Effect of *Phyllanthus emblica* Linn. on Tensile Strength of Virgin and Bleached Hairs

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Abstract: In Ayurveda medicine, *Phyllanthus emblica* Linn. (emblica) has been used as a hair nourisher for more than a decade by soaking it overnight, but no study has proved the effect of emblica on hair. This research aims to determine the effect of emblica solution on the tensile strength of three types of hair: virgin hair (VH), bleached hair (BH), and twice bleached hair (TH). The investigated active substances were deionized water (DI water) as a control, 3% emblica extract solution (3% EXS), 6% emblica extract solution (6% EXS), and 9% emblica extract solution (9% EXS). Black Virgin Asian hair was measured and analyzed before bleaching with a 12% bleaching agent once (BH) and twice (TH). Three treatments and the control were applied to each type of hair under a controlled condition. The tensile characteristics and surface morphology of all treated hairs were measured and analyzed by texture analysis (TA.XT Plus Texture Analyzer, Stable Micro Systems), Aramo (Aramo-SG Skin & Hair analysis system), and scanning electron microscopy (SEM model JSM-5410LV JEOL). The results of the nanoindentation test proved that the tensile strength and extensibility of all three types of hair increased in all concentrations (DI water, 3% EXS, 6% EXS, and 9% EXS). High magnification SEM images were taken from the cuticle surfaces and cross-sections. Emblica extracted solution (EXS) formed a coating around the hair, especially cuticle damaged by bleaching (BH and TH). The breaking pattern from the cross-section images showed that emblica extract solution reinforced all hair types. In conclusion, the emblica extract solution has a significant positive effect on the tensile strength and extensibility of VH, BH, and TH. The result has proved the ancient intelligence that the emblica nourishes the hair. In addition, our results show additional benefit by strengthening virgin hair and bleached hair.

Keywords: emblica extract solution; tensile strength; extensibility; virgin hair; bleached hair

1. Introduction

Human hair is a keratin fiber with various properties, such as water absorbable, water-insoluble, physically durable, chemically inert, flexible, and recoverable from physical deformation. Hair consists of three concentric areas: the cuticle, cortex, and medulla. The cuticle is the outer layer (3.5–4.5 µm) that helps to protect the hair and reduce physical impacts. The cortex is the middle layer and the main part of the hair, which is essential for hair stability, cohesion, stiffness, and suppleness; there is melanin in this layer. The medulla is the core of the hair, which is transparent. The fundamental chemical composition of hair is keratin, up to 95%, which is contained in the cortex and medulla [1].
Hair bleaching is a chemical reaction that oxidizes melanin, damages keratin in the hair structure, and changes the appearance of the hair, such as color, smoothness, and endurance, which cause most of the hair to become brittle and fall out problems [2,3]. The chemical agent in the bleaching solution dramatically causes peeling and inflammation on the scalp, erythema, and pain on the skin nearby [4]. These problems have increased the need to use hair coloring products, via hair dyeing, in the senior population, and the popularity of hair color change fashion in juniors [5]. There are numerous studies on hair treatment before and after bleaching to reduce hair troubles and promote hair strengthening and growth such as green tea [6], Eclipta alba [7], or Hibiscus rosa-sinensis Linn [8].

Phyllanthus emblica Linn. (syn. Emblica officinalis), commonly known as emblica, amla, or Indian gooseberry, is highly nutritious; it contains vitamin C, amino acids, and minerals [9]. It is one of the well-known and valuable medicinal herbs in ancient medicine, such as Thai Traditional Medicine, Ayurveda (Indian Traditional Medicine), and Traditional Chinese Medicine. Based on studies in many countries, emblica helps to boost the immune system and has anti-cancer [10], antimicrobial, analgesic [11], and anti-oxidant activities [12]. It has been used as an ingredient to cure human illnesses, such as diarrhea, injuries, fever, cold, malaria, gout, tumor, etc. The chemical components of emblica include alkaloids, flavonoids, saponins, terpenoids, glycosides, and tannins. Among the more than 100 phenolic compounds in emblica, tannins are the main content with astringent properties [13,14]. They shrink the hair surface as well as tighten and make the hair stronger and healthier by coating the hair cuticle [15]. Emblica also helps to promote hair growth, length, density, health [16,17] and reduces hair loss by inhibiting 5α-reductase [18]. However, its effect on hair tensile strength has never been studied. In ancient Ayurveda, emblica has been used as a traditional hair tonic for hair growth (density and volume) and hair treatment (nourishment and pigmentation) by rinsing hair during the last wash with a tonic prepared by soaking emblica in water overnight [19].

