

NANO-ENCAPSULATION OF AGRO-WASTE DERIVED PIGMENTS FROM BANANA AND ONION PEELS FOR ENHANCED STABILITY IN HERBAL HAIR DYE APPLICATIONS: A REVIEW

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ABSTRACT

People now prefer natural, sustainable hair dye options because they understand how synthetic hair dyes damage their hair. The bioactive pigments found in banana and onion peel agro-waste materials contain natural colouring and antioxidant properties, owing to phenolics, flavonoids, carotenoids, and anthocyanins. Herbal hair dyes experience restricted usage because their products prevent stable colour retention while failing to achieve proper hair fibre absorption. Nano-encapsulation technology provides an optimal solution through its ability to protect pigments by using nanoscale carriers, which maintain their stability during controlled release. The study shows how researchers extract pigments from banana and onion peels and develop their nano-encapsulation techniques to enhance the efficiency of herbal hair dye systems. The research demonstrates how nano-formulated agro-waste pigments

function as environmentally friendly, safe, and effective substitutes for synthetic dyes.

1.1 INTRODUCTION

The cosmetic industry has undergone a significant transformation in recent years, with increasing consumer preference for natural and eco-friendly products. Synthetic hair dyes, which are widely used in the market, contain harmful chemicals that include ammonia and para-phenylenediamine (PPD), which cause scalp irritation and allergic reactions and create

long-term health problems. Natural hair dye formulations need to be developed through research into plant-based hair dye solutions. Agro-waste materials, especially fruit and vegetable peels, serve as an inexpensive and abundant source of important bioactive substances. Banana peel and onion peel, which people typically throw away, contain natural pigments and phytochemical substances. Banana peel contains phenolic compounds, flavonoids, tannins, and carotenoids, while onion peel contains flavonoids that include quercetin and anthocyanins, which give it strong colouring properties. Natural pigments possess potential for use, but their usage is restricted because of their weak stability, fast deterioration and their inability to attach to hair keratin. The field of nanotechnology offers an effective solution to these problems. The process of nano-encapsulation involves active compounds that get sealed inside nanoscale carriers to achieve enhanced protection and bioavailability and controlled release capabilities. The review investigates how nano-encapsulated pigments from banana and onion peel agro-waste can be used in sustainable herbal hair dye production.

1.2 AGRO-WASTE UTILISATION IN COSMETICS

Agro-waste refers to the by-products and residues generated from agricultural activities, which include fruit peels, vegetable residues and seeds and husks. Agricultural activities generate these materials, which people typically throw away, and this practice leads to environmental pollution and resource waste. Recent research shows that agro-waste can serve as an important source of bioactive compounds, which scientists use for various industrial applications and especially in the cosmetic industry. The natural ingredients that people use in their cosmetic products match the growing demand from consumers who prefer herbal and environmentally friendly products. The agricultural waste products create compounds which scientists use to develop skin care products, hair care products and natural colourants for cosmetics. Natural materials in herbal hair dyes offer sustainable solutions that replace synthetic dyes, which cause dangerous health effects. The use of banana and onion peels provides two benefits because it produces natural hair colour and support hair growth and scalp maintenance. The use of agro-waste materials in manufacturing processes supports green chemistry practices while promoting sustainable development. The system creates economic value through agricultural waste conversion, which transforms waste into valuable products. This method enables products to follow the circular economy system because it transforms waste into valuable cosmetic ingredients. Agro-waste utilisation in cosmetics offers a promising future for the industry.

1.3 AGRO-WASTE AS A SOURCE OF BIOACTIVE PIGMENTS

The practice of using agro-waste has become essential because it provides both environmental advantages and economic benefits. The peels of fruits and vegetables contain bioactive compounds that can be used in cosmetic product development.

