IMPLEMENTATION OF THE PRINCIPLES OF BIOECONOMY IN LEATHER PRODUCTION

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ABSTRACT. Bioeconomy is a promising approach to addressing resource conservation and negative environmental impacts. Given the high potential of bioeconomy principles, many countries worldwide are focused on developing plans with a perspective up to 2050. The main sectors where bioeconomy principles are applied globally include agriculture, light industry, and bioenergy. In Ukraine, the bioeconomy strategy is developing at a slower pace. However, the developed 10R bioeconomy strategies can be adapted in Ukraine, considering the processing industry's development trends. Given the active development of agriculture in Ukraine, including many raw hides (cattle cow, bovine, etc.), the tasks of processing animal hides are relevant. It is known that a large amount of water, energy resources, and chemicals are used in such processing. A significant amount of waste is also generated, which can be used to implement bioeconomy principles. The study optimized the use of raw materials and chemicals by reducing or reusing water and solid leather production waste. It was found that the principles of R2 (Reduce), R3 (Reuse), R8 (Recycle), and R9 (Recover) can be implemented in leather production. The principles of R8 and R3, through the processing of biogenic raw materials and reducing the use of chemicals at the stages of leather production, respectively, have the highest efficiency before implementation.

KEY WORDS: bioeconomy, leather, raw hide, water and solid wastes, technological processing

IMPLEMENTAREA PRINCIPIILOR BIOECONOMIEI ÎN PRODUCȚIA DE PIELE

REZUMAT. Bioeconomia este o abordare promițătoare pentru conservarea resurselor și diminuarea impactului negativ asupra mediului. Având în vedere potențialul ridicat al principiilor bioeconomiei, multe țări din întreaga lume se concentrează pe dezvoltarea unor planuri cu o perspectivă până în 2050. Principalele sectoare în care principiile bioeconomiei sunt aplicate la nivel global includ agricultura, industria ușoară și bioenergia. În Ucraina, strategia în domeniul bioeconomiei se dezvoltă într-un ritm mai lent. Cu toate acestea, strategiile dezvoltate în domeniul bioeconomiei 10R pot fi adaptate în Ucraina, ținând cont de tendințele de dezvoltare ale industriei de prelucrare. Având în vedere dezvoltarea activă a agriculturii în Ucraina, ce include și prelucrarea multor tipuri de piei brute (bovine, de vițel etc.), operațiunile de prelucrare a pieilor animale sunt relevante. Se știe că în astfel de operațiuni se consumă o cantitate mare de apă, resurse energetice și substanțe chimice. De asemenea, se generează o cantitate semnificativă de deșeuri, care pot fi utilizate pentru implementarea principiilor bioeconomiei. Studiul a optimizat utilizarea materiilor prime și a substanțelor chimice prin reducerea sau reutilizarea apei și a deșeurilor solide din producția de piele. S-a constatat că principiile R2 (Reducere), R3 (Reutilizare), R8 (Reciclare) și R9 (Recuperare) pot fi implementate în producția de piele. Principiile R8 și R3, prin prelucrarea materiilor prime biogene și, respectiv, prin reducerea utilizării de substanțe chimice în etapele producției de piele, au cea mai mare eficiență înainte de implementare.

CUVINTE CHEIE: bioeconomie, piele, piele brută, apă reziduală și deșeuri solide, procesare tehnologică

MISE EN ŒUVRE DES PRINCIPES DE LA BIOÉCONOMIE DANS LA PRODUCTION DE CUIR

RÉSUMÉ. La bioéconomie est une approche prometteuse pour conserver les ressources et réduire l'impact négatif sur l'environnement. Compte tenu du potentiel élevé des principes de la bioéconomie, de nombreux pays du monde entier se concentrent sur l'élaboration de plans avec une perspective allant jusqu'en 2050. Les principaux secteurs dans lesquels les principes de la bioéconomie sont appliqués à l'échelle mondiale comprennent l'agriculture, l'industrie légère et la bioénergie. En Ukraine, la stratégie bioéconomique se développe à un rythme plus lent. Cependant, les stratégies développées dans le domaine de la bioéconomie 10R peuvent être adaptées en Ukraine, en tenant compte des tendances de développement de l'industrie de transformation. Compte tenu du développement actif de l'agriculture en Ukraine, qui comprend la transformation de nombreux types de peaux brutes (bovins, veaux, etc.), les opérations de transformation des peaux d'animaux sont pertinentes. De telles opérations sont connues pour consommer une grande quantité d'eau, de ressources énergétiques et de produits chimiques. En outre, une quantité importante de déchets est générée, qui peut être utilisée pour mettre en œuvre les principes de la bioéconomie. L'étude a optimisé l'utilisation de matières premières et de produits chimiques en réduisant ou en réutilisant l'eau et les déchets solides issus de la production du cuir. Il a été constaté que les principes R2 (Réduire), R3 (Réutilisation), R8 (Recycler) et R9 (Récupération) peuvent être mis en œuvre dans la production du cuir. Les principes R8 et R3, en traitant respectivement des matières premières biogéniques et en réduisant l'utilisation de produits chimiques dans les étapes de production du cuir, ont la plus grande efficacité avant leur mise en œuvre.

