ABSTRACT

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). Yogurt acid whey qualities (e.g., low pH, mineral content, astringency, and saltiness) present challenges for processing, disposal, and ingredient use. A shelf-stable ranch dressing was formulated by replacing buttermilk in the control with YAW and concentrated YAW (6.3 to 25.2 °Brix). Added salt, gums, and acids were adjusted. The effects of buttermilk substitution on stability were studied on pasteurized samples (8 mo at room temperature). A consumer sensory study (n = 96) was conducted utilizing hedonic and just-about-right scales. Purchase intent and demographic data were also collected. A focus group (n = 7) evaluated the sensorial attributes of the samples after 6 mo. The experiment was performed in triplicate and all instrumental analyses (pH, soluble solids as °Brix, water activity, refraction index, and color) were conducted in triplicate for statistical analysis. Increasing the gum content in YAW samples resulted in equivalent texture liking compared with the control. Matching the control’s NaCl concentration resulted in undesirable higher saltiness. The pH of the 18.9 °Brix YAW ranch sample without lactic acid added was under 4.6, with no effect on flavor liking. Increasing concentrations of YAW decreased L* and water activity, and increased the refractive index and hue. The YAW samples presented minimum changes over 8 mo of storage and had better water retention than the control. We conclude that 15 to 17 °Brix YAW is the optimal replacement for buttermilk in a dressing. The formulation of dressings may be accomplished successfully, sustainably, and cost effectively, with minor processing adjustment, by substituting buttermilk with YAW.

Key words: yogurt acid whey, ingredient, salad dressing, quality

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 present in the milk (Nergiz and Sec, 1998; Božanić et al., 2014; 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 such as 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 such as Ricotta and Greek yogurt) produce acid whey, with a much lower pH (3.5–5), lower protein, and higher ash content.

The high biological oxygen demand of whey (Marwaha and Kennedy, 1988; Tsakali et al., 2010) makes its disposal in natural water streams or municipal waters threatening to the environment. Its acidity and nutrient content disrupt the natural equilibrium of stagnating waters, leading to algae blooms and loss of aquatic life (Carvalho et al., 2013; Kavaz and 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 closely regulated by the New York 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 biodigestion requires millions of dollars of infrastructure (Mawson, 1993; Angenent et al., 2014; 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 limiting physicochemical characteristics, mainly low pH and lack of protein, have posed significant challenges that constraint its spray-drying and restricted applica-
tion for concentration and nutrient extraction (Dec and Chojnowski, 2006; Smithers, 2015). The complexity of YAW disposal has made it a costly process (Smithers, 2015).

These limitations have caused YAW to be directed mostly toward 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 yr have resulted in it representing over 50% of the total US yogurt market today compared with less than 5% at the beginning of the century (Watson, 2014; Comick, 2015; Erickson, 2017). 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 waste. Thus, the upscaling of YAW and its reintroduction into the food supply chain would have a notable effect 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 (Smithers, 2015; Kavaz and Öztöprak, 2017).

The acidic and salty taste of YAW have been a barrier to its unprocessed use as an ingredient in value-added food products, as in a few experimental uses with no or minimal processing (Lievore et al., 2015; Wronkowska et al., 2015). 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. In this study, we evaluated the feasibility of formulating ranch dressing by replacing buttermilk with YAW. Results from this research can act as the back bone to the implementation of YAW as an ingredient in the manufacture of high-scale value-added food products.

**MATERIALS AND METHODS**

**Ingredients**

To assess the feasibility of replacing buttermilk with YAW in salad dressings, a pilot product with an intentionally astringent flavor profile (ranch dressing) was selected, thought to be likely to accommodate the flavors of YAW (Mcgugan et al., 1972; Gallardo-Escamilla et al., 2005). A control ranch dressing was developed using buttermilk (Byrne Dairy Fresh plant, Syracuse, NY), mayonnaise (Hellmann’s, Unilever, Lisle, IL), and a prepared mix of ingredients for flavor and texture [less than 2% of monosodium glutamate (MSG), salt, spices, dried parsley, sugar, white distilled vinegar, lactic acid, thyme, and xanthan and guar gums]. All ingredients were purchased from a national supermarket in Ithaca, New York, and the gums were received from a supplier (TIC Gums Inc., White Marsh, MD). Four versions were prepared with 48, 65, 74, and 79% YAW, respectively, in addition to the control. To achieve these YAW contents, 48%/wt YAW was added in each recipe (replacing the 48%/wt of buttermilk in the control formulation), with increasing soluble solids concentration (6.3, 12.6, 18.9, and 25.2 °Brix).

