IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Analytical Testing: A Review on Hair Health in Modern Era

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Abstract: Hair health earned more attention in recent years, as contaminants from the environment, lifestyle choices, and modifying beauty standards impact hair quality and appearance. Analytical testing for hair health boasts a scientific approach to recognizing and dealing with these problems. This article analyses the composition and action of hair cosmetics such shampoos and conditioners, as well as their prescription and safety. Dermatologists use their experience of hair care products and side effects to treat hair and scalp difficulties based on hair type and origin (Martha Srinivas, et.al, 2022). This article analyses the compositions and effects of multiple hair cosmetics, which involves shampoos, conditioners, smoothing treatments, hair colours, and henna. This article explores into the main analytical techniques utilized today, their applications in analysing hair health, and the factors that influence hair's structural and biochemical health in the modern era.

Index Terms **- Hair, hair health, analysis, genetic testing, trichogram**

I. INTRODUCTION

- ***Hair***

Hair is a very complex system with unique chemical and physical features. The structure is complex and consists of multiple morphological components that function together. Human hair shafts consist of three basic sections: the epidermis, cortex, and medulla. Grey, thick, and facial hair are examples of coarse hair that contains the medulla; thin children's hair does not.

The medulla may play a critical role in hair splitting by creating a point of weakness that allows cracks to spread along the fiber axis. The cuticle is a resistant to chemicals zone made up of small overlapping scales called keratinocytes, akin to roof shingles. The majority of the mass of human hair is found in the cortex, which is composed of long fusiform cells joined by a CMC and contains protein and melanin granules. The cortical cell consists of macro fibrils, spindle-shaped fibrous structures composed of micro fibrils, highly structured fibrilar units, and a matrix. The matrix consists of crystalline cysteine-rich protein (Robbins, C. R. 2012). The macro fibrils have been arranged into a spiral shape. Protofilaments are sub filamentous units found inside micro fibrils. They are made up of small alpha-helical proteins in coiled coils, creating polypeptide chains. Hair straightening removes the tensions that hold the coil in place, allowing for expansion. The process of breaking down chemical bonds and curling hair is known as "perm," which stands for "permanent curling." To reduce hair, alkaline chemicals with a pH above 9.0 are used.

- ***Hair structure***

Hair structure consists of the content and arrangement of the different parts that comprise a strand of hair. It has multiple layers and Components:

i.*Hair Shaft*

The apparent part of hair that extends over the skin's outermost layer. It's composed of:

- Cuticle: The outermost layer of the hair shaft, made up of flat, overlapping cells.
- Cortex: The thick centre layer composed of fibrous proteins (mostly keratin), which provides the hair with strength, texture, and flexibility.
- Medulla: The innermost core of the hair, which may be lacking in finer hair types. It's a delicate, middle section of the hair shaft.

ii.Hair Follicle

The structure alongside the skin's surface that holds the hair roots. The follicle bears responsibility for hair development and is supplied with blood vessels.

- Hair Bulb: The root of the follicle, where cells divide and develop to form the hair shaft.
- Papilla: Located at the base of the follicle and includes blood vessels that provide nutrition to the hair root.
- Matrix: A layer of cells that quickly divide in the bulb that forms the hair shaft.
- Sebaceous Gland: This is linked to the follicle and produces sebum (oil) to keep the hair moisturized and prevent it from drying out.
- Arrector Pili Muscle: Whenever an insignificant muscle attached to the follicle contracts, the hair stands upright (goosebumps) (Robbins, C. R. 2012).