Strength is one of the fundamental properties of a material. It is determined by measuring the amount of stress that makes a material deform or the maximum stress that breaks it. Material strength is related to elastic and plastic properties (the ability of a material to resist distortion) [20]. One of the popular strength testing methods is tensile testing. The test was placed on stretching a specific length of material at a fixed strain rate. The result would change the conditions and properties. The most common testing machine is a comprehensive and extensive tester that can test tension, compression, and bending in any material by changing grip [21]. In recent decades, tensile testing has been developed to test micro/nanomaterials and measure their properties precisely. The metrological and experimental techniques of material testing in micro size have become accessible and convenient in many fields of research, including hair and cosmetic industries [22]. Some studies that have used these techniques in the hair treatment field include Effects of Hard Water on Hair [23] and Tensile Strength of Bleached Hair [24]. Studies have shown that in the hair structure, the hair cortex has the highest effect on hair tensile properties [25]. The melanin causes the hair’s color is in the hair cortex. The effect of the bleaching agent destroys hair structure through the cortex and makes hair color fading [26]. As the Ancient know-how, emblica is a natural hair treatment. There is no previous study on the effect of emblica on the tensile strength of hair. In this study, three concentrations of emblica extract solution (3%, 6%, and 9%) were selected according to the result of a previous study on the effect of butterfly pea and emblica hair spray [27]. The best concentration of emblica was 6.66%.

The objective of this study is, therefore, to evaluate the effect of emblica extract solution on the tensile strength of virgin hair (VH), bleached hair (BH), and twice bleached hair (TH). The results of this study would prove the know-how of ancient herbal medicine and the effect of emblica on the tensile strength and extensibility of hair. The outcome would lead to further research in hair cosmetic product formulation.
2. Materials and Methods

2.1. Emblica Extract Solution and Dye Solution

Fresh emblica samples were purchased from Chiang Mai province, Thailand, and dried at 60 °C for three days. One hundred grams (100 g) of dried emblica was mixed with 1 L of water, boiled for 1 h, and the liquid collected. A filter (Whatman filter paper No.41) was used to separate the liquid. The emblica extract solution was kept (in a refrigerator) at 8 °C; 3%, 6%, and 9% emblica extract solutions were prepared by diluting emblica extract solution with deionized water based on each concentration, and they were kept at room temperature.

As per the manufacturer’s instruction, 15 g of Berina hair bleaching powder was mixed with 60 mL of Berina developer (12% w/w hydrogen peroxide). The mixture was stirred until becoming homogenous, and it was put on the hair immediately after mixing for 60 min and rinse water.

2.2. Tannin Assay Kit

Tannin Microplate Assay Kit (Catalog # CAK1060) was purchased from Cohesion Biosciences (London, UK). Tannin can react with phosphomolybdic acid, and this Assay Kit can be measured at a colorimetric readout at 650 nm. Emblica extract was a liquid sample which can be detected by the assay directly. The procedure from Cohesion Biosciences was to warm the reaction buffer, dye reagent to room temperature before use and add sample, standard, distilled water, reaction buffer, and dye reagent into the microplate. Mix the sample with the reagent and stay at room temperature for 10 min before measured at 650 nm and record the absorbance.

2.3. Total Iron Testing

Emblic extract sample was sent to Central Laboratory Co., Ltd. (Chiang Mai, Thailand) for total iron testing by ICP-OES technique. ICP- OES or Inductively coupled plasma- optical emission spectroscopy is one of the suitable element analytical techniques that can be quickly and simply measured most of the elements at trace levels that the plasma energy is given to analyze the element with high sensitivity.

