart Stores, Inc., Bentonville, AR), instant yeast (Lesaffre, Marcq-en-Baroeul, France), purified water (Nestlé S.A, Switzerland) and sucrose (Wal-Mart Stores, Inc., Bentonville, AR) were purchased from a national supermarket in Ithaca, New York. Dextrose and sodium bicarbonate were obtained from J.T. Baker Chemical Company (Phillipsburg, NJ). Defatted Bakers soy flour was obtained from ADM (Chicago, Il). Dried egg yolk was obtained from Sonstegard Food Company (Sioux Falls, SD). Buttermilk powder (raw spray powder, 31%) was obtained from Dana Food Inc. (Hillsboro, WI). Sodium acid pyrophosphate 40 (SAPP 40) and monocalcium phosphate monohydrate (MCP) were obtained from ICL Performance Products LP (St. Louis, MO).

Pancake preparation: Three pancakes formulations with acid whey were derived from a standard commercial pancake formula (used as the control sample: PanCo) made with purified water in place of YAW in the experimental samples. Table 5A shows the concentrations of each ingredient for the experimental samples as well as the commercial pancake formula. One experimental sample (PanY6.5) was made by replacing the water by weight with native concentration acid whey (6.5 °Brix), and omitting buttermilk powder, without any other change in the formulation. The other two experimental samples were made by replacing the water with the corresponding water content of acid whey at native concentration (PanY6.5A) and concentrated ~2.5X (15 °Brix) (PanY15A) respectively, based on our previous results concerning the replacement of buttermilk with acid whey (Chapter 1B).

In these two experimental samples buttermilk powder was also omitted, and sugar and salt were lowered proportionally to the sweetening and salting power of the corresponding acid whey. For native concentration, salting power was approximated by the total mineral content (total of 0.4%$_{YAW}$ of calcium, sodium, phosphorus, potassium and magnesium (Menchik et al. 2019)) while sweetening power was calculated as the product of the amount of sugars (3.3%$_{YAW}$ lactose, and 0.59%$_{YAW}$ galactose (Menchik et al. 2019)) by their corresponding sweetening power compared to 1 for glucose (0.16 and 0.6 respectively (Owl (Columbia), 2011)). The water content of the YAW (94.5% for native and 87.5% for concentrated) were obtained following the oven drying method (sand pan technique at 100°C) described in Pegg, W.O. Landen, & Eitenmiller R., 2010.

Pancake formulation and procedure were adapted from the method by Finnie, Bettge, & Morris (1996). The dry ingredients (sucrose, dextrose, sodium chloride, soy flour, dried egg yolk, sodium bicarbonate, SAPP 40, MCP and dried buttermilk if present) were weighed, combined and mixed by hand for 1min with a wire whisk for visual homogenization. Flour was then incorporated and mixed for 1 additional min. The liquid (purified water, native acid whey or concentrated acid whey) and the liquid vegetable shortening, both at room temperature (23°C), were added to the dry-mix in a stainless-steel mixing bowl and mixed by hand for 30sec with a wire whisk. The resulting batter was then rested for 3 min before measuring its viscosity and baking.

Three minutes after the incorporation of liquids into the dry pancake-mix, a 3Tbsp/45ml/1.5oz stainless-steel commercial scoop with mechanical sweep (Norpro 704 Grip-EZ, Everett, WA.) was used to pour equal volumes of batter onto a 20” ceramic electric commercial griddle (Wal-Mart Stores, Inc., Bentonville, AR) with a surface temperature of 190°C (±5°C). The batter aliquots were distributed onto the griddle from a height of ≈8 cm following the aforementioned method (Finnie, 1996). After 75 sec of baking on the first side, pancakes were flipped and baked for 75 more seconds on the other side. Ten pancakes of each of the 12 batches (triplicates of each of control and three experimental formulas) were made. The pancakes were then placed on a wire rack, first cooked side up until cooled below 25°C. Each was then stored in sterile digester bag (Nasco WHIRL-PAK, Milton WI), heat sealed twice at 1cm distance and stored in the dark at room temperature (23°C) for accelerated shelf life study.

Samples were prepared three times: 1) PanCo, PanY6.5, PanY6.5A, PanY15A samples were prepared using unpasteurized YAW (YAW stored in clean containers from the time of collection, and kept for 7 days refrigerated) for texture analysis; 2) samples were prepared using pasteurized YAW for consumer sensory testing; 3) samples were prepared using pasteurized YAW for physical analysis and textural and shelf life study. Sample PanY15A was excluded from the third phase based on the consumer sensory testing results.

Pizza and par-baked Pizza crust preparation: Two pizza formulations with acid whey were derived from a standard commercial pizza formula made with purified water used as the control (PzzCo). Table 5B shows the concentrations of each ingredient for the experimental samples as well as the commercial pizza crust formula. One experimental sample (PzzY6.5) was made by replacing the water by weight with native concentration acid whey (6.5 °Brix) without any other change in the formulation. The other experimental sample (PzzY6.5A) was made by replacing the water by the corresponding water content of acid whey at native concentration (6.5 °Brix) and lowering sugar and salt proportionally to the sweetening and salting power of the acid whey, calculated as stated above.

The dry ingredients (sucrose, flour and yeast) were weighed, combined and mixed in a stand mixer with 3.5 quarts stainless steel bowl and hook extension (Kitchenaid, Benton Harbor, MI) for 3min on the lowest setting. Liquid (purified water, native acid whey or concentrated acid whey) at 35°C/95°F was then incorporated and mixed for 7 min on the third setting. Sodium chloride and shortening were then added and kneaded in for an additional 6min on the second setting. The batter was then left partially covered for a 30min "open-proof" at room temperature, before being separated into 50g dough balls. The balls were sheeted by passing through a pasta roller (Weston, Southern Pines, NC 28387) 10 times with 5 mm spread between the two rolls to ensure even thickness. Dough sheets were then poked with a hand dough docker (Orblue, Miami FL). Ten mini-par-baked-pizza crusts were made for each of 9 batches (triplicates of the control and both experimental pizza crusts) and baked for 5min at 450°C turning trays around 180° half way through for even baking. After letting the crusts cool to below 25°C, each was stored in sterile digester bag (Nasco WHIRL-PAK, Milton WI), heat sealed twice at 1cm distance and stored in the dark at room temperature (23°C) for accelerated shelf life study. For sensory evaluation, 350g dough balls were stretched using the same method to rectangles of 15x45cm and docked. Half were covered in marinara sauce (Barilla, Parma, Italy) and mozzarella cheese (Great-value, Wal-Mart Stores, Inc., Bentonville, AR). Samples were baked for 12min at 450°C flipping trays half way for even baking. All rectangles were trimmed on each short side by 2.5cm, cut in half longitudinally once and vertically at 5cm interval to produce 16 equal-sized (7.5x5cm) pieces with one edge.

