

## Use of Whey and Whey Preparations in the Food Industry – a Review

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The interest in whey and whey preparations has considerably increased in recent years. Whey and whey preparations are the so-called “forgotten treasure” and, because of their unique properties, they have been “rediscovered” and have been increasingly frequently and successfully used by various production plants in the food industry. They have also been eagerly purchased by consumers who are aware of the role of whey preparations in adequate human nutrition. For many years, there has been a tendency in the food processing industry to use substitutes of ingredients in recipes of many products. This situation can be observed in the case of foods with reduced fat and sugar, or products for lacto-ovo-vegetarians. Whey – and more specifically, its preparations – can also be used as a substitute. According to many literature sources, its use can have a positive impact not only on the consumers’ health but also on the finances of many companies, by reducing the costs of raw materials, and thus production costs. This review paper presents selected uses of whey and whey preparations in the food industry. The uses of whey discussed include: meat and meat products, reduced-fat products, yoghurts and ice creams, cheeses, bakery products, confectionery and pastry products, infant formulas, and whey drinks.

### INTRODUCTION

Only a few decades ago, whey was a serious problem for dairy plants. It was not recycled to the extent it currently is. Whey was removed along with sewage, which posed a threat to the ecosystem due to the organic compounds it contained [Wesołowska-Trojanowska & Targoński, 2014]. In the case of cheese production, ten parts of milk give nine parts of whey and one part of cheese [Bylund, 2003]. The current use of whey, as well as its preparations, is made possible thanks to numerous studies in this area. Whey derived from cow’s milk, as well as sheep [Salvatore *et al.*, 2014], goat [Philippopoulos & Papadakis, 2001] or camel milk [Laleye *et al.*, 2008] can be processed. Production of whey powder has recently increased in the European Union from 1,950,000 t in 2011 to 2,200,000 t in 2014 [EWPA, 2015].

A tendency to use substitutes of ingredients in recipes of many products has been observed for several years in the food processing industry. It pertains to foods with reduced fat and sugar, or food products for vegetarians and people with lactose intolerance [Bolumar *et al.*, 2015; Garcia-Serna *et al.*, 2014]. Whey and its preparations may serve as substitutes. According to many sources, their use can have a positive impact not only on the consumers’ health, but

also on the finances of many companies by reducing the costs of raw materials, and thus lowering production costs [Bożanić *et al.*, 2014; Keaton, 1999; Singh & Singh, 2012]. Cost reduction is achieved by the use of whey preparations as partial or complete replacements of milk powder [De Wit, 2001], eggs [Stoliar, 2009], fat [Prabhu, 2006; Stoliar, 2009], sucrose [Pernot-Barry, 2008], or even other proteins [Keaton, 1999].

There are two different types of whey: sweet whey and acid whey. Sweet whey is a by-product of ripened cheese production (pH 5.8–6.6) whereas acid whey is obtained from cottage cheeses (pH 3.6–5.1) [Anand *et al.*, 2013]. Regulations about the use of whey are based on Codex Alimentarius concerning milk and milk products launched by the World Health Organization Food and Agriculture Organization of the United Nations [WHO, 2011].

The so-called whey proteins, which include  $\beta$ -lactoglobulin,  $\alpha$ -lactalbumin, lactoperoxidase, and lactoferrin, are the main source of whey health-promoting properties [Kumar *et al.*, 2008]. The following peptides were identified in the  $\beta$ -lactoglobulin sequences:  $\beta$ -lactoferrin which influences the smooth muscles,  $\beta$ -lactotensin which exhibits hypocholesterolemic and anti-stress activities, and in the  $\alpha$ -lactalbumin sequences –  $\alpha$ -lactoferrin which displays effects similar to that of morphine, namely blood pressure reduction [Chatterton *et al.*, 2006]. In turn, lactoferrin is a bioactive milk protein with a comprehensive activity. Although the mechanisms of its action are not

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fully known, a broad spectrum of its properties has been confirmed by scientific research. It shows many physiological functions, *i.e.* antifungal, antiviral, antibacterial, antitumour, and anti-inflammatory. Also, lactoferrin has a positive effect on the nervous system and is able to bind iron [Darewicz *et al.*, 2014]. Amino acids, minerals, and vitamins should also be taken into account [De Wit, 2001].

