

Review

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Few case studies as ideas for zero-waste from food production and processing

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DOI: 10.31383/ga.vol7iss2ga08

Abstract

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Received

December, 2023

Accepted

December, 2023

Published

December, 2023

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Keywords

by-products, crops,
coffee, whey, blood

Globally, the amount of agricultural waste is huge but not properly utilized yet. Precisely, about one billion tons of food produced for human consumption is wasted each year. This wastage global economy costs are estimated at US\$ 1 trillion on annual level. The definition of food waste varies globally depending on where food waste occurs in the food supply and consumption chain, how it is generated, and what it covers. This review is a compilation of few different approaches in the context of zero waste from food production and processing. Soybean hull exploitation due to mass production of tofu, soymilk, edamame, tofu sausages and burgers, soy breads, soy pasta and soymilk yoghurts and cheeses, animal feed leads to a formation of high waste load. There are several available ways for soybean hull valorization: as a biofertilizer, as a substrate for microbial growth, as an adsorbent, for extraction of antioxidants and in our case for extraction of enzymes. The global consumption of coffee is approximately 10 million tons, resulting in a substantial production of spent coffee grounds (SCG) worldwide. However, this by-product has recently gained attention as a valuable source of usable compounds, particularly in our case for essential oils. During the cheese production process, the whey obtained as a by-product can be used as a raw material for development of new dairy products and in the same time to prevent the potential pollution of natural watercourses. The valorisation of the waste whey obtained in the cheese production by using it in the development of new products also contributes in the environment protection. In N. Macedonia, about 1000 tons of blood waste from industrial slaughterhouses flow into natural watercourses every year and it can find application in various industries. These are just a few examples that show that the possibilities for the implementation of the zero-waste concept are unlimited.

Introduction

Food waste is a global challenge that has environmental, economic and social impacts. The zero-waste concept is a collection of waste prevention guidelines that encourages redesigning resource lifecycles to ensure that every production output is being reused (Sarangi et al., 2023). To improve the waste management practices, several original ideas are provided from various fields.

Globally, the amount of agricultural waste is huge but not properly utilized yet. Precisely, about one billion tons of food produced for human consumption is wasted each year. This wastage is estimated to cost the global economy is estimated at US\$ 1 trillion annually. The volume and value of wasted food presents a number of opportunities to identify where the greatest benefits can be achieved in avoiding food waste or where it can be repurposed. This approach is consistent with the idea of a circular economy where resources are kept in use for as long as possible while also minimising negative impacts (National Food Waste Strategy - Halving Australia's Food Waste by 2030, 2017).

Accurate estimations of the magnitude of losses and waste are lacking, particularly in developing countries. Nevertheless, there is no doubt that food loss and waste remain unacceptably high. Studies commissioned by FAO estimated yearly global food loss and waste by quantity at roughly 30 percent of cereals, 40–50 percent of root crops, fruits and vegetables, 20 percent of oilseeds, meat and dairy products, and 35 percent of fish. Food loss and waste are heavily dependent on the specific conditions and local situation in a given country or culture (Food and Agriculture Organization of United Nations, 2015).

In low-income countries food loss results from wide-ranging managerial and technical limitations in harvesting techniques, storage, transportation, processing, cooling facilities, infrastructure, packaging and marketing systems. The causes of food waste in medium- and high-income countries relate mainly to consumer behaviour and the

policies and regulations put in place to address other sectorial priorities. At the consumer level, inadequate planning of purchases and failure to use food before its expiry date also lead to avoidable food waste.

The issue of food waste is high on the political agenda in industrialized countries. Food waste is expected to constitute a growing problem in developing countries given the changes that food systems in these countries are undergoing because of such factors as rapid urbanization, expansion of supermarket chains, and changes in diets and lifestyles.

