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Short communication: Composition of coproduct streams from dairy processing: Acid whey and milk permeate

Pedro Menchik, Tristan Zuber, Anika Zuber, and Carmen I. Moraru*
Department of Food Science, Cornell University, Ithaca, NY 14853

ABSTRACT

This article provides composition information for 3 abundantly available but little characterized dairy coproduct streams: acid whey from Greek yogurt (GAW), acid whey from cottage cheese (CAW), and milk permeate (MP). Three replicate samples obtained on different dates from several dairy processors were analyzed. The main component in all streams was lactose, with up to 3.5, 2.1, and 11.9% in GAW, CAW, and MP, respectively. Crude protein content ranged from 1.71 to 3.71 mg/g in GAW, 1.65 to 5.05 mg/g in CAW, and 3.2 to 4.35 mg/g in MP, and pH ranged from 4.21 to 4.48, 4.35 to 4.51, and 5.4 to 6.37, respectively. Chemical oxygen demand varied from 52,400 to 62,400 mg/L for GAW, 31,900 to 40,000 mg/L for CAW, and 127000 to 142,000 mg/L for MP; biochemical oxygen demand ranged from 45,800 to 50,500 mg/L (GAW), 32,700 to 40,000 mg/L (CAW), and 110,000 to 182,000 mg/L (MP). The GAW had the lowest pH (4.21–4.48) and highest mineral content of all streams. These data will assist processors and researchers in developing value-added uses of these dairy coproducts.
Key words: Greek yogurt acid whey, cottage cheese acid whey, milk ultrafiltration permeate, dairy coproducts

Short Communication

The last decade was defined by a very high interest in high-protein foods, which resulted in the surge of high-protein dairy products such as Greek-style yogurt (**GSY**) or beverages fortified with proteins obtained by membrane fractionation of milk or cheese whey. During the manufacture of such products, a significant portion of the water and water-soluble components in milk such as lactose and minerals are being removed as either whey or permeate. With growing volumes of the high-protein products, high volumes of these streams are also produced. In the past, these streams were deemed as byproducts, and often times they were disposed as waste. However, such streams can present a huge environmental concern due to their high content of OM, which can lead to algal bloom and depletion of oxygen in water streams (Arla Foods Ingredients, 2017; Erickson, 2017). For example, the average biochemical oxygen demand (**BOD**) for some whey streams was reported to be around 40,000 mg/L (Jelen, 2011), which is about 30 times higher than the effluent limit prescribed for cultured dairy products and 130 times higher than the effluent limit for cheese products (CFR, 2017). Therefore, pressure is mounting on the industry to fully use all milk components. To reflect the change of attitude toward these streams, in recent years the term coproducts started being used instead of byproducts.

Acid whey and permeate from membrane fractionation represent, by volume, the most significant coproducts currently generated by the US dairy industry. Acid whey is generated from products such as cottage cheese or GSY, in which casein coagulation is driven by pH reduction by either lactic fermentation or direct acidification. Similar to the sweet whey obtained from cheese making, acid whey consists mostly of water, with lactose as the main solid, but has a much lower protein content, and higher acidity and mineral content than sweet whey. This results in significant differences in sensory, nutritional, and technological properties, as well as different strategies for its usage and processing for the 2 types of whey (Jelen, 2011). In particular, acid whey from Greek-style yogurt (**GAW**) has a lower protein content than the other types of whey, due to the depletion of whey proteins caused by the extended heat treatment used in yogurt making (Gyawali and Ibrahim, 2016).

Large volumes of GSY are currently produced, both in the United States and abroad. In 2004, GSY accounted for less than 2% of all yogurt types produced in the United States, but in 2015 this number skyrocketed to almost 40%, amounting to an impressive 771,000 t of Greek yogurt (Erickson, 2017). The straining or centrifugation associated with the manufacture of GSY results in high quantities of GAW, since on average 2

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*Corresponding author: cim24@cornell.edu

kg of whey are produced for every 1 kg of Greek yogurt (Erickson, 2017). In New York State alone, which is currently the largest yogurt-producing state in the United States, about 300,000 t of GAW were produced in 2012 (DEC, 2012). To date, GAW use has been limited to low added-value applications, and most processors have yet to find an economically feasible way to incorporate it into higher-value products. A few solutions have been proposed, so far with mild success (Arla Foods Ingredients, 2017; Erickson, 2017). Current applications of GAW include irrigation, feed for livestock, and energy generation in wastewater bioreactors (DEC, 2012).