MOTS CLÉS : bioéconomie, cuir, peau brute, eau résiduelle et déchets solides, transformation technologique

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INTRODUCTION

The Lund Declaration outlines challenges related to global environmental issues, food security, healthcare, industrial restructuring, and energy security [1]. These problems are defined as persistent, complex, and pressing. However, their resolution may lead to further crises for future generations. Therefore, safety, health, well-being, and environmental preservation issues are becoming increasingly relevant [2, 3].

With the advancement of scientific and technological progress, economic growth has become the primary priority of economic activities worldwide, while environmental sustainability has gained significant importance in recent times. The role of bioeconomy is aimed at combining these priorities.

Over the past two decades, bioeconomy has demonstrated its viability as a sustainable business model and economic development form for countries worldwide. Thanks to the application of modern technological methods (in the extractive and processing industries), it has become possible to reduce the absolute amount of extracted energy used and environmental pollution by reducing greenhouse gas emissions [3]. The place and role of bioeconomy in solving global human problems are defined in strategic programs for the transition to a bioeconomic development path of national economies in countries such as the United States, the United Kingdom, and the European Union, as well as by the amount of financial resources allocated for their implementation at the international, regional, and local levels [4].

Given the high potential of bioeconomy, many countries worldwide are focused on creating development plans with a perspective up to 2050. In EU countries, bioeconomy has various development characteristics. For example, the bioeconomy of Finland, Sweden, Estonia, and Latvia is primarily focused on the forestry sector; in Italy and Portugal, 14% and 16% of the bioeconomy model is implemented in the field of biotextile production, respectively; 36% of the bioeconomy value added in Ireland and 35% in Denmark falls on the production of biochemicals, pharmaceuticals, polymeric materials, and rubber.

Since 2018, the EU has been implementing a bioeconomy strategy in three key areas: accelerating the bioindustry development, promoting the bioeconomic development of urban and rural areas, and protecting ecosystems [5].

In 2021, the EU published the report "Foresight Scenario for the EU Bioeconomy in 2050: The Future Transition of the Bioeconomy towards Sustainable Development and a Climate Neutral Economy". According to the EU report, the bioeconomy should be aimed at sustainable development and climate neutrality, as well as improving its inclusivity in EU member states' economic and social realities [5].

In Ukraine, the bioeconomy strategy is developing at a slow pace and has a fragmented nature. The main sectors in Ukraine where bioeconomy principles are applied are agriculture, light industry, and bioenergy. In this regard, a targeted policy for the development of the bioeconomy in Ukraine, supporting the bioeconomy sector, can become a driving force in the sustainable development of the national economy [5].

EXPERIMENTAL

Material and Methods

This study aims to develop a set of guiding principles of bioeconomy for effective implementation in leather production, focusing on resource conservation, reducing biogenic waste, and promoting reuse.

The object of this study is the technological processes and parameters of leather production.

The subject of this research is the typical patterns of solid and liquid waste generation at different stages of the leather production process.

A combination of general scientific and specialized methods was employed in this research: analysis and synthesis, a systemic approach, comparison, and generalization of official data from the State Statistics Service of Ukraine and the State Customs Service of

Ukraine. Methods of logical analysis and generalization of scientific literature, statistical data on the cultivation of raw hides, skins, and pigs, production, export, and import of tanned leather from raw hides were used.

The definitions of "bioeconomy" and "bioeconomy strategies" were interpreted through theoretical research methods, including analysis, systematization, and logical generalization. A hypothesis was put forward regarding the implementation of bioeconomic strategies by conserving resources, reducing the quantity, and reusing biogenic waste generated during leather production. The obtained assumptions and conclusions were confirmed by existing methods of processing leather industry waste aimed at creating an environmentally friendly direction by reducing the amount of water and solid waste.

Traditional technologies for processing animal hides into natural leather were used to formulate the principles of the bioeconomy and their application in leather production. The sequence of technological processes involves preparatory (beamhouse), tanning, and finishing treatments.

A list of the most commonly used chemicals and their consumption was analyzed for the research. The types and stages of obtaining water and solid waste were analyzed.

Information on known methods of reducing the consumption of chemicals for processing hides and methods of reusing waste for both leather production and the creation of products for other purposes was used.

RESULTS AND DISCUSSION

Implementation Pathways for the Bioeconomy

The scientific community interprets the bioeconomy as a vast system that connects natural resources, technologies, markets, people, and policies. Bioeconomy unites processes that were previously impossible to combine: business and sustainability; ecosystems and industry; innovative and traditional processes, technologies; raw materials of biogenic origin and finished products [6, 7].

