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UTILIZATION OF WHEY: ENVIRONMENTALLY FRIENDLY USES

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ABSTRACT

The high organic matter concentration of the whey produced as a by- or co-product by the dairy industry has caused serious environmental issues. Over the past few decades, researchers have looked into ways to make better use of whey, turning it from a waste product into a useful raw ingredient. Developing whey powders, whey proteins, functional food and drinks, edible films and coatings, lactic acid and other biochemicals, bioplastic, biofuels, and related important bioproducts is a primary focus of sustainable whey management. Sustainable whey use is discussed in this study, along with new refining methodologies and integrated processes for transforming whey, lactose, and whey proteins into high-value-added whey-based products.

INTRODUCTION

Large quantities of by-products, primarily whey, are produced due to the expanding dairy sector. Due to its potency as an organic effluent, cheese whey can harm the environment if not handled correctly. Cheese whey has a COD that can go anywhere from 50 to 80 g L^{-1} and a BOD that can be anywhere from 40 to 60 g L^{-1}. The bulk of the organic burden is made up of lactose, fat, and protein. A considerable volume of whey is disposed of as wastewater, and this practise is linked to serious environmental concerns; without sustainable measures, whey is considered the most important environmental pollutant of the dairy sector. Whey management should be geared toward a cost-effective and sustainable method of utilisation and towards the manufacture of novel, useful goods to make use of the nutritious content of whey while simultaneously mitigating the adverse consequences of disposal in the environment. This research aims to find and benefit from the reuse of dairy waste and by-products, with a particular focus on the sustainable use of whey, as well as lactose and proteins from whey, to make high-value-added products (Çelik *et al*., 2016). Sustainable whey management is outlined, together with the most up-to-date research and developments in refining technology, and best practises for minimising the industry's environmental impact are discussed (Gadhe *et al*., 2015).

COMPOSITION OF WHEY AND POTENTIAL BENEFITS

The watery, yellow-green portion of milk (serum) that is left over after the curd is separated during the cheese-making process is known as whey. About 85–90% of milk's volume is made up of it, and it comprises 55% of the nutrients found in milk. The average composition of dry whey residue is as follows: 70% lactose (depending on how acidic the whey is), 14% proteins, 9% minerals, 4% lipids, and 3% lactic acid (Jambrak *et al*., 2018). It is divided into sour and sweet whey, depending on how the milk protein coagulates. The remaining whey is converted into sweet whey powder, demineralized whey, de-lactose whey, whey protein concentrate (WPC), whey protein isolate (WPI), or lactose. Sour whey with a pH whey powder (Çelik *et al*., 2016).

A pic of whey protein

USE OF WHEY AND ITS COMPONENTS IN A SUSTAINABLE MANNER

In order to reduce the environmental impact of whey disposal and the high operational costs of whey processing, new sustainable techniques of whey utilisation must be looked for as the dairy sector records continual growth in the volume of generated whey. In order to apply sustainable whey management, it is important to have a deeper understanding of how goods and services influence society and the environment over their useful lives and how their consumption affects them (Gadhe *et al*., 2015). There are numerous approaches to sustainable whey management, most of which focus on biotechnological and gastronomic applications for the creation of value-added products such lactic acid, bioethanol, bioplastics, biogas, etc. whey powder, and functional meals and beverages. While whey in large quantities can be converted to bioethanol, whey in smaller amounts is best used to make fermented or unfermented beverages. In this manner, sustainable whey management could help to meet some initial requirements, such as clean water and sanitation, industry: innovation and infrastructure, responsible consumption and production, and its subgoals: improving water quality, enhancing the sustainability of the infrastructure, mitigating global food waste and food losses, and decreasing waste generation. Making whey into useful raw material and then processing it further to create high-value goods can help limit the number of dangerous compounds released into the environment and lessen environmental pollution (Çelik *et al*., 2016). Additionally, it might reduce the amount of untreated wastewater by half and significantly boost worldwide recycling and safe reuse. Additionally, resource efficiency would be improved, clean, environmentally friendly industrial techniques would be used, and the amount of food lost globally per person in manufacturing and supply chains would be cut in half.

PROCESSING OF LIQUID WHEY

Whey powders: One of the most common methods to use liquid whey is to make whey powders. Even though 70% of yearly whey processing involves drying, new technologies have prompted the investigation of other methods for turning whey into significant value-added products (Gadhe *et al*., 2015). Whey powder manufacture often includes numerous steps, including A) whey clearing, B) cream separation and pasteurisation, C) evaporation-based concentration of total solids (40-60 %), D) lactose crystallisation and E) spray-dried whey drying (removal of water from whey) (Çelik *et al*., 2016).