The *definition* of food waste varies globally depending on where food waste occurs in the food supply and consumption chain, how it is generated, and what it covers. Broad and inclusive definition of food waste covers: 1) solid or liquid food that is intended for human consumption and is generated across the entire supply and consumption chain. 2) food that does not reach the consumer, or reaches the consumer but is thrown away.

The generated food waste is varied and complex, and occur at every point along the supply and consumption chain as follow: i) primary production, ii) product loss due to pests and diseases or weather, iii) damaged or discarded during production, iv) packing or handling, v) fall in market prices making it unprofitable to harvest, vi) inability to meet contracted produce specifications, such as quality or size, vii) changes in consumer tastes and preferences, viii) processing and manufacturing, ix) product damaged during handling, x) spoilage due to contamination or inadequate temperature control, xi) excessive trimming of vegetables for processed food, xii) changes in production due to consumer demand, xiii) equipment failure, damage to packaging resulting in food unfit for sale, xiv) produce no longer meets quality standards, xv) hospitality and food service, xvi) poor stock management, storage, and handling, xvii) practices Households Confusion over 'use-by' and 'best-before' date labelling, xviii) over-purchasing of food that is then thrown away, xix) limited

knowledge of how to safely repurpose or store food leftovers, xx) limited access to food waste collection systems etc. (National Food Waste Strategy - Halving Australia's Food Waste by 2030, 2017).

The extent of this wasted resource has prompted several *initiatives* across the world to address the problem. Due to the magnitude and complexity of the food loss and waste problem, *Food and Agriculture Organization (FAO)* of United Nations recognizes the need to undertake action in partnership with other regional and international organizations, and with food chain actors ranging from herders, farmers, and fishers to global companies. FAO Save Food Initiative (FAO SFI) helps countries in Asia, the Pacific, Middle East, and others identify and develop food waste reduction strategies adjusted to the specific needs of regions, sub-regions and countries. SFI gives priority to interventions that prevent food loss and waste from occurring in the first place, followed by interventions that can lead to reduced loss and waste. The main areas of action are: improved production planning, aligned with the markets; promotion of resource-efficient production and processing practices; improved preservation and packing technologies; improved transportation and logistics management; enhanced consciousness of purchasing and consumption habits; ensuring that all chain actors, including women and small producers, receive a fair share of the benefits. (Food and Agriculture Organization of United Nations, 2015).

In the context of *Green deal* initiative, various recent studies have analysed possible effects of the Farm to Fork and Biodiversity Strategies on agriculture in the *European Union*. They provide, both the scientific community and policy makers with a valuable insight on the choice of policy tools to mitigate the risks (European Commission: Directorate-General for Agriculture and Rural Development, 2022).

In one of the studies, *Green Peace* declare that many negative environmental impacts produced by modern human society can be attributed to our

relationship with food – how it's grown, harvested, processed, transported and disposed of. Capturing and utilising organic waste is one vital way to reduce emissions and pollution, and move towards a zero waste, circular economy (Greenpeace, 2021).

This review is a compilation of few different actions in the context of zero waste from food production and food processing.

Case studies

Production of peroxidases from various plant waste materials and their usage in the treatment of wastewater from textile industry

Synthetic dyes present in the wastewater from textile industry are mainly azo, anthraquinone, nitro and methane dyes. The dyes that belong to the azo and anthraquinone class are toxic, mutagenic, carcinogenic, and allergenic. Moreover, when present in the wastewater from this industry, are of great concern because they are extremely stable compounds, resistant to biodegradation. Dyes remain in water for a long period of time and exhibit harmful effects on organisms that are exposed to them. They give intense coloring even at low concentrations affecting the reflection and absorption of sunlight, which in return has a negative effect on the growth, development, and reproduction of aquatic organisms (Yurtsever et al., 2015). The difficult penetration of sunlight impairs the process of photosynthesis, which has a particularly negative effect on photoautotrophic organisms (Hassan and Carr, 2018).