Effective resource management and processing are also important directions of the bioeconomy. The conceptual model of the bioeconomy describes a system in which primary renewable resources, as well as secondary ones, which are waste, in the process of applying knowledge, innovations, and technologies, are transformed into environmentally oriented and resource-saving processes, products, and services. The originality of this phenomenon lies in the sustainability and efficiency of renewable resources [8].

The bioeconomy rethinks what is considered waste, using characteristic processes that can not only reduce waste generation but also reduce the number of raw materials required for production [5].

The first bioeconomy model was built on the principles of the "3R-strategy". These principles included the "Reduce, Reuse, Recycle" strategies, which appeared in the 1970s [5]. In recent years, the number of bioeconomy strategies has increased, given the expediency of waste processing. As of 2024, 10R strategies have been proposed (Table 1). To systematize the directions of bioeconomy development, the 10R strategies are aimed at creating, preserving, and restoring the value of invested resources and understanding the different stages of their use in the bioeconomy. R-strategies are resources and principles for shaping a sustainable circular future.

The 10R-strategies are categorized into three groups that demonstrate the length of the waste cycle (short, medium, and long). The shorter the cycle, the more sustainable the strategy. The higher the strategy in the hierarchy, the tighter the waste loop. This means that the strategy requires fewer materials and is therefore more circular. Smaller numbers also indicate the beginning of the value chain, while larger numbers indicate the end [9].

Short cycles focus on more efficient production and product use: R0 – Refuse, R1 – Rethink, R2 – Reduce. Medium cycles focus on strategies to extend product lifespan: R3 –

Reuse, R4 – Repair, R5 – Refurbish, R6 – Remanufacture, R7 – Repurpose. Long cycles focus on alternative uses of the material: R8 – Recycle, R9 – Recover. The positive impact on circularity and overall sustainability is higher at the beginning of the material value chain, where the strategies are numerically the smallest and the waste cycle is the shortest [9].

Table 1: Description of R-strategies for a sustainable bioeconomy

Strategy	Name	Characteristic	Scope of application
R0	Refuse	A strategy that prohibits the use of certain materials considered harmful.	
R1	Rethink	A strategy focused on intensive product use through the introduction of new products to the market.	
R2	Reduce	This strategy aims to minimize consumption and increase production efficiency.	
R3	Reuse	Extending the lifespan of products through reuse for their original purpose.	
R4	Repair	Repair and maintenance of a faulty product to restore its functionality.	
R5	Refurbish	Restoring an old product to its original condition.	
R6	Remanufacture	Remanufacturing involves integrating product components that are still intact into new ones.	Agriculture, food, medical, pharmaceutical, pulp and paper, forestry, fuel and energy, chemical, mechanical engineering
R7	Repurpose	This strategy incorporates waste into another product for benefit or an alternative purpose.	
R8	Recycle	Using materials through recycling when a product can no longer be used, but it contains materials that can be recovered.	
R9	Recover	Extracting value from waste through composting organic waste (producing biogas).	

These 10R-strategies can be adopted in Ukraine to address the development of agriculture and the processing industry. Ukraine is an agricultural country with a constantly developing livestock industry. Given the number of livestock, the issue of animal skin processing is relevant. As a result of such processing, a significant amount of waste is generated that can be used in the implementation of bioeconomy strategies in Ukraine, using the example of the leather industry.

Dynamics of Leather Raw Material Volumes

The state of the livestock sector is a significant component of the Ukrainian economy, as evidenced by the analysis of raw hides and pig production volumes during 2019-2023 (Figure 1).

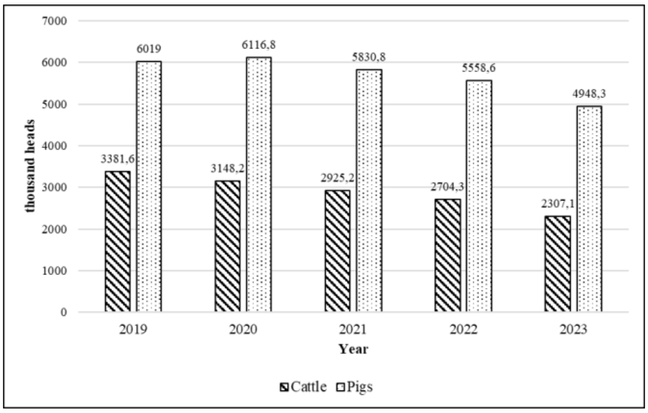


Figure 1. Dynamics of raw hides and pigs herd growth in Ukraine during 2019-2023 [10]

An analysis of the data in Figure 1 shows a gradual decrease in the number of raw hides raised during the studied period. As of 2019, this figure was 3381.6 thousand heads, and in 2023, it was 2307.1 thousand heads, a decrease of 31.7%.

A similar trend is observed in the case of pig farming. In 2019, the number of pigs raised was 6019.0 thousand heads, and in 2023, it was 4948.3 thousand heads, a decrease of 17.7%.