Similar to acid whey, the permeate obtained from the ultrafiltration of skim milk is also depleted from proteins, but contains the other soluble components of milk. The industry is actively seeking ways to find value-added uses for coproducts such as acid whey and permeate, which will help increase the value of milk and improve the sustainability of the dairy industry. These coproducts still contain important components such as lactose, minerals, AA, and even small amounts of protein that could be used in added-value products such as fermented goods, sports beverages, snacks, and baby food formula, to name a few (Arla Foods Ingredients, 2017).

One of the challenges in developing such applications is the fact that information about the composition of these streams is not readily available. In this context, the main objective of this paper is to provide a detailed composition of some less well-characterized dairy coproduct streams, including acid whey from GSY and cottage cheese, and milk permeate. This information will help dairy processors and researchers make more informed decisions regarding the valorization and potential applications of these coproducts in the future.

Four dairy coproducts were collected during September 2015 (1 replicate) and February 2016 (2 replicates) from 3 companies located in New York State: (1) acid whey from Greek-style yogurt from company A; (2) acid whey from Greek-style yogurt from company B; (3) acid whey from cottage cheese from company B (**CAW**); and (4) milk UF permeate from company C (**MP**). All samples were stored refrigerated from collection until the time of analyses. Details about sample handling are provided in Table 1. Each of the individual samples was analyzed in triplicate.

Table 1 summarizes the assays performed for the first batch of coproducts collected, the laboratories responsible, and the methodologies used. For the second batch of samples, the number of analyses was reduced to those deemed most critical, which are indicated in bold face font in Table 1. For the second batch of samples, the BOD and chemical oxygen demand (**COD**) assays were performed by a different laboratory, for logistical reasons.

Because some of the protein assays gave results that were below the limit of detection, total CP (in mg/g) was calculated as (total nitrogen/1,000) × 6.38. The amount of individual protein fractions, such as α-LA and β-LG, were then calculated by multiplying their reported percentages by the total CP obtained as mentioned above.

The methodologies used for determining the nitrogen fractions (nitrates, ammonia, urea) are described in the compendium of analytical procedures by Dairy One (Dairy One, 2015). The various protein fractions were analyzed by capillary gel electrophoresis by L. Metzger's laboratory at South Dakota State University, using the procedure described below, as provided directly by South Dakota State University.

A 10-μL sample was mixed with 85 μL of sample buffer (Beckman-Coulter, Fullerton, CA) and 5 μL of β-mercaptoethanol in a micro-vial. Each micro-vial was capped tightly, mixed thoroughly, and then heated in a water bath at 90°C for 10 min, then cooled to room temperature. The capillary gel electrophoresis was carried out using a Beckman P/ACE MDQ capillary electrophoresis system (Beckman-Coulter) equipped with a UV detector set at 214 nm. The separation was performed using a 50 μm bare fused silica capillary (20.2 cm effective length from the inlet to the detection window). All solutions and reagents were obtained as a part of the ProteomeLab SDS-MW Analysis Kit (Beckman-Coulter) designed for the separation of protein-SDS complexes using a replaceable gel matrix. The gel is formulated to provide an effective sieving range of approximately 10 to 225 kDa. A capillary preconditioning method was run every 3 samples. This consisted of a basic rinse (0.1 *N* NaOH, 5 min, 345 kPa), followed by an acidic rinse (0.1 *N* HCl, 2 min, 345 kPa), a water rinse (HPLC grade water, 2 min, 345 kPa), and finally a SDS gel rinse (SDS gel fill, 10 min, 275 kPa). After the preconditioning steps the sample was electrokinetically introduced at 5 kV for 20 s. The separation was performed at a constant voltage of 15 kV (at a temperature of 25°C and a pressure of 20 bar) with reverse polarity in the SDS-molecular weight gel buffer. Actual current values were recorded to determine the efficiency of each electrophoretic run. Molecular weight standards (Proteome Lab and Beckman-Coulter) and available pure milk protein fractions (Sigma, St. Louis, MO) were also separated using the method as described above to determine migration times. The peaks in the capillary electropherogram were identified by comparing the migration time of molecular weight standards and pure standard samples as well as by comparison