Sensory evaluation: In the first Central Location Tests (CLT), the four pancakes were served (at room temperature, 23°C) in a randomized and blinded consumer study (n=120) in a monadic sequential manner (Lawless & Heymann, 2010). On a separate day, the three pizza crusts were served (warm) in a randomized and blinded consumer study (n=108) in a monadic sequential manner, followed by all three samples of pizza served together for direct comparison. During the direct comparison stage of the pizza sensory study, a ranking of the three samples was requested as well as a score on the Labeled Affective Magnitude (LAM) scale for each, featuring a 100-point scale from greatest imaginable dislike (100) to greatest imaginable like (0). Demographic data was collected from the panelists in each test, with sensory data collected using the 9-point hedonic scale for overall, appearance, texture, color and flavor liking. Just About Right (JAR) scales were used for texture and flavor attributes, purchase intent (before and after giving information about the sustainability claims), preferential ranking, and short open-ended questions were also asked after liking. Testing was performed at the Cornell Sensory Evaluation Facility, in individual booths, under standard lighting. All procedures were evaluated and approved by the Cornell University Institutional Review Board for Human Participants, with all subjects providing informed consent. Panelists for both tests were users of the category (consuming the product in question at least a few times a year) and recruited with normal senses of smell and taste and with no salient food allergies. Sensory data and sensory data statistical analyses were gathered using RedJade (Curion Insights, Redwood City, CA).

Phisico-chemical evaluation: Before baking, batter viscosity of the pancake was measured. Pancake batter was poured into the reservoir of a Bostwick Consistometer (CSC Scientific Co., Fairfax, VA) excess batter was scraped off the top of the reservoir with a flat metal blade. The consistometer gate was released, and after 1min the distance (in cm) that the batter traveled was recorded as "Bostwick" batter viscosity.

Each day after production (Day 0), one sample was selected randomly for each of the triplicate batches of the four pancake samples and three pizza crust samples. The diameter of each was measured with a digital caliper (Fisher Scientific) at three points on the pancake (smallest, largest: 0°, and 90°) and averaged. Aliquots of 4cm diameter were cut out of each sample. On Day 1, one aliquot was randomly selected to observe the gas cell structure by peeling off the top layer. Three aliquots were measured for color components (UltraScan VIS, HunterLab, VI) on day 2, day 3 and day 4. Three aliquots were used on day 2 for moisture content analysis following the oven drying method at 70° as prescribed for samples high in carbohydrates by Pegg et al., 2010. The thickness of each aliquot was measured with a digital caliper at three points (thinnest, thickest, and center) and averaged. Each aliquot was then subjected to TPA (texture profile analysis) using a TA-XT2 Texture Analyser (Stable Micro Systems, Texture Technologies Corp. Scarsdale NY) equipped with a 50kg load cell and a round 75mm diameter compression platen probe (M. C. Bourne, Kenny, & Barnard, 1978; Malcolm C. Bourne, 1982). Each aliquot was placed under the probe (first baked side up for the pancake, top side up for the pizza crusts), and compressed to 50% of original height at a constant speed of 1mm/sec. After the initial compression, the probe withdrew for 5 sec, followed by a second compression of 50% of the original height. The computer software Texture Exponent 32 (Stable Micro Systems) was used both for the experimental phase, and to compute textural parameters from the TPA curve.

Shelf life evaluation: Given the difference in failure mechanisms, shelf life was assessed separately for pancakes and pizza crusts. In addition to the TPA recorded over 5 days, mold free shelf life of at least 12 units was recorded for each pancake sample over 8 days after production. Three pizza crusts samples were set aside from each batch (n=9) and the surface covered by mold was recorded as a percentage of the total surface using imageJ (open source software) over 8 days after production.

Statistical analysis: Throughout the study, samples were prepared in triplicates for instrumental testing, and measurements were performed in triplicates for each sample, leading to at least 9 individual observations for each variable for each condition. Statistical data analyses were performed using IBM SPSS Statistics (version 21). For hypothesis testing, a significance level of $p < 0.05$ was used.

TABLE 5

[A] Formulation of Pancakes: Ingredients as a percentage (%) and percentage of flour (Baker's %).

Ingredients	Control		Experimental 0		Experimental 1		Experimental 2	
	Baker's %	%	Baker's %	%	Baker's %	%	Baker's %	%
Sucrose	10.67	3.55	10.67	3.59	9.33	2.92	6.97	1.97
Dextrose	3.33	1.11	3.33	1.12	3.33	1.04	3.33	0.94
Sodium Chloride	0.67	0.22	0.67	0.22	0.00	0.00	0.00	0.00
Soy Flour	6.33	2.11	6.33	2.13	6.33	1.98	6.33	1.79
Egg Yolk Powder	1.33	0.44	1.33	0.45	1.33	0.42	1.33	0.38
Sodium Bicarbonate	2.00	0.67	2.00	0.67	2.00	0.63	2.00	0.56
Sapp40	2.80	0.93	2.80	0.94	2.80	0.88	2.80	0.79
MCP	1.30	0.43	1.30	0.44	1.30	0.41	1.30	0.37
Flour	100	33.28	100	33.62	100.00	31.34	100.00	28.22
Buttermilk Powder	1.33	0.44						
Shortening	3.33	1.11	3.33	1.12	3.33	1.04	3.33	0.94
Purified water	167.43	**55.71**						
YAW (6.7 Brix)			165.71	**55.71**	188.31	59.33		
YAW Water			155.61	52.31	177.77	**55.71**		
YAW Solids			10.11	3.40	11.55	3.62		
Salting power			0.66 (total minerals)		0.76 (total minerals)			
Sweetening power			6.49 (total sugars)		1.34 (sugars*relative sweetness)			
YAW (15.4 Brix)							225.55	63.91
YAW Water							268.40	**55.71**
YAW Solids							30.35	8.60
Salting power						(total minerals) 2.08		
Sweetening power						(sugars*relative sweetness) 3.70		

[B] Formulation of Pizza crusts (Ingredients as a percentage of flour, Baking %).

Ingredients	Control		Experimental 0		Experimental 1	
	Baker's %	%	Baker's %	%	Baker's %	%
Flour	100	57.64	100	57.64	100	56.07
Sodium Chloride	1.5	0.86	1.5	0.86	1.24	0.69
Sucrose	3	1.73	3	1.73	2.42	1.36
Shortening	8	4.61	8	4.61	8	4.49
Yeast	1	0.58	1	0.58	1	0.56
Purified water	60	**34.58**				
YAW (6.7 Brix)			60	**34.58**	65.7	36.84
YAW Water			56.34	32.47	61.69	**34.58**
YAW Solids			3.66	2.11	4.01	2.25
YAW Salting power		(total minerals) 0.24			(total minerals) 0.26	
YAW Sweetening power		(total sugars) 2.352		(sugars*relative sweetness) 0.58		

Table 5. Formulation of Pancakes [A] (ingredients as a percentage (%) and percentage of flour (Baker's %)) and Pizza crusts [B] (Ingredients as a percentage of flour, Baking %) made with or without YAW.

RESULTS AND DISCUSSION

Effect of YAW content on physical properties of baked goods

The use of whey minerals in breads to replace sodium from table salt showed favorable results in a previous study with decreased bread density when using 2% whey minerals instead of 2% table salt (Królczyk, Dawidziuk, Janiszewska-Turak, & Sołowiej, 2016). In our results, the density of the par-baked pizza crusts did not decrease, with a higher density for PzzY6.5 (likely due to a lower moisture content) and a similar density between control and PzzY6.5A (Table 6).