Banana Peel

The components of banana peel include

- ❖ Phenolic compounds
- ❖ Flavonoids
- ❖ Carotenoids
- ❖ Tannin compounds

The following functions exist for this item

- ❖ It creates a slight colour tint
- ❖ It protects against oxidative damage
- ❖ It works as a product that improves hair texture

Onion Peel

Onion peel contains

- ❖ Quercetin
- ❖ Kaempferol
- ❖ Anthocyanins

The following functions exist for this item

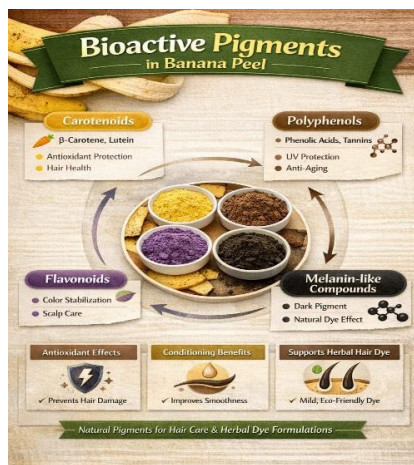
- ❖ It serves as a powerful natural colouring agent
- ❖ It exhibits properties that fight against harmful microorganisms
- ❖ It protects the scalp against different elements.

1.4 BIOACTIVE PIGMENTS IN BANANA PEEL

4.1 Chemical Composition

The functional properties of banana peel originate from its abundant content of bioactive compounds. The substance contains high levels of phenolic compounds, which include gallic acid, ferulic acid and flavonoids, which include catechin and epicatechin. The substance contains carotenoids, which include lutein and beta-carotene, and these compounds create its pigmentation. The combination of tannins and natural dopamine in banana peel boosts its

ability to fight oxidative damage. The formulation contains these compounds, which create light colour effects and provide protective functions and stability. The phytochemical components of banana peel make it a useful raw material for making herbal cosmetic products.



4.2 Colouring Properties

Banana peel pigments create light yellow to brown hair colours when applied to hair. The colouring effect comes from the tannins and phenolic compounds, which can be oxidised through the process of oxidation. The natural dyes produce a colour that appears less intense than other natural pigments. The dyeing process relies on three main components, which include extraction techniques, extract strength and application time. The banana peel base provides weak colouring, but it works effectively as a dyeing base, which boosts overall dyeing results.

4.3 Hair Benefits

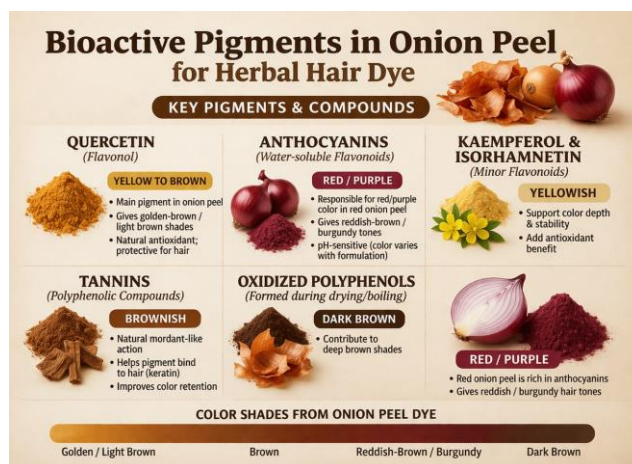
The high antioxidant content of banana peel makes it an effective treatment for hair care. The product protects hair from damage caused by environmental factors and oxidative stress. Natural oils and nutrients present in the product help to enhance hair texture and create a smooth and shiny appearance. The system works to condition hair while it decreases dryness and supports healthy scalp development. Banana peel provides two benefits for hair. It creates colour and enhances hair health and quality.

1.5 BIOACTIVE PIGMENTS IN ONION PEEL

5.1 Flavonoids and Anthocyanins

Onion peel serves as a major natural pigment source, which contains two flavonoids named quercetin and kaempferol. The compounds in this material produce both strong antioxidant

effects and the ability to create colours. Red and purple colours in some onion varieties emerge from their contained anthocyanins. Quercetin stands as the main flavonoid found in onion peel because its stability and biological activity make it perfect for use in cosmetic products. The compounds serve an essential function in the complete process of natural dyeing.



