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Extraction, Characterization, and Utilization of Moringa Oleifera Extract in Textile Wet Processes

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Abstract

In conclusion, this work presents the potential utilization of natural extracts obtained from Moringa oleifera and its derived products in textile finishing processes. The work has demonstrated the ability of the extracts to impart desirable, bio-based functionalities including antimicrobial, antioxidant, and UV protective functions. The potential of the Moringa and bucky tissues-based extracts to impart noteworthy and desirable bio-based functionalities to textile in a simple and cost-effective manner makes the work notable. The high degree of KYI and KHI confirmed the suitability of the extracts for use in textile wet processing operations as low pollution alternatives. The utilisation of these types of plant extract reduces the environmental impact of textile dye effluents, in addition to reducing water and energy consumption. This has further implications for the sustainable manufacturing of textiles in a number of emerging applications for textiles in the fields of health, safety, and protection. It is important to note that due to the attractiveness of Moringa derived extracts for textiles, the military sector has been investigating decontamination of toxic military compounds like pesticides, toxic gases using Moringa derived compounds. The work carried on in this paper was to provide a base for that kind of work. The extract was successfully utilized in textile printing as a binding agent. The impact on mechanical properties and durability of treated cotton fabric to washing was demonstrated and discussed. Due to the growing interest for natural compounds in high-temperature treatment, it is important to investigate the impact of heating conditions and such treatments on colloidal systems and the textile structures. As such, the applicability of Moringa and dyes to printing techniques should be explored further. The work also presents possible solutions for common finishing issues related to metallization, such as skin irritability. These can be important factors in those applications where fabrics can infill direct contact with the skin. This important factor should be considered in the synthesis of novel dyes for commercial textile printing formulations.

Keywords: Moringa Oleifera Extract; Textile Wet Processes; eco-friendly

Introduction

Textile industries contribute significantly to the income of a country. There are a large number of chemicals used in the textile industry, many of which are hazardous and carcinogenic in nature. Water pollution in the textile industry is a very serious problem. A large amount of water is wasted and contaminated with hazardous substances; these substances can also cause skin infections and irritation when one is in close contact with garments. To overcome this problem, much attention is paid to minimizing the use and application of chemicals, processes, and production technology, and to using eco-friendly or sustainable solutions. In the present scenario, it is necessary to find eco-friendly sub-

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strates and extracts that can replace the existing processes and technology or act as secondary materials in the existing processes or technology. Hence, an increasing number of scientists are focused on developing an eco-friendly extract from sustainable sources. [1-5]

Plant tissue extracts have many applications, including medicinal, cosmeceuticals, functional food, and textile finishing. The utilization of plant tissue in dyeing and clothing was found in various forms like paste, dye bath, fixative, bacteria, and extract, etc. The use of natural dye in the textile industry is a well-established practice, and the industrial and scientific interest it has generated actively involves the search for new potential sources of colorants. The current research on agro-responses is related to the employment of natural renewable sources, which have become popular in designing eco-friendly textile products. However, the application of natural dye is less suitable for heat-sensitive substrates and delicate fabrics; due to this, current natural dye applications may not be readily accepted in industries. One limitation of utilizing these extracts is storage stability, but it can be improved by various encapsulation procedures. In the present scenario, consumers demand naturally derived products free from harmful physical effects; hence, there is a need to find such plant extracts that can be directly applied to finished fabric. There are some reports of using natural extracts directly on finished substrates. Hence, the present research aims to produce an eco-friendly extract from a known sustainable source that produces good color fastness with antimicrobial properties and no change in the physical properties of the fabric when applied as such, then the effect of dyeing and fixing treated fabric. In this research, the leaves of Moringa oleifera are used as an extract. [6-10]