Table 1. Methodology employed and laboratories responsible for each analysis

Analysis	Handling	Laboratory	Analytical method[2]
Acidity, titratable (lactic)[1]	Samples kept in vials under refrigeration and then shipped overnight on wet ice	Medallion Labs, Minneapolis, MN	AOAC 942.15, 962.12; 984.24
AA profile (acid hydrolyzed: alanine, arginine, aspartic acid, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, phenylalanine, proline, serine, threonine, tyrosine, and valine)			AOAC 994.12 HPLC-UV
AA profile (cysteine and methionine)			AOAC 994.12 HPLC-UV
AA profile (free AA)			AOAC 994.12 HPLC-UV
AA (tryptophan)			AOAC 994.12 HPLC-UV
Ash[1]			AOAC 923.03
Chloride[1]			AOAC 915.01
Fat analysis			Röse-Gottlieb method
Fat analysis by GC with fatty acid profile			AOAC 996.06
Minerals (Ca[1], Fe, Na[1], Cu, K[1], Mg[1], Mn, P, Zn)			AOAC 2011.14
Moisture (vacuum oven at 70°C/16 h)[1]			AOAC 925.09
NPN[1]			AOAC 991.21
Organic acids (citric, acetic, glutaric, lactic, malic, oxalic, quinic, succinic, and tartaric)			AOAC 986.13 via HPLC
pH (direct)[1]			AACC 02–52; AOAC 943.02
Resistant oligosaccharides with total soluble and insoluble dietary fiber			AOAC 2001.03 and AOAC 991.43
Sugars by HPLC (fructose, glucose, lactose, galactose, maltose, and sucrose)[1]			AOAC 977.20–HPLC–RI detection
Vitamin A (retinol, concentrate)			AOAC 2005.07–HPLC–UV/visible
Vitamin B_9 (folic acid-folate), total IU			AOAC 2011.06–UH LC
Vitamin B_3 (niacin)			AOAC 944.13; AOAC 960.46
Vitamin B_1 (thiamine)			AOAC 942.23; AOAC 970.65; AOAC 981.15
Vitamin B_2 (riboflavin)			AOAC 942.23; AOAC 970.65; AOAC 981.15
Vitamin B_{12} (cyanocobalamin)			AOAC 952.20; AOAC 986.23
Vitamin B_6 (pyridoxine)			AOAC 961.15; AOAC 985.32; AOAC 960.46
Vitamin B_5 (pantothenic acid)			AOAC 945.74; AOAC 960.46; AOAC 992.07
Vitamin C			AOAC 967.22; AOAC 984.26
Vitamin D			AOAC 2002.05
Total N–ammonia, nitrate, urea, organic[1]	Same as above	Dairy One, Ithaca, NY	Methodology described elsewhere (Dairy One, 2015)
Chemical oxygen demand	Same as above	Certified Environmental Services, Syracuse, NY	ASTM 5220C
Biochemical oxygen demand			ASTM 5210B
Ortho-phosphorus			EPA 365.3
α-LA, β-LG, α_{S1}-casein, α_{S2}-casein, β-casein, γ-casein, κ-casein, total casein, other peptides, total low molecular weight[1]	Pasteurized 63°C/30 min, frozen, shipped on dry ice	South Dakota State University, Brookings, SD	Methodology described in Materials and Methods

[1]The most critical analyses, which were repeated for the second batch of coproducts.

[2]AOAC International (1995), ASTM (1995), and AACC International Method 02-52.01.

Table 2. Composition data for the first batch of coproducts [replicate (Rep.) 1][1]