5.2 Dyeing Potential

Onion peel shows better dyeing capability than most other natural materials. It produces dark brown to reddish colours, which depend on the amount used and the processing methods applied. The pigments have a higher affinity towards hair keratin, resulting in better colour deposition and retention. Mordants, which include iron salts, create better colour results through their ability to increase both colour depth and colour staying power. Herbal products use onion peel as their main natural dye source because of its powerful colouring ability.

5.3 Biological Activities

Onion peel not only provides colour but also brings multiple health advantages that support hair and scalp wellness. The substance protects against oxidative stress because it contains strong antioxidant abilities. The substance protects against scalp infections while treating dandruff through its ability to kill microbes. Onion peel helps to relieve scalp problems through its anti-inflammatory effects. The multiple health advantages of onion peel make it a perfect component for herbal hair dye systems.

1.6 LIMITATION OF NATURAL HAIR DYES

Natural plant-based hair dyes are becoming increasingly popular because they provide safe and environmentally friendly options. The cosmetic industry can use these products because

they provide multiple benefits, but their several weaknesses create obstacles that prevent their full adoption.

6.1 Poor Colour Stability

Natural pigments lose their colour because of their high sensitivity to environmental conditions, which include light, oxygen, and temperature changes. The materials experience accelerated deterioration, which leads to colour loss because synthetic materials maintain their colour better than natural materials.

6.2 Low Colour Intensity

Natural dyes produce light to medium shades because they do not create the strong, bright colours that synthetic dyes deliver. The desired colour intensity requires multiple applications to reach the required level.

6.3 Limited Penetration into Hair Shaft

Natural pigments face penetration challenges because their molecular size exceeds hair cortex absorption limits. The result provides temporary hair colour that lasts only briefly.

6.4 Shorter Duration of Colour Retention

Natural dyes exhibit weak attachment to hair keratin, which results in rapid colour fading. This leads to shorter-lasting results and frequent reapplication.

6.5 Lack of Shade Variety

Natural dyes offer limited colour options compared to synthetic dyes. The creation of multiple natural sources results in difficulties when trying to achieve various shade combinations.

6.6 Batch-to-Batch Variation

Natural raw materials display different composition characteristics that change based on their origin, seasonal conditions and methods of processing. This results in inconsistent colour and performance.

6.7 Requirement of Mordants: Natural dyes require metal salts as mordants, which function to enhance both colour intensity and fixation. The use of mordants leads to a situation where the natural formula aspect of the product becomes less authentic.

1.7 Limitations and Challenges

The application of nano-encapsulated herbal hair dyes presents benefits but faces multiple restrictions that require resolution.

❖ Complexity of Formulation

The process of nano-encapsulation demands both advanced equipment and specialised knowledge. The preparation process is more complex compared to conventional herbal formulations.

❖ Higher Production Cost

The use of agricultural waste materials proves to be cost-effective, yet their production expenses increase because nanotechnology requires advanced processing techniques.

❖ Stability Issues During Storage

The incorrect storage of nanoformulations results in nanoparticles losing their stability, which leads to either particle aggregation or particle breakdown.

❖ Lack of Standardisation

The absence of standardised procedures for extracting, encapsulating, and creating agro-waste-derived pigments results in difficulties with reproducibility testing.

❖ Regulatory and Safety Concerns

All cosmetic products that use nanotechnology need to follow specific regulatory requirements. The commercial launch of products requires extended studies that examine their safety and toxic effects.

❖ Scale-Up Challenges

Industrial-scale production processes face significant difficulties because of both technical and economic obstacles that emerge from laboratory-scale production methods.