TABLE 6

Physical attributes (color, water activity, dimensions, moisture content,batter viscosity) of pancakes and par-baked pizza crust samples formulated with or without acid whey.

	Pizzas			**Pancakes**		
	Control	Experimental PzzY6.5	Experimental PzzY6.5A	Control	Experimental PanY6.5	Experimental PanY6.5A
Color (n=27)						
L*	75.30 (±1.68)	76.20 (±1.38)	74.36 (±1.49)	55.60 (±12.05)	72.60 (±5.86)	73.96 (±4.76)
a*	1.73 (±0.14)	1.56 (±0.18)	1.46 (±0.20)	10.49 (±3.09)	2.65 (±3.31)	3.47 (±2.77)
b*	15.44 (±0.62)	16.67 (±0.57)	16.34 (±0.51)	22.14 (±1.61)	28.83 (±5.77)	27.96 (±3.98)
Water activity (aw, n=9)	0.951 (±0.01)	0.946 (±0.00)	0.950 (±0.01)	0.966 (±0.012)	0.958 (±0.006)	0.966 (±0.005)
Moisture (%, n=9)	33.08 (±0.83)	31.78 (±0.46)	33.18 (±0.98)	53.30 (±0.80)	49.72 (±0.36)	52.67 (±0.83)
Dimensions (n≥ 12)						
Height (mm)	11.1 (±1.5)	11.4 (±2.0)	11.7 (±1.6)	11.63 (±1.03)	12.26 (±1.11)	9.16 (±0.80)
Diameter (mm)	103.6 (±6.3)	97.1 (±5.5)	95.9 (±5.5)	81.01 (±16.71)	96.53 (±6.28)	86.68 (±15.92)
Weight (g)	41.51 (±0.1)	45.91 (±0.07)	40.81 (±0.16)	30.17 (±3.15)	35.84 (±3.12)	38.21 (±3.17)
Volume (mm^3)	93214	84603	84645	59919	89722	54033
Density (g/cm^3)	0.445	0.543	0.482	0.503	0.399	0.707
Viscosity (n=3)				9.17 (±0.58)	9.83 (±0.38)	14.83 (±0.76)

Table 6. Physical attributes (color, water activity, dimensions, moisture content, batter viscosity) of pancakes and par-baked pizza crust samples formulated with or without acid whey.

Par-baked pizza crust samples made with YAW seemed to have a stronger gluten structure. This can be seen in the smaller diameter (PzzY6.5A< PzzY6.5< PzzCo) due to the retraction of the dough during baking, a higher thickness (PzzY6.5A>PzzY6.5>PzzCo), reflecting a high capacity to retain gas formation in crumb cells, and an aerated crumb structure (Figure 13A). The gluten network within a fermented dough is developed during kneading time and is influenced by the minerals present in the dough leading to its specific rheological properties (Ștefan, Voicu, Constantin, Ferdes, & Muscalu, 2016). On the other hand, high levels of salts (including added NaCl) restrain yeast activity in fermented doughs, thus mineral salts present in YAW and added to the dough may have the same effects. The marginally lower volume of the experimental samples is not observed in the cell structure of samples (Table 6). The use of YAW in bread doughs may allow for lower kneading energy requirements than the corresponding dough made with water to reach the desired gluten development and potentially thinner sheating to decrease the height to diameter ratio. Higher levels of yeast or longer floor time may help increase total fermentation to maintain total volume.

The reaction of the acids present in YAW with the chemical leavening agent (sodium bicarbonate), leading to a faster release of carbon dioxide gas in the pancake batter (Stanley P. Cauvain & Young, 2008b, p83), would explain the lower density of PanY6.5 (0.399g/cm^3) compared to control (0.503g/cm^3) (Table 6). This early release of carbon dioxide is beneficial to the volume of pancakes in the case of a higher viscosity batter (PanY6.5, ~10 Botswick score like control), but detrimental in the case of a lower viscosity batter (PanY6.5A, ~15 Botswick score) which limited gas retention through the baking period, leading to a higher density of the final product (PanY6.5A: 0.707g/cm^3). The crumb structure of pancake samples revealed larger less numerous gas pocket in the control than in PanY6.5, and the smallest gas cells in PanY6.5A (Figure 13B).

[A1]

[A2]

[A3]

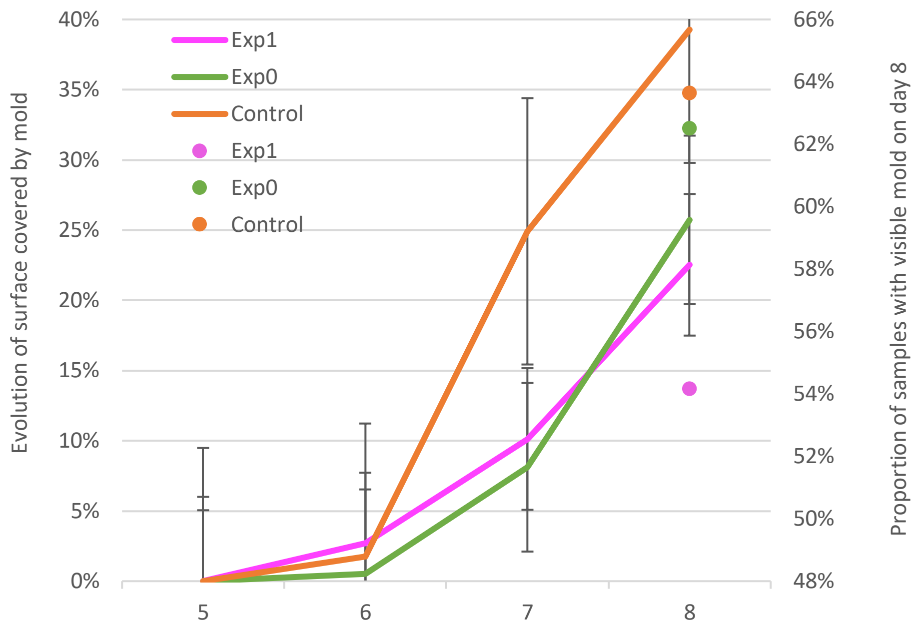
[B1]

[B2]

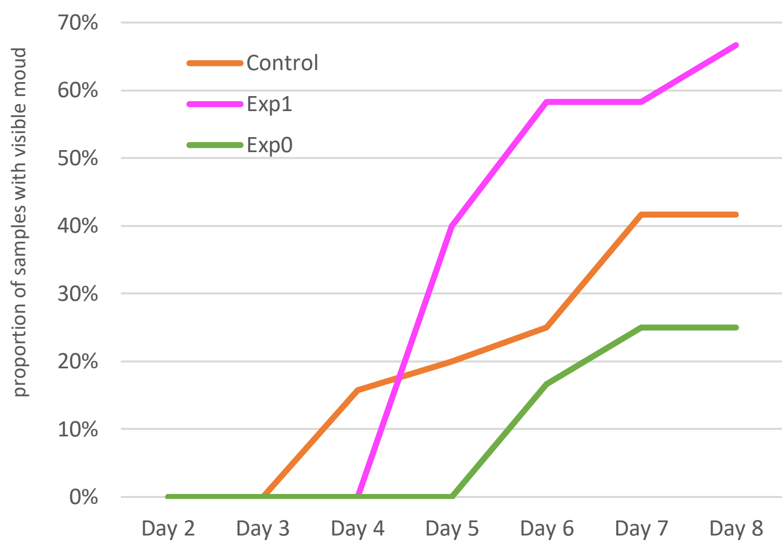
[B3]

[B4]

Figure 13. Crumb structure of the control pizza [A1], PzzY6.5 [A2] and PzzY6.5A [A3] and the control pancake [B1], PanY6.5 [B2], PanY6.5A [B3] and PanY15A [B4].