2.4. Hair Preparation

The hair samples used in this experiment were purchased from U And I Cut And Beauty (beauty supply store) (Bangkok, Thailand); the samples were black, straight, and virgin hair (never been bleached or dyed before). All samples were washed with room temperature water (22–25 °C) for 2 min and dried at room temperature before been measured and cut to 10 cm length. Thirty hair samples were randomly chosen and weighted in the preliminary analysis, and their weights were sorted in ascending order. The ten medium weights were chosen as the representative weight range to select 360 samples to be used in the study (0.00063–0.00095 g). The hair diameters were measured with the Aramo-SG Skin & Hair analysis system with a 200× magnifying camera. Each hair was measured three times, at both ends of the hair and in the middle. The average diameter from the three measurements is shown on the monitor by “Hair Pro X” analysis program, as shown in Figure 1. The measured hairs were separated into 12 groups: (1) VH with DI water (B0E0), (2) VH with 3% EXS (B0E3), (3) VH with 6% EXS (B0E6), (4) VH with 9% EXS (B0E9), (5) BH with DI water (B1E0), (6) BH with 3% EXS (B1E3), (7) BH with 6% EXS (B1E6), (8) BH with 9% EXS (B1E9), (9) TH with DI water (B2E0), (10) TH with 3% EXS (B2E3), (11) TH with 6EXS (B2E6), and (12) TH with 9% EXS(B2E9), as shown in Table 1. The purpose of using the bleached hair was to compare the strength of VH, BH, and TH before and after treatments. Various concentrations of emblica solution (3%, 6%, 9% w/w) were used to treat each type of hair (virgin, bleached, and twice bleached). The processing parameters include temperature: 22–25 °C, relative humidity: 52–57%, and pH of solutions: 3.41–6.54. All hairs were immersed in the solutions for 3 h, dried at room temperature and kept in zip-lock plastic bags. Then, as per the manual (Hair and Hair Product testing: Texture analysis application overview, Stable Micro System),
square-hole papers (87 × 52 mm with 55 × 30 mm hole) were prepared for each hair, as shown in Figure 2a. One hair shaft was put in the middle of the paper and glued at both ends of the hair before putting another prepared square-hole paper on it, as shown in Figure 2b. The hair-attached paper was mounted on Tensile Testing Grip (A/TG) with a 5 kg load cell, and both sides of the paper were cut, as shown in Figure 2c.

Figure 1. Hair diameter measurement by the Aramo-SG Skin & Hair analysis system with 200× magnification, which is shown on the Hair Pro X analysis program.

Table 1. The 12 groups of hair after measurement before bleaching and treatment.

| Number of Bleaching Times (B) | Emblica Extract Solution Concentration (E) |
|-------------------------------|------------------------------------------|
|                               | 0% (E0) | 3% (E3) | 6% (E6) | 9% (E9) |
| 1. VH (No bleaching) (B0)     | B₀E₀    | B₀E₃    | B₀E₆    | B₀E₉    |
| 2. One time bleaching hair (B₁) | B₁E₀    | B₁E₃    | B₁E₆    | B₁E₉    |
| 3. Twice bleaching hair (B₂)  | B₂E₀    | B₂E₃    | B₂E₆    | B₂E₉    |

Figure 2. (a) Prepared square-hole paper (87 × 52 mm with 55 × 30 mm hole); (b) one hair glued in the middle of the paper before being attached to another paper; (c) cut both sides of the paper after mounting it on the Tensile Testing Grip (A/TG).
2.5. Tensile Testing

Tensile strength and the corresponding failure strain of all 360 samples were tested on the TA.XTplus Texture Analyser and Exponent Texture Analyser software. Tensile strength force (N) and extensibility (mm) were measured by “Hair Mono Filaments” product, and force was measured in “Tension” mode, 0.5 mm/s test-speed, 200 mm distance, and 20 g break detect. The machine was calibrated before the experiment. All hair samples were prepared and tested under ambient laboratory conditions (temperature 22–25 °C and 52–57% relative humidity). The test results are shown on the monitor in the “Texture Exponent” program, as shown in Figure 3. Tensile strength force (N) and time(s) were plotted continuously until hair breaking.