1.8 NANO-ENCAPSULATION TECHNOLOGY

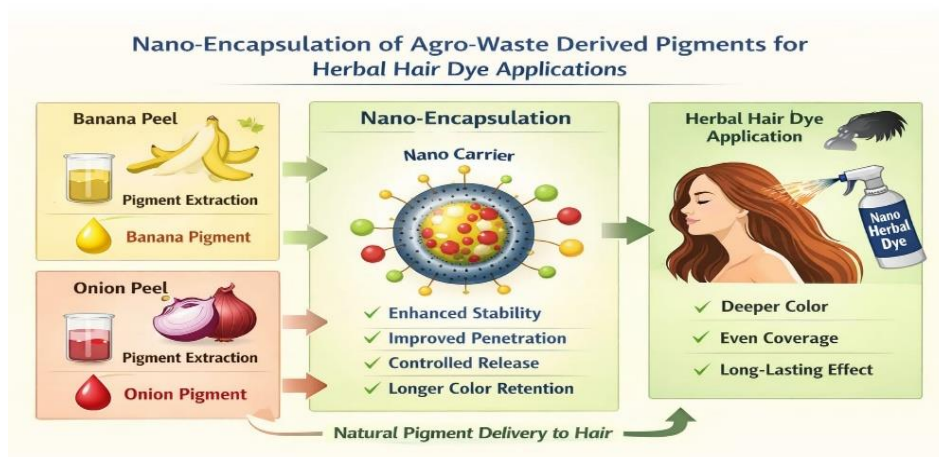
8.1 Definition

Nano-encapsulation is an advanced drug delivery technique that enables the packaging of bioactive substances inside tiny carriers that measure between 1 nanometre and 100 nanometres. The method improves active ingredient stability while providing protection and enabling regulated ingredient discharge. The implementation of nano-encapsulation in herbal

hair dyes requires the development of nanoscale systems that incorporate natural pigments extracted from banana and onion peels to enhance their functioning and lasting power.

8.2 Advantages of Nano-Encapsulation

The advantages of nano-encapsulation provide multiple benefits to the pharmaceutical industry, which uses traditional methods of drug development. The system provides two main benefits, which protect pigments from oxidation while preventing their degradation.



The following are the advantages of nanoencapsulation

- ✓ **Improved stability** - protects the pigments from degradation and the oxidation process.
- ✓ **Controlled release** - allows gradual release of colour as time passes.
- ✓ **Enhanced penetration** - allows for much deeper penetration into the hair shaft.
- ✓ **Improved Colour Retention** - longer-lasting dyeing effect.
- ✓ **Uniform distribution** - means even application to hair.

The benefits of using nano-encapsulation in herbal cosmetics are very positive, and this technology opens up many new possibilities.

8.3 Types of Nano-Carriers

8.4 Nano emulsions

Nano emulsions are tiny oil-in-water or water-in-oil mixtures stabilised by surfactants. The system requires tiny particles to stay active for extended periods without losing their ability to maintain stability. The system enables users to create products without difficulty, while products maintain their capacity to spread over surfaces. The system enables products to spread over surfaces because it improves the ability of pigments to dissolve in water. The system enables users to create products without difficulty, while products maintain their

capacity to spread over surfaces. The system enables products to spread over surfaces because it improves the ability of pigments to dissolve in water. The system enables users to create products without difficulty, while products maintain their capacity to spread over surfaces. The system enables products to spread over surfaces because it improves the ability of pigments to dissolve in water.

8.5 Liposomes

Liposomes function as spherical vesicles that contain phospholipid bilayers that resemble the structure of biological membranes. The system provides users with two advantages, which make the system suitable for use with various types of biological materials. The system enables users to create products without difficulty, while products maintain their capacity to spread over surfaces. The system enables products to spread over surfaces because it improves the ability of pigments to dissolve in water. The system enables users to create products without difficulty, while products maintain their capacity to spread over surfaces. The system enables products to spread over surfaces because it improves the ability of pigments to dissolve in water.