[A]



[B]

Figure 14. Shelf life study of par-baked pizza crusts and pancakes stored at room temperature (23C) in the dark in individual aseptic packaging: total surface covered by mold on days 5 to 8 and proportion of samples presenting visible mold colonies on day 8 of par-baked pizza samples made with and without YAW [A] number of samples with at least one visible mold colony on pancakes samples between days 2 and 8 [B]

The Maillard reaction, responsible for many attractive aromas in baked goods as well as a desirable coloration, renders a darker (lower L* value) and more yellow (higher b* value) bread (Wu et al., 2018). In the case of the par-baked pizza crusts, no significant color difference was detected, and color liking was not significantly different for the three samples tested (ANOVA, p-value = 0.38). For all the pancakes, both experimental samples had a higher L* (lighter) and b* (yellower) values and lower a* (less red) values than the control (Table 6). When compared to results of consumer testing results, color liking was also significantly higher for PanY6.5 (7.10) followed by PanY6.5A (6.70) and control (6.47). Pancakes made with YAW were more attractive visually due to the deeper yellow color, and had a higher tolerance for increased baking time or temperature (which would decrease L* to the level of the control samples).

Effect of YAW content on shelf life of baked goods

The speed of microbial spoilage on bakery products is determined by the microbial load of the ingredients, the environmental conditions (microorganisms present, moisture and temperature), the product's water content, water activity, pH and the presence of mold inhibitors (Stanley P. Cauvain & Young, 2008a). The shelf life test of all samples was conducted for 8 days at room temperature (23C°) to be able to observe major changes in quality due to the different formulations. Since samples were packaged in sealed, sterile bags, apparent differences in shelf life between control and experimental samples can be due to water activity, moisture content, microbial load, product pH or antimicrobial compounds. All of these characteristics can be directly related to the inclusion of YAW or the changes in formulation related to the addition of YAW for water, sugar and salt content adjustments.

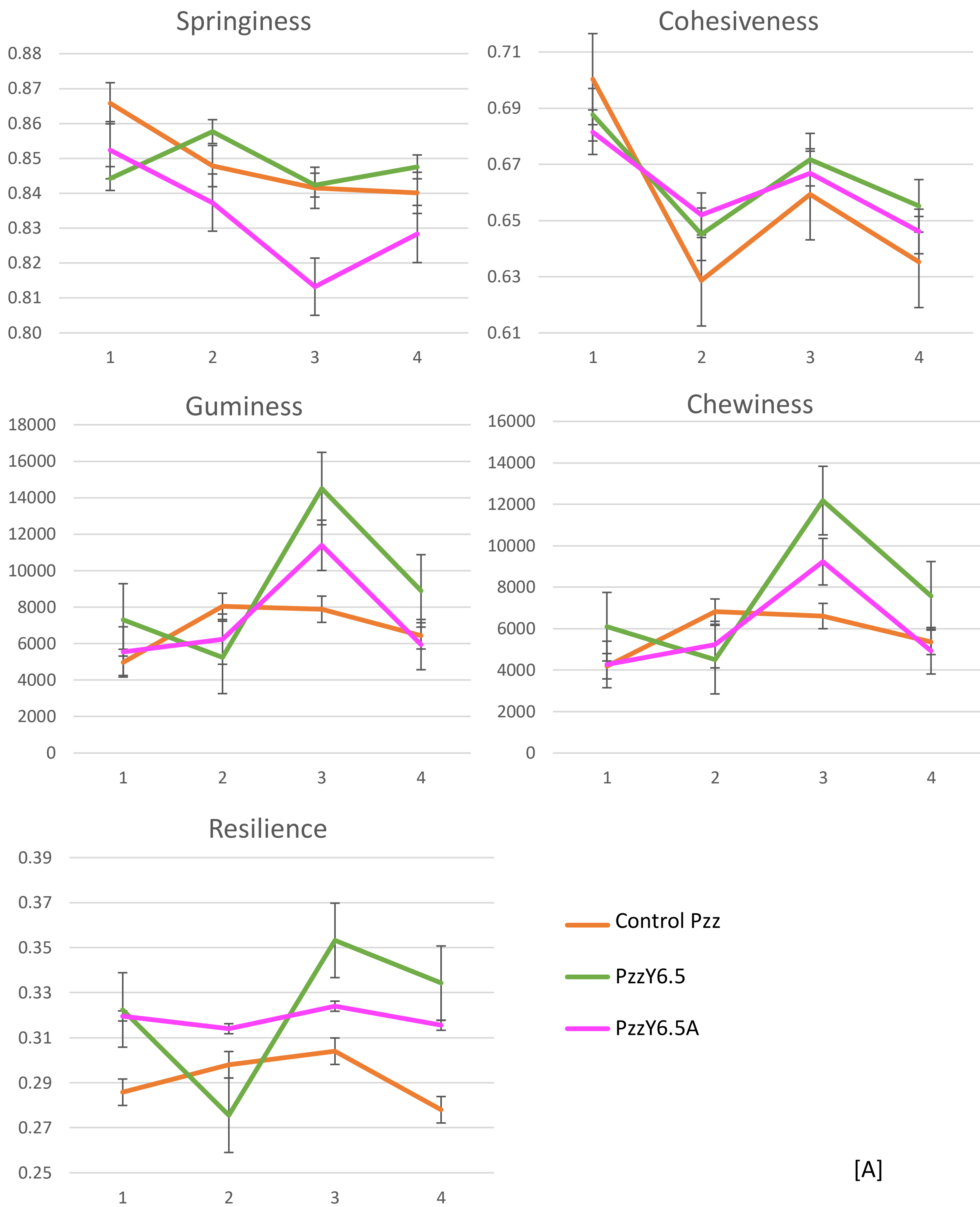
Pancake and par-baked pizza crusts made for this study with a moisture content of 33.08% to 54.42% are representative of the average moisture content of intermediate moisture range baked goods

(Stanley P. Cauvain & Young, 2008b).