![Figure 3. “Texture Exponent” program showing a graph of test result involving Tensile strength force (g) and time(s).](image)

2.6. SEM Analysis

After tensile testing, a hair sample was randomly chosen from each group and cut at 0.5 cm from the hair breaking terminal. The prepared samples were mounted on metal aluminum to be coated with gold under vacuum. Multiple sections were scanned and analyzed by scanning electron microscopy (SEM) to check hair surface and hair cross-section to check the breaking texture at the hair terminal by SEM model JSM-5410LV JEOL, Japan at Tarabusiness Co., Ltd. (Bangkok, Thailand).

2.7. Statistic Analysis

After testing, all data were collected and checked for validation before being processed using SPSS. t-test was used to compare the means of data. One-way ANOVA was used to check all hair samples before bleaching or treatment with emblica extract solution. One-way ANOVA was used to compare the tensile strength/extensibility of VH, BH, and TH before treatment with EXS to check the effect of bleaching on hair. One-way ANOVA with LSD comparison was also used to compare the tensile strength/extensibility of the12 groups of hair (B0E0, B0E3, B0E6, B1E0, B1E3, B1E6, B1E9, B2E0, B2E3, B2E6, and B2E9). The Spearman’s correlation was used to check the mutual relationship and to find the correlation coefficient (R) between emblica extract solution concentration and tensile strength/extensibility.
3. Results

3.1. Hair Data

The results showed in Table 2 displays the means, Standard error of the mean (SE), and p-values of hair weight, diameter, and density of the groups (30 hairs per group). All hairs were measured before bleaching or treatment with emblica extract solution. The p-value showed non-significant differences (p > 0.05) between each group. The prepared hairs had the same size (10 cm), and non-significant differences of weight and diameter. The measurement in this table aimed to compare all hair in each group before the experiment to normalize and choose the virgin hairs that were non-significant differences.

Table 2. Hair weight, diameter, and density before bleaching or treatment with emblica extract solution.

| Hair Group Label | Emblica (%w/w) | Weight ($\times 10^{-4}$ g) | Diameter (µm) | Density (g/cm$^3$) |
|------------------|----------------|----------------------------|---------------|-------------------|
| Virgin hair (B$_0$) | 0 | 8.21 ± 0.13 | 114.7 ± 1.34 | 0.0079 |
| | 3 | 8.14 ± 0.12 | 115.7 ± 1.67 | 0.0078 |
| | 6 | 8.16 ± 0.13 | 112.9 ± 1.08 | 0.0082 |
| | 9 | 8.04 ± 0.11 | 114.3 ± 1.26 | 0.0079 |
| BH (B$_1$) | 0 | 8.02 ± 0.14 | 111.4 ± 2.13 | 0.0084 |
| | 3 | 8.04 ± 0.14 | 113.5 ± 1.51 | 0.0079 |
| | 6 | 8.18 ± 0.13 | 113.9 ± 1.97 | 0.0082 |
| | 9 | 8.07 ± 0.14 | 114.7 ± 1.62 | 0.0078 |
| TH (B$_2$) | 0 | 8.15 ± 0.12 | 113.5 ± 2.14 | 0.0083 |
| | 3 | 8.10 ± 0.14 | 114.0 ± 1.75 | 0.0081 |
| | 6 | 7.89 ± 0.12 | 112.0 ± 2.31 | 0.0084 |
| | 9 | 8.10 ± 0.12 | 111.6 ± 1.47 | 0.0083 |
| Means | | 8.095 | 113.52 | 0.0081 |
| SE | | 0.037 | 0.495 | 0.00007 |
| p-value * | | 0.936 | 0.834 | 0.511 |

* One-Way ANOVA compares data in the same column with LSD comparison.

3.2. Effect of Bleaching Agent on Hair

Table 3 shows the effect of bleaching agents on hair tensile strength and extensibility before emblica extract solution treatment. The tensile strength) N (of VH was significantly higher than those of BH and TH) p < 0.01. (The tensile strength of BH was also significantly higher than that of TH) p < 0.01. The extensibility) mm (of VH was significantly lower than those of BH and TH) p < 0.01. (The extensibility of BH was insignificantly lower than that of TH) p < 0.01. We found that the bleaching agent) 12% H$_2$O$_2$) affects the tensile strength and extensibility of hair.