		Company A	Company B		Company C
Analysis	Units[2]	GAW	GAW	CAW	MP
TS	% wt/wt	6.0	6.0	3.7	13.4
Total N (TN)	mg/kg	581	390	259	502
Ammonia-N		83	79	58	<5
Urea-N		ND	<5	<5	227
Nitrate-N		ND	ND	ND	ND
NPN	% of TN	0.17	0.16	0.13	0.35
Total protein (calculated)	mg/g	3.71	2.49	1.65	3.2
α-LA		0.50	0.47	0.22	0.52
β-LG		0.11	0.13	0.83	1.18
Total casein		0.00	0.02	0.07	0.00
α_{S1}-Casein		0.00	0.00	0.00	0.00
α_{S2}-Casein		0.00	0.00	0.00	0.00
β-Casein		0.00	0.00	0.00	0.00
γ-Casein		0.00	0.00	0.00	0.00
κ-Casein		0.00	0.00	0.00	0.00
Other peptides		0.00	0.00	0.08	0.08
Total low molecular weight AA		3.09	1.87	0.45	1.42
Hydroxyproline	%	ND	ND	ND	ND
Aspartic acid		0.011	0.018	0.034	0.012
Threonine		0.006	0.008	0.015	0.004
Serine		0.006	0.008	0.013	0.004
Glutamic acid		0.022	0.03	0.055	0.021
Proline		0.008	0.011	0.017	0.003
Glycine		0.002	0.004	0.005	0.005
Alanine		0.005	0.006	0.015	0.005
Valine		0.005	0.008	0.016	0.003
Isoleucine		0.006	0.009	0.017	0.004
Leucine		0.009	0.015	0.036	0.007
Tyrosine		0.002	0.005	0.011	0.002
Phenylalanine		0.004	0.007	0.012	0.002
Lysine		0.009	0.015	0.032	0.008
Histidine		0.004	0.005	0.007	0.002
Arginine		0.003	0.005	0.009	0.002
Total hydrolyzed AA		0.102	0.154	0.294	0.084
Cysteine		0.002	0.003	0.008	0.003
Methionine		0.001	0.002	0.006	0.001
Taurine		M/I	M/I	M/I	0.003
Asparagine		<LOQ	<LOQ	<LOQ	<LOQ
Glutamine		<LOQ	ND	<LOQ	ND
Cysteine		ND	ND	<LOQ	ND
Citrulline		ND	ND	0.001	<LOQ
Gamma-aminobutyric acid		0.003	0.004	0.007	<LOQ
Ethanolamine		0.001	0.001	0.001	0.007
Ornithine		<LOQ	ND	0.001	0.001
Total free AA		0.022	0.013	0.025	0.0035
Tryptophan		<0.01	<0.01	<0.01	<0.01
Ash	% wt/wt	0.64	0.75	0.42	1.13
Calcium	mg/100 g	121	120	69.9	96.3
Iron		<1.00	<1.00	<1.00	<1.00
Sodium		37.9	38.7	23.1	80.6
Phosphorus		66.8	66.5	46.3	99.9
Copper		<1.00	<1.00	<1.00	<1.00
Potassium		164	169	95.2	360
Magnesium		10.6	10.4	6.78	16.3
Manganese		<1.00	<1.00	<1.00	<1.00
Zinc		<1.00	<1.00	<1.00	<1.00
Total chloride	%	0.078	0.094	<0.06	0.207
Ortho-phosphorus	mg/L	558	530	391	712
Total sugar (including galactose)	%	3.92	4.02	1.99	10.6
Lactose		3.33	3.42	1.99	10.6
Galactose		0.59	0.60	<0.1	<0.1
Fructose		<0.1	<0.1	<0.1	<0.1
Glucose		<0.1	<0.1	<0.1	<0.1
Sucrose		<0.1	<0.1	<0.1	<0.1

Continued

Table 2 (Continued). Composition data for the first batch of coproducts [replicate (Rep.) 1][1]

		Company A	Company B		Company C
Analysis	Units[2]	GAW	GAW	CAW	MP
Maltose		<0.1	<0.1	<0.1	<0.1
Total fiber	%	0.4	0.3	0.2	0.2
Insoluble fiber		0	0	0	0
Soluble fiber		0.4	0.3	0.2	0.2
Resistant oligosaccharides		0	0	0	0
Total fat, chromatography[3]	%	0	0.01	0.01	0
Saturated fat		0	0.01	0	0
Monounsaturated fat		0	0	0	0
cis-cis PUFA		0	0	0	0
Trans fat		0	0	0	0
Total fat, gravimetric		0	0	0	0.01
Fatty acid					
12:0 Lauric		0	0.001	0	0
16:0 Palmitic		0	0.006	0	0
18:0 Stearic		0	0.003	0.004	0
18:1 Oleic		0	0.003	0.004	0
18:2 Linoleic		0	0.001	0	0
Vitamin					
Niacin	mg/100 g	0.11	0.12	0.11	0.36
Vitamin B_1 [thiamine-HCl (US)]		0.1	0.06	0.06	0.1
Vitamin B_1 [thiamine (EU)]		0.079	0.074	0.047	0.079
Vitamin B_2 (riboflavin)		0.12	0.06	0.04	0.05
Vitamin B_6		<0.02	<0.02	<0.02	0.04
Pantothenic acid		0.459	0.268	0.246	0.983
Vitamin C		<0.5	<0.6	<0.5	<0.5
Vitamin B_{12}	µg/100 g	<0.10	<0.10	<0.10	<0.10
Folic acid		<5.00	<5.00	<5.00	8.12
Vitamin A	IU/100 g	<50	<50	<50	<50
Vitamin D total		<40	<40	<40	<40
Titratable acidity (lactic acid)	%	0.43	0.43	0.28	0.12
Organic acids					
Oxalic acid		<0.01	<0.01	<0.01	<0.01
Citric acid		0.18	0.17	0.09	0.4
Tartaric acid		<0.01	<0.01	<0.01	<0.01
Malic acid		<0.01	<0.01	<0.01	<0.01
Quinic acid		<0.01	<0.01	<0.01	<0.01
Succinic acid		<0.01	<0.01	<0.01	<0.01
Lactic acid		0.65	0.64	0.37	<0.01
Glutaric acid		0.06	0.06	0.04	0.14
Acetic acid		<0.01	<0.01	<0.01	<0.01
Fumaric acid		<0.01	<0.01	<0.01	<0.01
pH		4.4	4.4	4.41	6.37
Chemical oxygen demand	mg/L	62,200	64,400	40,000	142,000
Biochemical oxygen demand		>22,000	>7,300	>7,300	>7,300