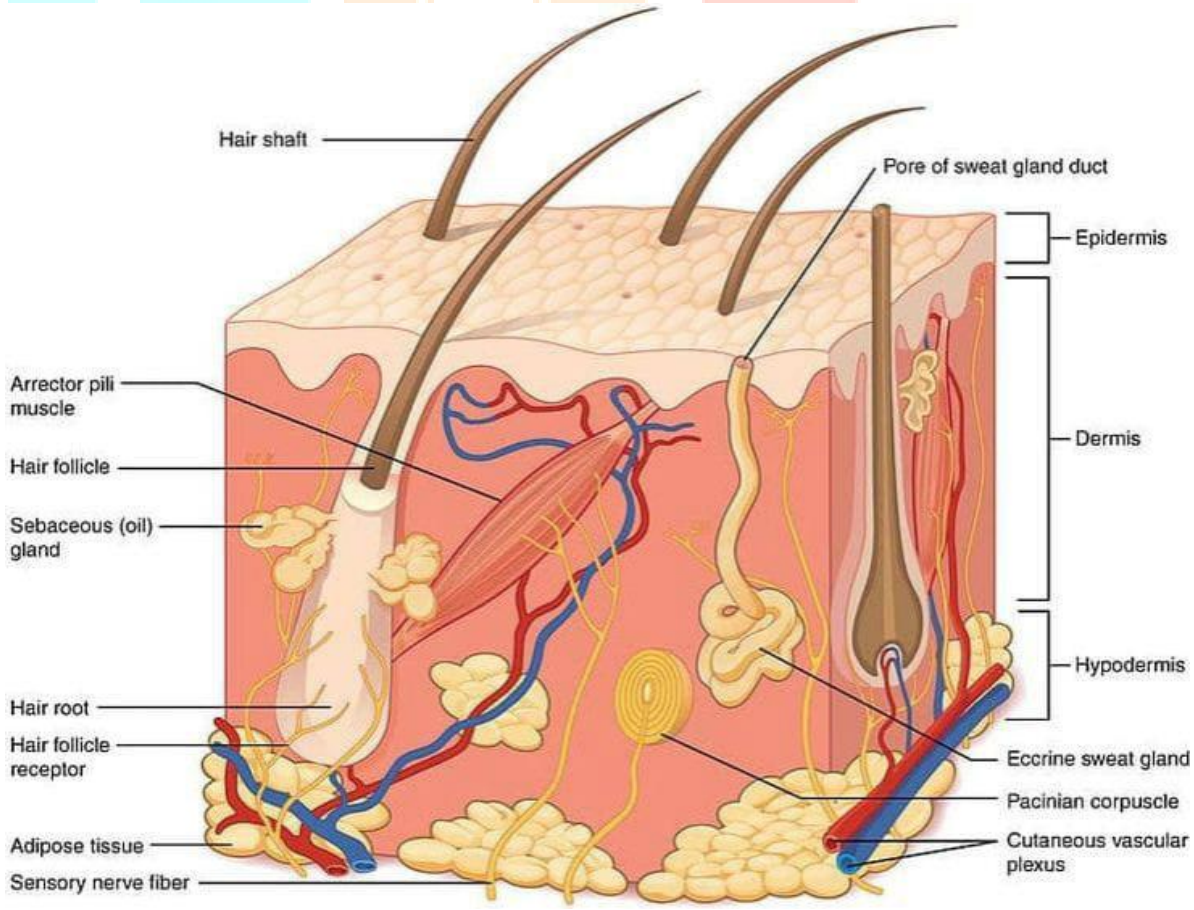

Figure 1: - Anatomy of Hair

II. HAIR PROBLEMS

- *Hair Loss:*

Hair loss/thinning is frequent among both men and women; despite being traditionally associated with men. Female hair loss might result from stress, medication, hormonal changes, or menopause. Hair loss can be caused by chemical and heat-based styling products.

- *Dry Hair:*

Shampooing too frequently creates dry hair. While having clean hair is beneficial, over cleaning can remove natural oils and cause damage.

- *Split Ends:*

Split ends can be caused by over-brushing, perming, high heat, and a lack of proper conditioner.

- *Oily Hair:*

Oily hair occurs when the scalp generates too much natural oil, known as sebum. Sebaceous glands create sebum, which can result in excessive oil production.

- *Frizzy Hair:*

Frizzy hair can be genetic or caused by low moisture levels.

- *Heat Damage Hair:*

Excessive curling or dry straightening might harm your hair.

- *Color Damaged Hair:*

Whenever you dye your hair, toxins apply to open the hair shaft, making it exceedingly porous and prone to brittleness and breaking.