Overall, the number of pigs raised significantly exceeds the number of raw hides. Moreover, in 2019, the difference was 1.7 times, and in 2023, it was 2.2 times. As of 2023, Ukraine ranked 25th in the world in terms of pig exports and 32nd in terms of raw hides exports.

Based on this, it can be concluded that there is an objective availability of a sufficient number of hides obtained from livestock, and, accordingly, the emergence of tasks for processing leather raw materials. There are a significant number of leather enterprises in Ukraine: Kyiv (LLC "ULTRA LEATHER"), Voznesensk (LLC "V-CENTER", LLC "UKRTAN", LLC "UtaCo Ltd"), Berdychiv (LLC "SHKIRZAVODVELEC"), Vasylkiv (LLC "SLAVA"), Zhytomyr (LLC "EMI-UKRAINE LTD"), Lviv (LLC "STROFARIYA"), Bolekhiv (Tzov "SVIT SHKIRY").

These enterprises provide sufficient volumes of natural leather production (Figure 2), however, an analysis over five years indicates a significant reduction in the production of leather from rawstock.

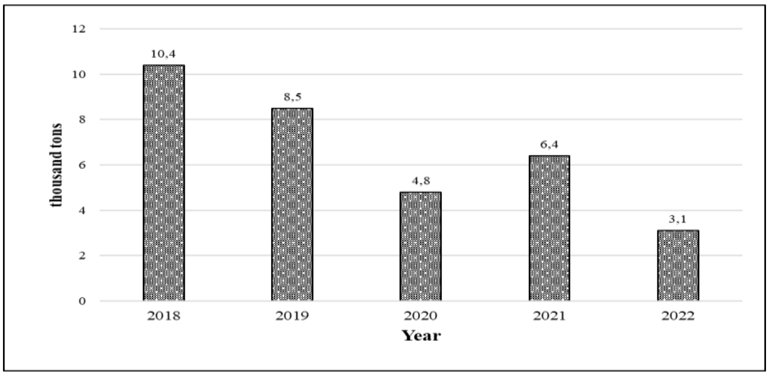


Figure 2. Dynamics of leather production volumes from raw hides in Ukraine during 2018-2022

Figure 2 demonstrates a more than threefold decrease in the production of leather from raw hides between 2018 and 2022. However, in 2021, compared to 2020, there was a 33.3% increase in the production of leather from raw hides. The most significant decline was observed in 2022 compared to the previous year [11].

It should be noted that Ukraine has a high export potential for semi-finished items made from hides and skins of bovine (Figure 3).

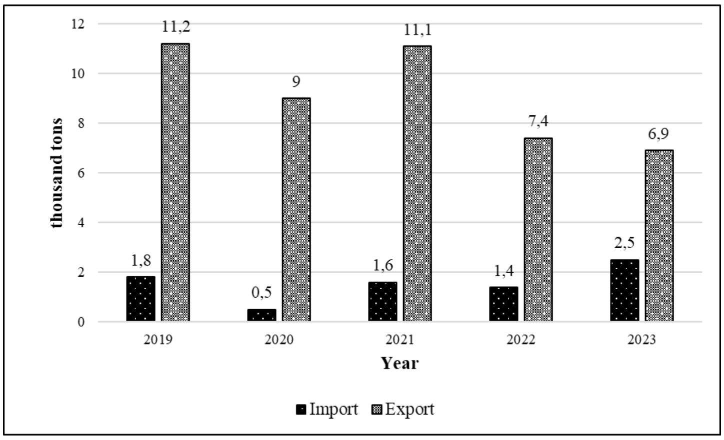


Figure 3. Dynamics of imports and exports of semi-finished items of bovine (HS code 4104) in 2019-2023, in physical terms

According to the State Customs Service of Ukraine, the dynamics of Ukraine's foreign trade in semi-finished items from bovine hides (HS code 4104) exhibited an unstable trend from 2019 to 2023. There was a tendency towards a decrease in exports of semi-finished items by 38.4% [12]. During 2019-2020, exports decreased by 19.6%. In 2021, this figure increased to 11.1 thousand tons. However, in 2023, there was a decline of 6.7% compared to 2022.

Export volumes were significantly higher than imports. However, while in 2020 exports exceeded imports by a factor of 18, in 2023 this ratio decreased to 2.7. An analysis [12] showed a decrease in imports of semi-finished items into Ukraine by 22.2% from 2019 to 2022. In 2023, there was an increase in this indicator from 1.4 thousand tons to 2.5 thousand tons compared to 2022, or 1.7 times [12]. Italy was the main importing and exporting country for semi-finished items in 2023. Its share in imports was 40.2%, and in exports, it was 91.4%. In addition, among the main importing countries were Kyrgyzstan with a share of 29%, and Kazakhstan with 14.3%, while among the exporting countries were Turkey and Poland with 6.8% and 1.1%, respectively [12].