**Ranch Dressing Preparation**

Ingredients were weighed (Table 1) and thoroughly mixed until visual homogenization of fat and water components. Heat treatment was applied to the final ranch dressing; 93°C/181°F for 3 min in a water bath followed by hot filling in 1-L glass canning jars (Ball, Broomfield, CO) to achieve shelf stability (Padilla-Zakour, 2009). The YAW (6.5 °Brix, pH 4.45) was collected (Byrne Dairy), stored refrigerated (6°C) for no more than a week, pasteurized (93°C/181°F for 3 min), and concentrated using a freeze dryer (Harvestright freeze dryer, North Salt Lake, UT). Additional formulations replaced the buttermilk in the control recipe with YAW at 4 different levels: sample YAW1 was made with YAW at 6.3 °Brix (lowest native concentration observed in a period of 4 mo from the facility), sample YAW2 was made with YAW concentrated to 12.6 °Brix (2×), sample YAW3 was made with YAW concentrated to 18.9 °Brix (3×), and sample YAW4 was made with YAW concentrated to 25.2 °Brix (4×). No lactic acid was added (lactic acid is naturally present in YAW), and the amount of gums was increased inversely proportional to the YAW concentration.

**Consumer Acceptance**

The 5 dressings (control, YAW1, YAW2, YAW3, and YAW4) were compared in a consumer sensory study (n = 96). Thirty milliliters of each sample was served at room temperature in a 60-mL plastic cup, with a spoon, in a monadic sequential manner. Panelists had access to unsalted crackers and water for palate cleansing. Sensory data were collected using 9-point hedonic scales, just about right (JAR) scales, purchase intent, and short open-ended questions (Lawless and 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 mo: d 1, wk 2, wk 5, wk 9, wk 15, wk 23 (5 mo), and wk 36 (8 mo). 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 et al., 2005). Three aliquots of 1.6 mL of each triplicated sample \((n = 9)\) were centrifuged with a microfuge at 503 × g continuously for 10 min (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; https://imagej.nih.gov/ij] as a proportion of the total volume (percentage of the water-based filtrate to the fat-containing supernatant). On the first 2 stages of the shelf-life study, soluble solids as °Brix (pocket digital refractometer, 300053, Sper Scientific, Phoenix, AZ) and pH (Orion 3-star pH Benchtop, Thermo Electron Corporation, electrode Orion 8172BNWP rose flow combination pH, Thermo Fisher Scientific Inc., Waltham, MA) were also measured. Data presented for \( L^*a^*b^* \) and water retention are the average of all time point measurements because no effect of time was detected (2-way ANOVA, \( P > 0.05 \)).

Shelf-Life Focus Group

At 23 wk, 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 mo) 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 sex (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 before 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

The experimental design was conducted in triplicate: 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, Armonk, NY). Sensory data were analyzed using RedJade, with liking scores analyzed using Cochran’s q test followed by post-hoc Tukey’s tests. For hypothesis testing, a significance level of 0.05 was used.

RESULTS AND DISCUSSION

Consumer Response to a Ranch Dressing Prepared by Replacing Buttermilk with YAW

For most sensory attributes evaluated in this study, overall flavor liking was poorest at the lowest (YAW1)

<table>
<thead>
<tr>
<th>Item (%)</th>
<th>Control</th>
<th>YAW1</th>
<th>YAW2</th>
<th>YAW3</th>
<th>YAW4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buttermilk</td>
<td>48.15</td>
<td>48.03</td>
<td>48.06</td>
<td>48.06</td>
<td>48.06</td>
</tr>
<tr>
<td>YAW1 (6.3 °Brix)</td>
<td>—</td>
<td>48.03</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>YAW2 (12.6 °Brix)</td>
<td>—</td>
<td>48.06</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>YAW3 (18.9 °Brix)</td>
<td>—</td>
<td>—</td>
<td>48.06</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>YAW4 (25.2 °Brix)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>48.06</td>
<td>—</td>
</tr>
<tr>
<td>Mayonnaise</td>
<td>48.15</td>
<td>48.03</td>
<td>48.06</td>
<td>48.09</td>
<td>48.11</td>
</tr>
<tr>
<td>Gums (1:1 xanthan and guar gum)</td>
<td>0.05</td>
<td>0.10</td>
<td>0.09</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>0.58</td>
<td>0.77</td>
<td>0.72</td>
<td>0.67</td>
<td>0.63</td>
</tr>
<tr>
<td>Sugar</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Monosodium glutamate</td>
<td>0.96</td>
<td>0.96</td>
<td>0.96</td>
<td>0.96</td>
<td>0.96</td>
</tr>
<tr>
<td>Lactic acid</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Vinegar</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Spices (parsley flakes, garlic powder, onion powder, black pepper, ground thyme)</td>
<td>1.54</td>
<td>1.54</td>
<td>1.54</td>
<td>1.54</td>
<td>1.54</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