All experimental samples made with pasteurized YAW exhibited a higher proportion of mold-free samples by day 8 (Figure 14), most likely due to the presence of lactic acid. In the case of the pancakes, the proportion of mold-free samples was higher in PanY6.5, likely due to the lower moisture content (50% vs 53% for the control) and water activity (lowered by around 0.01). However at the same water content of 53% and the same water activity of 0.966, the control sample had a faster mold-growth onset but a slower increase of the percentage of spoiled samples than PanY6.5A. Visible mold colonies appeared on the experimental samples on day 4 and 5 for PanY6.5A and PanY6.5 respectively, compared to day 3 for control samples (Figure 14B), suggesting a longer "mold-free shelf life" of experimental samples. The strong putrid smell of control pancake samples and the moist, sticky and stringy nature of the crumb by day 5 indicated that the microbial growth was not limited to mold and that the failure mechanism for the pancakes may be bacterial (Rosenkvist & Hansen, 1995; Saranraj, 2012). Thus, the control pancake samples had a shorter shelf life than presumed from mold growth observations, placing it second with 42% of samples presenting visible mold against 25% for PanY6.5 and 66% for PanY6.5A (Figure 14B).

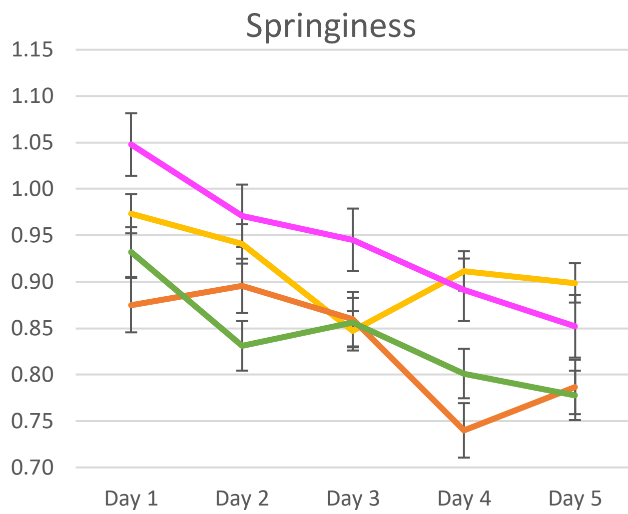
In the case of the par-baked pizza crusts, both experimental samples performed better than the control in terms of speed of mold growth (based on the total surface of pizza samples covered by mold) with a lower percentage of mold surface area (22-27% for PzzY6.5 and PzzY6.5A, 38% for control) and lower or similar number of samples with visible mold by day 8 (54% for PzzY6.5 and 63-64% for PzzY6.5A and control), for the same onset at day 5 (Figure 14A). These improved shelf life results were irrespective of their lower (32% for PzzY6.5) and equal (33% for control and PzzY6.5A) moisture content at the same water activity of 0.95 (all samples).

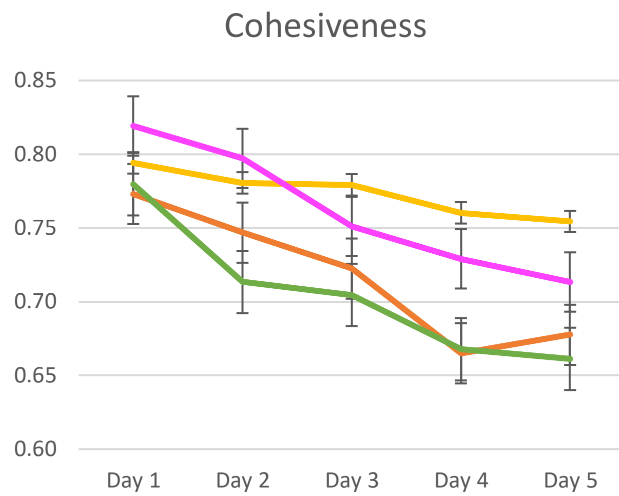
Our results indicate that the use of YAW may reduce microbial growth, and therefore provide shelf life extension of some baked goods in formulations without added preservatives.

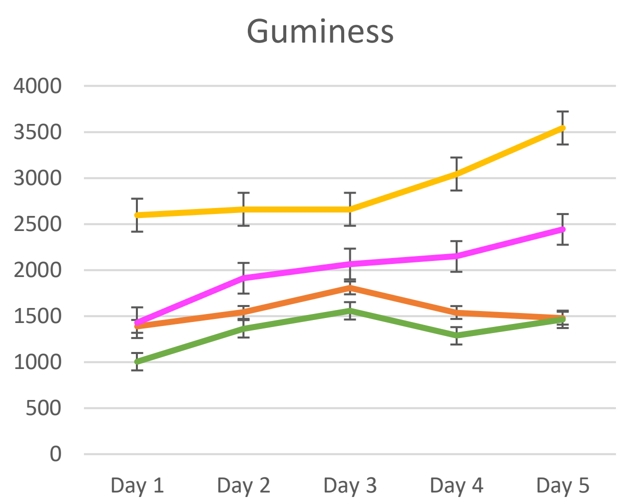


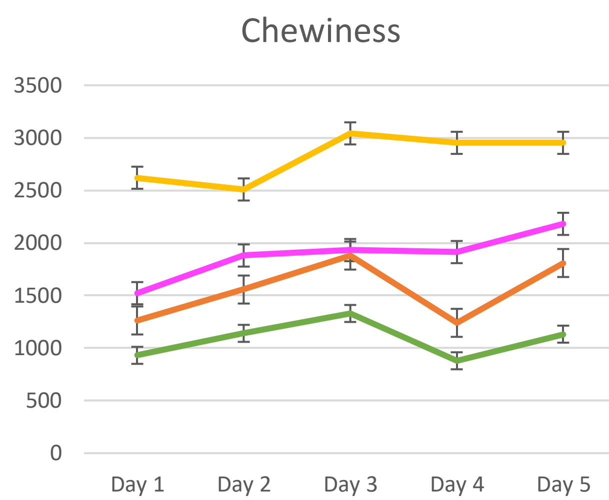
Springiness
0.88
0.87
0.86
0.85
0.84
0.83
0.82
0.81
0.80
1
2
3
4
Cohesiveness
0.71
0.69
0.67
0.65
0.63
0.61
1
2
3
4
Guminess
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1
2
3
4
Chewiness
16000
14000
12000
10000
8000
6000
4000
2000
0
1
2
3
4
Resilience
0.39
0.37
0.35
0.33
0.31
0.29
0.27
0.25
1
2
3
4
Control Pzz
PzzY6.5
PzzY6.5A

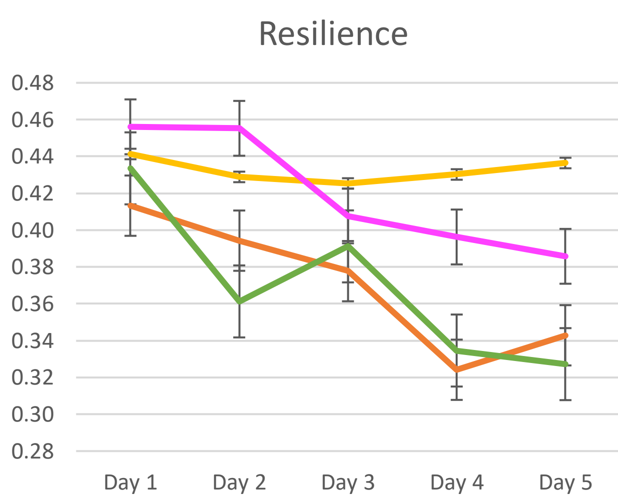
[A]











[B]

Figure 15. Textural analysis (TPA) of the control pizza, PzzY6.5 and PzzY6.5A [A] and the control pancake, PanY6.5, PanY6.5A and PanY15A (average of similar unpasteurized and pasteurized data) [B]

All textural attributes seemed to be similar between the experimental and control samples (Figure 15) even though PzzY6.5 and PanY6.5 had lower moisture content. Textural properties of par-baked pizza samples did not change significantly across the 5-day period, confirming that the failure mechanism off par-baked pizza shelf life was not textural but microbiological. The pancake samples showed significant differences in texture for the PanY15A and PanY6.5A compared to PanY6.5 and control, showing stronger values. The increase in gumminess over the storage time of all pancake samples may be indicative of bacterial spoilage.