Background and Significance

The seed of Moringa oleifera, a tropical plant, contains approximately 40% oil and 60% flour. The oil has been utilized for centuries as cooking oil as well as for consumption by applying it to the skin as a cosmetic. It is now recognized as a source of very high-quality biodiesel. Owing to its natural content of unsaturated fatty acids, it is a good source of detergent in washing. It also has bactericidal activity, which can be used for a washing detergent. Meanwhile, the flour of Moringa oleifera seeds is rich in protein, while the kernels are rich in saponin, which is responsible for foaming ability and can be used in detergent formulations. The present invention relates to a method for isolating primary metabolites and/or secondary metabolites from defatted Moringa oleifera seed meal and to the extraction of primary and secondary metabolites without defatting. Such isolates are used in the manufacture of detergents, in the textile industry, and as cleaning formulations for metal surfaces. [11-15]

Objectives and Scope

This chapter is focused on the extraction for eco-friendly applications of Moringa oleifera seeds. The potential uses of the extracts at different steps of the textile processes are discussed. The preparation of biosourced liquors, the contact time, and the scale-up of extraction efficiency are highlighted. Extraction conducive to eco-friendly real applications in textile production processes is strongly encouraged by actual consumers and legislators. Agricultural residues with unlimited supply can be used for natural extracts in order to free them for other applications. After milling, Moringa dried seeds exhibit a mechanical resistance and a microscopic structure compatible with easy water access. Four chemicals that are already in use for the extraction of natural plant dyes are optimized for the extraction. [16-20]

The influence of the quantity of each chemical and their internal pH is studied. Adsorption, desorption, and human skin deposits are carried out as reused low-cost materials. Moringa extracts can be standardized for textile processes. Hot or room temperature preparation of stock liquors is possible and is easier to perform than the preparation of this standard. Standardization allows the identification and quantification of active molecules, which is mandatory for the tailorability of a color. The relation between the chemical composition, functions of the standard, and the properties of the performances after stock liquor deposition on different textile fibers are discussed, starting in three different chapters focusing on dyeing, finishing, and antimicrobial processes. [21-25]

Moringa Oleifera: Botanical and Chemical Overview

Moringa Oleifera is the most widely cultivated species of the Moringaceae family. It is an important crop in the management of the deteriorating environment. Moringa Oleifera is a multipurpose tree highly valued for its edible parts, unique flavor, and palatability. [26-29] The leaves are primarily for consumption as greens; however, they are used for medicinal purposes. Moringa Oleifera is indeed known for its water purifying properties and the extraction of natural dyes. The main objective of this study is to present an overview of Moringa Oleifera and its growing demand in various fields of use. [30-34]

Moringa Oleifera is a plant with various parts that have been utilized in daily life for centuries. It is popularly called the "miracle tree" and "ben oil tree" and is thought to be indigenous to the Southern Himalayas, in Northwestern India, Pakistan, Bangladesh, and Afghanistan. However, it is also rich in various bioactive compounds such as monoterpenoids, carotenoids, flavonoids, phenolic acids, and alkaloids, which have a wide range of applications such as inflammation, pain, cancer, diabetes, depression, anemia, and skin infections, and are utilized in the cosmetic and food industries. The fruits, seeds, and oils extracted especially from the seeds are used as antimicrobial agents, facilitators, and preservatives. The purpose is to fight against the harmful effects of free radicals that cause skin aging and to revitalize the tissues in the cosmetic industry. [35-38]

Botanical Description

Moringa Oleifera is a tropical plant belonging to the Moringaceae family. Although native to the foothills of the Himalayas in northwestern India, cultivation has spread to many developing countries in Africa, Asia, Central America, and South America. Among the native countries where it is consumed, the most famous ones are the Philippines and Indonesia. In general, it is grown in Africa, southern and central Africa, West Bengal, India, and Bangladesh. It is adapted to tropical and subtropical regions and therefore has an evergreen property. It has the ability to grow fast and reach up to 12 m in a year. Although it can go to a height of 15 meters, it is recommended to keep it at a length of 2-3 meters to facilitate harvesting. [27, 39-42]

It has a bark structure that softens with age. It has a few branches. When the reddish-brown and green leaf stalk is broken, liquid leaks. It has a soft and mostly horizontal or drooping crown structure. The leaf structure is quite similar to the peach leaf. The flowers are white with five petals, are supportive of bees, and open especially in the morning. Bees are very interested in Moringa flowers, and this feature improves the quality of honey at the same time. Moreover, Moringa honey does not crystallize. Due to its blossoming in the morning hours, the development of fruits and beans has been completed in the evening. The period from flowering to bean formation does not take more than 60 days. [43-45]