YAW = yogurt acid whey.
and highest (YAW4) YAW concentration, indicating the need for adjustment to an optimal level for buttermilk replacement (Figure 1). Aside from this point, however, YAW replacement resulted in no decrease in overall or flavor liking up to a level of 18.9 °Brix 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 JAR score frequency (65% JAR) and smallest standard deviation (±0.7). All YAW samples received lower frequency of JAR scores (YAW1: 59%; YAW2: 61%; YAW3: 51%; YAW4: 51%), skewing “too salty.” We speculate that this highlights a possibility that YAW supplementation may assist in developing reduced sodium formulations 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 1B). The only sample with a significant increase in mean perceived sourness from control was YAW4 (Cochran’s Q test P = 0.001, post hoc honestly significant difference: 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%; and 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 1C). That increase in the proportion of panelists perceiving too much herb-and-spice intensity (despite the standard amounts used in all samples) is proportional to the amount of YAW in the samples. The YAW may therefore enhance the flavor of the herbs and spices within our formulation, and thus could allow for a decrease in spices as a silent change in commercial products, with associated cost benefits.

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 YAW3 was most similar to that of the control, with a mean of 4.0 (±0.8) compared with 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. The increase in mean JAR score for smoothness (Figure 1D) 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 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 2), yogurt acid whey allows for increased smoothness despite lower fat content. No differences were observed 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.

Sensory data suggest that the ideal acid whey ranch dressing would be made with 15 to 17 °Brix YAW. At that level, calories, sodium, and protein are the only nutritional parameters affected sufficiently (>5 kcal or 0.5 g/serving) to be noticeable on the US FDA 2016 Nutrition Facts (FDA, 2016; Figure 2A). Specifically, we would observe a 5 to 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 0.5 g/serving decrease in protein, which, as discussed, is separated from the acid whey and retained in Greek-style yogurt.

The YAW samples had significantly lower scores than the control for 2 attributes. The first attribute was the color liking (Figure 3D). These results can be explained by the higher darkness (lower lightness: L*) and higher yellow color (b*) of the YAW samples (Figure 4). 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.

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 and 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 effect 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 1. 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 just-about-right scale. The thicker line corresponds to a significant ($P < 0.05$) difference from the control (more information in Supplemental Figure S1; https://doi.org/10.3168/jds.2018-16158). Ranch dressing formulations made with yogurt acid whey (YAW) at concentrations of 6.3 (YAW1), 12.6 (YAW2), 18.9 (YAW3), and 25.2 (YAW4) °Brix.
Despite no difference in overall liking (Figure 3A), YAW samples scored 2.9 on average (from 2.76 for YAW4 to 3.08 for YAW3) compared with 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 to 17 °Brix, would further improve appeal.

**Effect of YAW on Shelf Life at Room Temperature**

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 5). The elimination of lactic acid would contribute to a cleaner label, desirable for today’s consumers.

The stability of the emulsion was improved by YAW as can be seen in Figure 6. After centrifugation, there was less separation of the aqueous portion and herbs from the fat compared with 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 6A).

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 6C). As a result, the water retention...

![Figure 2](image_url)
measurements were artificially increased (Figure 6B). Particle suspension was therefore measured to assess its effect on the water retention measurements. Particle suspension seemed not to be correlated with the YAW content but correlated with the viscosity of the samples (high concentration YAW and control being the thickest samples with the highest particle suspension, and YAW1 and YAW2 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 is underestimated by the previous measurement method (Sodini et al., 2005).

**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 descriptive 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,

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Figure 3. Overall liking (A), overall flavor liking (B), texture liking (C), and color appearance liking (D) distribution of ranch dressings made with buttermilk or yogurt acid whey (YAW) on the 9-point hedonic scale (n = 97). Letters (A–C) represent statistically significantly different mean scores based on Cochran’s q test followed by post-hoc comparison using Tukey’s honestly significant difference. *Asterisks represent statistically different distribution of scores within the variable. Error bars indicate SE. Ranch dressing formulations made with YAW at concentrations of 6.3 (YAW1), 12.6 (YAW2), 18.9 (YAW3), and 25.2 (YAW4) °Brix.
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 (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 consumers’ 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 to 75%/wt in the total formulation of acid whey at native concentration of 6.3 °Brix (equivalent to 48% acid whey after concentration to 15 to 17 °Brix) is the acceptable range to formulate dressings with an astringent flavor profile like ranch dressing. The YAW concentration to 15 to 17 °Brix is necessary to mimic buttermilk with the right YAW-solids content 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 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 showed no negative effect on shelf life (8 mo at room temperature) of replacing buttermilk by any concentration (from 6.3 to 25.2 °Brix) of acid whey. A benefit was observed on emulsion stability at higher levels of YAW concentration (48%/wt of YAW at 18.9 and 25.2 °Brix). The development of value-added products using YAW represents a key component to ensure the sustainability of Greek yogurt operations.

ACKNOWLEDGMENTS

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