Table 3. Effect of bleaching agent on tensile strength and extensibility.

| Strength | No of Bleaching (Times) | p-Value * |
|----------|-------------------------|-----------|
|          | 0 | 1 | 2 | |
| Tensile strength (N) | 0.958 ± 0.019 $^a,b$ | 0.884 ± 0.023 $^a,c$ | 0.810 ± 0.032 $^b,c$ | 0.000 |
| Extensibility (mm) | 22.79 ± 0.497 $^a,b$ | 31.05 ± 0.787 $^a$ | 32.41 ± 1.202 $^b$ | 0.000 |

Mean ± S.E * One-way ANOVA with LSD comparison. $^a,b,c$ There are no statistically significant differences between means with the same alphabet in the same row. (p < 0.01).
3.3. Effect of Emblica Extract Solution on Hair

Emblica extract solution has been tested for tannin content (1.25 g tannin/1000 g emblica extract solution) and iron content (6.01 mg iron/1000 g emblica extract solution). Then it was used in the experiment.

3.3.1. Effect of Emblica Extract Solution on Tensile Strength

Figure 4 demonstrates the effect of emblica extract solution on the tensile strength of three types of hair: The tensile strength of VH (0.958 ± 0.102, 1.020 ± 0.086, 1.13 ± 0.165, and 1.124 ± 0.123 N) was higher than those of BH (0.884 ± 0.126, 0.927 ± 0.188, 0.951 ± 0.141, and 0.981 ± 0.147 N) and TH (0.810 ± 0.175, 0.874 ± 0.177, 0.801 ± 0.170, and 0.881 ± 0.241 N). Emblica extract solution extremely affected VH. The tensile strength of hair treated with 9% EXS was higher than those of 6% EXS, 3% EXS, and DI water, respectively. Only the increase in the tensile strength of VH caused by 3% EXS was statistically insignificant. The tensile strength of BH and TH were statistically insignificantly increased by all concentrations of emblica extract except for the tensile strength increase of BH by 9% EXS, which was statistically significant. The hair with the highest tensile strength was VH treated with 9% EXS, while that with the lowest tensile strength was TH treated with DI water. Emblica extract solution increased the tensile strength of VH by 14.76% and that of BH by 9.88%. The result showed that the more the concentration of emblica extract solution, the more the tensile strength for VH and BH.

Figure 4. Mean of tensile force (N) of 3 groups of hair samples treated with DI water, 3%, 6%, 9% emblica extract solution using a texture analyzer (n = 30 each, p < 0.05); error bars represent standard error of the mean. (3 groups: virgin, bleached, and twice bleached).

Analysis of correlation was conducted on the result with Spearman’s correlation coefficient to measure the statistical relationship. Regarding VH, the degree of correlation between the concentration of emblica solution and tensile strength was “moderate positive association” (0.656) (p < 0.01), that of BH was “low positive association” (0.234) (p < 0.01), and that of TH was “no linear association” (0.050) (p > 0.05).
3.3.2. Effect of Emblica Extract Solution on Extensibility

Figure 5 demonstrates the extensibility effect of emblica extract solution on three hair groups. The extensibility of VH (22.79 ± 2.72, 25.24 ± 4.76, 32.20 ± 3.22, and 37.14 ± 5.95%) was lower than those of BH (31.05 ± 4.31, 35.54 ± 4.59, 39.46 ± 5.32, and 39.78 ± 3.50%) and TH (32.41 ± 6.59, 33.98 ± 6.69, 30.18 ± 6.22, and 31.60 ± 7.40%). Emblica extract solution increased the extensibility of VH by 38.63% and that of BH by 21.94%. For VH and BH, the extensibility of hair treated with 9% EXS was higher than those of 6%, 3%, and DI water, respectively. The extensibility of VH and BH were statistically significantly increased by all concentrations of EXS except for the increase in the extensibility of BH caused by an increase from 6% EXS to 9% EXS, which was statistically insignificant. The hair with the highest extensibility was BH treated with 6% EXS, while that with the lowest extensibility was VH treated with DI water. The result showed that the more the concentration of emblica extract solution, the more the extensibility for VH and BH. For TH result, the tensile strength and extensibility showed fluctuations and inconclusive results.