In the dyeing process, 5-40% of the used dyes go into wastewater (Silva et al., 2013). In order to protect people and the environment, before they reach water bodies, wastewater must be treated to a degree of purity that does not lead to harmful effects on the environment and human health. Traditional methods used in wastewater treatment can be divided into: physical, chemical, biological and combined methods.

In the last few decades, the attention of researchers has been focused on examining the possibility of applying enzymes in the treatment of wastewater, that is, removing synthetic dyes from wastewater. Compared to traditional methods, enzymatic color removal is more efficient, environmentally friendly, and cost-effective. Enzymes that are used as catalysts in the processes of removing synthetic colors are polyphenol-oxidases, lignin-peroxidases, laccases, azo-reductases, and peroxidases (Rauf and Salman, 2012). These enzymes catalyze redox reactions and show broad specificity towards the substrate (Durán and Esposito, 2000).

Peroxidases that can be efficiently isolated from plant material possess great potential for bioremediation, treatment of wastewater from textile, petrol, pharmaceutical industry (Silva et al., 2023). Horseradish peroxidase is the most studied enzyme derived from plant material, which is used as a very effective biocatalyst in the treatment of various recalcitrant pollutants (i.e. dyes, phenols, etc.) present in wastewater (Bilal et al., 2023). Šekuljica et al. (2015) observed the oxidation of two anthraquinone dyes using commercial horseradish peroxidase, while Wang et al. (2023) performed immobilization of horseradish peroxidase in zwitterionic polymer hydrogels, polycarboxybetaine (PCB) and polysulfobetaine (PSB), and used it for successful phenol removal. The research group from China achieved 90% of phenol removal in 12 minutes. Peroxidase from turnip was used for dye removal by Ahmed et al. (2015). Immobilization of partially purified turnip peroxidase was performed by encapsulation in spherical particles of calcium alginate. Dye removal of 94 % was achieved after 1 h of reaction in a batch process. At pH 2.0 and 40°C. Variety of plant materials have been used for peroxidase isolation, which then was used for decolorization of textile effluents (Sarkar et al., 2017).

One of the main challenges of enzymatic wastewater treatment is the application of crude

enzyme extracts that have not been subjected to purification.

Also, the use of the solid phase of the waste material which peroxidase is extracted from, can be observed as naturally immobilized enzymes that are simple to manipulate with. Potato pulp, soybean flakes, soybeans, and bananas, all have been used in the treatment of contaminated wastewater (Dahiru et al., 2018). Treating industrial solid waste as a material for extraction of enzymes, and using the extract from what was once waste, for treatment of another waste is complementary with the design of sustainable development. Deva et al. (2014) performed extraction of peroxidase from cauliflower stem and leaf. The partially purified peroxidase was applied in oxidation and polymerization of phenolic compounds in synthetic wastewater. A research group from Iraq performed screening of several waste plant materials such as peels from: beans, peas, watermelon, melon, bitter orange, and lemon (Mathkor et al., 2019). They have shown that the source of peroxidase that yields the highest enzyme activity is melon peel.

Peroxidase has been also isolated and partially purified from grape wine waste (Alijanipoor et al., 2018). The crude extract showed high specific activity of peroxidase 5100 U/mg. Guaiacol was used as a standard method for the enzyme activity assay. Vegetable sources such as radish, tomato, turnip and cabbage have shown great potential for peroxidase isolation. The crude enzyme extracts had activity of 1 -1.5 IU/mL. The activity was measured using 3, 5, 5 tetra methyl benzidine as a substrate. Later, the peroxidase was used for phenol degradation (Rathnamsamy et al., 2014). Orange peel was also used as a source of peroxidase. After the extraction of peroxidase, the solution was partially purified by ammonium sulphate. The enzyme activity assay was performed by guaiacol as a standard substrate (Salgaonkar et al., 2019). One of the most exploited sources of peroxidase, after horseradish, is soybean hull.