This review paper presents selected uses of whey and whey preparations in the food industry. The uses of whey discussed include: meat and meat products, reduced-fat products, yoghurts and ice creams, cheeses, bakery products, confectionery and pastry products, infant formulas, and whey drinks.

## MEAT AND MEAT PRODUCTS

Whey processing products used in the meat industry are as follows [Keaton, 1999; Prabhu, 2006]: sweet whey powder, whey protein concentrates (WPCs) (34–80% protein content), whey protein isolate (WPI) (> 90% protein), whey with reduced lactose content, demineralised whey, and lactose. They are used especially in the production of comminuted products, such as: frankfurters, sausages, mortadellas, luncheon meat, or surimi [De Wit, 2001].

Whey protein may partially replace meat protein, as well as partially or completely substitute for soy protein and other binding agents, fillers, modified starch and hydrocolloids [Keaton, 1999; Prabhu, 2006; Youssef & Barbut, 2011].

Whey proteins with improved flavour and increased functionality are obtained with new technologies. While choosing a particular whey product, it is essential to match its function to the characteristics we want to achieve. For example, high-protein concentrates or isolates are used to modify fat content [Prabhu, 2006]. A slight increase in sweetness occurs, especially with the addition of sweet whey (which enables reduced addition of sweeteners) [Keaton, 1999].

According to Keaton [1999], the properties of whey proteins used in the processing of meat products, poultry, and fish are as follows:

- water binding capacity that prevents the depletion of mass during thermal processing and storage of the product, increases juiciness of the final product and facilitates cutting cold meat products into slices;

- viscosity which improves the consumers' palatable impressions during consumption of the product (biting and chewing); which is directly related to the ability to bind water;

- high solubility – in the range of pH from 2 to 10 (ideal for use in injected products), while sodium caseinate is soluble at above pH 5.0, and soy protein isolate only at pH above 5.5;

- the formation of stable emulsions, which is particularly important in the production of finely comminuted meat products, especially when the raw material is of poor quality; here, whey proteins may partially or completely replace other emulsifiers.

Furthermore, the addition of whey proteins affects the taste and improves the gelation. They can be used in the production of edible sausage casings. They are also used in the finishing of semi-products, as their addition has a positive effect on the adhesion of batter to portions of meat, poultry, or

fish. They may also exhibit antioxidant activity (this refers to the oxidation of fat in pork meat, in salmon meat, or in products rich in lipids) [Prabhu, 2006].

Keaton [1999] in his paper presented an example for a recipe of mortadella using WPC34 (whey protein concentrate with protein content of approx. 34%) and WPI (90% protein), and revealed an increase in the effectiveness of this product (Tables 1–3).

TABLE 1. Contents of fat, protein, and moisture in meat and whey products used in the production of Frankfurter/Bologna (adopted from Keaton [1999]).

Specification	Fat (%)	Protein (%)	Moisture (%)
Lean beef	20.0	18.0	63.0
Pork trim	40.0	10.0	49.0
WPI (90% protein)	1.5	90.0	3.5
WPC34	4.0	34.0	3.5

TABLE 2. Composition of raw materials in production of Frankfurter/Bologna (adopted from Keaton [1999]).

Specification	Control sample		WPC34		WPI90	
	kg	%	kg	%	kg	%
Lean beef	21.50	15.96	12.0	7.76	20.0	11.56
Pork trim	78.50	58.25	88.0	56.89	90.0	52.02
WPI(90% protein)	–	–	–	–	3.00	1.73
WPC34	–	–	4.68	3.03	–	–
Salt	2.25	1.67	2.25	1.45	2.25	1.30
Corn syrup solids	2.00	1.48	–	–	–	–
Hydrolysed milk protein	1.00	0.74	1.00	0.65	1.00	0.58
Hydrolysed beef stock	0.50	0.37	0.50	0.32	0.50	0.29
Sodium tripolyphosphate	0.45	0.33	0.45	0.29	0.45	0.26
Frank/bologna seasoning	0.50	0.37	0.50	0.32	0.50	0.29
Sodium erythorbate	0.06	0.04	0.06	0.04	0.06	0.03
Modern cure (nitrite/salt)	0.25	0.19	0.25	0.16	0.25	0.14
Ice	27.70	20.56	45.00	29.09	55.00	31.79
Total	134.71	100	154.69	100	173.01	100

TABLE 3. Increase in productivity in production of mortadella with use of WPC34 and WPI90 (adopted from Keaton [1999]).