8.6 Polymeric Nanoparticles

These particles exist as solid substances that create natural or synthetic polymer bioactive solids. The system allows for pigment release according to a specific timetable, which enables users to achieve their desired results. The system offers complete protection for materials against all forms of deterioration. The system enables users to maintain their food products for extended periods because it maintains their quality.

1.9 METHODS OF NANO-ENCAPSULATION

9.1 Emulsification Technique

This method ranks as the most popular technique used for nano-encapsulation. Process Oil phase and aqueous phase are prepared. Surfactants are added. High-speed stirring is applied. Result: The process creates nano-sized droplets, which contain pigments. The method presents an advantage because it remains both affordable and easy to use.

9.2 Ultrasonication

Ultrasonication uses high-frequency sound waves to reduce particle size. Process: The ultrasound process applies to the pigment and carrier mixture. The process creates nanosized particles by destroying larger ones. Result: The process creates a uniform distribution of

nano-sized particles. The method produces stable nano systems while it enhances encapsulation efficiency.

9.3 Solvent Evaporation Method

This technique mainly applies to nanoparticles made from polymer materials. Process: The process starts when the polymer and pigment are dissolved in a solvent. The process creates an emulsified mixture, which gets turned into an aqueous solution. The process ends when the solvent completely disappears. Result: The process results in the creation of solid nanoparticles. The method enables researchers to control particle dimensions. The method serves as an ideal solution for extended-release applications.

1.10 CHARACTERISATION OF NANO SYSTEMS

The process of characterising systems that contain nano-sized particles requires direct testing to determine their content before testing for quality assessment and performance evaluation. The studies confirm the presence of properly developed nano formulation, which can be used in applications for herbal hair dye systems.

10.1 Particle Size Analysis

The size of particles represents one of the most important factors that determine the behaviour of nano systems. The ideal size range is between 1 and 100 nanometres. The smaller particle size enables better penetration through hair shafts, which results in improved dyeing performance. Dynamic Light Scattering (DLS) serves as the standard method to measure the distribution of particle sizes.

10.2 Zeta Potential

Zeta potential measures the surface charge of nanoparticles and indicates their stability. High zeta potential values indicate good stability, while low values result in particle aggregation. The appropriate zeta potential level must be maintained to achieve stability in nanoformulations.

10.3 Morphology (Shape and Structure)

Morphology describes the particle shape together with the actual physical structure of nanoparticles. The surface and structural properties of nanoparticles are examined through Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM)

techniques. Most nano-carriers exhibit spherical shapes, which are suitable for uniform application.

10.4 Encapsulation Efficiency (EE%)

The encapsulation efficiency measurement indicates the amount of pigment that has been successfully captured inside the nano-carrier system. $EE (\%) = (\text{Amount of entrapped pigment} / \text{Total pigment used}) \times 100$. The system delivers more effective results when it achieves higher levels of encapsulation efficiency using its nano delivery system.

10.5 In-Vitro Release Study

The in-vitro release studies examine the process by which pigment escapes from the nano system throughout different periods. The herbal dye requires controlled and sustained release because this method will produce lasting colour effects and enhance the dye's overall performance.

1.11 MECHANISM OF HAIR DYEING USING NANO-ENCAPSULATED PIGMENTS

The process of hair dyeing through nano-encapsulated pigments operates through multiple interactions that take place between the nano-sized dye particles and the hair structural components. The method increases colour penetration together with binding and retention capabilities when compared to traditional natural dyes used in the process.

11.1 Structure of Hair

Human hair contains keratin protein as its main structural component, which forms three distinct layers

- **Cuticle** – the outer protective layer consists of overlapping cell structures
- **Cortex** – the middle layer includes both colour deposition and structural strengthening functions
- **Medulla** – the innermost core (less involved in dyeing)

The primary location of dye molecule deposition is within the cortical region.