Effect of YAW content on sensory attributes of baked goods

All panelists participating in the studies were frequent consumers of pancake (consuming them few times a year (37%), every month (48%) or every week (15%)) and pizza (consuming pizza a few times a year (12%), every month (52.8%) or every week (35.2%)). The panel was 71% female and 29% male, and 8% over 55 years old, 57.5% 23 to 54 years old and 34.5% under 22years old.

Overall liking of the pancakes was on par (ANOVA, $p > 0.05$) between the control 6.41 (±1.40) and PanT6.5 6.33 (±1.6). PanY6.5 also received the significantly highest (ANOVA, post-Hoc p-value < 0.05) overall appearance liking (7.10±1.32 compared to 6.72±1.50 for control), color liking (7.10±1.38 compared to 6.47±1.78 for control) and textural appearance liking scores (7.23±1.26 compared to 6.79±1.59 for control). Dairy flavor JAR score was equal for the control and all Experimental samples (averaging 3.70) suggesting that the removal of buttermilk powder from the formulation without losing the dairy flavor was achievable when using YAW instead of water.

All sensory measures of texture were equivalent between the control and PanY6.5 (texture liking 6.51±1.77 and 6.54±1.88, fluffiness JAR 3.93±0.69 and 3.83±0.62, chewiness 4.39±0.81 and 4.44±0.81, moistness 3.92±0.74 and 3.89±0.69, softness 4.09±0.61 and 4.03±0.42), despite a 3.5%

lower moisture content (51% for PanY6.5 compared to 54.5% for the control, Table 2). Moisture content of pancakes, like other cake-products, is a key factor in the consumer's perception of freshness and therefore product quality (Guy, 1983). The replacement of water and buttermilk powder in batters with YAW was best achieved with a per-weight replacement of water with YAW (rather than a per-water-weight replacement, leading to texture JAR scores different from control for PanY6.5A) for the retention of perceived textural properties on a lower moisture content product. These results are consistent with TPA analysis conclusions that YAW allows for similar textural properties (physical and sensorial) at a lower moisture content of the final product.

According to penalty analysis (Figure 16), the lower overall liking score of PanY15A was mainly due to the increased bitterness and sourness brought by YAW. These results coincide with the lower scores of PanY15A for appearance, color, texture and aroma liking, the strongest aroma intensity, and 68% of panelists reporting an aftertaste (compared to 11% for the control, 18% for PanY6.5 and 15% for PanY6.5A) leading to the exclusion of PanY15A from further testing. For pizza, PzzY6.5 received a higher flavor intensity score (3.84±1.04) than its respective control (3.35±1.01), otherwise, all other experimental samples received a similar flavor intensity as their respective control (despite the removal of buttermilk powder in the case of pancakes). These results are in agreement with the potential flavor enhancing effects of YAW as an ingredient demonstrated in our earlier study on Ranch dressing (Chapter 1B).

Penalty analysis (Figure 16) showed similar results in the case of pizza crust samples to the pancakes, with a lower overall liking score (PzzY6.5 (5.54±1.74) and PzzY6.5A (5.42±1.87) compared to the control (6.32±1.64)) caused by the increase in sourness and decrease in saltiness.

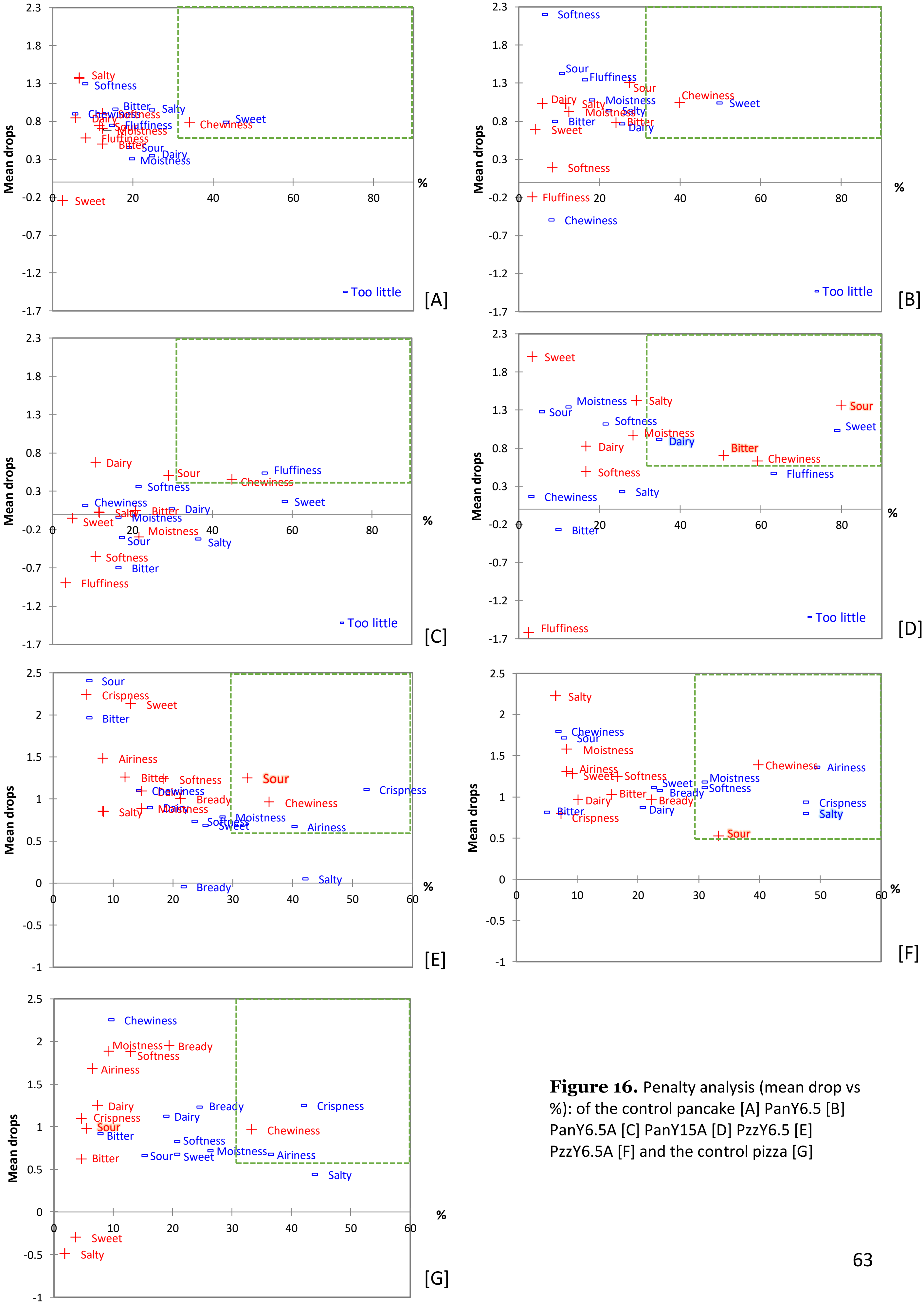


Figure 16. Penalty analysis (mean drop vs %): of the control pancake [A] PanY6.5 [B] PanY6.5A [C] PanY15A [D] PzzY6.5 [E] PzzY6.5A [F] and the control pizza [G]