According to SOPA (Soybean Processors Association of India), the world production of soybean for 2021-2022 was 385.524 million metric tons (<https://www.sopa.org/statistics/world-soybean-production>). Hulls represent about 8% of the seed weight generating about 31 million tons of hulls, the major by-product of soy industry (Cabezudo et al., 2021). This is why a lot of research is focused on extraction of bioactive compounds from soybean hull (Canaan et al., 2022). Svetozarevic et al. (2020) used soybean and soybean hull for peroxidase extraction. The crude enzyme extract was then used for degradation of anthraquinone dye. Immobilization of peroxidase from soybean hull was also performed in a batch and continuous system (Svetozarević et al., 2022). The crosslinking of peroxidase was achieved by modified pectin. The microfluidic reactor was used as a continuous system. The morphology of the inner wall of the microreactor before and after immobilization of peroxidase from soybean hull by modified pectin is given in Figure 1. The continuous system has shown higher efficiency in the degradation of the anthraquinone dye. Moreover, it showed higher operational stability. The immobilized enzyme used in a batch reactor had the ability to be reused for 3 cycles, while in the continuous system peroxidase retained about 60% of its initial activity after 10 cycles of dye decolorization.

Valorizing spent coffee grounds for sustainable extraction of oil and essential oils with potential multi-industrial applications

The global consumption of coffee stands at approximately 10 million tons, resulting in a substantial production of spent coffee grounds (SCG) worldwide, as reported by the International Coffee Organization (ICO). Various byproducts emerge from coffee consumption, including coffee husks, pulp, silver skin, and SCG.

SCGs are produced by entities ranging from instant coffee industries and households to coffee factories, restaurants, and cafeterias (Vandeponselee et al., 2021).

Remarkably, the preparation of 1 kg of soluble coffee yields 2 kg of SCG, and a staggering 650 kg of SCG is obtained from one ton of green coffee beans converted into a coffee drink (Vandeponselee et al., 2021; Brekalo et al., 2023). It is reported that about 6 million tons of SCG are collected annually worldwide (Dordevic et al., 2023).

Regrettably, the entirety of these SCGs often finds its way to landfills without proper composting, posing a significant environmental and economic challenge. SCGs contain abundant organic substances and water, requiring extended periods for decomposition.

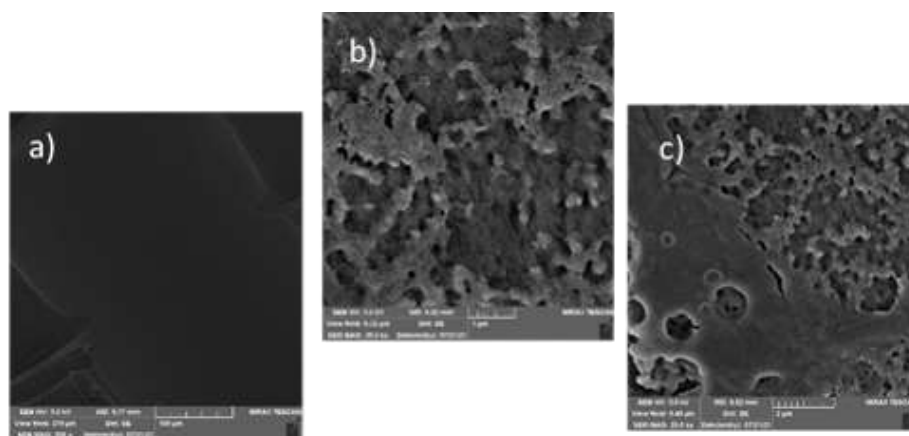


Figure 1. SEM analysis of the morphology of the microreactor's inner wall: a) before immobilization, b) and c) after immobilization of soybean hull peroxidase by modified pectin

Consequently, the improper disposal of SCGs contributes to environmental pollution, underscoring the urgent need for sustainable solutions to address this prevalent issue.