Specification	WPC34	WPI (90% protein)
The increase in productivity compared to a control sample (kg)	19.98	38.30
The increase in productivity compared to a control sample after heat treatment (kg)	17.98	34.47

## PRODUCTS WITH REDUCED FAT CONTENT

High consumption of fats, particularly those of animal origin, may have a negative impact on human health. It contributes to many diseases that are nowadays classified as civilization diseases, *e.g.* atherosclerosis. This leads to the simple conclusion that it is advisable to limit the consumption of fat and replace fatty foods with the low-fat ones [Ellander *et al.*, 2015; Sołowiej, 2012].

Fat is an important component of many food products. It affects the taste of the finished product, improves the texture, springiness, mouthfeel, juiciness and stability during storage. As a result of its reduction, the obtained product is tasteless and unacceptable to consumers [Johnson, 2000; Prabhu, 2006].

Replacing part of the lipids with the so-called fat substitutes can help prevent negative phenomena. Whey proteins are widely used during the production of salad dressings, soups and sauces, mayonnaise, meat, yoghurts, and ice cream preparations [De Wit, 2001; Johnson, 2000; Yilsay *et al.*, 2006; Zhang *et al.*, 2015]. According to Johnson [2000], these replacers can be divided into two groups: substitutes and mimetics. The WPCs are classified as fat mimetics because they have various functional properties similar to those that lipids have. WPC34 and WPC80 are commonly used. They can completely or partially replace egg yolk, hydrocolloids, soy protein, or modified starch. The most important functions of WPC in low-fat products are: water binding, emulsification, high solubility, gelation, increasing the viscosity, and increasing the adhesive interactions [Johnson, 2000].

DeWit [2001] proposes that, to fully utilise the emulsifying properties of WPCs, emulsions could be prepared before the addition of components with low pH. Johnson [2000], in turn, suggests a new approach in which WPC34 and carrageenan are combined in order to obtain best quality in the production of low-fat sausages. WPCs with a high protein content have very little perceptible flavour. Low-protein WPCs such as WPC34 can, in turn, impart a slightly milky, sweet aftertaste to products to which they have been added. Therefore, when fat content is reduced and a WPC is added, the composition of the product should be corrected; addition of spices and flavourings may be required [Johnson, 2000].

## BAKERY AND CONFECTIONERY PRODUCTS

Whey may be widely used in the baking, confectionery, and pastry industries for the production of breads, cakes, cookies, biscuits, crackers, muffins, and icing [Burrington, 1999; Ceglińska *et al.*, 2007; De Wit, 2001; Stoliar, 2009].

The product, in which eggs play a key role are cakes. Eggs contribute to the development of their structure and taste. Protein is a significant factor affecting the structure, therefore it is recommended to replace it only partially. A hen's egg weighs, on average, from 52 to 55 g, of which 76% is water, so when replacing whole fresh eggs, water needs to be added to the WPCs. The proposed proportions of WPCs and water, if added, in substitution of hen's eggs are as follows:

100 g fresh whole eggs = 15 g WPC80 + 75 g water

100 g fresh whole eggs = 35 g WPC34 + 75 g water

100 g dried whole eggs = 57 g WPC80

Replacing eggs with whey proteins is also an effective means of reducing production costs (the obtained product crumbles less during cutting and packaging – which means a lack of additional costs) [Stoliar, 2009].

Furthermore, as a result of the presence of cholesterol in egg yolk, due to dietary reasons, there is a growing interest in the replacement of this component. An experiment was conducted in which one cake was prepared using a standard cake recipe and a second with the addition of WPCs. The appearance of both cakes was similar, but the volume of the sample with the addition of WPCs was increased. However, replacing eggs with WPCs resulted in a poorer taste and dry structure of the cake [De Wit, 2001].