[1]GAW = acid whey from Greek-style yogurt; CAW = acid whey from cottage cheese; MP = milk UF permeate; ND = not detected; M/I = matrix interference; LOQ = limit of quantification.

[2]Units as reported by the analytical laboratories.

[3]Fatty acids not found in any of the samples are not shown in the table.

to results reported by other researchers (Creamer and Richardson, 1984; Miralles et al., 2000; Anema, 2009). The area of each identified peak was calculated from the electropherogram using a valley-to-valley approach, as described in literature (Miralles et al., 2000). The area of the each identified individual casein fraction (α_{S1}-CN, α_{S2}-CN, β-CN, κ-CN, and γ-CN), serum protein fraction (α-LA, β-LG), peptides (peaks between 10 and 20 kDa), and NPN fraction (all positive peaks below 10 kDa) was calculated as a percentage of total area (positive peaks).

All analyses were performed in triplicate. Data were analyzed using Microsoft Excel (2013, Microsoft Corp., Redmond, WA). Statistical differences among observed means were determined using an unpaired *t*-test with a significance level $\alpha = 0.05$.

The complete results for the analyses are presented in Tables 2 and 3. All products analyzed consisted mostly of water, with a TS content of 6 to 6.2% for GAW, 3.3 to 3.7% for CAW, and 13.4 to 15.4% for MP. The main solid was lactose, for all samples: 3.3 to 3.5%, 1.9 to 2.1%, and 10.6 to 11.9% for GAW, CAW, and

MP, respectively. Ash, galactose, lactic acid, and citric acid were some of the other major components for all products. The pH ranges were 4.21 to 4.48, 4.35 to 4.41, and 5.4 to 6.37 for GAW, CAW, and MP, respectively. The MP is not a fermented product, hence its pH was around 6.3, similar to sweet whey (Huma al., 2015).

Crude protein ranged from 1.71 to 3.71 mg/g for GAW (both processors), 1.65 to 5.05 mg/g for CAW, and 3.2 to 4.35 mg/g for MP. The concentration of α-LA was found to be very low in GAW, and it ranged from 0.17 to 0.77 mg/L. Interestingly, this concentration was not found to be statistically different from those of CAW and MP, and neither were the CP contents ($P > 0.05$). By comparison, the protein content in sweet whey usually ranges from 6 to 10 mg/g (Jelen, 2011).

Besides being very small, the concentration of α-LA in all streams showed high variability (CV = 99%), which is also true for the total amount of CP (CV = 29%). Most of the CP analyzed was represented by low molecular weight in acid whey, which likely corresponds to the water-soluble products of proteolysis that formed during yogurt fermentation (Sfakianakis and Tzia, 2014).