- *Dandruff:*

Dandruff is a white build-up of layers of dead skin in the hair that might fall out. Malassezia restricta, a fungus, and Globosa malassezia, formerly known as Pityrosporum, may be yeasts that cause skin and scalp infections. Causes include not brushing hair, allergies, stress, inadequate washing, and other factors.

III. LITERATURE REVIEW

Hair health is a vital part of personal hygiene and appearance, reflecting an individual's entire well-being. Scientific research is currently utilizing analytical tools to better understand the different aspects that influence hair health, such as nutrition, environmental stresses, deficiencies in hormones, and hair treatments. Analytical testing technologies have improved to provide greater insight into the biochemical and physical aspects of hair, allowing for the development of more tailored treatments for hair-related problems like hair loss, thinning, and damage. This literature review examines the primary analytical approaches used in hair health research and emphasizes current advances in the field.

1. Analytical Techniques for Hair Composition and Structure

a. Microscopic Techniques

Microscopy examination remains a key tool for understanding hair structure at the cellular and subcellular stages. The surface and interior design of hair fibers can be visualized using methods such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM). SEM is commonly used to study hair surface morphology, including cuticle damage and cortical structure (Polgár et al., 2021). In contrast, TEM reveals more comprehensive images of the hair's Interior architecture, such as keratin filament organization and the presence of lipids in the cortex

b. Fourier-Transform Infrared Spectroscopy (FTIR)

FTIR spectroscopy is a critical tool which determines the molecular constituents of hair, including keratin, lipids, and water content. By recognizing characteristic absorption bands, FTIR can provide information about the chemical composition of hair, and investigators have used it to investigate changes in hair protein structure under various situations. FTIR is also used for analyzing the impacts of hair treatments including bleaching, coloring, and straightening, which can change the protein structure and overall health of hair (Lee, J., Kim, S., & Hwang, M. 2019).

c. Raman Spectroscopy

Raman spectroscopy is a non-invasive approach to analyze the molecular structure of hair, specifically its composition of protein and lipid molecules. This approach has been utilized to investigate hair damage caused by various chemical therapies, including permanent wave and straightening processes (Proulx et al., 2020). Raman spectroscopy delivers understanding of the changes in both the tertiary and secondary structures of hair proteins like keratin, offering valuable information.

2. Chemical Analysis of Hair Samples

a. Hair Mineral Analysis

Hair evaluation for minerals and minor elements is a standard technique for identifying nutritional deficiencies and harmful exposures that may affect hair health. Inductively coupled plasma mass spectrometry (ICP-MS) and atomic absorption spectroscopy (AAS) are commonly employed techniques for evaluating elements in hair samples, involving zinc, copper, iron, and lead. These components are necessary for hair growth and health, with shortages or imbalances being associated with disorders such as hair thinning or loss (Manczak et al., 2020).

b. Hair Protein Analysis

Hair is primarily composed up of keratin proteins, and changes in protein structure or quantities might have a big impact on how durable and strong it is. Hair protein content was profiled using high-performance liquid chromatography (HPLC) and mass spectrometry (MS), and the protein composition modifications were recognized. Such approaches are useful for evaluating the impacts of various hair treatments and environmental stresses on hair protein integrity (Steiner et al., 2022). Additionally, electrophoresis methods such as SDS-PAGE are commonly used in protein analysis, providing researchers to identify molecular weight distribution and protein degradation patterns in damaged hair.

c. Hair Lipid Analysis

Lipids in hair helps it stay healthy and well-hydrated. Gas chromatography (GC) and liquid chromatography (LC) techniques are frequently utilized for analyzing the lipid content of hair fibers. According to studies, changes in the composition of lipids can affect the physical characteristics of hair, such as elasticity and smoothness (Jones et al., 2021). Lipid analysis can assist measure the influence of many therapies like as conditioning or oiling on the health of hair.