11.2 Penetration of Nano-Encapsulated Pigments

The small particle size of nano-encapsulated pigments enables them to penetrate the cuticle layer more effectively than traditional dyes. The nanoparticles penetrate through tiny openings that exist in the cuticle. They reach the cortex layer, where colour deposition occurs. The deep penetration process enhances both dye absorption and product longevity.

11.3 Interaction with Hair Keratin

The pigments start to interact with keratin proteins through different types of intermolecular forces, which include

- ❖ Hydrogen bonding
- ❖ Van der Waals interactions

The interactions provide a mechanism for pigment molecules to bond with hair material, which results in improved colour retention.

11.4 Controlled Release of Pigments

The nano-encapsulation process establishes a controlled release system through which pigments get released from their nano-carrier system over an extended time period. The system prohibits immediate colour disappearance. The system provides stable colour brightness throughout an extended period. The system increases the duration of colour effects.

11.5 The Uniform Distribution of Colour

The nano-encapsulated pigments achieve uniform spread across hair surfaces because their tiny particles maintain a high surface area. The system guarantees complete colour distribution throughout the material. The system prevents any irregular colour application, which leads to uneven results.

11.6 Improved Colour Maintenance

The system produces better colour retention through its deep penetration ability, which interacts strongly with keratin while controlling its release. The system provides two benefits, which include reduced fading during washing and a longer-lasting dye effect.

1.12. FORMULATION STRATEGIES

The process of formulation establishes which nano-encapsulated herbal hair dyes will show which levels of effectiveness, stability and practical usage. The final product performance improvements result from selecting proper materials and using appropriate formulation methods.

12.1 Individual Extract-Based Formulation

In this approach, banana peel and onion peel extracts are used separately to prepare formulations. The banana peel extract functions as a conditioning agent while providing antioxidant protection. The onion peel extract functions as a powerful dyeing agent. The method enables researchers to compare how each pigment operates under specific conditions.

12.2 Combined Extract Formulation

The combined formulation process requires the use of both banana and onion peel extracts. The process increases total dyeing effectiveness. The method creates a connection between colour strength and hair conditioning properties. The method enhances how the product performs its intended functions. The method functions better than other approaches when utilised in real-world herbal hair dye applications.

12.3 Nano-Encapsulated Formulation

The method uses nano-carriers to deliver extracted pigments through nano emulsions and, liposomes and polymeric nanoparticles.

Basic components

The ingredient list includes banana peel pigment extract and/or onion peel extract. The product contains nano-carrier material, which exists as either a lipid or a polymer. The product contains either a surfactant or a stabiliser. The product contains gel, cream, or lotion as its base material.

Advantages

- ❖ The method produces stable pigments that will maintain their original state.
- ❖ The method allows pigments to penetrate hair shafts more effectively.
- ❖ The method enables controlled colour release from the product.
- ❖ The method creates a dye effect that will remain intact for an extended period.

12.4 Suggested Formulation Composition (Example)

The formulation contains

- 30% onion peel nano-extract
- 20% banana peel nano-extract
- 5% surfactant
- 10% polymer/carrier

- 20% aloe vera gel (base)
- 5% preservative
- water (qs)

which exists in sufficient quantity to reach the required amount (qs). The formulation creates an equal distribution of colour intensity while maintaining stability and delivering hair care advantages.

1.13. COMPARATIVE ANALYSIS

The assessment of various pigment sources and their formulation methods can be conducted through comparative analysis.

13.1 Banana Peel Vs Onion Peel

Parameter	Banana peel	Onion peel
Pigment strength	Mild	Strong
Major compounds	Phenolics, carotenoids	Flavonoids, anthocyanin
Colour produced	Light yellow/brown	Dark brown/reddish
stability	moderate	high
Hair benefits	conditioning	Colouring +scalp protection

The banana peel is more susceptible to dye, while the onion peel is very good for the health of hair.