Figure 5. Mean extensibility (mm) of 3 groups of hair samples treated with DI water, 3%, 6%, 9% emblica extract solution using a texture analyzer \((n = 30\) each, \(p < 0.05\)); error bars represent standard error of the mean. (3 groups: virgin, bleached, and twice bleached).

The analysis of correlation was also conducted on the result with Spearman’s correlation coefficient. Regarding VH, the degree of correlation between the concentration of emblica solution and extensibility was “moderate positive association” \((0.656)\) \((p < 0.01)\), that of BH was “moderate positive association” \((0.608)\) \((p < 0.01)\), and that of TH was “no linear association” \((-0.091)\) \((p > 0.05)\).

All images in Figures 6 and 7 were taken from a group hair sample; thus about 50 SEM images were obtained in each group. Representative SEM images were chosen when >80% of electron micrographs showed a similar pattern of damage [28].

Figure 6 illustrates the magnified Scanning Electron Microscope (SEM) images of hair surface in the cuticle scales. All VH surfaces treated with DI water (a), 3% EXS (b), 6% EXS (c), and 9% EXS (d) were normally smooth.

The VH surface in Figure 6a was flat compared with the BH surface in Figure 6e, which was slightly damaged, and the TH surface in Figure 6i, which was dramatically damaged. On precise inspection,
the surfaces of BH and TH were damaged and lifted as much as the number of bleaching times. The damage of bleaching remains on treated TH (Figure 6i–l) more than on treated BH (Figure 6e–h).

By comparing the pictures in the horizontal direction, emblica treated BH and TH (Figure 6e–l) showed that the higher the concentration of emblica extract solution, the smoother the surface.

From the illustrations of BH (Figure 6e–h), 9% EXS could coat BH surface as smooth as VH, but the cuticle was more damaged and fractured.

From the illustrations of TH (Figure 6i–l), 9% EXS could coat TH surface, but the cuticle was much more fractured and lost than VH and BH. Emblica extract could recover some parts of damaged hair. It could cover VH, BH, and TH and treated hair cuticle as confirmed by SEM analyses. From previous studies, emblica extract solution composed of gallic acid, tannic acid, and iron [20,21] therefore, it could imply that the emblica extract solution could coat VH, BH, and TH firmly, as shown in Figure 6b–d,f–h,j–l.

**Figure 6.** SEM images of damaged cuticle scale of VH/BH/TH after treatment with DI water and different concentrations of emblica extract solution: (a) VH + DI water, (b) VH + 3%EXS, (c) VH + 6%EXS, (d) VH + 9%EXS, (e) BH + DI water, (f) BH + 3%EXS, (g) BH + 6%EXS, (h) BH + 9%EXS, (i) TH + DI water, (j) TH + 3%EXS, (k) TH + 6%EXS, and (l) TH + 9%EXS.
Figure 7. Cross-sectional SEM images of VH/BH/TH after treatment with DI water and 9% concentration of emblica extract solution: (a) VH + DI water, (b) VH + 9%, (c) BH + DI water, (d) BH + 9%, (e) TH + DI water, and (f) TH + 9%.

The high magnification SEM images were taken from cross-sections of VH, BH, and TH. Figure 7a,c,e, (left column) shows that the bleaching agents cause hair structure damaged based on the number of bleaching times. By comparing the breaking pattern of VH between Figure 7a,b, 9% EXS made hair more rigid and harder to break than DI water.

In Figure 7d, it is shown that 9% EXS consolidated the damaged hair than in Figure 7c, and the breaking pattern of BH showed more durability than when treated with DI water; however, it was inadequate for it to recover as well as VH. The breaking pattern of TH treated with 9% EXS (Figure 7f) was more rigid than when treated with DI water (Figure 7e); however, the damage of 2-times bleaching was too severe for 9% EXS to recover.

