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A comprehensive review on the utilization of waste generated from dairy industry

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Abstract
Waste is a natural and unavoidable component of all processes, and it can be caused by a number of things, including resource utilisation, process inefficiencies, and the removal of less usable feedstock components. Due to the growing worldwide population, the dairy sector is expanding and producing waste such wastewater (from cleaning, processing, and maintenance), whey, and sludge. These elements are nutrient-rich and contain both organic and inorganic compounds. Dairy waste is also a danger to the environment due to the alkaline and acidic detergents and sterilising agents that are included in it. Thus, utilisation of biological techniques, such as microbial treatment, is necessary for the sustainable valorization of dairy waste. This paper highlights recent advancements in the use and valuation of dairy waste by microorganisms. Using microbes to handle dairy waste aerobically and anaerobically can be a sustainable and environmentally friendly way to produce biofertilizers, biofuels, electricity, and other biobased products.

Keywords: Waste, dairy industry, usable feedstock components

Introduction

With the development of cutting-edge technology to boost the production of milk and milk-based products, the dairy industry has experienced significant growth in recent years. A significant amount of waste has been produced as a result of the expansion of the dairy business. Global milk production increased by a total of 2.2% in 2018, representing for 843 million tonnes, and the dairy products increased by 2.9% in 2018, representing for 75 million tonnes (FAO, 2019) [16]. According to estimates, the processing of one litre of dairy milk produces 6 to 10 litres of effluent (Gramegna *et al*., 2020) [19]. Lactose, nutrients, lipids, sulphates, chlorides, and suspended and dissolved solids are all present in dairy wastewater, which is typically characterised by high biological oxygen demand (BOD) and chemical oxygen demand (COD) (Yonar, Sivrioglu,& Ozengin, 2018) [53]. The dairy wastewaters should be managed appropriately for the safety of the environment and human beings. The pollution control board determines discharge standards for wastewater treatment in the industries (Sivaprakasam and Balaji, 2021) [48].

Different types of colloidal particles are seen in dairy effluent. Several conventional techniques, including ion exchange, flocculation, flotation, coagulation, membrane filtering, and solvent extraction, can be used to remove these colloidal particles. The use of artificial coagulants like fava beans, chitosan, common beans, and Moringa oleifera is what makes flocculation and coagulation the most suitable of these techniques (Tripathi *et al*., 2021) [50]. Dairy effluent biotechnological approaches have been shown to be effective alternatives. These techniques can be used to reduce the organic load from dairy waste in an effort to find solutions to environmental issues (Faria *et al*., 2017) [17]. It is crucial to analyse the waste's content, describe it, and offer potential applications due to the increased interest in using dairy waste to minimise pollution (Daneshvar *et al*., 2018) [11]. Henceforth this dairy waste can be utilized in production of biodiesel, bioenergy, ethanol, functional beverage, biohydrogen, biocatalyst, single cell protein, organic caids and organic fertilizers (Awasthi *et al*., 2022) [4]. This chapter aim to review the information available on dairy waste utilization and its treatment.

Dairy wastes generated during processing of dairy products

The dairy industry's significant environmental impact can be attributed to its wastewater. Dairy products can be processed to produce wastes from milk fermentation or by-products that can be used to make additional dairy products, such as whey concentrates from cheese whey. Dairy wastes typically contain organic debris, suspended particles, high levels of nitrogen and phosphorus, as well as the presence of oils and greases. Additionally, they may contain remnants of the cleaning agents used to clean the equipment and utensils (Ahmad *et al*., 2019) [1].

Due to the rising demand for milk and milk products, dairy businesses have experienced tremendous expansion in many nations. Processing dairy products produces a lot of waste, much of which takes the form of chemically altered liquid and uses a lot of water. Every stage of the procedure involves the utilisation of this water (Sarkar, Chakrabari,Viyajkumar & Kale, 2006) [45]. Consequently, the dairy industry's effluent outflow has also increased. Dairy companies produce 6–10 L of effluent for every litre of processed milk. Dairy products wastewater can be divided into processing water, cleaning wastewater, and sanitary wastewater depending on their composition and origin (Leonard *et al*., 2021) [25].

