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Effect of mineral oil, sunflower oil, and coconut oil on prevention of hair damage

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Synopsis

Previously published results showed that both *in vitro* and *in vivo* coconut oil (CNO) treatments prevented combing damage of various hair types. Using the same methodology, an attempt was made to study the properties of mineral oil and sunflower oil on hair.

Mineral oil (MO) was selected because it is extensively used in hair oil formulations in India, because it is non-greasy in nature, and because it is cheaper than vegetable oils like coconut and sunflower oils. The study was extended to sunflower oil (SFO) because it is the second most utilized base oil in the hair oil industry on account of its non-freezing property and its odorlessness at ambient temperature. As the aim was to cover different treatments, and the effect of these treatments on various hair types using the above oils, the number of experiments to be conducted was a very high number and a technique termed as the Taguchi Design of Experimentation was used. The findings clearly indicate the strong impact that coconut oil application has to hair as compared to application of both sunflower and mineral oils. Among three oils, coconut oil was the only oil found to reduce the protein loss remarkably for both undamaged and damaged hair when used as a pre-wash and post-wash grooming product. Both sunflower and mineral oils do not help at all in reducing the protein loss from hair.

This difference in results could arise from the composition of each of these oils. Coconut oil, being a triglyceride of lauric acid (principal fatty acid), has a high affinity for hair proteins and, because of its low molecular weight and straight linear chain, is able to penetrate inside the hair shaft. Mineral oil, being a hydrocarbon, has no affinity for proteins and therefore is not able to penetrate and yield better results. In the case of sunflower oil, although it is a triglyceride of linoleic acid, because of its bulky structure due to the presence of double bonds, it does not penetrate the fiber, consequently resulting in no favorable impact on protein loss.

INTRODUCTION

Morphologically, a fully formed hair fiber contains three and sometimes four different units or structures. At its surface, hair contains a thick protective covering consisting of layers of flat overlapping scale-like structures called the cuticle. The cuticle scales surround the cortex, which contains a major part of the fiber mass. The cortex, the second unit, consists of spindle-shaped cells that are aligned along the fiber axis. Cortical cells contain the fibrous proteins of hair. Thicker hairs often contain one or more loosely packed porous regions called the medulla, located near the center of the fiber. The fourth

unit is the intercellular cement that glues or binds the cells together, forming the major pathway for diffusion into the fibers.

The cuticle consists of flat overlapping cells (scales). The cuticle cells are attached at the proximal end (root end), and they point toward the distal end (tip end) of the hair fiber. However, cuticle damage evidenced by broken scale edges that can usually be observed several centimeters away from the scalp is caused by weathering and mechanical damage from the effects of normal grooming actions, such as combing, brushing, and shampooing. Because of extensive cross-linking, cuticle cells tend to be brittle and, therefore, are susceptible to damage by grooming procedures, especially wet combing (1). In long hair fibers (25 cm or longer), progressive surface damage may be observed. The loss of cuticle cells by gradual chipping impairs the structural integrity of hair, leading ultimately to split ends and fracture. This limits the length and the cosmetic qualities of hair such as

Table I
Design of Experiment Using the Taguchi Model

No.	Oils	Hair type	Hair treatment	Oiling sequence	Shampooing
1	CNO	Straight	Undamaged	Before	Once
2	SFO	Curly	Undamaged	Before	Once
3	MO	Wavy	Undamaged	Before	Twice
4	MO	Permed	Undamaged	Before	Twice
5	CNO	Straight	Bleached	Before	Once
6	SFO	Curly	Bleached	Before	Once
7	MO	Wavy	Bleached	Before	Twice
8	MO	Permed	Bleached	Before	Twice
9	SFO	Straight	Boiled	Before	Twice
10	CNO	Curly	Boiled	Before	Twice
11	MO	Wavy	Boiled	Before	Once
12	MO	Permed	Boiled	Before	Once
13	SFO	Straight	UV-treated	Before	Twice
14	CNO	Curly	UV-treated	Before	Twice
15	MO	Wavy	UV-treated	Before	Once
16	MO	Permed	UV-treated	Before	Once
17	MO	Straight	Undamaged	After	Once
18	MO	Curly	Undamaged	After	Once
19	CNO	Wavy	Undamaged	After	Twice
20	SFO	Permed	Undamaged	After	Twice
21	MO	Straight	Bleached	After	Once
22	MO	Curly	Bleached	After	Once
23	CNO	Wavy	Bleached	After	Twice
24	SFO	Permed	Bleached	After	Twice
25	MO	Straight	Boiled	After	Twice
26	MO	Curly	Boiled	After	Twice
27	SFO	Wavy	Boiled	After	Once
28	CNO	Permed	Boiled	After	Once
29	MO	Straight	UV-treated	After	Twice
30	MO	Curly	UV-treated	After	Twice
31	SFO	Wavy	UV-treated	After	Once
32	CNO	Permed	UV-treated	After	Once