Baked goods are products rich in carbohydrates, but poor in proteins, as a result of which they do not belong to dietary products. Therefore, whey processing products in combination with sugar alcohols or artificial sweeteners contribute to a reduction in carbohydrate content of the discussed products. For example, WPC34 is suitable for products such as spice cookies or chocolate chip cookies as a partial replacement for both egg and fat. On the other hand, WPC80 is a good substitute for eggs in products such as bread, cakes and biscuits (both dry and soft) and muffins. Using WPCs, which are classified as fat mimetics, we can lower fat content by up to 50%, and thereby increase the moisture content of the finished product, such as cakes, cookies, muffins [Stoliar, 2009].

In baking, confectionery and pastry, lactose is often used as a substitute for sucrose as it enhances the Maillard reaction, improves emulsification and crumb structure, and enhances the flavour [Burrington, 1999; Stoliar, 2009].

In addition, whey proteins contain a high level of essential amino acids; they are also considered a source of high quality protein. In addition, they are characterised by a high content of calcium and other minerals, such as potassium and zinc. Thanks to these properties, whey protein is a valuable additive to bakery products [Burrington, 1999; Ceglińska *et al.*, 2007; Munaza, 2012]. Ceglińska *et al.* [2007] proposes replacing sodium chloride (table salt) in the production of bread with minerals derived from ultrafiltration of whey. The results of quality tests of bread with various combinations of contents of salt and of minerals from whey powder are presented in Table 4. The largest volume of bread and the smallest crumb hardness was obtained in sample 2. The use of minerals derived from whey as substitutes for table salt is therefore recommended in bread production in quantities not exceeding 3% [Ceglińska *et al.*, 2007]. In turn, the addition of whey preparations to bakery and cake products proposed by Burrington [1999] is shown in Table 5.

Whey products, including, demineralised whey powders, low-lactose whey powders, WPCs and isolates, and lactose have been used in the following confectionery: chocolates and chocolate chips, candies, jellies and chewing gums [Bouzaz, 1999; Pernot-Barry, 2008]. Lactose – milk sugar – can serve as a bulking agent. It is slightly sweet, less soluble than sucrose, and has a low hygroscopicity level; however, it influences the colour, the taste, and the texture

TABLE 4. Results of quality tests of bread in various combinations of content of salt and of minerals from whey powder (adopted from Ceglińska *et al.* [2007]).

Additive	Baking loss (%)	Yield of bread (%)	Bread volume (cm <sup>3</sup> )	Absolute weight (g/cm <sup>3</sup> )	Hardness (N)	
					24 h	72 h
1	11.5	138.6	213.9	0.289	5.35	8.10
2	11.7	137.6	297.5	0.252	3.21	5.37
3	10.4	141.0	223.6	0.287	6.15	9.77
4	9.6	141.4	184.4	0.332	6.38	10.22
5	9.5	142.2	213.8	0.295	4.99	10.58
6	9.7	142.0	187.7	0.315	7.59	10.45

The legend for the applied additives 1–6: 1 – 2.0% of table salt, 2 – 2.0% of whey minerals, 3 – 3.0% of whey minerals, 4 – 4.0% of whey minerals, 5 – 1.5% of table salt + 1.5% of whey minerals, and 6 – 1.0% of table salt + 3.0% of whey minerals.

TABLE 5. Recommended proportions of addition of whey preparations for selected bakery and cake products (adopted from Burrington [1999]).

Type of product	Sweet whey powder (%)	WPC34 to WPC50 (%)	WPC80 (%)	Demineralised whey powder (%)
White bread	1–5	1–4	1–3	2–6
Sweet rolls	2–5	1–4	1–3	2–6
Cakes and biscuits	1–5	1–5	1–4	2–5
Crackers	1–5	1–4	1–3	2–6
Pizza dough	1–5	1–4	1–3	2–6
Cakes	1–6	1–4	1–3	2–6

of the finished product and takes part in the Maillard reaction [De Wit, 2001; Pernot-Barry, 2008]. For these reasons, use of lactose can be more or less reduced, which depends on many characteristics of the confectionery. For example, in the case of milk fudge, replacing sucrose by lactose causes the formation of caramel flavour, and sugar content is reduced. Products in whose manufacture lactose was added include hard candy, fillings, chocolate bars, and toffee candy [Pernot-Barry, 2008].