Composition of dairy waste

Salts, lipids, chlorides, sulphates, dissolved solids, soluble proteins, D-lactose, and chlorides are all components of dairy effluents. Organic content is abundant in dairy effluent. As a result, both the chemical oxygen demand (COD) and the biochemical oxygen demand are high (BOD). Additionally, it has significant amounts of phosphate and nitrogen. As a result, if released into the environment untreated, it may result in eutrophication, endangering aquatic species. When grease and oil are discharged into water bodies, a thin layer of oil forms on the water's surface that blocks the passage of oxygen and air. Additionally, casein, lactose, inorganic salts, N, P, and K are present in the dairy wastewater (Ahmad *et al*., 2019) [1]. The primary by-product of the dairy industry created during the production of casein and cheese is whey. It has fats, carbs, and soluble vitamins (Arefin *et al*., 2020; Egas *et al*., 2019) [3, 15]. Clarified butter sediment waste, which is created during the production of butter or clarified ghee, is another waste product of the dairy industry (Arefin *et al*., 2020; Egas *et al*., 2019) [3, 15]. Essentially, it is made up of proteins and lipids. Dairy effluent typically has a pH between 4.7 and 11, which indicates the quantity and diversity of cleaning chemicals needed for sterilisation. Dairy wastewater is white in appearance, smells nasty, and has an average temperature of 17 to 25 C. (Mishra *et al*., 2021; Li *et al*., 2021) [33, 26].

Various processing technologies of dairy waste

Aerobic digestion

By degrading lipids and other substrates as well as reducing odour through the fermentation of diverse microorganisms, the aerobic treatment improves food processing wastes. At high temperatures (over 45 °C), thermal aerobic therapy can also eradicate harmful germs. This technique can lower the amounts of BOD, COD, and the odour of food, animal by-products, and whey (Liu *et al*., 2021) [27-29]. The nitrogen content of the end product could also be preserved hence end product can also be utilized as biofertilizer (Mahboubi *et al*., 2017) [32].

Anaerobic digestion

Due to high organic content of whey, particularly lactose, it has a high chemical oxygen demand (COD) value. Numerous wastes, including cheese whey, might be thought of as possible hydrogen sources because carbohydrates constitute the primary ingredient in the synthesis of hydrogen (Azbar *et al*., 2009a). Both energy savings and pollution reduction are advantages of using whey in anaerobic digestion (Choudhary *et al*., 2021; Wainaina *et al*., 2020). Due to its low bicarbonate alkalinity, high COD concentration, and rather quick acidification propensity, anaerobic treatment of whey may be challenging. Despite having a longer lag phase than mesophilic bacteria, thermophilic bacteria were more efficient at producing hydrogen. (Kargi *et al*., 2012). Combination of dairy waste with substrates like vinasse and cow manure can also lead to increased methane production (Sar *et al*., 2019; Patel *et al*., 2021) [44, 37].

Biotechnological production

Cheese whey in particular is produced in large amounts and might be considered a valuable source of substrate due to its composition. Dairy waste could be treated using anaerobic techniques to generate hydrogen and methane, but these wastes could also be examined for useful biotechnological outputs such ethanol, organic acids, enzymes, and single-cell protein (Li *et al*., 2021) [26]. The fermentation of microorganisms such as Kluyveromyces lactis, Kluyveromyces marxianus, Candida pseudotropicalis, engineered, and Saccharomyces cerevisiae, ethanol-producing E. coli strains, that can consume the lactose in whey, results in the production of bioethanol, one of the most promising materials. In order to use S. cerevisiae, which can make ethanol but cannot normally use lactose, recombinant S. cerevisiae bearing lactose-consuming genes (β-galactosidas and lactose permease) or with other organisms (Beniwal *et al*., 2018) [6].

Bioaugmentation

It is a remediation technique called bioaugmentation can lower levels of COD and organic matter (carbohydrates, proteins, and lipids). Through the application of bioaugmentation technology, anaerobic sludge cultures and a fungus consortium (Aspergillus niger, Mucor hiemalis, and Galactomyces geotrichum) can be utilised to purify whey (Djelal and Amrane, 2013) [14]. Additionally, by boosting the activity of target microorganisms (such as lactic acid bacteria) in this process, both the productivity of bioproducts (such as ethanol, lactic acid, and acetic acid) and the efficiency of their removal can be enhanced. (Luongo *et al*., 2019; Policastro *et al*., 2021) [30, 38].