Treatments were sequential. If the treatment is designated as CNO–Permed–Boiled–After–Once, it means permed hair was first put in boiling water for 120 min and air dried, and then 0.2 ml of CNO was applied to it. This treatment was carried out for all 25 hair tress samples. Twenty-five replicate tresses were used for each treatment.

Table II
Analysis of Variance Data for Half-Head Treatments for Protein Loss

Hair type	Source of variance	Degrees of freedom	Sum of squares	Mean square	F-Value at 95% confidence level
Normal Oil type MO	Between treatments	1	34.8	34.8	0.6
	Experimental error	38	2234.6	58.8	
Bleached Oil type MO	Between treatments	1	42.8	42.8	1.1
	Experimental error	38	1545.7	40.7	
Normal Oil type SFO	Between treatments	1	39.6	39.6	1.1
	Experimental error	38	1345.6	35.4	
Bleached Oil type SFO	Between treatments	1	48.6	48.6	1.5
	Experimental error	38	1195.6	31.5	
Normal Oil type CNO	Between treatments	1	31.6	31.6	6.2
	Experimental error	38	195.6	5.1	
Bleached Oil type CNO	Between treatments	1	36.5	36.5	4.9
	Experimental error	38	286.5	7.5	

F theoretical for 1.38 degrees of freedom at 95% confidence level = 4.08.

smoothness and shine. Grooming methods involving abrasive procedures are known to damage hair and its appearance.

Historically, coconut oil has been used as a hair dressing in the developing countries in the tropical regions of the globe where the coconut is cultivated extensively. Prolonged use of coconut oil has been known to lead to healthy looking long hair, suggesting that it may prevent damage to the cuticle in grooming procedures involving abrasion. Obvious is the lubricating effect of oil on fiber friction, which reduces abrasive damage, especially in combing. However, in modern times, the trend in hair oil formulations is more towards the use of non-sticky oils such as mineral oil or less greasy oils such as sunflower oil. This is done primarily because of cost differentials as well as to overcome the undesirable properties of coconut oil such as greasiness, its strong smell, and freezing at ambient temperatures.

This investigation is aimed at comparing the effects of these two oils along with that of coconut oil in preventing hair damage when used as a preconditioner. Although several methods involving scanning electron microscopy (SEM) measurement of combing forces and tensile mechanical properties have been used earlier to characterize hair damage, we have used protein loss and water uptake methods for this purpose. Furthermore, these methods have been extended to study the beneficial effects of these oils in preventing chemical, thermal, and UV damage. Efficacy of these methods has been established in an earlier paper from this laboratory (3).

MATERIALS AND METHODS

MATERIALS

Samples of straight, curly, wavy and permed hair of Indian origin were used in this work. The length of the Indian hair strands was 25 cm.