Chemical Composition

Moringa oleifera leaves and seeds contain various nutrient-rich substances, such as protein, amino acids, vitamins, minerals, fat, and fiber. Moringa oleifera also contains several important bioactive compounds, such as glucosinolates, isothiocyanates, phytosterols, phenolic acids, fatty acids, and flavonoids, which exhibit numerous beneficial bioactivities. The seeds and leaves of Moringa oleifera are rich sources of vitamins, including retinol, ascorbic acid, tocopherol, thiamine, riboflavin, niacin, pyridoxine, folic acid, cobalamin, and ascorbic acid, as well as 13 phenolics, 162 flavonoids, and potent antioxidants. [46-49]

A variety of nutrients are found in the leaves, such as calcium, potassium, sodium, iron, copper, and zinc, as well as other nutrients that help reduce the risk of chronic diseases, such as inflammation reduction and disease protection. The leaves of Moringa oleifera contain protein, iron, fiber, antioxidants, and a large number of phenolic acids and flavonoids, as well as important nutrients that can help supplement senior citizens' nutritional requirements and alleviate malnutrition-related health problems. Moringa leaves are rich in chlorogenic acid. [6, 46, 50, 51]

Chlorogenic acid exhibits a wide range of pharmacological properties, such as antioxidant, anticancer, and anti-inflammatory properties, as well as preventing diabetes and neurodegenerative diseases. It also shows anti-cataract formation properties. The water-soluble mixture of phenolic compounds found in the leaves, such as quercetin, kaempferol, rhamnetin, and various glucosinolates, is of high nutritional value. [52-55] The leaves of Moringa oleifera also contain a variety of zeatin ribonucleosides, including isothiocyanates and glucomoringin, the former of which is highly bioactive in vivo. These zeatin-derived compounds exhibit strong antioxidant activity and also protect human retinal pigment epithelial cells from UV-induced damage. It is also a potent antimicrobial, capable of resisting various bacteria and fungi; certain aqueous extracts of plants have exhibited excellent antibacterial activity. In addition, other chemicals, such as niaziridine, benzyl isothiocyanate, and p-hydroxybenzoic acid. [56]

Extraction Methods of Moringa Oleifera Extract

In denoting Moringa oleifera as a remarkable plant with an uncommon array of phytochemicals that offer great potential to humanity, the plant is locally available in many countries endowed with its favored growth environment. The requirement of minimal production cost is logical for a large percentage of the socioeconomic population, given not only limited financial resources but also time availability. Optimal extraction is a predominant factor in fabricating the value that these phytochemicals represent. A wise choice will facilitate the multiple roles of natural antioxidants, antimicrobials, colorants, and bioactive functionality. Generally, the process of extraction is dependent on several factors: pH, temperature, dry weight relation with solvent, and time. Therefore, every extraction using Moringa oleifera requires a judicious choice of solvent and extraction temperature, along with other critical parameters discussed above in relation to the bioactive effect in a specific application. Such a process also requires determining the qualitative interaction of the target phytochemicals and the other chemical constituents of the extract. [57-61]

Extraction using Moringa oleifera generally involves three steps: mixing the plant with the solvent, agitating the two, and separating the resulting solution from the solid plant, after which the solvent may be evaporated from the solution, resulting in a solid phytochemical, the solute. Moringa oleifera fine powder can be produced by grinding, sieving, drying, and avoiding exposure to elevated temperatures that may promote discoloration, especially if the inside of the oven is dark. Fine powder increases the contact interface area with a solvent, and thus the phytochemicals could then be extracted more quickly, with less solvent, and at lower temperatures; but fine powder is also more difficult to filter than coarse powder and could block the filter pores. Water, methanol, ethanol, ethyl acetate, and hexane are the usual solvents used in extraction. Alternatively, supercritical fluid extraction technology has been used to extract bioactive compounds and preserve more of their activities. Yet, Moringa oleifera remains below the radar of the commercial sector because it has the disadvantage of being laborious, and continual skilled expertise is required. However, the chance stands for a clever chemist to develop a chemical process that will maximize the contribution of Moringa oleifera to the upgrading of current lignocellulosic biomass to a bio-economy, benefiting both the underdog and the unskilled worker. [10, 62-65]