The purchase intent of pizza crusts (Table 7) was also lower for experimental samples (2.81±1.05 for PzzY6.5 and 2.78±1.11 for PzzY6.5A) than for the control (3.24±1.09), accompanied by a higher percentage of panelists detecting an aftertaste (19% and 14%) in experimental samples than in the control (5%). This lower overall liking score of the crust alone did not translate to a decreased liking of the final pizza product ($p = 0.46$, ranked sum test), with a similar overall liking score on the LAM scale: 32.23±14.00 for the control, 34.10±15.50 for pizza made with PzzY6.5 crust and 32.28±14.83 for pizza made with PzzY6.5A crust.

Furthermore, purchase intent was collected once for all samples without information, and a second time after informing the panelists that samples are "made with upcycled ingredients from the dairy industry which avoids pollution by dumping nutrients in water streams and reduces food waste by reintroducing nutrients in food products rather than disposing of them". The purchase intent of the experimental pizza crusts after informing the panelists of the sustainable nature of the product were not different (1-way ANOVA, p-value: 0.0968) from that of the control. Similar results were obtained for pancakes PanY6.5A and PanY6.5 receiving purchase intent scores not different (1-way ANOVA $p > 0.05$, post Hoc p-value < 0.05) from that of the control after stating their appropriate sustainability claim.

TABLE 7

Purchase intent of all samples before and after informing panelists of sustainability claims.

Purchase intent	Pizzas			Pancakes			
	Control	Experimental Y6.5	Experimental Y6.5A	Control	Experimental Y6.5	Experimental Y6.5A	Experimental Y15A
Without Sustainability claim	**3.24** (±1.09)	2.81 (±1.05)	2.78 (±1.11)	**3.25** (±0.99)	3.17 (±1.03)	2.75 (±1.02)	1.84 (±0.99)
With sustainability claim	3.32 (±1.11)	**3.06** (±1.12)	**2.92** (±1.08)	3.54 (±1.14)	**3.44** (±1.18)	**2.99** (±1.18)	**1.94** (±1.11)

Purchase intent scale:

1- Definitely would not 2- Probably would not 3- May or may not 4- Probably would 5- Definitely would

Table 7. Purchase intents of all samples before and after informing panelists of the sustainability claims.

Nutritionally, an increase in Vitamin D (+ 2-8%$_{DV}$) calcium (+ 4-13%$_{DV}$) and potassium (+ 2-4%$_{DV}$) can be observed for all samples containing YAW. The decrease in added sugars and added sodium in the formulations for PanY6.5A, PanY15Aand PzzY6.5A is evident in the nutrition labels (Table 8) lowered by 0.5 to 1g/serving and 55 to 110mg/serving for added sugar and sodium respectively between PzzY6.5A, PanY6.5A and their respective controls. These decreases did not translate to any decrease in sweetness or saltiness perception in pizza: on the 7-points JAR scale saltiness perceptions were rated 3.39(±0.89) for the control, 3.54(±1.02) for PzzY6.5 and 3.45(±0.95) for PzzY6.5A, and sweetness was rated as 3.79(±0.59) for the control, 3.86(±0.78) for PzzY6.5 and 3.81(±0.70) for PzzY6.5A. However, these improvements on the nutrition facts panel do translate in a sweetness and saltiness decrease in the case of PanY15A pancakes: on the 7-points JAR scale saltiness perceptions were rated 3.70(±0.86) for the control, non-significantly different from 3.87(±0.86) for PanY6.5 and 3.61(±0.99) for PanY6.5A but 4.09(±1.27) for PanY15A was significantly higher. Similarly, sweetness perceptions were rated as 3.46(±0.82) for the control, not different from PanY6.5 (3.36(±0.90)), but significantly higher than 3.22(±0.98) for PanY6.5A and 2.70(±1.13) for PanY15A. This suggests that YAW minerals and native sugars can replace added sucrose and salt nutritionally and perceptively to a certain extent, possibly up to total mineral amount and up to sweetness power (as defined earlier as the sweetness equivalent of glucose) in the case of breads (~60 baker's% water content) but to a lower extent for cakes (>150 baker's% water content) especially for sucrose replacement.

TABLE 8

Nutritional information (as would appear on a 2016 Nutrition fact panel) for control and experimental Pizza crusts and pancakes. formulations.

	Pizzas			Pancakes			
	Control	Experimental		Control	Experimental		
		PzzY6.5	PzzY6.5A		PanY6.5	PanY6.5A	PanY15A
Calories	250	260	250	160	160	150	130
Total Fat	4.5	4.5	4.5	1.5	1.5	1.5	1
Saturated Fat	0.5	0.5	0.5	0.5	0.5	0	0
Trans Fat	0	0	0	0	0	0	0
Cholesterol	0	0	0	10	10	10	10
Sodium	335	350	280	650	670	540	530
Total Carbohydrate	42	44	43	31	31	28	25
Dietary Fiber	2	2	2	1.5	1.5	1.5	1
Total Sugars	2	3	3	5	7	6	9
Added Sugars	2	2	1	4.5	5	4	3
Protein	7	9	8	6	7	6.5	8
Vitamin D	0%	2%	2%	0%	4%	4%	8%
Calcium	0%	4%	4%	2%	6%	6%	15%
Iron	15%	15%	15%	10%	10%	10%	10%
Potassium	0%	2%	2%	2%	4%	4%	6%

Table 8. Nutritional information (as would appear on a 2016 Nutrition fact panel) for control and experimental Pizza crusts and pancake formulations.

CONCLUSION

YAW use as a per-weight basis replacement of water may lead to an increase in protein calcium and potassium and decrease in sodium and added sugars whilst conserving flavor attributes. Textural attributes, sign of baked product's freshness, are conserved in YAW-based products even at a lower moisture content. In the case of baked goods, the ingredient list is unlikely to be extended by the introduction of YAW compared to products currently available on the market; it may even be shortened by removing acids, salt, sugar, dairy powders or added dairy flavors. Additives and preservatives may also be omitted, taking advantage of the shelf-life extension provided by YAW. This elimination of ingredients from the list is accompanied by an equivalent subtraction of the cost of these ingredients, which can provide a competitive advantage to the manufacturer, and benefit the consumer.