13.2 Normal Vs Nano-Encapsulated Formulation

Parameter	Conventional formulation	Nano formulation
stability	Low	High
Colour retention	Poor	Improved
penetration	Limited	Enhanced
Release pattern	Immediate	Controlled
Uniformity	Uneven	Uniform

The significant improvement in terms of end product performance is due to nano-encapsulation in herbal hair dyes.

13.3 Overall Evaluation

The comparative analysis demonstrates that

- ❖ Onion peel is a more effective natural dye source
- ❖ Banana peel acts as a supportive and conditioning agent
- ❖ Nano-encapsulation enhances the stability, penetration, and durability of pigments
- ❖ Herbal hair dye development requires an optimised solution that combines both agro-waste sources and nano-technology.

13.4 Comparative Study of Banana Peel and Onion Peel Derived Pigments in Nano Herbal Hair Dye Systems

The two materials, banana peel and onion peel, show distinct differences in their chemical components, which result in different outcomes for their dyeing capabilities. Banana peel contains phenolic compounds and flavonoids, carotenoids and tannins, which create mild colour effects while delivering powerful antioxidant protection. The high flavonoid content of onion peel contains both quercetin and anthocyanins, which create its deep colour. Onion peel shows stronger colouring capabilities than banana peel, which provides conditioning and protective functions. The two agro-waste sources display different dyeing efficiency because their colour pigments interact with hair keratin in different ways. The banana peel generates a light yellow to brown colour, which it maintains at a moderate level. The onion peel produces dark brown and reddish colours, which maintain their colour at an increased level of intensity. The dyeing efficiency of onion peel exceeds that of other materials because it contains more pigment, and its pigments adhere better to hair proteins. Natural dyes need to maintain stability because it determines their operational effectiveness. The pigments found in banana peel face a higher risk of oxidation and degradation. The pigments from onion peel show better stability except for the quercetin pigment. Nano-encapsulation technology gives both systems improved protection against environmental damage. The two materials offer hair colouring benefits, but they also deliver extra advantages for hair treatment. The banana peel delivers three hair benefits through its conditioning effect, which enhances hair smoothness and shine, while it also reduces hair dryness. Onion peel delivers two benefits, which include its antimicrobial effect and its ability to protect the scalp and decrease dandruff. The banana peel promotes hair health, while the onion peel focuses on hair dyes. The nano-encapsulation enhances a lot the properties of both pigments, making them more potential for a practical application.

13.5 Overall Comparative Evaluation

The study shows that three main findings exist through its comparative evaluation results.

- ❖ Onion peel serves as the main colouring agent because it contains high levels of pigment.
- ❖ Banana peel functions as an ingredient that supports products while also providing conditioning benefits.

The two systems achieve better performance through nano-encapsulation because it improves their stability, penetration ability and durability. The nano-encapsulated system, which

combines banana and onion peel pigments, creates a complete product that delivers both effective hair colouring and hair care advantages.

1.14 ADVANTAGES OF NANO HERBAL HAIR DYE

The use of nano-encapsulated herbal hair dyes provides multiple benefits that surpass the performance of both natural and synthetic hair dyeing methods. The advantages of these products establish them as a viable solution for contemporary beauty treatment needs.

14.1 Enhanced Stability

The process of nano-encapsulation safeguards bioactive pigments from harmful effects that arise from exposure to light, oxygen and high temperature conditions. The system ensures pigment protection, which allows the dye to maintain its quality throughout extended time periods.

14.2 Improved Colour Retention

The system uses nano-carriers to deliver pigments, which create hair colour that lasts for an extended period. The system requires fewer touch-ups when compared with traditional natural hair dyes.

14.3 Better Penetration

The tiny dimensions of nanoparticles enable them to go through human hair cuticles, which results in access to the hair cortex. The method enables deeper colour penetration, which results in higher dyeing performance.