The major minerals found in GAW were K (157 to 169 mg/100 g), Ca (120 mg/100 g to 128 mg/100 g), and P (66.5 to 69.2 mg/100 g). The respective amounts found in CAW and MP were of the same order of magnitude, but GAW had clearly the highest concentration of Ca of all streams. Sweet whey, by comparison, is reported to have less than half of the Ca content present

Table 3. Composition data for the second batch of coproducts [replicates (Rep.) 2 and 3][1]

		Company A		Company B				Company C	
		GAW		GAW		CAW		MP	
Analysis	Unit[2]	Rep. 2	Rep. 3	Rep. 2	Rep. 3	Rep. 2	Rep. 3	Rep. 2	Rep. 3
TS	% wt/wt	6.2	6.1	6.0	6.1	3.6	3.3	14.8	15.4
Total N	mg/kg	371	268	431	489	791	552	682	584
Ammonia-N		79	79	87	64	55	57	<5	<5
Urea-N		<5	<5	<5	<5	<5	<5	251	224
Nitrate-N		ND[3]	ND	ND	ND	ND	ND	ND	ND
Total protein	mg/g	2.37	1.71	2.75	3.12	5.05	3.52	4.35	3.73
α-LA		0.25	0.17	0.77	0.63	0.71	0.39	1.62	1.57
β-LG		0.00	0.00	0.20	0.16	2.11	1.53	0.00	0.00
Total casein		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
α_{S1}-Casein		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
α_{S2}-Casein		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
β-Casein		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
γ-Casein		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
κ-Casein		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other peptides		0.00	0.00	0.25	0.22	1.02	0.57	0.00	0.00
Total low molecular weight		2.11	1.54	1.53	2.10	1.20	1.03	2.73	2.15
Ash	%	0.67	0.71	0.67	0.69	0.41	0.33	1.20	1.25
Calcium	mg/100 g	122	128	122	122	68.3	70.7	102	106
Sodium		37.6	41.9	38.5	39.3	21.6	22.5	85.8	88.6
Phosphorus		68.2	69.2	69	68.5	48.1	48.9	108	113
Potassium		162	158	157	156	90.8	93.3	364	381
Magnesium		11	10.5	10.5	10.4	6.56	6.67	17.6	18.2
Total chloride		0.08	0.09	0.11	0.09	0.06	0.06	0.22	0.25
Total sugar		4.11	3.98	3.98	3.97	2.2	2.28	11.8	12.2
Lactose		3.5	3.33	3.39	3.41	2.06	2.13	11.5	11.9
Galactose	%	0.61	0.65	0.59	0.56	0.14	0.15	0.13	0.16
Fructose		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Glucose		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.151	0.16
Sucrose		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Maltose		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Titratable acidity[4]	%	0.48	0.53	0.45	0.42	0.30	0.31	0.21	0.31
pH		4.21	4.22	4.35	4.48	4.37	4.35	5.88	5.4
Chemical oxygen demand	mg/L	56,100	53,700	52,400	54,900	31,900	38,700	127,000	133,000
Biochemical oxygen demand		45,800	45,800	50,500	46,100	32,700	40,000	182,000	110,000

[1]GAW = acid whey from Greek-style yogurt; CAW = acid whey from cottage cheese; MP = milk UF permeate.

[2]Units as reported by the analytical laboratories.

[3]ND = not detected.

[4]Expressed as lactic acid.

in GAW (Jelen, 2011). Other minerals of importance include Na and Mg, with Na concentration being the highest in MP, which explains its potential use as a salt replacer in some applications.

Interestingly, all streams also presented small quantities of fiber, which may be galacto-oligosaccharides formed during the manufacturing process, because acids can act as catalysts for the polymerization of lactose (Tremaine et al., 2014). The main vitamins found in the coproducts were pantothenic acid, niacin, thiamine, and riboflavin, the latter being responsible for giving whey the characteristic bright yellowish-green color.

The COD varied from 52,400 to 64,400 mg/L for GAW, 31,900 to 40,000 mg/L for CAW, and 127,000 to 142,000 mg/L for MP, whereas for BOD the ranges were 45,800 to 50,500, 32,700 to 40,000, and 110,000 to 182,000 mg/L, respectively. The BOD ranges for GAW are almost 40 times the effluent limitation guidelines for cultured dairy products (CFR, 2017).

Overall, the dairy coproducts characterized in this study contained some milk solids that could potentially be extracted, purified, and used in certain applications, particularly lactose, minerals, and some low-molecular-weight nitrogen compounds. The composition data provided will assist dairy processors and product developers make better-informed decisions about how to best use these coproducts, with nutritional benefits for consumers, economic benefits for industry, and environmental benefits at the societal level.

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