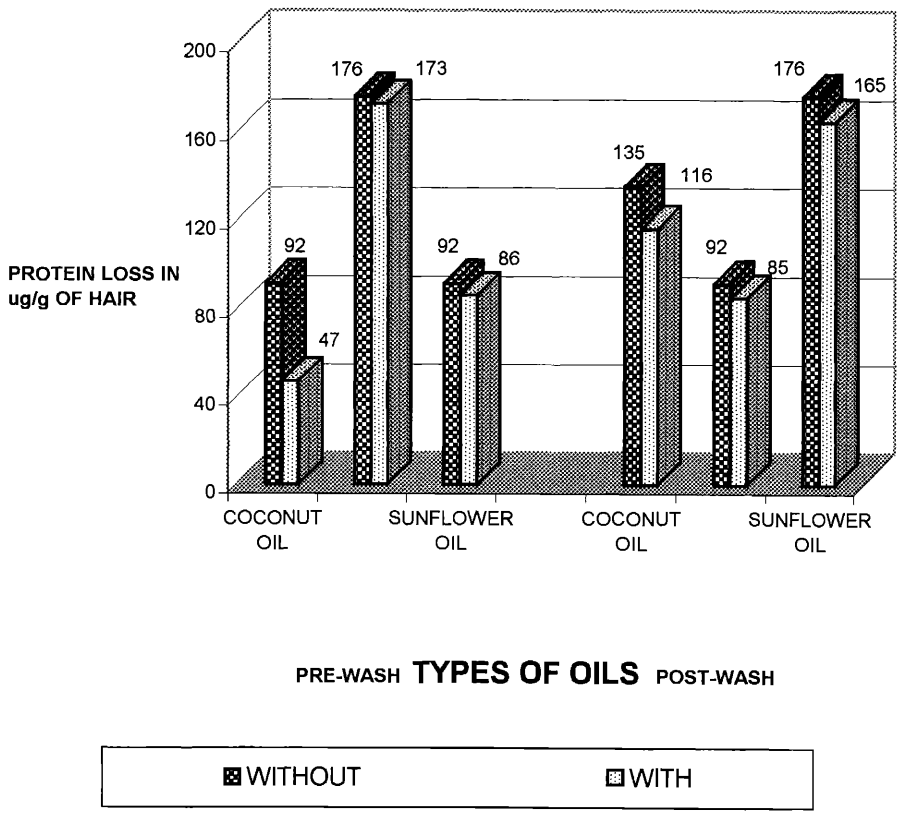

Figure 1. Comparison of protein loss from undamaged hair.

The reagents for protein estimation were obtained from Sigma Chemical Co. (St. Louis, MO). The other reagents such as buffers and salts were of analytical grade, whereas the oil samples were used as they are available commercially.

METHODS

Sample preparation. Hair tresses of 3±0.5 g were prepared for this investigation. They were secured at the root end by a crochet so that they remained firmly in place, and not a single hair came out of the tress during experimentation (either because of combing or during the procedure). They were cleaned by soaking in 0.01% (w/v) of polysorbate 80 (30 min at 28°C), de-ionized water at room temperature (several rinses), and 0.01% (w/v) of acetic acid (15 min at 28°C), in that order. Finally, they were extensively rinsed in water and air dried.

Bleached hair was prepared by using a bleaching kit containing 30 vol. hydrogen peroxide and ammonia solution to adjust the pH to ~10. Five milliliters of this solution was used per tress (cleaned by the procedure mentioned earlier), and the treatment time was 120 min at room temperature. With this treatment the tresses became light brown with a red tone.

A boiling water treatment was carried out for 120 min. The hair tresses were placed in