3. Biological and Genomic Approaches

a. Genetic Markers for Hair Health

Hair texture, the density, and growth patterns are all heavily influenced by genetics. Recent investigations utilize DNA sequencing and gene expression analysis to discover genetic factors associated with hair loss, such as those related to androgen receptor (AR) genes, which are involved in both male and female pattern hair loss (Huang et al., 2021). Whole-genome association research (GWAS) have proven critical in determining the genetic basis of hair health issues, opening the path for tailored hair care treatments.

b. Microbiome Analysis

According to recent research, the scalp's microbes have an important influence in hair health. Advances in 16S rRNA sequencing and metagenomics study have allowed researchers to investigate the microbial composition of the scalp, discovering bacterial species that may contribute to dandruff, seborrheic dermatitis (SD), and hair loss (Gao et al.,2022). Examining the scalp microbiota reveals fresh information about the external factors that influence hair health and can lead to more effective scalp treatments.

4. Biophysical and Mechanical Testing

a. Hair Tensile Strength Testing

Evaluating mechanical qualities of hair, such as tensile strength and elasticity, is critical for understanding damage to the hair and resiliency. Universal testing machines (UTMs) are used to measure hair fiber quality under a variety of situations, including chemical therapies, humidity, and heat styling. Bleaching and straightening procedures have been found in studies to decrease hair's structural strength, making it more prone to breaking (Beattie et al., 2023).

b. Hair Surface Roughness

The roughness of the hair's appearance may indicate injury or cuticle breakdown. Atomic force microscopy (AFM) and contact angle measurements are used to examine the roughness and hydrophilic properties of hair fibers, revealing surface condition and the efficacy of conditioning treatments. These technologies are especially beneficial in the cosmetics sector to produce products that enhance hair appearance and texture.

IV. METHODOLOGY

Analytical analysis for hair health employs a variety of scientific approaches to evaluate hair arrangement, composition, and the potential impact of both internal and external factors on hair growth and integrity. The following provides an overview of various methodologies, as well as the references to research or publications that support their use.

- ***Microscopic Examination***

Purpose:
To diagnose hair structure, damage, and problems in individual strands.
Method*:*
Light microscopy is widely used to examine the surface and cuticle of hair, identifying split ends, roughness, or thinning. Scanning electron microscopy (SEM) offers high-resolution images of hair's the ultrastructure, such as surface damage, cuticle lifting, and fiber wear (Sharma RK, Kaur S, Gupta A, et al.2009).

- ***Hair Trichogram***

Purpose:
Analyze hair development cycles (anagen, catagen, telogen) and follicle health.
Method:
A small number of hairs are removed from the scalp, and the follicles are inspected under a microscope to measure the proportion of hairs in the growth (anagen), shedding (telogen), and transitional phases (catagen).

- ***Hair Mineral Analysis***

Purpose:

To determine nutrient deficits or excesses that may impact hair health.

Method:

Minerals and trace elements found in hair, such as zinc, iron, copper, and magnesium, are measured using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) or Atomic Absorption Spectroscopy (AAS).

- ***Protein and Keratin Analysis***

Purpose:

To detect an appearance and integrity of proteins, especially keratin, in the hair shaft.

Method:

Protein electrophoresis and mass spectrometry (MS) are used to study the types and quantities of proteins found in hair fibers, which aids in understanding hair damage or structural changes.

- ***Chemical Analysis (Hair Toxicology)***

Purpose**:**

To determine exposure to environmental contaminants, heavy metals, or drug residues.

Method:

Chemical pollutants and trace chemicals in hair are analyzed using gas chromatography-mass spectrometry (GC-MS) and liquid chromatography-mass spectrometry (LC-MS).

- ***Hair Tensile Strength Test***

Purpose:

To assess the mechanical strength and elasticity of hair fibers, which are indicators of damage or fragility.

Method:

A tensile strength test involves subjecting the hair sample to mechanical stress to measure the force required to break it, often using a universal testing machine.

- ***Colorimetry and Spectrophotometry***

Purpose:

To identify damage or color changes in hair as an indirect indicator of its health.