Therefore, Ukraine has significant livestock numbers and efficient leather production, and thus, bioeconomy strategies in Ukraine can be implemented through resource-saving and waste processing of leather raw materials.

Implementation of Sustainable Bioeconomy Principles in Leather Processing

The leather production process involves a complex series of treatments of raw materials and semi-finished products, which can be divided into liquid processes (carried out in an aqueous environment using chemicals) and mechanical operations (changing the shape of the processed dermis structure) [13].

Generally, the leather production process is divided into three stages: preparatory (beamhouse), tanning, and finishing. The preparatory stage includes soaking, liming, unhairing, fleshing, splitting, deliming, bating. Preparatory processes are aimed at performing several sequential tasks: hydrating the dermis structure, loosening collagen fibers, removing interfibrillar proteins, hair, epidermis, and flesh, peptization of structural elements, and lowering pH for their structuring.

The fixation of the dermis structure is ensured by the tanning process, usually chrome tanning. Tanning provides stability to the leather semi-finished product to external factors: light, heat, ultraviolet radiation, and the action of microorganisms, and also forms high hydro-thermal stability and physical and mechanical properties. Subsequent retanning of the dermis is carried out with vegetable tannins and syntans to form the hygienic and organoleptic properties of leather, giving it softness, fiber density, and elasticity. During wet finishing, polymeric or mineral fillers, dyes, and fatliquoring materials complete the formation of the volume structure of the dermis, capable of elastic-plastic deformation, with a high level of elasticity and air permeability. The finishing stage of the leather surface includes drying and moisturizing processes and coating finishing, which include: setting, sammying, trimming, staking, drying, moisturizing, boarding and softening, buffing, dedusting, pressure treatment, as well as applying a protective coating to the grain surface of the leather.

After finishing, the leather acquires the necessary appearance and corresponding hygienic properties [14]. Acids, alkalis, chromium salts, tanning agents, solvents, sulfides, dyes, auxiliaries, and many other compounds used in the processing of leather raw materials to obtain natural leathers are not completely fixed in the dermis and create a significant amount of water waste (Ww – Water wastes). These wastes are the cause of increased levels of biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and total suspended solids (TSS).

It has been established that chemical compounds that are difficult to purify in wastewater are obtained during the tanning process. Considering that about 30-40 liters of water is used for each kilogram of raw hides, of which 35% is used during washing, and 55% is used during liquid processes or mechanical operations, a significant level of environmental pollution by leather production can be predicted [14].

The stages of the leather production process and the scheme of waste formation during the processing of leather raw materials are presented in Figure 4.