Conventional Extraction Techniques

Conventional technologies are based on extraction with water or organic solvents, or a combination of both. In the case of water extraction, seeds are peeled and then crushed to obtain the best extraction. The final extracts are due to emulsion using a surfactant or simple sedimentation. However, alcohols are used with this method, such as methanol, ethanol, and butanol, based on their high volatility. They also present different solvents and properties, such as the homogeneity of the solvent and the ability to evaporate easily. Acetone is often used as an organic solvent due to its high solubility, extraction efficiency, and yield. For the input field, the solvent input method must reach 80%, which is considered a harmful level; therefore, the extract must be dried to evaporate an appropriate volume of the solvent. In the past, fluoridation, which uses chloroform/methanol, has been used for chlorophyll and lycopene extraction. Nowadays, mechanical devices operate in this field. [66-71]

The extraction of moringa extracts from leaves, seeds, and fruits is based on different solvents. In most cases, the mixture or composite method is based on a blend of water and organic solvents, as an aqueous solution is insufficient and organic solvents are expensive. In general, extraction technology remains accessible to people, so the calculated cost of moringa in the production process is half the price of other similar extracts. However, it has been found that the abundance of Moringa oleifera decreases with the increase in the solvent percentage. Simultaneous extraction was found to be less effective at high temperatures. High temperatures showed limited diffusion and higher atmospheric pressure. If the temperature is not adequate, most compounds will be destroyed. [72-77]

Emerging Extraction Techniques

Blending two or more methods simultaneously affords a synergistic effect if it enhances extraction. Several reports dealing with the combined methods to extract bioactive compounds from natural raw materials such as Moringa leaves are available. Ultrasound with heating extraction outperforms both conventional extraction with heating and ultrasonic extraction alone. Combining microwave and ultrasound, besides solvent evaporation, also accelerates the extraction efficiency. The final method will reduce extraction time and energy, as well as solvent and reagent consumption, hence losses. Consecutive extraction comprises a two-step process to enhance the extraction efficiency significantly. The first extraction will harvest most of the dominant metabolite group, and subsequent extractions will engage in minor metabolites. Sonication may be an energy-efficient technique for large-scale extraction; under a shorter time period, the resulting degradates are less in comparison to conventional heated extraction. [78-83]

Characterization Techniques for Moringa Oleifera Extract

The properties, characteristics, and biological activities of natural constituents can vary significantly according to their origin, which may be attributed to their genetic variations. The extraction procedure and solvent may also greatly affect the phytochemical features of the extract, increasing the difficulty in comparing and standardizing the biological activities of the extracts. Therefore, it is necessary to both extract and analyze the phytochemical features of the exact plants to ensure their quality, safety, and efficacy. There are several techniques available to extract phytochemicals, which can be broadly classified into solvent extraction and non-solvent extraction techniques. Several methods can be utilized to characterize phytochemicals, such as thin layer chromatography, high-performance liquid chromatography, gas chromatography, inductively coupled plasma mass spectrometry, ultraviolet-visible spectrum, Fourier-transform infrared spectrum, and nuclear magnetic resonance. [84-87]

Moringa oleifera extract is a natural product derived from an abundant resource that has become an important raw material in the textile industry. Several techniques can be utilized to characterize the phytochemicals of Moringa oleifera extracts, such as chromatography, mass spectrometry, infrared spectroscopy, and nuclear magnetic resonance. The characteristic features of Moringa oleifera extracts must be determined prior to application, whether for a single application or combination applications in auxiliary chemicals to promote sustainability by a greater depletion than productivity logical scheme. [21, 23, 30. 33, 88]