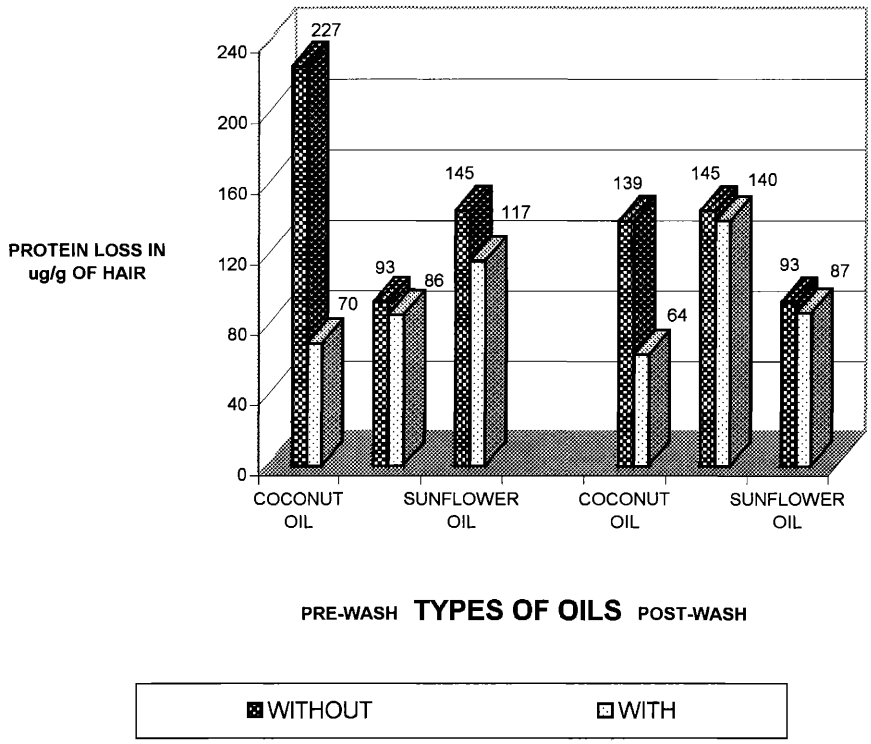

Figure 2. Comparison of protein loss from bleached hair.

a beaker containing boiling distilled water. The hair tresses were immersed in it. This was not done to simulate any real-world process but in order to create extreme stressful conditions. This was primarily done to assess any impact on hair in water at high temperature, as Indian consumers largely use a hot water bath for hair.

In the case of UV treatment, the hair tresses were exposed to simulated sunlight in a xenostat, wherein each hair tress was exposed at 50°C and 65% relative humidity for a period of 300 hr. The tresses were turned over during the period of exposure to attempt a uniform exposure of all fibers to the radiant source.

In some cases hair tresses were treated with 0.2 ml of coconut oil/mineral oil/sunflower oil before exposure, with the oil spread uniformly across the hair tress before exposure to UV light. In a few cases, the treatment with oil was carried out after UV exposure. The tresses were stored at room temperature for 48 hr before they were subjected to protein loss determination. This was designed to simulate density of hair on scalp and scalp treatments.

For the oil application, to each hair tress was applied 0.2 ml of oil (the quantity of oil normally applied by an Indian hair oil user). It was allowed to remain on the hair for at least 14 hr to simulate overnight application (the normal habit of the Indian consumer). These hair tresses were then subjected to both protein loss and WRI tests.

The entire study involved samples of straight, curly, wavy, and permed hair of Indian origin. Because the number of variables was high, i.e., the type of oil, type of hair,