Another use of derivatives of WPCs is the production of the so-called aerated confectionery and chocolate. The foaming properties of concentrates are used in this case. In addition, WPI and concentrates of high protein content (WPC80) can be successfully used in the production of protein bars for athletes [Bouzas, 1999]. Another example

is meringues, in whose production great emphasis is put on foam stability [De Wit, 2001]. The author proposes a total replacement of egg protein with skimmed WPCs, as the shape and size of the product (meringue) containing WPCs is similar to that obtained on the basis of egg protein. On the other hand, Nastaj *et al.* [2014] found that in the case of foams obtained from WPI and WPC80 prior to thermal fixation (in the production of meringues), increased protein content and reduced sucrose addition led to an improvement of their rheological properties. The obtained high-protein meringue with a reduced sucrose level may be a new food product, attractive for physically-active people and athletes with increased demand for complete protein.

Both demineralised whey powder, as well as WPCs can be used as a source of milk solids in the production of chocolate-flavoured coatings (for ice cream and bars), and the kaymak mass. The additive also affects the costs of raw materials and the production costs. Fat is reduced as well [Bouzas, 1999]. Examples of whey preparations additives in selected confectionery indicated by Bouzas [1999] are presented in Table 6.

## DAIRY PRODUCTS

### Yoghurts and ice creams

A growth in the consumption of fermented milk beverages has been observed in recent years; the most important of these is the consumption of yoghurt. For this reason, the quality characteristics of the finished product are very important. These characteristics can be successfully modified using whey preparations [Kozioł *et al.*, 2014; Liu *et al.*, 2016].

TABLE 6. Typical whey preparations and lactose additive in the selected confectionery (adopted from Bouzas [1999]).

Product	Demineralised whey powder (%)	WPC34 (%)	WPC80 (%)	WPI90 (%)	Lactose (%)
Milk chocolate	0–5	0–5	–	–	3–7
Chocolate flavour topping	0–20	0–20	–	–	3–7
Kaymak mass	0–50	0–50	–	–	–
Protein bars	–	–	0–20	0–35	–

Hugunin & Lucey [2009] presented the whey products used in the production of yoghurt. These include:

1. sweet whey powder, which may replace skimmed milk powder at the level 2–5.2%;
2. WPCs, which are most often used by manufacturers of yoghurt. Addition of WPC34 at the level 0.7–2.0% or WPC80 at 0.5–0.8% is sufficient in the case of mixed yoghurt (a greater amount of the additive may adversely affect some quality characteristics). Replacing skimmed milk powder with WPCs causes, among other effects, an increased gel strength in solid yoghurt, increasing the viscosity of mixed yoghurt, and reduces the risk of syneresis in both types of yoghurt;
3. WPI which, due to the low content of lactose and milk fat, is used in yoghurts with reduced lactose content;
4. demineralised whey powder, with reduced mineral content, which accelerates the fermentation process. On the other hand, low mineral content weakens the structure of the gel, so it is necessary to add milk protein hydrolysates when this type of formulation is used.

The consistency of the finished product has a significant influence on the choice of product by consumers. The texture of yoghurt can be improved through the use of the above-mentioned products by increasing the viscosity and stability and reducing the risk of syneresis. Furthermore, the addition of whey protein gives yoghurt a smooth and creamy texture; it also increases its nutritional value [De Wit, 2001; Hugunin, 2009; Hugunin & Lucey, 2009].

It is suspected that the bioactive components present in whey and whey protein can stimulate the growth of probiotic bacterial cultures (both in the finished product, and in the human digestive tract). Research carried out by Hugunin [2009], Hugunin & Lucey [2009] indicate that the addition of *Bifidobacterium bifidum* to standard yoghurt cultures (*Lactobacillus delbrueckii ssp. bulgaricus*, *Streptococcus thermophilus*), increases the number of viable *B. bifidum* in the samples that contain the sweet whey or whey proteins.

Whey preparations used in the manufacture of ice-creams and sundaes include whey powder, demineralised whey powder, WPCs and WPI [Young, 2007]. Features and benefits that result from the use of whey products are presented in Table 7.

In addition to the aforementioned properties of whey preparation, their other important properties include: water binding capacity, ability to form foam, and high nutritional value [Young, 2007; Jasińska *et al.*, 2012].