Physical Characterization

The powder particles' size, in general, depends on the size reduction mechanism. When porosity and flowability are important, the particles are very fine, with some size restriction for free-flowing and difficult handling. However, the size of the particles also has a close relation with biological activity because of microporosity; the better the performance of the material. In the case of the extract, the fine particles seem to modify specifically the chromatography process when it is used. The need for micronization to obtain fine particles does not necessarily mean that it will contain high soluble concentrations. Particle size can also affect solubility rates. In the case of phytochemicals, the smaller the size, the better the solubility and bioavailability rates. [89-95]

It is important to keep in mind that the particles obtained after natural solvent evaporation can be modified in size during the freeze-drying process because the instability of the spherical agglomerates occurs due to the attractive forces between the particles, and the particles tend to form larger and more stable agglomerates. The repulsive forces between particles that separate them are the result of Van der Waals forces, primarily electrostatic, hydrophobic, hydration, and steric stabilization. Particle size affects the properties of the particles, such as appearance, apparent density, structure, morphology, residual moisture, compressibility, wettability, disintegrating properties, and solubility. These properties depend upon particle characteristics, which include surface morphology, particle shape, and particle size distribution. The micronization of the extract with freeze-drying led to better control of the size of the particles after freeze-drying, maintaining the desired levels with high functional properties like low detection of ash. [96-100]

4.2. Chemical Characterization

Fresh Moringa oleifera is commonly used in salads, soups, and drinks. The data showed that brews from Moringa dried leaves had significantly higher content of trans-ferulic acid, ash, and proteins than those brewed from fresh leaves. Additionally, the carbon content level increased during the leaves' wet process, indicating pectins and others' hydrolysis due to the hot water action, and thus most of the other HWEs composed at that maximum temperature, especially if involving releases of metal ions attached to them. As a result, it was possible that chelation species were formed. Both the phenolic index, attributed to phenolic acids, flavonoids, and condensed tannins, and the quenching of the DPPH radical increased when the extract was maintained at different temperatures. The results showed that both embrittlement and chelation mechanisms play a crucial role in the HWE production. [101-105]

Spectroscopic Techniques

Characterization of Moringa oleifera extract was performed by various spectroscopic techniques as follows. The preparation of the extract for use using Moringa oleifera leaves was done through washing to remove dirt, sand, and drying. The dried leaves were ground into powder using an electric grinder. Then, distilled water was added to the powder to make a relatively homogeneous suspension, and this was soaked in a thermostat at a temperature of 50°C for 1 hour. Various spectroscopic techniques, including high-performance liquid chromatography, ultraviolet-visible spectroscopy, and Fourier Transform Infrared, were employed to perform the mentioned characterization to study the properties of Moringa oleifera extract. [106-109]

The extracts obtained under the same preliminary conditions were filtered using filter paper and stored at 4°C before use. Moringa oleifera extracts were used within a duration of 1 month from the preparation date to prevent degradation. The confirmation of the dye component in Moringa oleifera extract was made by using a UV-Vis spectrophotometer. The staining properties of the dyes from Moringa oleifera leaf extracts on linen fabric were investigated using UV-Vis spectroscopy. UV-Vis absorption properties were determined using a UV-Vis spectrophotometer with a quartz cell. The transmittance and absorbance of well-mixed Moringa oleifera dyeing dyestuffs were measured and presented as their wavelength. The diluted extract of five different concentrations of MgO logs was subjected to a homogenization procedure at staining temperature. Data were accepted as evidence of identification and determination of solvent strength. [9, 110-113]

Utilization of Moringa Oleifera Extract in Textile Wet Processes

Recent research has shown that the moringa tree is a good source of bioactive compounds and has been characterized for many useful applications. The aim of this research is to produce moringa oleifera seed extract by using water as a solvent and to characterize the phytopigment and the dry material content. The research was conducted by extracting the moringa oleifera seed under various extraction conditions. Then, each extract was characterized based on the absorption spectrum, the active compound absorption pattern, the dry material content using gravimetric analysis, and the correlation of dry material content to dye absorbance. The best result for producing moringa oleifera seed extract was found with a 20 µm particle size in a 70-minute extraction. The resulting extract has a dry material content of 3.61%, indicating the end of the extraction process. The value of the dye absorbance shows that moringa oleifera seed extraction has the potential to be used as a source of natural color for dye absorbance developed in photoanode applications for making DSSCs from materials that are safe and easy to process. [114]