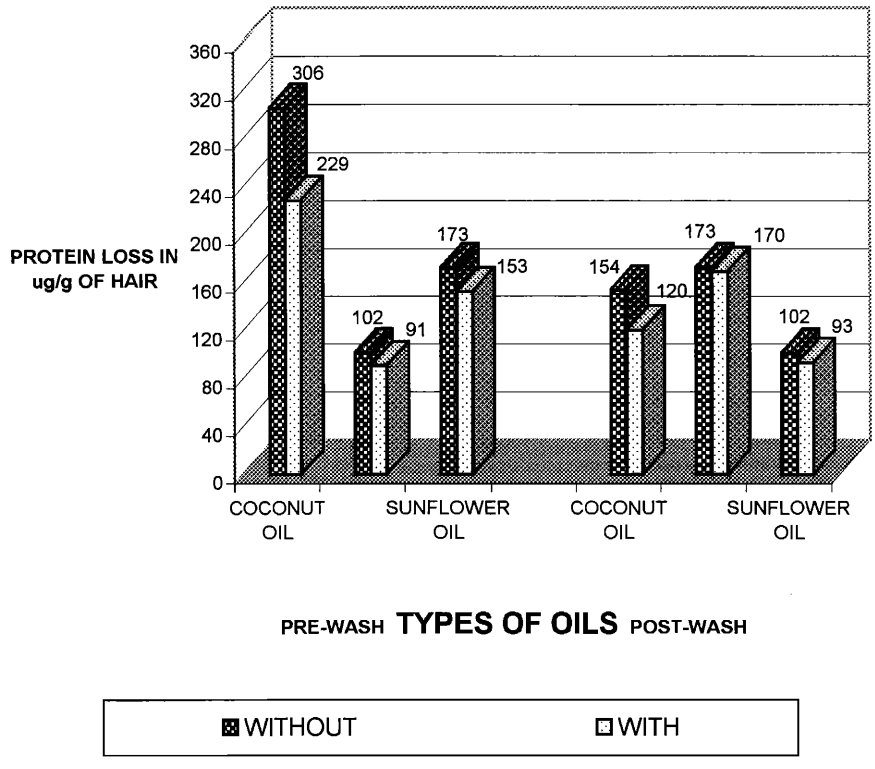

Figure 3. Comparison of protein loss from hair treated with boiling water.

sequence of oiling, the total number of oil applications, and the number of shampoo applications, the study had become quite complex in nature. In order to simplify the complexity of the experiment, i.e., to reduce cost, time, and energy without compromising on the quality of results, a statistical tool was selected, termed the Taguchi Design of Experimentation. This is a tool used in research and development of products in an engineering industry wherein, depending upon the levels and factors, an appropriate design, either orthogonal array or factorial design, is selected. This helps to reduce the number of experiments without affecting the result. Using this statistical model, it was possible to complete the entire study in the stipulated time frame without losing vital information, as it cut the number of experiments to be conducted from 14400 to 800 (considering 25 hair tresses per variable). As the experiment was quite complex, we had to select the design of an orthogonal array, L32, to conduct the experiment. The design of experiment was as presented in Table I.

The tresses were wetted under running tap water (28°C) and washed with a 20% solution of sodium laureth (3 moles of EO) sulfate (SLES). One milliliter of the solution was applied per tress, and the tresses were worked between fingers to produce a lather. Following this, they were extensively rinsed to remove all the SLES residues. After this treatment the tresses were subjected to the following investigations.

Combing damage. The protein loss method of Sandhu and Robbins was used in the following manner. Each of the wet tresses was combed with a fine-tooth nylon comb (20–22 teeth/inch) 50 times, rather vigorously along the entire length of the tress on

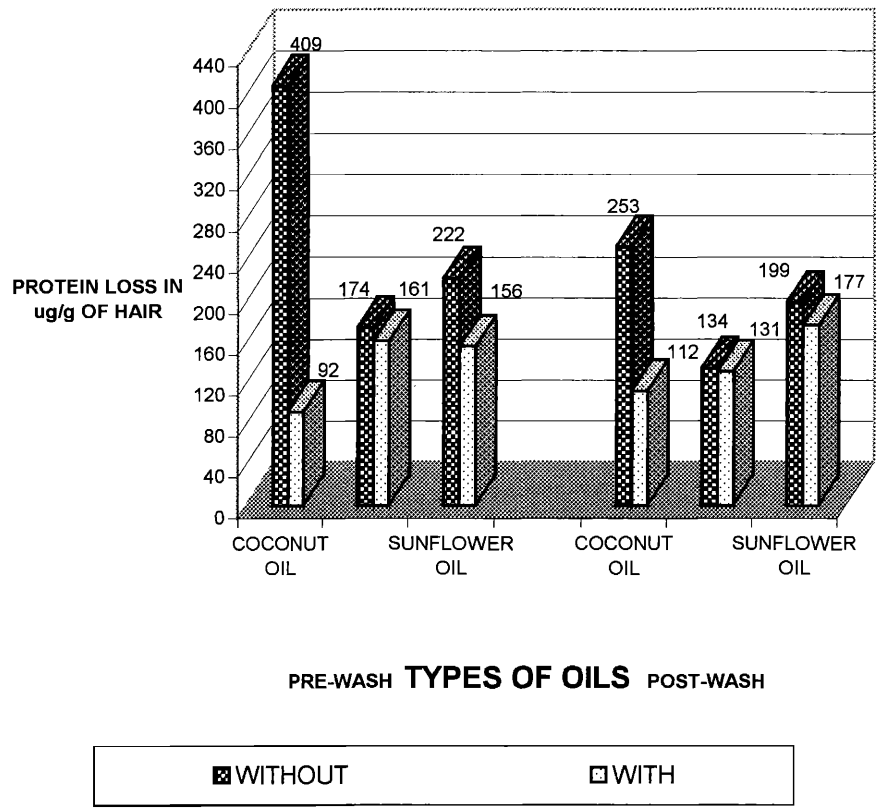

Figure 4. Comparison of protein loss from hair exposed to UV treatment.