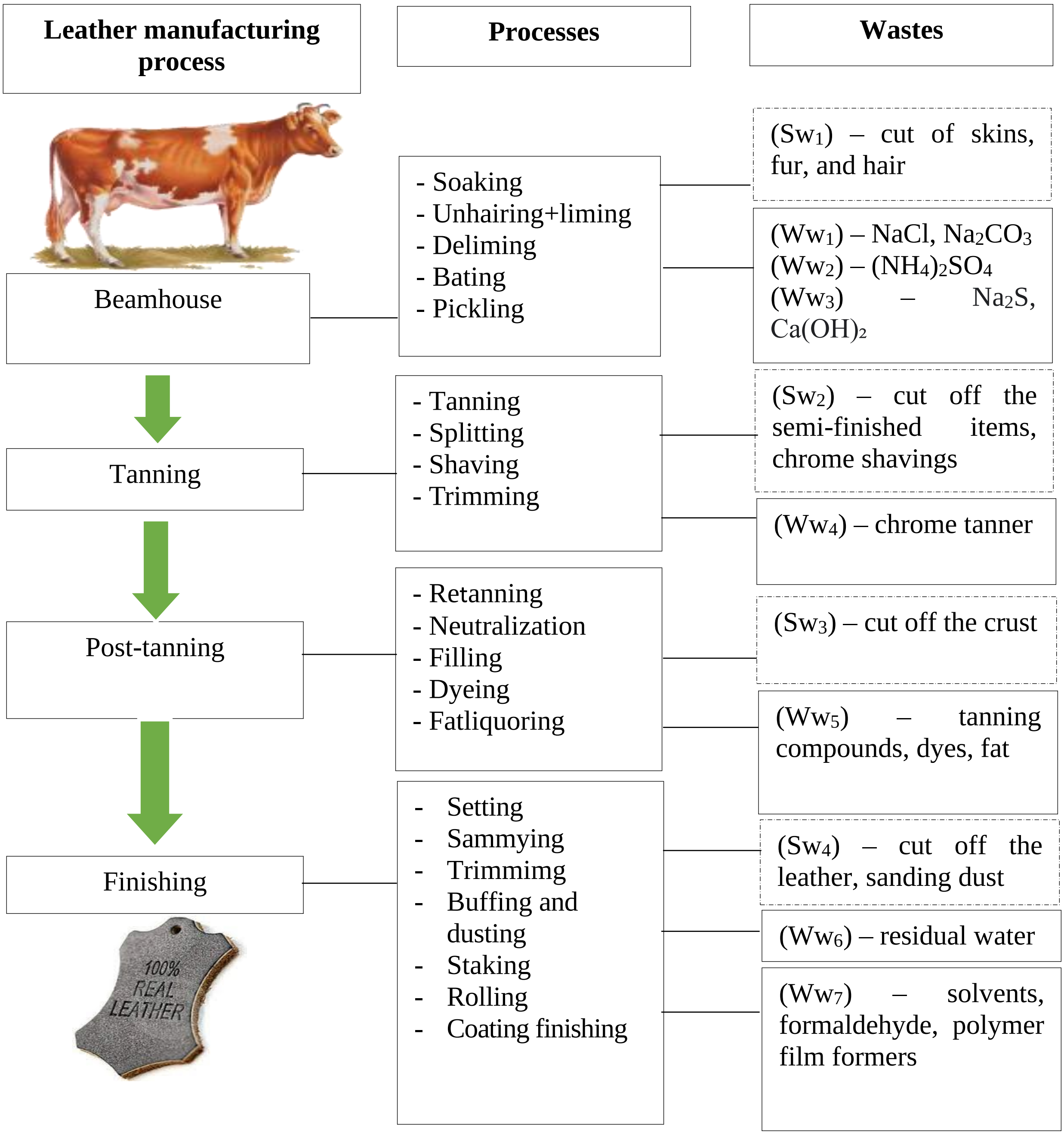


Figure 4. The leather manufacturing process and the waste materials produced at each stage

It is known that approximately 0.80 kg of waste is generated from each kg of raw hides. These wastes are used for the production of other materials, such as glue, gelatin, and protein feed for pets. Extracted collagen, peptides, and amino acids obtained from leather production waste are actively used in cosmetology, biopharmaceutics, wound healing materials, etc. [14].

During leather production, solid wastes (Sw – Solid wastes) is also generated, which poses a significant economic and environmental problem for society and the environment. According to research [15], the composition of solid waste from leather production includes removed salts, hair waste, shaving trimmings, leather shavings, etc. Additionally, during the treatment of leather production wastewater, sediments, and other solid waste are also formed.

Environmental problems associated with improper disposal of leather industry waste arise both from the quantity and quality of waste. On average, the leather industry produces 45-50 m^3 of water waste and 800 kg of solid waste per 1 ton of finished leather product. The processing of one ton of raw materials produces an average of 200 kg of finished tanned leather, 200 kg of tanned leather waste, 250 kg of untanned waste, and 50 m^3 of wastewater. The most common method of managing solid waste from the leather industry is landfilling. However, due to the unpleasant odor caused by putrefaction and the harmful content of fat-containing waste, landfilling negatively affects the soil and water resources of the environment [15]. In this regard, environmental protection agreements are gaining momentum worldwide, forcing the leather industry to reuse waste generated at various stages of leather production [16].

Today, there are many methods for processing leather industry waste aimed at creating an environmentally friendly direction by reducing the amount of water and solid waste.

As a result, the introduction of the principles of a sustainable bioeconomy in the processing of raw hides and skins will reduce waste generation and save the resource-saving raw stock.