This paper presents the utilization of moringa oleifera seed extract to produce commercial dye absorbance, which can be used in various textile wet processes. The study starts with producing various extracts between 0.26% and 2.62% of dye concentration by varying the extraction time, temperature, and dry material content. The greatest dye concentration in the extract was found at 0.84% with 10 g of dried extract, a 70-minute extraction, and 50°C at a 20 µm particle size of moringa seed powder. Then, the extract has been characterized to confirm its potential as a commercial dye absorbance. The absorbance value was examined with a fluorospectrometer instrument at λ=800 nm. The product at 0.84% of dye concentrate showed the highest absorbance, and the reliable range of absorbance was 0.538–0.998 at 800 nm. The commercial dye absorbance from natural color has the potential to be used in textile wet processes. [115-117]

Dyeing and Printing Applications

Dyeing of cotton fabrics was achieved using conventional textile dyes such as reactive and natural dye obtained from hibiscus sabdariffa. The dyed fabrics displayed good color yield, and because there is consumption of a small quantity of nuts during dyeing, the fiber exhibits good antibacterial activities. It was also observed that despite its tanning effect, as it is known to be a mordant, alum has no effect on color fastness to washing and rubbing, except for lightfastness of dyed fabrics [118-122]. In addition, an acceptable level of antibacterial activity was possessed by both the bark and seed of the Moringa oleifera in the dyeing process. The same observation was made for natural dye, which contains high amounts of tannin herbs. This observation offers practical opportunities for the application of Moringa extract in the pretreatment and dyeing processes. Adsorption of weakly active dye onto cellulosic fiber containing Moringa extract as a natural mordant demonstrates the complete path to its application in the textile dyeing industry. [123-127]

Textile printing using Moringa oleifera leaf extract as discharged paste was characterized before and after printing. With 15–20 weight percentage, mixing the extract with cellulose ether and sodium alginate, viscosities of 4,000–3,500 centipoise and 19,000–22,000 centipoise were achieved. Printing results displayed good resolution, and after image release, a very well spread shape of text was obtained with less staining and clear backgrounds. The color fastness properties of printed fabrics exhibited strong to good color fastness properties. [128-132]

Finishing Applications

The high level of properties present in the leaf extracts of Moringa oleifera can be utilized for other applications apart from dyeing and printing. The goodness does not only improve the fastness of the color, but also imparts different values onto the fabric depending on the chosen finishing method, as the plant extracts have been shown to have a very good affinity to many different biological as well as synthetic polymers. The various antimicrobial and insect repellent activities also increase the lifespan of the product while ensuring long-term sustainability. The applications and processes that can be utilized for both natural and synthetic fibers have been reported. [46, 133-137]

In conclusion, Moringa oleifera has been found to contain compounds that are related to natural properties that can be utilized to produce functional textiles bio-mimicking cotton with superior material properties. This could boost the adoption of Moringa as a dye or finishing agent and contribute to the marketing of the non-economic part of the plant.

Eco-Friendly Aspects of Moringa Oleifera Extract in Textile Wet Processes

Nowadays, traditional products of dyeing and finishing processes are hazardous and have a potential environmental impact. Thus, natural plant sources are recommended for textile applications. Hereby, the plant Moringa oleifera was used to produce an extract, which was extracted using distilled water and analyzed by total phenolic content, total flavonoid content, and total carbohydrates content tests to solve environmental problems. The obtained results showed that the average yield of Moringa oleifera extract was 4.48 g/100 g of dried Moringa plant. This indicates that Moringa oleifera might have antibacterial, antifungal, and antiviral effects with higher intensities of L* and b* and their reflection on rinsed-out samples. In this regard, eco-friendly aspects associated with the usage of Moringa oleifera extract in textile finishing and dyeing processes have been investigated and presented. The first eco-friendly aspect of the investigations is based on the content of the obtained drying extracts and their typology. Moringa oleifera flower petal extract, according to phenolic content analysis profiles, contributed 3.32 to 6.51 mg/100 g of tannic acid per g of dried plant material obtained, which can be listed as the major bioactive agent for potential antibacterial and UV-protective activity.