Functional foods and beverages: Functional foods and beverages are one of the most ambitious and novel food categories. They continue to attract the curiosity of many consumers since they provide health advantages beyond basic nutrition (Zandona *et al*., 2021). Whey and its components are becoming more popular as functional ingredients in dietary and health products, whilst bioactive proteins are becoming more popular in the pharmaceutical and nutritional industries. Until now, researchers have concentrated on manufacturing whey-based beverages from either native sweet and sour whey or powdered, deproteinised, and thinned whey. The world's leading dairy businesses have launched a new generation of whey-based products. The production of such beverages is proving to be the most cost-effective method for using whey in human nutrition. Still, there are several challenges involved in doing so, including the high-water content's susceptibility to microscopic microbial spoilage and the sensitivity of whey proteins to heat treatments at temperatures above 60°C (Çelik *et al*., 2016). After the typical heat treatment of whey (at 72 °C for 15-20 s), most whey proteins precipitate. In order to produce whey beverages, significant research is focused on using non-thermal methods such as membrane separation, high-intensity ultrasound, or supercritical CO2 technology.

Biogas: Due to the increased environmental regulations, fermentation techniques are now a widely used alternative to traditional methods for treating agro-industrial leftovers. Additionally, the digestion of garbage yields biogas that can be utilised to generate electricity, providing both environmental and financial advantages (Jambrak *et al*., 2018). Whey should be combined with other forms of waste or manure to boost productivity because anaerobic digestion results in rapid acid evolution and low biogas production due to its high organic content and low buffer capacity. The enormous energy potential of the biogas created when cheese whey is digested utilising swine wastewater as researchers' team revealed inoculum. At 32°C, they observed a reduction of 53.11 % in volatile solids and a biogas yield of 270 L with 63 % methane, and at 26°C, a decrease of 45.76 % in volatile solids and a biogas yield of 171 L with 61 % methane (Çelik *et al*., 2016).

Lactose recovery and utilisation: Whey is a possible raw material for developing lactose and whey-based value-added products because lactose (4-O-d-galactopyranosyl-d-glucose) is a fundamental component of its solids (70–72 % total solids). Because it functions as dietary fibre and has prebiotic qualities, lactose offers a number of advantages from a health and nutritional standpoint. In this way, lactose helps the body absorb different minerals like calcium, phosphorus, and magnesium through the intestinal tract (Jambrak *et al*., 2018). Additionally, it is used by intestinal bacteria as a food source and a substrate for the formation of lactic acid and short carbon cycle fatty acids (SCFA), which creates a moderately acidic reaction in the intestine and inhibits the growth and spread of dangerous bacteria (Zandona *et al*., 2021). Additionally, because to its low glycaemic index (which is half that of glucose), it has less of an effect on blood sugar levels. Several techniques, such as evaporation to concentrate the whey, crystallisation of the lactose from concentrated whey, and centrifugation or decantation to separate the resulting crystals, can be used to recover lactose from deproteinized whey (such as whey permeate obtained by ultrafiltration). Since lactose is the primary factor contributing to whey's high BOD and COD levels, its recovery might more than halve the BOD value.

In this approach, lactose recovery may be able to address both environmental and waste management issues. The recovered lactose may also be supplied to the food, pharmaceutical, dairy, and beverage (e.g., food-grade or pharmaceutical-grade) businesses, depending on its quality (Chatzipaschali and Stamatis, 2012). It is typically employed as an excipient in the pharmaceutical business as well as in the food and confectionery industries, particularly in baking as a crust browning enhancer. Furthermore, the microbial breakdown of lactose can be used to create novel whey-based products (Gadhe *et al*., 2015).

Lactic acid: Two isomers of lactic acid (LA; 2-hydroxy propanoic acid) exist as prospective platform chemicals, L (+) and D (-). Since D (-) is toxic to humans, only the D (+) isomer can be manufactured via biotechnology and employed in the food sector. Contrarily, D (-) can be transformed into a number of important industrial compounds, including pyruvic acid, acrylic acid, 1,2-propanediol, and lactate ester, and has a variety of uses in the synthesis of polymers based on polylactic acid (PLA). LA and its derivatives have long been used as preservatives and acidifiers in the food, pharmaceutical, textile, leather, and chemical sectors. Its production has recently expanded due to its use in the manufacture of ecologically friendly biodegradable polymers (PLA) to replace a sizable portion of petroleum-based plastics and assist in climate change mitigation (Jambrak *et al*., 2018). With the help of bacteria, fungi, and yeast, lactose can be successfully transformed to lactic acid by fermentation. It is a fermentation by-product of various microorganisms, including filamentous fungi *Rhizopus oryzae*, *Lactobacillus*, *Bacillus*, *Enterococcus*, *Lactococcus*, *Pediococcus*, *Streptococcus*, and *Candida*. A select few of these, including the native LA producers Lactobacillus delbrueckii and *Sporolactobacillus*, *Escherichia coli*, *Bacillus coagulans*, *Corynebacterium glutamicum, and B. licheniformis,* are employed by the industry. Using Kluyveromyces marxianus var. marxianus for LA production has also been successful. LA is first produced using pricey, pure lactose, glucose, or sucrose. Due to the expensive cost of pure raw materials, research is focused on more practical and sustainable methods, such as getting LA from waste effluents like whey. Prior to the creation of LA, whey must be processed using membrane methods to lower its protein content and enhance the concentration of lactose and mineral salts (Zandona *et al*., 2021).