both sides. After every five strokes, the comb was dipped in 50 ml of water contained in a beaker to dislodge the debris. The same 50 ml of water was used to collect all the loosely held protein eluted from the comb for a given tress. The entire tress was dipped in water after every five strokes to collect the damaged and dislodged cuticle cells. The water suspension was tested for protein content using the Lowry method. It was compared against standard bovine serum albumin procured from Sigma Chemical Co. This bovine serum albumin was diluted so as to get readings within which the maximum and minimum reading for the sample would fall. The method involves the formation of a copper–protein complex in alkaline solution that, in turn, reacts with phosphomolybdic-phosphotungstate reagent (Folin-Ciocaltaeu Phenol reagent) to yield an intense blue-colored solution, which is analyzed spectrophotometrically. It was checked that the blue color development occurring in both standard and sample was of the same color with different intensity, depending on the amount of protein being eluted from the hair fibers, thereby indicating that none of the oils was interfering in the color development. The methodology is discussed to a great extent in reference (2).

Water retention index (WRI). The SLES-washed tresses were soaked in a 0.01% solution of polysorbate 80 for 30 min. Following this procedure, the entire tress was placed over a hollow glass cylinder with a glass lid with perforations to hold the tress properly and to separate the hair from capillary water in the glass centrifuge tube of diameter 3 cm and height 8 cm. It was centrifuged at 8000 rpm for 15 min to remove capillary water

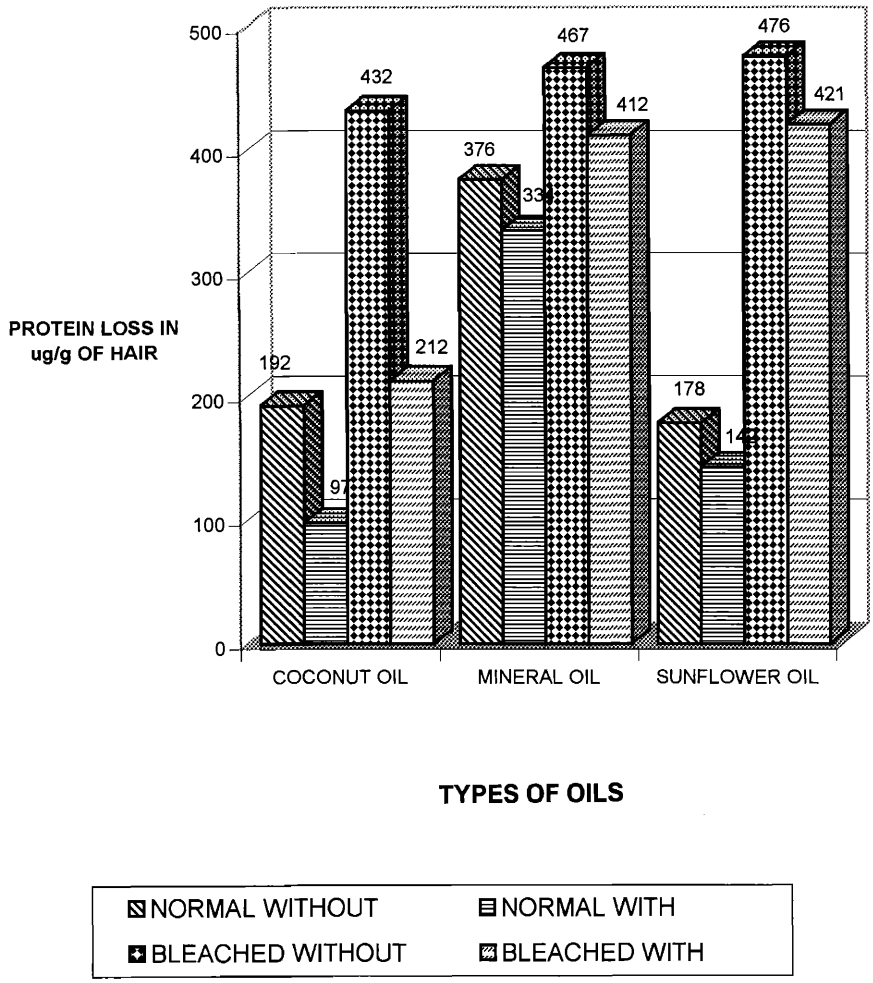

Figure 5. Comparison of protein loss from normal and bleached hair in a salon trial.