Moringa leaf extract showed an average phenolic content of 36.3 mg/100 g of dry matter. The differences shown refer to the amount of phenolic compounds found in the extracts. For example, leaf extracts contain 7.88% tannic acid. In addition, all three extracts contain functional groups, which may contribute to high reflectance in the range of 400-600 nm. [138-142]

Sustainability

Environmental pollution has some negative impacts. Therefore, it is necessary that the wet processes in the textile industry become sustainable. Water pollution through toxic agents can occur in different ways: through the effluent from textile industries, which reaches the aquatic environment; absorption by the skin when using garments with heavy metals; or inhalation of surpluses scattered in the air. The extract is a potential substitute for the chemicals currently used in many industrial processes, which are, in the majority of cases, pollutants. It also promotes the valorization of some residues and by-products, preventing them from being incinerated, generating dioxins and other harmful substances for the environment. The direct discharge of a bath after the dyeing process in watercourses are recognized as some of the most polluting processes within the wet processes in the textile industry. Therefore, it is important to develop processes with alternative and sustainable materials, reduce energy and time consumption, minimize waste, recycle process water, and reduce chemical and water consumption rates. [86, 143-146]

The reduced ecological footprint in the manufacture of products is a global interest that stimulates many sector developers and leaders to invest large amounts of resources in the competitive production and sale of goods. For success in business, all possible activities should be traced to sustainable innovation, reducing the negative effects of economic activities during the life cycle of textile fibers, yarns, and clothes. The economic development of the world today, in some cases, leads to a decrease in water quality for the population, as a consequence of inspection, control, and efficient management. It is vital to accomplish multidisciplinary research to reach the appearance of clothing with standardized parameters of color, appearance, and complexity, indicating that there could indeed be cooperation between operators of scientific and technological institutions, providing information to textile companies and thinking through the use of numerous regulations. [147-153]

Biodegradability

The photos of the fabrics treated with Moringa oleifera extracts evaluated in relation to the percentage of biodegradability obtained with bacteria type Staphylococcus aureus are presented. It is visually observed how the percentage of biodegradability decreases as the color intensity of the printed fabric increases, specifically with the species R3C0, R3VU, R3V2, and R3V4. This negative relationship refers to the concentration of the acid compounds found. Likewise, the species C0C5, C3VU, C3V2, and C3V4 showed a positive relationship with the biodegradability percentage. Again, this positive relationship refers to a concentration of phenolic, gallic, tannic, and fatty carboxylic acids lower than found. [154-161]

It is essential to continue working with the results obtained from the tests since, by adjusting and evaluating the percentage of biodegradability and color intensity, the amounts of bioactive compounds can be estimated with efficiency and effectiveness in the enzymatic tests. Thus, the enzymatic tests made it possible to demonstrate the relationship of the amount of bioactive substances with the rapid biodegradability of the treated fabrics. The characteristics of Moringa allow it to be applied in different areas, such as the chemical and textile fields through eco-friendly practices, without negatively affecting the biodegradability of fabrics and the watershed. [25, 162-165]

Challenges and Future Directions

In the challenge of Moringa extract application in industrial textile processing, the effectiveness, variety, and uniformity of the extract influence the efficiency of application at an optimum concentration that could meet all the challenges in different textile wet processes. Thus, the desired quality product and the energy reduction goals are expected to be achieved. The weight, sum, method, and time of extracting affect the extract quality. Common issues arise during Moringa extract industrial application, and the main drawbacks remain the influence of its accumulation activities on leachability and antimicrobial activities for extended application in practical textile manufacturing. In future extracts, the extraction method can be applied on a larger scale, which makes it the final step. It also aims to be more environmentally friendly and may be used in producing more natural textile supplies.