On the other hand, from the point of view of ice-cream manufacturers, it is important to reduce the costs of production. Rationalisation of these costs can be achieved by using cheaper substitutes of certain ingredients of the recipes. The relatively expensive components include milk powder and egg yolk [Alfaifi & Stathopoulos, 2010; Jasińska *et al.*, 2012]. Jasińska *et al.* [2012] suggested replacing milk with WPCs and with protein-fat preparations. They compared the control sample without the addition of whey products or fat-protein preparations with ice mixtures with a 50% addition of WPC65 and WPC80, as well as with 50% addition of whey-fat preparations containing vegetable fats (coconut oil, palm oil). The organoleptic properties, fat content and dry

TABLE 7. Selected functional properties of whey preparations and benefits that can be obtained with their use in the production of ice creams and sundaes (adopted from Young [2007]).

Functions	Impact	Benefits
Viscosity	Compaction	Stabilising air bubbles, obtaining creamy structure
Gelation	Formation of gel during heat treatment and the improvement of viscosity	Increasing resistance to high temperatures; improvement of the structure
Emulsification	The formation of a stable emulsion	The ability to partially replace casein
Taste and flavour	Mild, sweet, milky flavour	Compatible with flavouring additives

matter content was evaluated, and the acidity and hardness of the blend and the ice cream, as well as fluffiness and meltability were measured. The best result was obtained with the addition of WPC80 (a high score in the organoleptic evaluation, low melting behaviour and the degree of aeration) [Jasińska *et al.*, 2012].

Alfaifi & Stathopoulos [2012] analysed the impact of substituting powder from dried egg yolks with WPC80 in Gelato ice cream production. They replaced 0, 20, 50 80 and 100% of the egg yolks with WPC80 in two different parts of the samples. In the first part of the samples, the whole egg yolk was 4.5% of the whole sample; in the second 9%, of the whole sample.

Based on the results, they noticed a pronounced effect on the physical properties of Gelato ice cream, such as viscosity of the mixture of ice, fluffiness (degree of aeration) and texture. Lower viscosity was achieved with 4.5% of added egg yolk. Additionally, increasing the content of WPC80 led to an increase of fluffiness [Alfaifi & Stathopoulos, 2010]. Along with an increase of percentage of protein concentrate, improvement in the structure of the finished product has been observed as well. Thus, WPC80 as a replacer for egg yolk seems to be a rational solution in the case of Gelato ice creams for producers who want to reduce manufacturing costs without change desired characteristics of the finished product [Alfaifi & Stathopoulos, 2010]. However, according to Palka & Palich [2008], increased aeration can lead to a deterioration in the quality of ice creams during storage.

Before developing a product's recipe, it should be experimentally determined what amount of whey products should be in the final product. More recipes are given by Young [2007] who recommend the addition of different types of whey powders to the entire ice blend, *e.g.* whey powder (2–3%) or WPC34 (1.5–3%) or WPI (0.5–1) or WPC60 – WPC80 (0.5–2%).

### Cheese, processed cheese, and their analogues

Whey preparations, such as sweet whey powder, powdered whey with reduced lactose content, WPCs and WPI can be successfully used in the production of processed cheese and processed cheese analogues [Young, 1999]. Liquid, sweet whey left after cheese making from cow and sheep milk, can be used in manufacturing whey cheeses [Philippopoulos & Papadakis, 2001; Salvatore *et al.*, 2014; Wendorff, 2008].