14.4 Controlled Release Mechanism

The pigment release through nano systems occurs as a gradual process, which prevents immediate pigment discharge. The procedure establishes consistent colour strength while increasing product lifespan.

14.5 Uniform Distribution

The system enables nano-formulations to distribute pigments evenly throughout the entire hair surface. The system prevents patchy colouration, which results in a uniform colour distribution across the surface.

14.6 Reduced Toxicity

The safety profile of nano herbal dyes, which originate from natural sources, stands in contrast to the synthetic dye products. The products help to decrease the chances of users experiencing allergic responses and scalp discomfort.

14.7 Eco-Friendly and Sustainable

The use of banana and onion peel as waste materials enables waste valorisation, which helps to decrease environmental contamination. The process follows the principles that define green chemistry.

1.15. ENVIRONMENTAL AND ECONOMIC BENEFITS

The use of agricultural waste and nano-technology, together with herbal hair dye products, results in both environmental benefits and economic advantages.

15.1 Waste Utilisation

People typically throw away banana peels and onion peels as useless waste materials. The process of pigment extraction from these materials leads to decreased waste generation while increasing the efficient use of available resources.

15.2 Reduction of Environmental Pollution

Natural dyes, which people create from agricultural waste materials, become biodegradable because they do not discharge any toxic substances into nature. This process results in decreased pollution because it uses natural dyes instead of synthetic ones.

15.3 Cost-Effectiveness

The market offers accessible and affordable agricultural waste materials that businesses can use to produce herbal dye products. The production expenses of herbal dye products decrease because of this cost reduction.

15.4 Sustainable Production

The cosmetic industry achieves eco-friendly manufacturing through the combination of green extraction methods with nano-encapsulation technology.

15.5 Value Addition to Waste Materials

The process of transforming agricultural waste into valuable cosmetic products creates new market opportunities while increasing the economic worth of waste materials.

15.6 Support for Circular Economy

The method operates according to the circular economy framework, which transforms waste materials into products while keeping most resources from being lost.

1.16. FUTURE PERSPECTIVES

The future of nano-encapsulated herbal hair dyes shows positive development because the field offers multiple chances for progress and creative breakthroughs.

16.1 Development of Smart Nano Systems

Dye performance will improve through advanced nano systems, which develop responsive abilities that include pH-sensitive and temperature-sensitive systems.

16.2 Use of Green Nanotechnology

Sustainable nano formulations receive enhancement through eco-friendly synthesis methods, which use natural materials and non-toxic solvents.

16.3 Multi-Herbal Nano Formulations

The combination of different plant-based pigments improves colour variety and functional characteristics.

16.4 Improved Stability and Shelf-Life

Research dedicated to enhancing nano formulation stability over extended periods will make these products more suitable for commercial use.

16.5 Commercialisation Potential

The rising need for natural cosmetic products creates strong industrial market opportunities for nano-herbal hair dyes.

16.6 Clinical and Safety Studies

Researchers need to conduct additional *in vivo* and clinical studies to determine product safety and effectiveness, and consumer acceptance.

1.17. CONCLUSION

The technique of nano-encapsulating pigments from banana and onion peel waste creates a sustainable method for producing herbal hair dye products. The technology successfully solves the problems that natural dyes face because they maintain weak stability and exhibit

minimal colour retention, while their hair fibre penetration ability remains restricted. The use of bioactive pigments through nanoscale carriers leads to improved stability and operational performance of the dyeing system. The system delivers long-lasting results through its controlled release method, which enhances its ability to interact with hair keratin for consistent colour results. The process of using agro-waste materials for production helps protect the environment by decreasing waste and increasing resource efficiency. Although there are obstacles, including regulatory issues, high costs, and complex formulation processes, scientific research in nanotechnology and green chemistry will create new possibilities for future development. The next generation of cosmetic products will use nano-encapsulated herbal hair dyes, which provide a safe, effective and environmentally friendly option compared to synthetic dyes.

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