ACKNOWLEDGMENTS

Research was supported by the NYS Department of Environmental Conservation "A comprehensive strategy for the value-added utilization of acid whey streams” and Terre d’enfant (Art de Vivre high-end and eco-friendly for children) sustainability fund. Recognition to Kyle Kriner for his technical assistance and Byrne Dairy for the acid whey.

AUTHOR CONTRIBUTIONS

J. Camacho Flinois designed the study, collected test data, interpreted the results and drafted the manuscript.

R. Dando contributed to study design, data analysis and manuscript editing.

O. I. Padilla-Zakour contributed to study design, data analysis and manuscript editing.

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CONCLUSIONS AND FUTURE WORK

Scope of application: products and flavors

Preliminary work during the first part of this study showed greater difficulty working with the astringency of acid whey in dips and sauces with other flavor profiles (e.g. spinach cheese dip). The flavor attributes of YAW seemed most fitting in Ranch-dressing of all tested products, with an acceptable flavor even at high YAW concentration. Similar conclusions were drawn from the work on baked products, when preliminary data showed perfect acceptance of YAW in lemon-flavored scones. Because this study aimed to assess the limits of applications of YAW as an ingredient, we focused on high proportions of YAW incorporations. We therefore decided not to include scones in the study for their lower moisture content which would have led to least significant results.

The increase in sourness and bitterness perception in YAW samples leads us to believe that YAW has the greatest potential in products welcoming such flavors, such as citrus-flavored products, or products with related notes like sourdough bread, cheesecake-flavored confectionary or cakes, or other products traditionally made with buttermilk (which often contain added flavors like butter or cream).

Future directions might include work on flavor pairing and the study of flavor profiles that best welcome the addition of acid whey, and why. Astringency is known to be strong in ingredients such as coffee, lime, mint, vinegar and jalapeno; thus there might be an opportunity in the case of products with flavor profiles containing these ingredients. Physico-chemical composition thermal-mouth-feel (e.g. cool mint, hot chili), or intrinsic astringency of ingredients (green apple, pomegranate) might be relevant factors in the inclusion of acid whey. Whey protein beverages developed in the past have had more success with tropical flavors (mango, pineapple and coconut) as well as citrus, peach and apple rather than berry flavors (strawberry, raspberry, blueberry, etc.) which are not as efficient at masking the taste flavor and astringency of whey (Burrington, 2012). The type of acid whey may also have an impact on the liking scores of products they are used in (Gallardo-Escamilla et al., 2005b).

Preliminary work on crêpes showed an increased difficulty in flipping the crêpes due to stickiness of the cooked batter onto the griddle. These observations showed that YAW may not be suitable as milk replacement in products with over 65% moisture content pre-bake, due to the high amounts of lactose contained in YAW. The crepes were also much too astringent at that level of YAW incorporation. For these types of products, we could recommend partial incorporation of YAW for shelf life extension, nutritional benefits, added flavors, and sustainability.

Preliminary work on sourdough culture/starter was also performed: two sourdough starters were cultured over two weeks (one with tap water, the other with YAW) using whole wheat flour on the first day and all-purpose flour on the following feeding days. The starter made and fed with YAW went from the bacterial phase (foul vinegar smell, few bubbles, little rise, water layer from bacterial activity at the surface) to the yeast phase (fermented smell, doubles in volume each day due to abundant CO2 formation, homogeneous batter) in 5 days. The starter made with tap water remained predominantly in the bacterial phase for over 8 days, after which 0.1%/wt lactic acid was added to aid microorganism selection. Two days later, the control starter was in the yeast phase although it never reached the quality of the YAW based starter (see image 1 in supplemental materials). The nutrients contained in YAW as well as its pH was believed to create a very prosperous environment for yeast development and selection over bacterial development.

Product manufacturing using YAW

Preliminary results obtained in the first phase of pizza and pancake sample preparation made with unpasteurized YAW (YAW stored over 7 days in refrigerated conditions in clean containers) showed that the increased microbial load of the YAW negated its shelf life benefits and decreased the sample's mold-free shelf life making the shelf life shorter than that of the control. However, communications with dairy plant managers who produce and manage YAW have led to the conclusion that in the context of high scale production, YAW would either be rerouted within a factory from the Greek-style yogurt line onto a baked goods line (with negligible effect on its food-safe condition) or be transported to another nearby baked-goods factory for repurposing. In the second case, the containment and transportation of the YAW would to be similar to its current containment and transportation needs (for disposal) and would represent no significant additional cost compared to its current use, provided a similar transportation distance. In any case, the management required for the repurposing of YAW as a value-added ingredient is anticipated to be similar to the cost of the management required for its disposal and lower than that of utilizing new resources as ingredients which also require handling and transportation.

Demographic questions to panelists have revealed that their principal pancake consumption (61.7%) happens at restaurants, either served on a plate, from a bakery or in a fast food restaurant, followed by prepared from a commercial dry mix (58.3%), baked from scratch (43%) and bought frozen (18.3%). With the first category being often purchased by restaurants in their frozen form from co-packing-manufacturers, we can conclude that dairy plants producing frozen pancakes containing YAW for service-retailers would represent a substantial share of pancakes consumption.

While the implementation of the use of YAW is not expected to increase costs for manufacturing companies (personal communications) and may even represent a lowering of total costs as seen previously, the final product will benefit from the premiumization attached to a sustainability claim. According to Marketwired (MacMillan & Lu, 2017), 66% of millennials are prepared to pay more for sustainable food products.

Consumer perception

Apart from the nutritional, sensorial and physical effects of YAW on products, its use as an ingredient with minimal processing equates to a low-energy-requirement method to lower food waste whilst avoiding pollution. These effects are likely to be welcomed by consumers with a growing need for global sustainability in their food: the sustainability claims provided to the panelists significantly increased their purchase intent for all tested products.

Consumer perception of repurposing “waste” was questioned during the course of the study. To assess the reticence on the part of consumers, products (pancake and ranch dressing) were presented as an item at a university cafeteria. Students were shown a bottle of acid whey and the nutritional information of the Ranch dressing compared to the average commercial product right next to the sample plates (see image 2 in supplemental materials). The samples were received very positively, with numerous students coming back to ask for seconds.

Buttermilk (by product of butter production) and whey protein powders (by product of cheese production) are examples of successful consumer approval of repurposed dairy byproducts that are no longer viewed as waste. The growth of butter and cheese manufacture and sales being inferior to that of Greek-style yogurt, the efforts for the shift of dairy waste into valuable ingredient should now be concentrated towards acid whey. YAW can then be expected to follow in the footsteps of buttermilk and whey protein powders as common ingredient with progressed consumer perception, provided that the food production sector takes the first step in considering it valuable.

Future work should concentrate on the implementation of the use of YAW as a valuable ingredient in value-added food products, from manufacturing facilities to the retail market.

ADDENDUM: SUPPLEMENTAL MATERIALS

[A] [B]

Image 1: Sourdough starters (on day 5) made with water and YAW respectively and fed (6 volumes of water [A] or YAW [B], 6 volumes of flour and 3 volumes of previous day's starter) every day.

Image 2: Counter presentation of cafeteria servings of YAW pancake with fried egg and aioli kimchi (left) and cauliflower buffalo wings in YAW ranch dressing (right).