Method:

Spectrophotometric methods or colorimetry are used to determine the reflectance and absorption of light by the hair, indicating changes in texture, porosity, or color that may suggest damage.

- ***Hair Follicle Biopsy***

Purpose:

To examine scalp issues at the follicular level and better understand the histology of hair problems.

Method:

A scalp tissue biopsy is performed, and the tissue is processed for histological investigation utilizing standard staining techniques (e.g., H&E staining) or more sophisticated procedures such as immunofluorescence.

- ***Genetic Testing***

Purpose:

To determine genetic characteristics that affect hair health, such as vulnerability to the loss of hair or other problems.

Method:

Genetic study includes gathering DNA from hair follicles to find mutations or markers associated with disorders like androgenetic alopecia or alopecia areata.

V. RESULTS

Analytical evaluation for hair health may offer significant data on the fundamental root causes of hair problems such as damage, thinning, or hair loss. The results of such testing are useful to personalize treatment options to improve hair quality. I'll go over typical hair health diagnostics and what outcomes may suggest, citing scientific literature and clinical applications.

A. Microscopic Analysis

Purpose:
Examine the hair's structure, which includes cuticle health, split ends and shaft damage.
Results:
Healthy hair seems reliable, with smooth cuticles.
Damaged hair may have shattered the cuticles, split ends, or uneven hair shafts.
Microbial or bacterial infection can be found in the scalp or hair follicles, which leads to hair loss.

B. Trichogram

Purpose:
To measure development of hair cycle phases (anagen, catagen, and telogen) to recognize hair loss patterns.
Results:
Increased telogen hair count may suggest telogen effluvium (temporary hair loss).
A high percentage of anagen hairs usually suggests normal hair development.
Hair cycle irregularities, such as an increased proportion of hairs in the catagen or telogen phase, may indicate androgenic alopecia or other conditions.

C. Hair Mineral Analysis

Purpose:
To detect essential mineral deficits or excesses that may impair hair health (for example, zinc, iron, magnesium, and copper)
Results:
Low zinc or iron levels may lead to hair to thin or shed (for example, iron deficiency anemia).
Toxic compounds such as mercury and lead can be detected in high concentrations, which may cause to hair loss.
Imbalances in key minerals might be contributed to poor hair quality and breakage.

D. Keratin Content Analysis

Purpose:
Analyze the protein content of hair fibers, specifically keratin. Damaged hair usually has reduced keratin content

Results:
Healthy hair has a strong keratin structure, resulting in strength and flexibility.
Damaged or chemically treated hair frequently reveals keratin breakdown or decreased keratin content, which leads to weaker hair that is more prone to breakage.

E. Genetic Testing

Purpose:
To determine genetic predispositions for disorders such as androgenic alopecia (male or female pattern baldness), alopecia areata, and other genetic hair conditions.
Results:
Androgenic alopecia may be characterized by mutation in androgen receptor-related genes.
Alopecia areata may be connected to immunological gene markers.
Other inherited disorders, such as monilethrix (beaded hair), may include particular gene mutations.

F. Hormonal Testing

Purpose:
To determine hormonal imbalances that can affect hair health, such as thyroid hormones, androgens, estrogen, and cortisol levels.
Results:
Elevated androgens (such as testosterone or dihydrotestosterone) may be related to male and female pattern hair loss.
Hypothyroidism can cause thinning or the loss of hairs due to reduce the metabolism and hair follicles malfunction.
Cortisol levels may indicate stress-induced hair loss (telogen effluvium).

G. Scalp Analysis

Purpose:
To detect scalp disorders such as seborrheic dermatitis, dandruff, and folliculitis, which can damage hair health.
Results:
A healthy scalp appears clear and has minimal inflammation.
Seborrheic dermatitis may cause red, flaky patches and contribute to hair loss.
If untreated, folliculitis (hair follicle infection) can cause scarring and irreversible hair loss.

H. Protein and Amino Acid Profiling

Purpose:
Because hair is mostly made up of proteins and amino acids, identifying amino acid imbalances that can have an impact on hair health is essential.
Results:
Deficiencies in necessary amino acids such as cysteine and methionine can impair hair structure, causing breaking.
Abnormal protein composition in the hair shaft may indicate nutritional deficiencies or systemic disorders, such as liver illness.