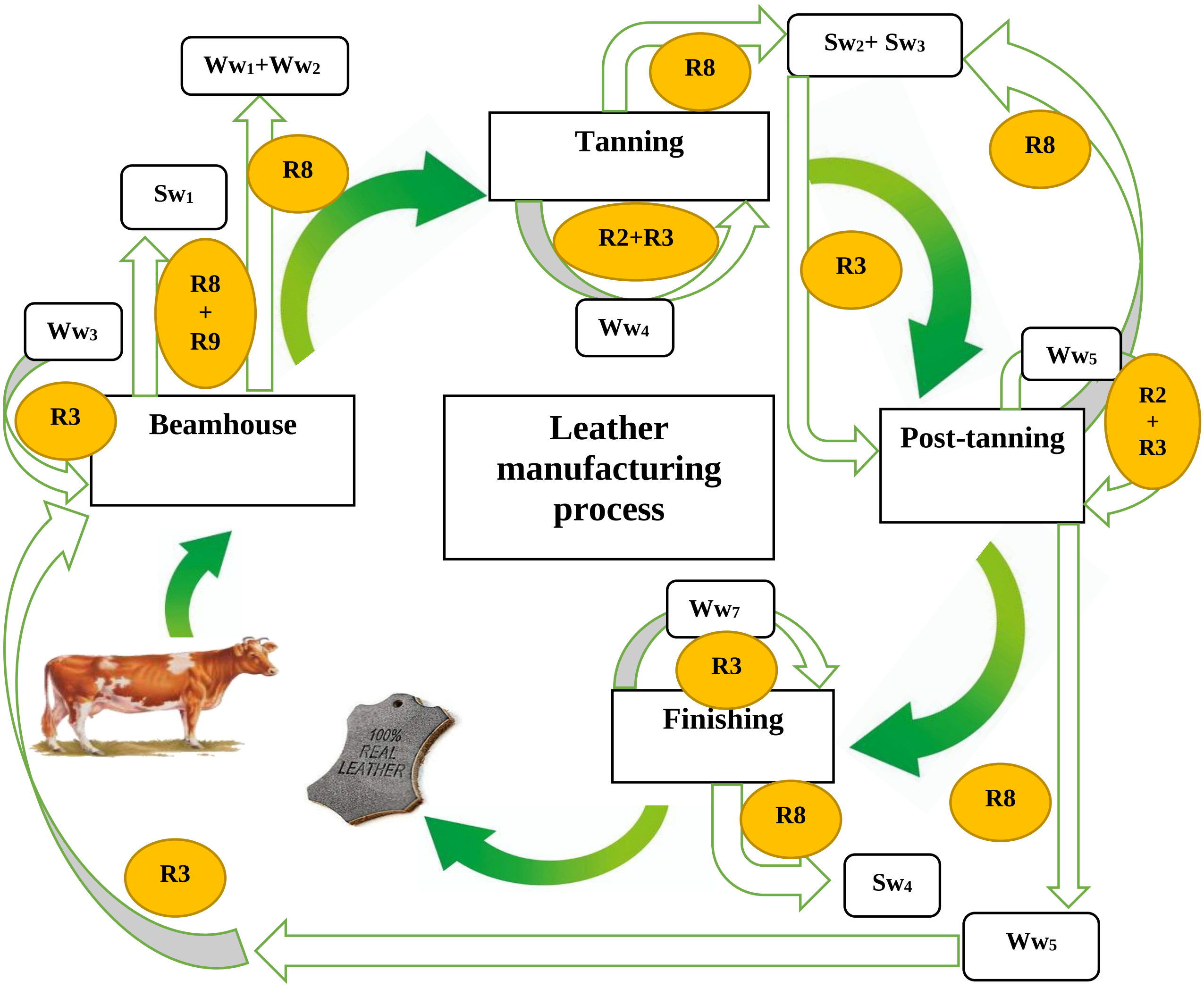
Among the existing 10R-strategies of the bioeconomy (Table 1) for the processing of leather raw materials, the following can be introduced: R2 – Reduce, R3 – Reuse, R8 – Recycle, R9 – Recover [5]. The sequence of leather production stages, a schematic representation of the formation of water and solid waste, and the appropriate introduction of the indicated principles of bioeconomy strategies are presented in Figure 5.

After the beamhouse stage, Sw_1 (cut of skins, fur, and hair), (Ww_1) – NaCl, Na_2CO_3; (Ww_2) – $(NH_4)_2SO_4$; (Ww_3) – Na_2S, $Ca(OH)_2$ are formed.

The implementation of the sustainable bioeconomy principle R3 can be achieved by reusing $Ca(OH)_2$ from Ww_3 (adjusting its concentration to– 10-15 g/l) [17]. Principles R8 and R9 can be ensured by recycling and recovering Sw_1 in other industries, respectively. Additionally, Ww_1, and Ww_2, formed at this stage of leather production, can be purified and used in other areas by implementing principle R8. For example, there are known methods for processing untanned solid waste to produce fleshing glue, collagen hydrolysates of varying degrees of dispersion, animal feed additives, components of water treatment filters, biohumus, plasticizers, mixtures for wool yarn sizing, etc. [18-23].

The implementation of the sustainable bioeconomy principle R9 is focused on the processing of fat-containing waste from the leather industry through anaerobic digestion to produce biogas. Typically, when using fat-containing waste, co-fermentation with cellulosic feedstock is used to stabilize the pH value [24].

The literature [24] discusses a method for obtaining biogas from water waste produced in the manufacture of chrome semi-finished products. The process involves the fermentation of pre-heat-treated chrome leather waste in the form of shavings and gelatin, with the latter being separated from chromium hydroxide during primary processing.



- leather manufacturing process;

- leather production waste and ways of its utilization;

R - implementation of the bioeconomy principle.

Figure 5. Implementation of the principles of bioeconomy in leather manufacturing process

After the tanning stage, Sw_2 (cut off the semi-finished items, and chrome shavings) and Ww_4 (cut off the leather, and sanding dust) are formed.

The implementation of sustainable bioeconomy principle R2 in leather production can be achieved by reducing the amount of Ww_4 during the tanning process using montmorillonite [25]; R3 - by reusing purified water waste after the tanning process Ww_4 [26]; R8 – by recycling tanned waste Sw_2 and using it at the next stage of leather production in the filling process [21].