4. Discussion

Hairs in this experiment were black and straight. They were bought from a beauty supply store that sells Thai healthy hair in Thailand. The hair diameters, which were measured by ARAMO, were used to find the hair cross-sectional area. The SEM images of VH show that all hairs were
almost circular in cross-section, which is confirmed and consistent with previous studies on hair from subjects of different ethnic origins (Caucasian, Asian, and African). African hair tended to be flat oval, while Asian hair tended to be round [29]. The hair diameters, which were measured by ARAMO, were 101–132 µm, consistent with a previous study on 2249 healthy subjects from 24 ethnic groups. The hair diameters from Thailand and China were 73–136 µm [30] and consistent with a previous study about ethnic variation in hair. The hair diameter of people who are referred to as Oriental or Asian hair were generally ranging from 100–130 µm. [31].

The damage of bleaching agents regarding one-time bleaching and twice bleaching is consistent with previous studies on morphological and histological bleached hair. Even though the percentage of hydrogen peroxide solution of bleaching agent and bleaching time were different, SEM images showed hair damage and lifted cuticle [32]. In accordance with studies on hair dying [33], hair color was also lighter from black to brown and light brown as the concentration of bleaching agent and the number of bleaching time increased. The bleaching agent oxidizes hair melanin in the cortex and medulla through the cuticle. The more the cuticle damage is, the less the hair color left and the less the tensile strength but with increased extensibility.

The effect of bleaching on hair decreased the tensile strength from 0.958 ± 0.019 to 0.884 ± 0.023 N, or about 7.72% decrease, which is consistent with previous studies on the tensile strength of bleached hair. Tensile strength was decreased from 14.66 g/cm² to 12.95 g/cm², or about 11.66% decrease [27]. The extensibility of bleached hair increased from 22.79 ± 0.497 to 31.05 ± 0.787%, or about 36.24% increase, which is consistent with previous studies on the effect of bleaching time and hydrogen peroxide concentration on hair damage. The extensibility increased by about 35.71% [31]. The bleaching agent was dramatically affected both the tensile strength and extensibility of twice bleached hair. The tensile strength decreased to 0.810 ± 0.032 N, or about 15.44% decrease, and the extensibility increased to 32.41 ± 1.202%, or about 42.17%, which is consistent with previous studies on the damage of hair bleaching. The result of the previous study showed that the more times of bleaching agent the more tensile strength decreased and the more extensibility increased [34].

Test-speed in the tensile testing was 0.5 mm/s, which made a strain rate of 0.05/s, the stress of 74.49–123.3 MPa, and strain of 0.198–0.299, which is consistent with previous studies on female hair of about the same age. The hair diameter was about 90 µm, the strain rate was 0.1–0.01/s, the stress was 100–160 MPa, and the strain was 0.2–0.3 [25].

After three concentrations of emblic extract treatment, the best and only one concentration that statically significantly effect on BH was 9%EXS treatment. It was a 10.97% increase, which is better than the previous study on a novel leave-on technology combination (caffeine, niacinamide, panthenol, dimethicone, and an acrylate polymer (CNPDA)). The tensile stress effect between bleached untreated and bleached CNPDA treated hair had a 5.00% increase [35] and consistent with another previous studies on Glycolipid Biosurfactants, Mannosylerythritol Lipids, Repair the Damaged Hair. The tensile strength effect on MEL-A treatment had a 22.00% increase and on MEL-B there was a 19.40% increase [36].

Tannins are influential chemical components for emblica extract to coat hair. In this study, 9% EXS [37] treated VH caused tensile strength of 1.29 times and extensibility of 1.63 times more than DI water treated VH. This is consistent with previous studies on the effect of eucalyptus ash on hair, which caused tensile strength to increase by 1.17 times and extensibility by 1.38 times. The tannin in the ash, which is bonded (s-bond) with iron (Fe), made hair stronger and darker [38].

The result of tannin testing is 1.25 g tannin/1000 g emblica extract solution, or 12.0 mg tannin/1 g dried emblica weight which is calculated according to 960 mL emblica extract solution was obtained from 100 g dried emblica. Compare with the tannin from the previous studies, “Acute and chronic oral toxicity of standardized water extract from the fruit of Phyllanthus emblica Linn.” [39], the tannin content of Amla (Phyllanthus emblica) fruit was 24.32% w/w or 41.32 mg tannin/1 g dried emblica weight, which is higher than tannin in our study. The higher tannin content may be due to two times the
Another study of the iron content from the nutritional value of Phyllanthus emblica fruit, “Indian gooseberry (Emblica officinalis): Complete pharmacognosy review” [40] found that the total iron was 0.0150 mg iron/1 g dried emblica, which is lower than in our study.