Bioremediation

Activated sludge, aerobic-anaerobic fermentation, filters, and other techniques have all been utilised in the biological treatment of food wastes, including waste from dairy production (Wang *et al*., 2021; Das *et al*., 2016) [52, 12]. As an alternative, bioremediation can be carried out inexpensively utilising non-pathogenic microorganisms. Escherichia coli, Streptococcus faecalis, Enterobacter, Bacillus cereus, Bacillus subtilis, Pseudomonas aeruginosa, Pseudomonas fluorescens, Candida, Saccharomyces, and Cryptococcus can all be naturally isolated in wastewater from the dairy sector (Liu *et al*., 2021) [27-29]. By cultivating the microorganisms (P. aeruginosa, B. subtilis, Lactobacillus delbrueckii, Staphylococcus aureus, Enterococcus hirae, Alternaria sp., Fusarium sp., and Aspergillus sp.) isolated from dairy wastewater, the amount of organic load of the waste can be significantly reduced, and its physico-chemical properties can be reduced (Jain *et al*., 2022) [22].

Value added-products derived form dairy waste

Biohydrogen

Combining hydrogen generation with other bio-based technologies to create energy responsibly is another topic that has been researched. For instance, the next phase in producing green energy from trash has been hailed as merging the production of methane with hydrogen from the biodegradation of organic waste, such as dairy waste, food waste, and other organic industrial waste (Kothari *et al*., 2017; Aziz, 2016) [24, 5]. Energy recovery has been proven to benefit from the creation of a two-stage technique that combines the reduction of dairy wastewater pollution with the production of bioenergy (methane and hydrogen) via a two-phase process (Chu wang, 2017) [9].

Biofuels

As biofuels have a better emission profile, are biodegradable, and generally contribute to sustainability, biofuels have become a possible replacement for non-renewable resources. One example of a clean fuel is biodiesel, which burns with substantially reduced emissions of carbon monoxide, hydrocarbons, and particulate matter due to its lack of sulphur and other harmful chemical. There are various yeasts that can be used to produce ethanol utilising dairy waste as a substrate, including Kluyveromyces marxianus, Kluyveromyces lactis and Candida inconspicua. So, it can be said that growing microorganisms on dairy waste can be used to make biofuel. However, further research is needed to determine how temperature, pH, lipid production, and other factors affect the biomass that results from this process (Usmani *et al*., 2021) [51].

Biopolymers

Utilizing lactose and dissolved lipids from dairy waste as feedstock for the synthesis of biopolymers like poly-hydroxyalkanates is a creative bio-refinery approach to managing dairy waste (PHA). Polyhydroxybutyrates (PHB) are often the biopolymers that fermentation most frequently produces. Microorganisms with the genetic machinery can concurrently co-metabolize glucose and galactose from whey permeate to create PHB include Bacillus megaterium, Brevibacterium casei, Pseudomonas hydrogenovora, and Pseudomonas sp.. (Liu *et al*., 2021) [27-29]. It is plausible that adding bio-polymers to the dairy effluent stream will result in the production of bio-plastic films (Luqman & Al- Ansari, 2021; Ryder *et al*., 2020) [31, 40]. Due to the use of gelling polymers, this concept may have significant implementation costs; however, due to its overall advantages, it is a strong biorefinery strategy.

Biosurfactants

Biosurfactants, also known as surface-active agents, are produced by a variety of microbes including bacteria, fungi, and yeast and can be employed in place of other organic surfactants (Gaur *et al*., 2019) [18]. According to estimates, the global market for biosurfactants is worth $30.64 billion (Singh *et al*., 2019) [47]. In numerous research and pilot size implementations, the microbe genera Pseudomonas, Candida, Rhodococcus, and Bacillus have been primarily employed to produce biosurfactants (Santos *et al*., 2016) [42]. A biosurfactant often has both a hydrophobic and a hydrophilic component (Almeida *et al*., 2018; Otzen, 2017) [2, 36]. Depending on their molecular weight, physicochemical characteristics, and mode of action, biosurfactants can be divided into two categories: high and low molecular weight (Jimoh and Lin, 2019) [23].