I. Chemical Exposure Testing

Purpose:
To determine the presence of harmful compounds (e.g., lead) in the hair that may affect its health.
Results:
High levels of heavy metals in hair, such as lead or mercury, can suggest environmental exposure and contribute to hair loss or damage.
Toxic exposure can alter hair growth patterns and strength.

VI. DISCUSSIONS

Analytical testing is essential for understanding hair health because it provides information on its composition, composition, and biological mechanisms that control hair growth, quality, and loss.

- **Hair Composition and Structure**

Hair is essentially made up of keratin, lipids, water, and trace minerals. Microscopic examination, for example, allows for the study of hair structure that involves the cuticle, cortex, and medulla, and can identify damages such as split ends or thinning.

- **Biochemical and Mineral Analysis**

High-performance liquid chromatography (HPLC) and mass spectrometry (MS) are commonly employed for evaluating hair proteins, amino acids, and trace substances like zinc, iron, and copper. ***(***Fiedorowicz, J. G., et al. 2018)

- **Genetic Testing**

Genetic review of hair follicles can reveal mutations connected to hereditary hair problems including androgenic alopecia. Advances in next-generation sequencing (NGS) have enabled a more in-depth investigation of the genetic variables influencing hair growth, which include mutations in the androgen receptor gene, which play an important role in male-pattern baldness. ***(***Unger, W. W., & Ramasamy, M. 2021).

- **Imaging Technologies**

Non-invasive Trichoscopy and optical coherence tomography (OCT) are routinely used to examine the scalp and hair follicles in greater detail. Trichoscopy detects follicular shrinking or inflammation, whereas OCT gives cross-sectional pictures to evaluate follicle health and therapy efficacy ***(***Tosti, A., et al. 2017).

- **Environmental Factors and Toxins**

Analysis can also reveal environmental toxins such as lead or mercury, which may cause hair loss. (Pinto, C., et al. 2020). Heavy metals in hair are measured using inductively coupled plasma mass spectrometry (ICP-MS), providing insights into the environmental impact on hair health.

- **Hair Treatment Efficacy**

Analytical testing is critical in determining the efficacy of hair treatments like minoxidil and platelet-rich plasma (PRP). Digital photography and image analysis techniques are used to monitor changes in hair density and follicle health, which aids in determining the effectiveness of these treatments.

VII. REMEDIES

Healthy hair involves a combination of regular care, good habits, and lifestyle choices.

i.Maintain a Healthy Diet

- **Protein:**

Although hair is composed of keratin (a kind of protein), consuming enough protein is critical for its growth and strength.

- ***Vitamins and Minerals:***

1. Vitamin A:

Essential for scalp health and hair growth..

2. Vitamin E:

Stimulates the health of hair follicles and could aid in avoiding dryness.
Include almonds, sunflower seeds, and avocados.

3. Biotin (Vitamin B7):

Promotes hair growth and strength. For ex: eggs, nuts, and whole grains.

4. Iron:

It prevents hair thinning and loss. Foods such as spinach, red meat, and lentils are good sources.

5. Omega-3 Fatty Acids:

Reduce inflammation while promoting scalp health.

6. Proper Hair Care Routine

- **Gentle Shampooing:**

To avoid loss of your scalp and hair of natural oils, wash it 2-3 times a week using a light, sulfate-free shampoo.

- ***Condition Regularly:***

Use a conditioner to moisturize and protect your hair health. To prevent dryness and split ends, focus on the ends.

- ***Avoid Over-washing:***

Washing your hair too frequently can cause dryness. Wash your hair according to its type (oily hair may require more frequent cleaning than dry hair).

ii.Use Natural Oils for Scalp and Hair Health

- **Coconut Oil:**

Coconut oil can be used to moisturize the scalp and hair and is well known for its deep hydrating properties. Use a small amount, leave it on for half an hour, and then rinse it off.