For the production of processed cheese analogues, cheese is replaced by milk proteins (casein, whey proteins) or vegetable proteins [Sołowiej, 2007; Sołowiej *et al.*, 2014, 2015]. Vegetable proteins are mainly used because of their price. Production of 1 kg of soy protein is more than three times cheaper than the production of milk protein [Aljewicz *et al.*, 2011]. A key factor in the use of whey preparations in this product range is, therefore, their cost-effectiveness [Sołowiej, 2007; Young, 1999]. Their emulsifying properties are valuable, especially during heat treatment, packaging, and cooling. The ability to bind water can disrupt the technological process if it is carried out in an inappropriate way. This affects the melting of the mixture and spreadability of the finished product. The big advantage of whey preparations is their high nutritional value [Young, 1999]. Sołowiej [2007] and Sołowiej *et al.* [2008] showed that the addition of whey protein preparations to processed cheese analogues, as well as replacing casein with these proteins, increases the hardness of the final product which may be important for the preparation of products for slicing. In turn, the analogues supplemented with whey products exhibited lower meltability compared to cheese analogues prepared solely on the basis of acid casein in a pH range of 5.0–7.0 [Sołowiej *et al.*, 2008]. Moreover, the use of high-protein formulations such as WPI and WPC80 allowed for the partial elimination of the flux emulsifying salts (*i.e.* a reduction in disodium phosphate content from 2.0% to 0.8%) [Sołowiej *et al.*, 2014].

Young [1999] recommends control of lactose content during the production process to prevent its crystallisation and browning of the product (therefore, it seems reasonable to use products with a low content of milk sugar – WPCs, WPI). The recommended addition of whey preparations to cheese mixtures is as follows: sweet whey powder: 4–8%, whey with reduced content of powder lactose: 5–8%, WPC34 and WPC80: 1–5%, WPI90: 0.5–1% [Young, 1999].

The most popular whey cheeses include myzithra, ricotta, mysost, gjetost, manouri, anthotyros and giza [Philippopoulos & Papadakis, 2001; Salvatore *et al.*, 2014; Wendorff, 2008].

Wendorff [2008] presents two ways of producing cheese on the basis of whey:

1. exposure of whey to heat treatment and then acidifying it to separate the fat and the protein. Optionally, milk components can be added. The final step is to separate the liquid from the curd, for example in ricotta.
2. slow evaporation of the whey in open containers until lactose contained in it causes browning, *e.g.* mysost, gjetost.

Ricotta is produced from sweet whey left after the production of such cheeses as Cheddar, Mozzarella, *etc.* It is recommended to add skimmed milk in the amount of 5–10% to increase dry milk mass and to improve the taste of the final product [Wendorff, 2008]. It is believed that production of ricotta cheese is one of the most convenient, least problematic ways to utilise whey [Salvatore *et al.*, 2014]. This cheese has a soft, fine texture and a slightly caramel flavour [Wendorff, 2008]. Salvatore *et al.* [2014] showed that the use of whey concentrate in the production of ricotta cheese increases the productivity and the recovery rate of  $\alpha$ -lactalbumin protein.

Myzithra, a traditional Greek cheese with a fat content of 19–25%, is used as a table cheese and as an ingredient

of many dishes. It is produced in a partially dehydrated form as grated cheese, the so-called “dry myzithra” [Philippopoulos & Papadakis, 2001]. It is recommended to filter the whey before production to remove any residues [Wendorff, 2008].

In the case of mysost and gjetost cheeses, lactose plays a key role (Maillard reaction). Mysost is produced from sweet whey from cows’ milk, while gjetost is based on sweet sheep’s whey. The production process of the aforementioned cheeses is very unusual, because the whey is subjected to a process of condensation; thus, a brown concentrate is obtained. It is then heated to a temperature of approx. 95°C, until it obtains the desired colour and intense caramel flavour. The final product contains approx. 33% of fat and 40% of lactose [Wendorff, 2008].

#### OTHER USES OF WHEY IN THE FOOD INDUSTRY

Other uses of whey in the food industry include the production of infant formulas and whey drinks. Whey preparations, being a source of high quality protein and of active peptides, are widely used by manufacturers of baby foods [Chung & Yamini, 2012; Lloyd, 2002; Murphy *et al.*, 2015]. It is a standard procedure to establish an appropriate ratio of whey proteins to casein, which in the case of whey-based supplements should reach 60:40, *i.e.* the same ratio that is found in breast milk (in cow’s milk the ratio is 20:80). WPCs and demineralised whey powder are mainly used in this case [De Wit, 2001; Lloyd, 2002]. Also important is the increased amount of amino acids in infant formulas (they are of particular importance in the nutrition of infants born prematurely). It is especially true about lysine, methionine and threonine. The essential amino acids also include phenylalanine, the percentage of which is lower in supplements based on whey than in human milk. It is very important for infants suffering from phenylketonuria [De Wit, 2001].