It has been established that the range of uses for tanned waste in recycling is significantly narrower. This is due to the presence of salts, mineral tannins, and fats in the waste; the formation of additional bonds with chemical materials in the protein structure, and, consequently, a change in the properties of collagen itself. The list of technologies different countries proposed for processing tanned by-products includes various methods for obtaining biogas and biodiesel, mineral or organic fertilizers, filler compositions for artificial leather, polymeric and composite materials, concrete mixtures, etc.

The implementation of principle R8 involves the recycling of tanned collagen-containing waste, which can be used as fillers in leather production. They fully retain the unique hygienic properties of natural leather. For filling leather semi-finished products, fleshing glue, a hydrolyzate obtained by an enzymatic method from untanned waste, is used. Retanning and filling are carried out with an alkaline hydrolyzate of chrome shavings, and an acid hydrolyzate using sulfuric and acrylic acids. Positive results were obtained when fatliquoring leather semi-finished products with a fat emulsion of synthetic fat, in the manufacture of which a hydrolyzate obtained by an enzymatic method of fleshing glue was used as an emulsifier and stabilizer [21, 27]. The use of collagen dissolution and dispersion products in coating finishing contributes to improving the hygienic properties of the finishing leather and increasing its adhesion to the leather.

In addition, collagen-containing waste is a valuable raw material for producing artificial leather. Tanned waste is subjected to mechanical fiberization before use, from which fabrics and non-woven materials are formed [20].

After the post-tanning stage, Sw_3 (cut off the crust) and Ww_5 (tanning compounds, dyes, fat) are formed.

The implementation of sustainable bioeconomy principles R2 and R3 can be achieved by reducing the amount and reusing Ww_5 respectively, during the post-tanning stage of leather production [21], while R8 will ensure the recycling of Sw_3 in the production of leatherboard, which is an auxiliary shoe material used in the manufacture of shoe components, such as backstays, insoles, etc. One of the most rational ways to utilize tanned waste is the production of leatherboard, which contains 70-75% leather fiber [20, 21].

It is advisable to process Sw_3 in such a way that it can be used to produce fillers for leather that can simultaneously chemically bond with it and retan it [21]. A large part of such fillers consists of partially hydrolyzed leather protein, that is, a substance that is close in its chemical composition to natural leather. In this regard, as a result of filling, it is necessary to expect the preservation of the most valuable quality of natural leather – its hygienic properties. When obtaining fillers for leather, the waste is detanned with an alkali solution, separated from chromium salts, washed, transferred to a solution when heated with water, and then polymerized together with vinyl monomers. The resulting products have a good effect when filling the leather. However, there are significant losses of alkali and chromium salts [20, 21].

After the finishing stage, Sw_4 waste (cut off the leather, sanding dust) and Ww_7 waste (solvents, formaldehyde, polymer film formers) are generated. The implementation of R3 sustainable bioeconomy principles can be achieved through the reuse of liquid Ww_7 waste [17]; R8 will allow the use of leather pieces, substandard products, defects, and trimmings of finished leathers as raw materials for the further production of various products or their finishing. Examples include the production of leatherboard, stamping buttons from scraps of sole, harness, saddle, or technical leathers, and the production of decorative and applied leather goods.

It should be noted that after each stage of leather production, water waste (Ww_1, Ww_2, Ww_3, Ww_4 and Ww_5), is generated, causing significant damage to the environment. Using waste treatment methods, these wastes can be used in other areas of agriculture and industry. Therefore, the implementation of principle R8 can be realized by recycling and using treated water waste for irrigation of agricultural lands, and R3 – by reusing treated wastewater in leather production [21].

According to the above and based on Figure 5, bioeconomy strategies can be implemented through (Figure 6):

- reducing the consumption of harmful chemicals during tanning and post-tanning processes (R2);
- reusing spent process liquids and products of leather waste recycling in the leather production process (R3);
- recycling solid waste and creating new products or materials (R8);
- recovering the chemical component of leather production waste into energy-useful compounds (R9).

Figure 6. Effectiveness of implementing the principles of bioeconomy in the leather manufacturing process

An analytical assessment of the potential for using bioeconomy strategies indicates that the total number of solutions for waste processing and resource conservation in leather production can be implemented according to the R8 (40%), R3 (40%), R2 (15%), and R9 (5%) principles.

CONCLUSIONS

Based on the findings, strategies R8 and R3 are deemed most suitable for the leather industry. These strategies enable efficient utilization of leather raw materials, leading to economic and resource savings in material and water usage, reduced costs for treating spent process liquids and wastewater, and the production of new technologically valuable materials for leather manufacturing or products for agriculture, other industries, medicine, and pharmaceuticals. Strategies R2, focusing on reducing chemical consumption, and R9, aimed at recovering waste from biogenic raw materials for bioenergy products, while beneficial, are expected to have a lesser impact on the leather industry.

Overall, the implementation of bioeconomy principles (R2, R3, R8, R9) within the leather production process can significantly reduce solid and water wastes, promoting the recycling and reuse of valuable secondary materials both within the leather industry and other sectors of the Ukrainian economy.

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