and then weighed. In the next step, the dry weight of the hair was determined by drying the tress in a vacuum oven at 50°C for 90 min, and then weighing it again. The percentage water retention index (WRI) is given by:

$$WRI = (W_{wet} - W_{dry})\ 100/W_{dry}$$

Half-head tests. Each half-head test involved 20 clients each with normal and bleached hair. The hair was parted in the middle and half the head was treated with the respective oil (3 ml approx.) and massaged thoroughly, while the other half was left without treatment. The oil was left on the hair for approximately 8 hr. Then the hair was washed with warm water (28°C, 200 ppm hardness) using 20% SLES, and rinsed well to remove any residue. To avoid inherent differences in damage from left to right side, the application of the treatment was randomized. Panelists with odd numbers were treated on the left side, while those with even numbers were treated on the right side.

After shampooing and rinsing, the hair was combed with a fine-tooth comb (separate

Table III
Pair-Wise Comparison Data for Treatment Effects for Protein Loss (t-values at 95% confidence level)

Treatment	Straight	Wavy	Curly	Permed
Undamaged—with and without MO (MO as post-wash)	0.452	—	0.106	—
Undamaged—with and without CNO (CNO as post-wash)	—	1.779	—	—
Undamaged—with and without SFO (SFO as post-wash)	—	—	—	0.461
Undamaged—with and without MO (MO as pre-wash)	—	0.431	—	0.103
Undamaged—with and without CNO (CNO as pre-wash)	1.814	—	—	—
Undamaged—with and without SFO (SFO as pre-wash)	—	—	0.515	—
Treatment with boiling water—with and without MO (MO as post-wash)	0.507	—	1.312	—
Treatment with boiling water—with and without CNO (CNO as post-wash)	—	—	—	1.762
Treatment with boiling water—with and without SFO (SFO as post-wash)	—	1.108	—	—
Treatment with boiling water—with and without MO (MO as pre-wash)	—	0.484	—	0.354
Treatment with boiling water—with and without CNO (CNO as pre-wash)	—	—	1.738	—
Treatment with boiling water—with and without SFO (SFO as pre-wash)	1.565	—	—	—
Treatment with bleaching agent—with and without MO (MO as post-wash)	0.139	—	0.092	—
Treatment with bleaching agent—with and without CNO (CNO as post-wash)	—	—	—	1.728
Treatment with bleaching agent—with and without SFO (SFO as post-wash)	—	0.210	—	—
Treatment with bleaching agent—with and without MO (MO as pre-wash)	—	—	0.583	0.407
Treatment with bleaching agent—with and without CNO (CNO as pre-wash)	—	—	2.012	—
Treatment with bleaching agent—with and without SFO (SFO as pre-wash)	1.588	—	—	—
Exposure to UV light—with and without MO (MO as post-wash)	0.345	—	0.098	—
Exposure to UV light—with and without CNO (CNO as post-wash)	—	—	—	1.780
Exposure to UV light—with and without SFO (SFO as post-wash)	—	0.345	—	—
Exposure to UV light—with and without MO (MO as pre-wash)	—	0.265	—	0.087
Exposure to UV light—with and without CNO (CNO as pre-wash)	—	—	1.850	—
Exposure to UV light—with and without SFO (SFO as pre-wash)	0.684	—	—	—

t theoretical for 48 degrees of freedom at 95% confidence level = 1.645.

comb for each side). After each of the ten combing strokes, both the hair and the comb were dipped in 200 ml of distilled water to recover broken cuticle debris. A total of 100 strokes (50 on each side) were applied. The suspension with cuticle debris was used for protein estimation. Analytical controls were run in the form of determination of the