- **Jojoba Oil:**

Jojoba oil, like the natural oils produced by the scalp, can aid with dryness and flakiness, resulting in a healthier scalp.

iii.Scalp Massage

- **Boost Circulation:**

Massage your scalp to increases blood flow to the hair follicles, which promotes growth. Use your fingertips in gently circular strokes for 5-10 minutes per day.

- **Essential Oils:**

Including essential oils such as rosemary or peppermint in the massage may enhance circulation and promote hair growth.

iv.Limit Heat Styling

- **Minimize Heat Exposure**:

A high temperature from hairdryers, straighteners, and curling irons may damage hair and cause breakage. When utilizing these tools, always use a heat-protectant spray or serum.

- **Allow Hair to Air-dry:**

Allowing your hair to dry naturally whenever possible will help to avoid heat damage.

v.Avoid Chemical Damage

- **Limit Chemical Treatments:**

Hair can be damaged if it is colored, permed, or relaxed frequently. If you must dye your hair, try semi-permanent solutions that are less harmful, and always seek professional assistance.

- **Deep Conditioning Treatments:**

Once a week, apply a deep conditioning treatment or hair mask to replenish moisture and heal any damage caused by chemicals or heat.

vi.Protect Your Hair at Night

- **Silk Pillowcases:**

Using a silk or satin pillowcase may minimize friction, preventing hair breakage and broken ends.

- **Loose Hairstyles**:

Avoid tight hairstyles (such as tight ponytails or braids), which may pull on your hair and result in breaking, particularly at night.

vii.Reduce Stress

- **Practice Stress Management:**

Stress can cause hair loss, therefore adding relaxation practices like yoga, meditation, or deep breathing exercises will help lower stress levels.

- **Sleep Well:**

Adequate sleep is beneficial to general health, containing hair health.

viii.Hydration

- **Drink Water:**

Maintaining hydration is critical for hair health. Dehydration can cause dry, brittle hair that is more susceptible to breaking.

ix.Protect Your Hair from Environmental Damage

- **UV Protection:**

The sun's UV radiation can cause your hair to become dry and fragile. When spending long periods of time in the sun, wear a hat or use UV-protectant hair spray.

- **Pollution Protection:**

Polluting substances in the environment can harm hair follicles. Wear a scarf or cap can help shield your hair from pollutants.

VIII. CONCLUSIONS

Analytical testing in hair health research gives significant information on the numerous elements that influence hair growth, loss, and general hair health. Studies frequently measure multiple indicators, nutritional ingredients, hormones, as well and genetic factors, as well as assess the influence of external therapies or environmental exposures. Researchers discovered that oxidative stress, nutritional deficiencies (such as iron, zinc, and vitamin D), hormonal imbalances, and heredity all have a substantial impact on hair health.

Furthermore, the use of modern technologies such as high-performance liquid chromatography (HPLC), mass spectrometry (MS), and DNA sequencing has improved our knowledge of the molecular mechanisms underlying hair follicle activity. These techniques allow for a thorough examination of the biochemical environment in the scalp, which aids in the creation of targeted treatments for hair problems like in the alopecia, male pattern baldness, and telogen effluvium.

Analytical testing in hair health studies has shown to be critical for expanding our knowledge of hair biology and identifying the various elements that influence hair growth and loss. Investigators have used rigorous testing procedures to identify particular biomarkers, detect nutrient shortages, and measure environmental or lifestyle factors that contribute to hair diseases such alopecia, telogen effluvium, and hair loss.

To summarize, analytical testing is critical for determining the underlying causes of hair health issues and supporting the discovery of more effective, evidence-based therapies. Continuous research that combines clinical data with modern analytical tools is critical to developing a greater knowledge of hair biology and improving therapy outcomes for persons experiencing hair loss or other hair-related diseases.

IX. ACKNOWLEDGMENT

The author(s) would like to express sincere gratitude to all those who contributed to the development of this review paper. Special thanks to Dr. Pallavi N. Patil for their invaluable guidance, support, and insightful feedback throughout the preparation of this manuscript.

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