Whey preparations are also used as media in the microencapsulation of sensitive food ingredients which are fragrances, dyes, or various types of probiotic bacteria (*e.g.* *Bifidobacterium*-BB-12). The use of whey protein supports protection of the above-mentioned active ingredients and prevents the loss of their properties in the long-term. Additionally, after the microencapsulation process, a product is obtained in the form of powder or granules, which allows for controlled release of the component and new uses for food additives [López-Rubio & Lagaron 2012; Pinto *et al.*, 2015].

Another protective use of whey proteins is as an edible coating for food [Galus & Kadzińska, 2016; Frenzel & Steffen-Heins, 2015; Pintado *et al.*, 2009]. According to many authors, coating based on whey preparations is characterised by good mechanical properties, a good barrier against lipids, aromatics and, especially, oxygen. Fruit and vegetables can be coated successfully with whey protein [Galus & Kadzińska, 2016; Seydim & Sarikus, 2006]. Production of alcoholic beverages based on whey seems to be an interesting application of whey. These products include: whey beer, wine, and sparkling wine called whey “champagne”. They are characterised by a low alcohol content ( $\leq 1.5\%$ ). They are manufactured mostly from whey permeate (characterised by a low content of protein) with the addition of yeast strains *Kluyvero-*

*myces fragilis* or *Saccharomyces lactis*. Addition of sweeteners and flavours is optional [Jeličić *et al.*, 2008; Wendorff, 2008]. According to Wendorff [2008], whey is the ideal raw material for beer production, mainly due to the high mineral content (as in the case of broth) and lactose content, which, as a result of the Maillard reaction, affects the colour and the flavour of the final product (as in the case of roasted malt). However, as Jeličić *et al.* [2008] declare, the fat content in whey might be problematic, as fat has a destructive effect on beer foam.

In addition to alcoholic beverages, there are also soft whey drinks [Smithers, 2008; Baldissera *et al.*, 2011]. Fruit concentrates based on citrus fruits, mangoes, bananas, strawberries and others are used in their production. It is possible to add cocoa, vanilla, honey (which can be a substitute for other sweeteners) or bran (which enriches the finished product with dietary fibre). Powdered whey drinks (instant), which may be enriched with vitamins and minerals are a large group [Jeličić *et al.*, 2008]. Other products popular among consumers include RTD (Ready To Drink) beverages, manufactured on the basis of whey protein isolates and concentrates [Rittmanic, 2006].

## CONCLUSIONS

In recent years there has been a growing interest in the use of whey and whey preparations in food production. The practical application of whey proteins is due to their high nutritional value, excellent functional properties and the absence of negative taste. Optimal utilisation of whey ingredients has a significant impact on reducing the production cost of many food products. Such a solution contributes in consequence to greater profitability in production and to lower environmental risk. Whey proteins, thanks to a better knowledge of their physicochemical and biological properties, are currently conceived as main nutrients in food products and physiologically-active substances in novel foods.

Whey preparations which are used in the food industry are: sweet and acid whey powder, demineralised whey powder, whey with reduced lactose content, and whey protein concentrates and isolate. As a result of the application of appropriate technology, lactose, minerals, as well as whey proteins and their fractions (lactoferrin or lactoperoxidase) can be recovered from whey. Whey preparations are also used as media in microencapsulation of sensitive food ingredients (fragrances, dyes, various types of probiotic bacteria) and as edible coatings of foods.

Products whose production involves the above-mentioned preparations include: sausages, hams, pastries, bakery and confectionery products, fermented dairy products, cheeses, low-fat products, and infant formulas. The functional properties of whey proteins are mainly used in their production; they include: solubility, gelling, emulsifying, foaming and water binding properties. In the manufacture of food products, whey and whey preparations can be used as functional additives or for partial substitution of fat and non-fat constituents. Also, partial replacement of fat by high-protein preparations is uniquely associated with a reduction in the caloric value of the final product. In addition, the improvement of the functional properties of food products, *i.e.* textural properties, seems to be a key issue from a practical stand-

point. Health characteristics *i.e.* the hypocholesterolemic, antifungal, antibacterial, anti-inflammatory and anti-stress activities of whey proteins are also important.

## CONFLICT OF INTEREST

None declared.

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