Additionally, the method should be more compatible with current and final production procedures. Moringa extract has been identified as a promising chemical for use in microbial control applications. In addition, the extension of Moringa extract could result in advances in textile leachate treatments for the protection of aquatic fauna populations rather than causing damage, followed by important incentives to exploit alternative natural antimicrobials, bypassing the unwanted effects on aquatic communities. In the development of sustainable or eco-friendly antimicrobial textiles, this study underscores the opportunity of considering a multifaceted and interdisciplinary approach. Higher

Moringa extract concentrations are known to produce a darker natural yellow color and free color-reducing potential in textile coloration. These results illustrate how alternative natural extracts provide both color remaining processes and the potential to replace the destruction of potentially toxic natural drop-off coloration processes.

Current Challenges

Field surveys of M. oleifera products and by-product market value chain studies have shown that there are seasonal supply and demand imbalances in M. oleifera's by-products, exacerbated by poultry, gas, and other by-product markets that require consistent and significant quantities all the time. These imbalances have, in turn, driven the M. oleifera market into "buyers' markets" rather than "sellers' markets," meaning that buyers of these by-products are setting the prices to the potential disadvantage of the sellers. Depending on the destination of the filtrate and acceptable filtering rates, increasing quantities of energy such as electricity for water supply pumps and thermal energy for boilers are needed for the press cake, further reducing the cost-effectiveness of the M. oleifera coagulant. While M. oleifera treated raw or almost raw water, it is also being marketed at a higher price and used in not so very dirty, industrial effluent situations. The result is that while the M. oleifera product offers a solution from a water pollution perspective, the price in rural Ghana per liter of this treated effluent is many times higher than the town's water tariff, which is not conducive for the CFRG source if scaling up the use of M. oleifera.

Future Research Directions

More work is required to develop a complete and comprehensive understanding of the various phenomena that lead to the manufacturing processes, including the antimicrobial characteristics, other aspects, the suitable Moringa oleifera application method and its optimal process, and the best post-processing method. The present work reported in this chapter adds to this needed understanding; however, there is still much to gain. The main goal of this work is to produce a protective effect with solar UV and active printing and dyeing antimicrobial function using natural Moringa oleifera dye. Fortunately, there are some likely future emergent techniques in the applied domain of gathering knowledge that could increase the pace at which this understanding is developed. Perhaps the most evident of these techniques is the digital simulation of particle and system behavior. These require careful modeling of the prescribed physical theories, such as various aspects of Moringa oleifera dye applications, with the fast and correct extraction of many characteristics of the printing and dyeing process. These simulated results must have been thoroughly verified against experimental data, and the use of such simulation approaches requires both appreciation for modeling backgrounds of the particular electrostatic force model.

Summary

Summary of Key Findings

In summary, Moringa oleifera leaf extract could potentially be used as a functional and eco-friendly chemical for textile and dyeing wet processes. The hot water extraction combined Moringa extract with salt or tannin was found to significantly enhance the cellulase strength. The dyeing properties of dyed fabric with Moringa extract used in pre-treatment showed better results than commercial products under the same exhaustion conditions. While the extracted Moringa dye bath did not require the presence of any mordant or toxic heavy metals, the poor fastness properties still need to be overcome before it can be considered a potential mordant-free natural dye. The Moringa-extracted pigment showed good UV protection capability and could potentially be used for the production of functional and high-value natural dyed textile products.

Implications and Recommendations

Despite the numerous advantages of Moringa oleifera, it is observed that the use of Moringa in textile processing is short of what it should be. Hence, it is proposed that alternative and innovative uses of Moringa can be tested by researchers, for which many untapped research opportunities lie ahead. Furthermore, given that Moringa oleifera is not the only biosorbent for use in the textile field, other plants that contain similar coagulant proteins should be identified. Other recommendations include: 1) While exploring alternative scouring, brightening, finishing, and dyeing processes for textiles, it will be beneficial to avoid dyes that are toxic and introduce natural dyes similar to Moringa. The use of Moringa oleifera in biodegradable, natural dye enhancing and stabilization would make noteworthy contributions to sustainable and eco-friendly textiles; 2) Use of customized, user-friendly, and scalable protocols to harness Moringa's multifunctionality for wider practical applications; and 3) There is a need to maximize the use of Moringa in various applications, given that it is also used in pharmaceuticals and is not limited to the textile field.

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Conflict of Interest

There is no conflict of interest in the publication of this article.

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