The global surge in coffee consumption has led to a significant increase in the production of spent coffee grounds, traditionally considered waste. However, this byproduct has recently gained attention as a valuable source of valuable compounds, particularly oils and essential oils. Coffee oil, extracted from spent coffee grounds, is rich in bioactive compounds like esters, fatty acids, and phenols, endowing it with diverse pharmacological properties such as anti-aging, antioxidant, and anti-cancer effects. Notably, the applications of coffee oil extend across various industries, including cosmetics, food, and pharmaceuticals (Dordevic et al., 2023).

Within the cosmetic industry, coffee oil has found utility due to its skin-friendly properties. It exhibits softening and moisturizing effects on the skin, reduces inflammation, and provides protection against harmful UV rays. Additionally, there is a growing expectation that coffee oil might replace toxic and chemical substances commonly used in sunscreens, as discussed in the study by Dias et al. (2023). These applications underscore the multifaceted benefits of coffee oil and its potential to drive innovation in diverse industrial sectors.

Spent coffee grounds (SCG) are considered crucial residues in the coffee industry, with the potential to yield approximately 15 wt% of coffee oil during extraction (Obruca et al., 2014). This coffee oil is enriched with diverse bioactive compounds, including caffeine, fatty acids, diterpene esters, and polyphenols. SCG oil has demonstrated antioxidant properties, anti-inflammatory activity, anti-bacterial activity, and enzyme inhibitory properties (Zengin et al., 2020).

Brekalo et al. (2023) employed SCG extraction, initially using Soxhlet extraction to obtain SCG oil by permeating n-hexane as an organic solvent. The remaining solid residue underwent sequential subcritical continuous flow solvent extraction with 96% ethanol and 50% water. Soxhlet extraction

from 100 g of SCGs yielded 10.58 g of SCG oil, containing linoleic and palmitic acids. Proteins, sugars, caffeine, chlorogenic acid, and 5-(hydroxymym) were obtained from the solid residue subjected to continuous solvent flow sequential subcritical extraction.

Soxhlet extraction for oil extraction from SCG was employed as a method in the laboratory of Technological Science, Mother Teresa University, Skopje. The research team found that the yield of extracted oil was 3,59% when n-hexane was used as a solvent. Essential oils were also extracted using hydro distillation, but the yield of essential oils was lower than anticipated. As with Soxhlet extraction, the oil yield is calculated based on the dry weight of the sample, and it was 1.45%. The aim of this study was to find suitable ways for using SCG, since the oil obtained from SCG with different extraction methods can be used in different industrial fields.

The extraction of coffee oil from SCG is very important as it should be sustainable and low-cost. In the last period, the waste obtained from SCG, which is considered as agro-industrial waste, has different applications in the biorefinery (Tinoco-Cacedo et al., 2023). Based on this, it is important that in addition to the yield of oil extraction, other aspects of the process such as sustainability and profitability should be studied.

The successful extraction of oils and essential oils from spent coffee grounds opens up a spectrum of potential applications across various industries including Food Industry, Cosmetic and Personal Care, Pharmaceutical Industry, Biofuel Production, Agriculture, Water Treatment, Bio - Based Material. In the Figure 2 are shown variety of by-products obtained from SCG.

In the food industry the extracted essential oils can be used as natural flavor, imparting a unique coffee aroma to a variety of products, including baked goods, confectioneries, and beverages. Bioactive compounds such as chlorogenic acid and its derivatives can be used in the production of beverages, dairy products and baking products as antioxidants and colorants (Bondam et al., 2022).