Another consistent study involves tannic acid, gallic acid, and iron bonded with protein [41], and they were all found in emblica [37,42]. The study was conducted on the chemical bond in dyed hair [42]. The ingredients used in their formulation included tannic acid, gallic acid, and Fe$^{2+}$ (D-gluconate). The formulation is oxidized upon exposure to air and coats hair firmly as blackish tannin nano molecule, as shown in Figure 8. Among the numerous emblica chemical component studies, there are pieces of evidence that emblica extract has a lot of phytochemical compounds, such as gallic acid, tannic acid, iron (Fe), ascorbic acid, ellagitannin, ellagic acid along with flavonoids and kaempferol [43,44]. Emblica extract solution could be able to coat hair like a chemical bond in hair dyeing.

![Figure 8](image-url)

**Figure 8.** The air oxidation of soluble ferrous during hair dyeing and the possible binding of tannic acid, gallic acid, and ferrous. This image was modified with permission from Han, S.Y.; Hong, S.P.; Kang, E.K.; Kim, B.J.; Lee, H.; Kim, W.I.; Choi, I.S. Iron, Gall Ink Revisited: Natural Formulation for Black Hair-Dyeing; published by Cosmetics, 2019 [41].

The SEM images selection method is consistent with a previous study of the comparison of hair shaft damage after chemical treatment in Asian, White European, and African hair [28].

The bleaching agent concentration and bleaching time were the major cause of hair damage. As the manufacturing instruction, 12% of Hydrogen peroxide for 1 h causes the cuticle lifted and damaged on bleached hair more than previous studies on 6% of Hydrogen peroxide for 0.5 h. After treated with polyquaternium 7® solution, the SEM images showed a roughness caused by the solution on the hair surface which similar to the SEM in this study that EXS were coated on the hair surface. [45].

Comparing the breaking patterns of cross-sectional images of DI water treated hair in Figure 9 (left column) (m, o, q) and 9% EXS treated hair in Figure 9 (right column) (n, p, r) indicates that 9% EXS improved the condition of hair and made it more rigid and harder to break compared with DI water. This experiment is consistent with a previous study on the breaking pattern of hair. There usually are four types of hair fracture patterns, as shown in Figure 9. Fibrillation and splitting tend to occur more in hair in poor condition than smooth and step patterns [46].
Emblica has been ubiquitously used in Ayurvedic medicine for nourishing hair since ancient times. The results of this experiment show that emblica extract solution promoted hair strength (tensile strength and extensibility). Among all treatments (DI water, 3%EXS, 6%EXS, and 9%EXS), the results showed that tensile strength/extensibility of VH and BH and concentration of emblica extract solution are directly related; 9% EXS was the best concentration that could achieve the maximum tensile strength (1.124 ± 0.123 N) and extensibility (37.14 ± 5.95%) for VH. Only the effect of 3% EXS on VH led to a statistically insignificant increase, which means that the emblica extract solution can increase the tensile strength of VH when the concentration is more than 3%. All concentrations of emblica extract solution increased the tensile strength of BH and TH in a statistically insignificant manner except for the increase of the tensile strength of BH by 9% EXS, which was statistically significant; this means that emblica extract solution can increase the tensile strength on BH when the concentration is more than 9%.

The extensibility of VH and BH were statistically significantly increased by all concentrations of EXS except for the increase in the extensibility of BH caused by an increase from 6% EXS to 9% EXS, which was statistically insignificant; this means that 6% EXS was the minimum concentration that could cause the maximum extensibility for BH (0.40 ± 0.05%).

The extensibility of TH fluctuated with statistically insignificant changes. The microscopical surface and cross-sectional images of SEM showed the morphological attachment of emblica on VH, BH, and TH. As an extract solution, emblica has potential as a hair strengthening treatment for virgin hair and 12% of hydrogen peroxide on BH.

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