Bioplastic: A crucial tactic for maximising the utilisation of agricultural and industrial wastes and raising the potential income of the entire bioprocessing chain for the creation of bioplastics is the interlinkage of biotechnology processes. Due to the ease with which the lactose in whey permeate may be transformed into polyhydroxyalkanoates (PHAs) and polylactic acid (PLA), the use of cheese whey as a substrate for the manufacturing of bioplastics has recently gained attention. The industries of packaging, spraying materials, device materials, electronic products, agricultural products, automation products, chemical media, and solvents can all make use of the bioplastics that were thus generated (Musci *et al*., 2016).

Bioethanol: Future fuel alternatives that are environmentally beneficial have stood out, particularly bioethanol (green fuel). Bioethanol is useful in lowering air pollution and minimising global warming because it doesn't emit any hazardous gases during combustion. Legislative incentives are used to support its production as a result everywhere in the world. The majority of the ethanol purchased in the USA in 2007 originated from maize, with the remaining 5% coming from wheat, barley, or agro-industrial wastes (such as cheese whey and some beverage residues). Diverse strategies for producing bioethanol have been created based on applying non-food agriculture crops and various agro-industrial wastes to prevent the absence of food crops or rural assets and alleviate the environmental impact of industrial and agricultural wastes (Zandona *et al*., 2021). Due to its high organic load and high contamination potential, whey has distinguished itself as a viable substrate for bioethanol synthesis among these wastes (Chatzipaschali and

Stamatis, 2012). The bioconversion of whey into ethanol attracts attention, even though the conversion of lactose and other whey constituents into bioethanol is hardly competitive with the present methods employing sugarcane, maize starch, or utilising lignocellulosic biomass as raw material. Due to the low lactose content and low bioethanol yield (2–3%), direct fermentation of whey is not economically feasible and results in expensive capital expenditures at the distillery. Whey concentrated by ultrafiltration and/or reverse osmosis, which has a high lactose content, can be fermented to produce more bioethanol. Lactose must be enzymatically hydrolyzed before Saccharomyces cerevisiae can ferment it into alcohol since the traditional industrial strain lacks the enzymes necessary to break down lactose. In contrast, *Kluyveromyces marxianus* strains, often employed yeast strains for the fermentation of lactose into bioethanol, can metabolise lactose (Jambrak *et al*., 2018).

Polylactic acid: One of the most promising environmentally friendly (green) plastics of the time, polylactic acid (PLA) is a biodegradable bio-polyester created by condensation of lactic acid (LA) monomers, and shares many characteristics with polystyrene (PS) and polypropylene (PP). PLA has a GRAS rating (Generally Regarded as Safe) because of its low toxicity, making it suitable for use in food packaging. It can be composted in earthen trenches with other biodegradable materials, such as plant and animal wastes, because it is biodegradable, and its disposal won't adversely affect the environment (Zandona *et al*., 2021). Despite being biodegradable, it will persist for years like petroleum plastics if incorrectly disposed of in landfills. Three distinct types of PLA exist poly (l-lactic acid), poly (d-lactic acid), and poly (dl-lactic acid (PDLLA). Although PLLA is acceptable for industrial usage, its low thermal stability (melting point 180 °C) restricts its applicability. In contrast, PLLA and PDLA stereo complexes (SC) are more heat stable (melting point 230 °C), hydrolysis resistant, and have superior mechanical qualities (38). Since the demand for d-LA increased due to the manufacture of PLA, eco-friendly microbial d-LA production has gained attention. *Sporolactobacillus laevolacticus, Lactobacillus plantarum, Sporolactobacillus ilulins,* and *Lactobacillus bulgaricus* are examples of wild-type bacteria that can manufacture it (Musci *et al*., 2016).

*Single cell proteins:*One of the fundamental steps in addressing the issue of rising demands for novel and alternative food sources is the production of single cell protein (SCP). According to its definition, SCP is a "protein extracted from cultivated microbial biomass," which refers to dehydrated cells of various microorganisms (algae, actinomycetes, bacteria, yeast, moulds, and higher fungi) grown in large-scale culture systems for use as a source of protein in human food or animal feed. In place of pricey conventional sources like soy meat and fish meat, it can be used as a protein supplement (Chatzipaschali and Stamatis, 2012). Utilizing whey as a substrate for the synthesis of SCP may lower its polluting potential and produce a product with enhanced value. Whole whey or whey permeate a useful substrate for synthesising SCP through the utilisation of lactose directly by lactose-consuming microbes or indirectly for a microorganism that does not grow on lactose following the breakdown of lactose by enzymatic or chemical methods. The *Kluyveromyces* species, particularly *K. marxianus or K. fragilis* strains, which are GRAS microorganisms and offer benefits of strong growth yields, have been the subject of the most research for SCP manufacture from whey (Zandona *et al*., 2021).

CONCLUSIONS

Environmental concerns have compelled governments to pass laws governing the disposal of whey, which has prompted the dairy sector to look for alternative strategies and prospects for the management of dairy wastes. Whey recycling and reuse have become major scientific problems in reducing dairy waste because of their significant polluting potential. These scientific efforts led to the creation of several environmentally friendly whey disposal techniques. Whey is an excellent starting point for developing various innovative products or a perfect substitute for more conventional compounds due to its components.

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