Coffee oil can be used as a substitute for butter in baked goods. The antioxidant properties inherent in the extracted oils may find application as natural preservatives in food products, contributing not only to shelf-life extension but also to health benefits. In the cosmetic industry essential oils can be used in aromatherapy products such as perfumes, scented lotions, and candles. The antioxidant and antimicrobial properties of the extracted oils may be harnessed in the formulation of skincare products, offering potential benefits for skin health. This is attributed to the presence of bioactive compounds in coffee oils (Bondam et al., 2022). The bioactive compounds present in the oils may have therapeutic properties, paving the way for the development of natural remedies for various ailments. Another important application of the oil extracted from spent coffee grounds, rich in fatty acids, is for biodiesel production, contributing to sustainable energy solutions. Coffee oil is very stable because it has high antioxidant content, while the low levels of saponified matter make the oil remain viscous and do not curdle easily, these properties make coffee oil suitable for biodiesel production. Through valorization of spent coffee grounds Jin Ong et al. (2023) investigated the possibility of using coffee oil as a bio-based PCM with the aim of being applied for thermal energy storage at low temperatures. The antimicrobial properties of the

extracted oils may be harnessed in the development of eco-friendly biopesticides for agricultural use. According to Ayilara et al. (2023), biopesticides emerge as a favorable alternative to synthetic pesticides due to their specificity in action, cost-effectiveness, and environmental sustainability. Derived from diverse sources such, biopesticides offer targeted and effective pest control without the associated risks of residual effects, ensuring a safer and more eco-friendly approach to agriculture and pest management. The spent coffee ground residue, post-extraction, can be repurposed as a nutrient-rich soil amendment, promoting sustainable agricultural practices (Santos et al., 2017). The extracted oils might also serve as bio-based additives in the production of biodegradable polymers, contributing to the development of sustainable packaging materials (Dordevic et al. 2023).

Whey obtained as a by-product from cheese production and development of new dairy products

Whey is a by-product in the cheese manufacturing process, in general defined as the serum or watery part of milk that remains after the separation of the curd that forms as a result of the milk coagulation (Thompson et al., 2009). Whey proteins are well known for their high nutritional value and versatile functional properties in food products.



Figure 2. Potential by-products from spent coffee ground

The worldwide production estimation of whey indicate that about 700,000 tons of whey proteins are available as valuable food ingredients. Whey products, such as whey protein concentrate or whey protein isolate are widely used in the food industry due to the high functional and nutritive properties. Also, these products represent the best way for the utilization of whey proteins (Jovanović et al., 2005).

Another option for whey utilization is whey cheese production. Worldwide, the whey cheese types are manufactured according to traditional procedures by denaturation of whey proteins. Ricotta is the most important, and well-known, whey cheese in the world. The Macedonian type of whey cheese recognised as urda is produced from whey originating from kashkaval production (Pintado et al., 2001).

In the Laboratory for Protein and DNA Engineering was performed a study to compare protein profiles of different types of whey in relation to develop possible technology for the whey cheese obtained from white cheese. Utilization of the remaining proteins in whey waste water after the cheese-making process was the topic of this study with two objectives. The first one was to protect the natural water streams from pollution, and the second was to recycle the valuable remaining compounds to develop a new by-product. For such purposes were estimated the profile of the protein residues in whey waste water and their quantity. The samples of the whey obtained at the white brined cow cheese and yellow hard cow cheese production were analysed. Electrophoretic analysis was done to determine the composition of whey proteins using sodium dodecyl sulphate polyacrylamide gel electrophoresis - SDS-PAGE (Svetozarevic et al., 2014; Popovski et al., 2016). The electropherogram with the composition of whey proteins is shown in Figure 3.

The photometric quantification of total proteins was performed to determine the residues of proteins in waste water after the cheese-making process. The knowledge of the protein profile of

the whey derived from white and yellow cheese production contributed in the development of procedures for valorization of the waste whey from white cheese production process.