Nutraceuticals

A potential application of integrated biorefinery principles is the production of prebiotic oligosaccharides from dairy waste products. According to Sar *et al*. (2017) [43] & Sakarika *et al*., 2020 [41], galacto-oligosaccharides (GOS) with a terminal glucose molecule of the form Glu 1-4 (Gal 1-6) n and a degree of polymerization (DP) around 2-9 are typically not edible. A mixture of oligosaccharides, monosaccharides, and disaccharides is produced as a result of the trans-galactosylation activity of -galactosidase. Lactulose (4-O-d-galactopyranosyl-d-fructose) is the second lactose-based prebiotic. It is an indigestible oligosaccharide pre-biotic that has medical potential (Ottaviano *et al*., 2017; Nooshkam *et al*., 2018) [35, 34] and is added to infant formula to balance the composition of their gut microbiota.

Single Cell Proteins

Single Cell Proteins (SCPs), which are dried and extracted protein-rich contents of microorganisms, have been thoroughly explored, successfully commercialised, and included into human meals and animal feed to meet the demands of nutritious proteins in the foodstuff of living beings (Mahboubi *et al*., 2017; Rubio-Texeira *et al*., 2000) [32, 39]. Numerous bacteria, including Aeromonas hydrophylla, Sacchromyces cerevisiae, and Candida intermedia, can only rely on leftover protein, nitrogenous dissolved solids, and carbon sources to meet their needs for growth. The most common types of microorganisms that successfully use lactose and galactose as a source of energy are fungi like Candida sp. and Saccharomyces sp. (45-55% protein), bacteria like Cellulomonas sp. and Alcaligenes sp. (50-60% protein), and algae like Spirulina sp. and Chlorella sp. (40-60% protein). However, the major disadvantage of SCPs are the excess amount of nucleic acids (Arefin *et al*., 2020) [3]. Current advancements in SCP generation from cheese whey demonstrate highly encouraging outcomes with a significant decrease in COD as well as strong biomass production within an ideal time.

Table 1: Waste Utilization from dairy waste:

Waste utilized	Processing	End product	References
Waste water	Cultivation with Acutodesmus dimorphus for 4 days	Biomass, further converted to bioethanol and biodiesel	Chokshi *et al*., 2016 [9]
Whey	Culivation of mainly yeast (lactose fermenting microbes)	Single cell protein	Spalvins *et al*., 2018 [49]
Dairy waste	Anaerobic digestion and acidogenic fermentation	Bioenergy (CH_4 and H_2)	Chandra *et al*., 2018 [7]
Wastewater	Cultivation with Streptomyces sp, A. niger, Pseudomonas sp	Lipase	Jaganmai & Jinka, 2017 [21]
Dairy sludge	Using it as a growth medium for the Rhizobium	Biofertilizer	Singh *et al*., 2013 [46]
Fatty waste (from the flotation)	Anaerobic biodegradation	Biomethane	Hamawand *et al*., 2016 [20]
Scotta feedstock for ricotta cheese	Pancreatic enzyme and papain	Bioactive peptide	Dinesh *et al*., 2020 [13]
Whey	Utilization of latex form Maclura pomifera	Bioactive peptides	Corrons *et al*., 2012 [10]
Industrial whey	Batch fermentation pH 5.5 at 30°C temperature	Single Cell protein	Kavitha *et al*., 2019 [28]

Wastewater	Cultivation with Acutodesmus dimorphus	Biofuel (bioethanol & biodiesel)	Chokshi *et al*., 2016 [9]

Conclusion

The shift in the dairy industry's demand from direct consumption to production has led to massive resource consumption and the emission of toxic effluents into the environment. However, newer microbial treatment methods are advancing the transformation of dairy waste into usable products. While other biotechnological technologies can use the waste as a substrate for the manufacture of various value-added products such as biosurfactants, bioplastics, and biomolecules, anaerobic treatment can directly transform the trash into a useful energy resource. These tactics lessen the environmental effects of garbage disposal while encouraging the circular economy.

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