The results showed that the quantity and composition of proteins in whey waste water after the production of white and yellow cheese are stable and is a good basis for recycling of those proteins in development of new products. Future product development should be turned in the direction of valorisation of the white cheese whey waste for whey cheese production. Knowledge of whey composition and adjustments of the process parameters in whey cheese technology could allow manufacturing of whey cheese to realize maximal yield. Also, white cheese whey could be the basic raw material for development of a new product lactose free whey cheese (Walstra et al., 2006; Pulinas et al., 2017). Valorization of waste whey in some products will contribute in improvement of physicochemical parameters (COD, BOD, pH) of waste water and environmental protection (Britz et al., 2008).

Blood waste as a potential raw material for by-products in agriculture and pharmaceutical industry

In N. Macedonia, about 1000 tons of blood waste from industrial slaughterhouses flow into natural watercourses every year. On the one hand, this endangers the living world in these waters, and on the other hand, about 250 tons of high-quality proteins are lost. In the past, this waste was used for the production of blood meal as animal feed, but today, due to hygiene and health reasons, blood meal is no longer used as animal feed. But this by-product finds application as a fertilizer and for the production of adhesive mass that can be used in various industries. During the research deheminization and precipitation of blood proteins was approached with combinations of hydrogen peroxide, acetone, and hydrochloric acid (Popovski and Pendarovski, 1997). For decades, preparations obtained from deproteinized plasma

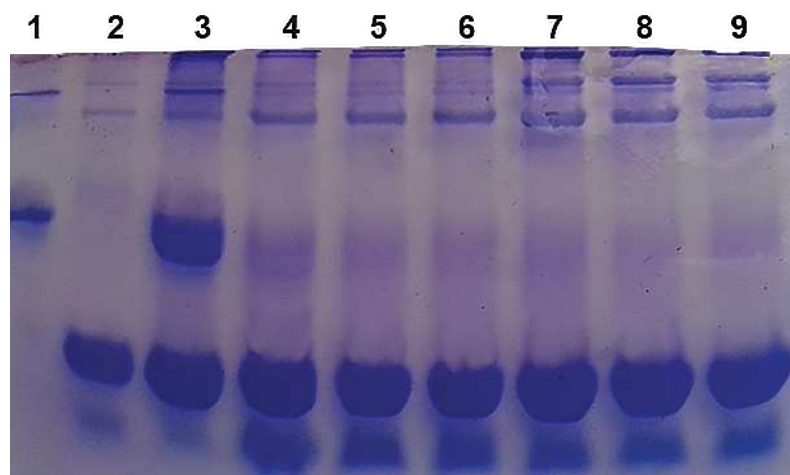


Figure 3. SDS-PAGE on milk proteins: #1 casein (standard), #2 lactoglobulin (standard), #3 milk proteins profile, #4-6 three whey samples after production of cow white brine cow cheese, #7-9 three whey samples after production of yellow hard cheese

from domestic animals have a wide application in tissue regeneration through rapid epithelization caused by increasing the speed of oxygenation during metabolic processes. We approached the collection of lamb plasma and its deproteinization following the example of the well-known product Solcoseryl, which is obtained and commercialized from calf deproteinized plasma. For the preservation of the deproteinized plasma we have been used methyl and propyl paraben in appropriate ratio. Its composition and effects in cell culture were analyzed using reverse phase and thin layer chromatography. Unfortunately, the mechanisms of action of this by-product, as well as for Solcoseryl, have not yet been determined (Simjanovska et al., 2003).

Conclusion

These and many other examples show that the zero-waste concept of agriculture and food processing has numerous benefits in: environmental, nutritional, social and economic sense, such as:

- reduced environmental impacts such as greenhouse gas emissions, natural watercourses pollution, climate changes, accumulation of solid waste on a global scale, air pollution;

- improved food security through the effective redistribution of surplus food;
- reduced costs for households by lowering food bills;
- increased economic opportunities, including employment through the creation and development of new products, services and markets;
- reduced costs for businesses in saved resource inputs, reduced waste management and disposal fees, and increased profits through efficiency gains;
- increasing profits by converting more ingredients that are saved into a saleable product.

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