Table IV
Analysis of Variance Data for Treatment Effects for Protein Loss

Hair type	Source of variance	Degrees of freedom	Sum of squares	Mean square	F-Value at 95% confidence level
Undamaged	Between treatments	2	22.2	11.1	5.3
Oil type MO (straight, curly)	Experimental error	2	4.2	2.1	
Undamaged	Between treatments	2	12.4	6.2	1.7
Oil type MO (wavy, permed)	Experimental error	2	7.2	3.6	
Undamaged	Between treatments	2	92.8	46.4	46.4
Oil type CNO (straight, wavy)	Experimental error	2	2.0	1.0	
Undamaged	Between treatments	2	80.0	40.0	8.0
Oil type SFO (curly, permed)	Experimental error	2	10.0	5.0	
Boiled	Between treatments	2	32.4	16.2	7.1
Oil type MO (straight, curly)	Experimental error	2	4.6	2.3	
Boiled	Between treatments	2	16.9	8.5	2.6
Oil type MO (wavy, permed)	Experimental error	2	6.5	3.3	
Boiled	Between treatments	2	20.4	10.2	5.6
Oil type SFO (straight, wavy)	Experimental error	2	3.6	1.8	
Boiled	Between treatments	2	34.8	17.4	24.8
Oil type CNO (curly, permed)	Experimental error	2	1.4	0.7	
Bleached	Between treatments	2	4.2	2.1	1.0
Oil type MO (straight, curly)	Experimental error	2	4.2	2.1	
Bleached	Between treatments	2	12.5	6.8	1.2
Oil type MO (wavy, permed)	Experimental error	2	11.5	5.8	
Bleached	Between treatments	2	38.0	19.0	5.0
Oil type SFO (wavy, straight)	Experimental error	2	7.8	3.9	
Bleached	Between treatments	2	43.0	21.5	19.5
Oil type CNO (curly, permed)	Experimental error	2	2.2	1.1	
UV-Treated	Between treatments	2	15.4	7.7	2.0
Oil type MO (wavy, permed)	Experimental error	2	7.6	3.8	
UV-Treated	Between treatments	2	22.2	11.1	6.5
Oil type MO (curly, straight)	Experimental error	2	2.3	1.7	
UV-Treated	Between treatments	2	10.4	5.2	4.7
Oil type SFO (wavy, straight)	Experimental error	2	2.1	1.1	
UV-Treated	Between treatments	2	44.6	22.3	37.2
Oil type CNO (curly, permed)	Experimental error	2	1.2	0.6	

F theoretical for (2.2) degrees of freedom at 95% confidence level = 19.0.

residue of oil on the scalp of the client after rinsing, and only after ensuring zero residue, the rinsings were collected in the manner mentioned above.

The outcome of these experiments was analyzed statistically (taking into account the mean and the standard deviation of the number of replicates for the significance of the treatment effects within the confidence limits). See Table II for analysis of variance (ANOVA) data.

Table V
Analysis of Variance Data for Treatment Effects for Water Retention Index

Hair type	Source variance	Degrees of freedom	Sum of squares	Mean square	F-Value at 95% confidence level
Undamaged Oil type MO (straight, curly)	Between treatments	2	29.2	14.6	6.2
	Experimental error	2	4.7	2.4	
Undamaged Oil type MO (wavy, permed)	Between treatments	2	19.1	9.6	2.4
	Experimental error	2	7.8	3.9	
Undamaged Oil type CNO (straight, wavy)	Between treatments	2	93.6	46.8	31.2
	Experimental error	2	2.9	1.5	
Undamaged Oil type SFO (curly, permed)	Between treatments	2	83.0	41.5	6.3
	Experimental error	2	13.1	6.6	
Boiled Oil type MO (straight, curly)	Between treatments	2	35.5	17.8	7.4
	Experimental error	2	5.3	2.7	
Boiled Oil type MO (wavy, permed)	Between treatments	2	19.1	9.6	2.4
	Experimental error	2	7.8	3.9	
Boiled Oil type SFO (straight, wavy)	Between treatments	2	20.4	10.2	4.8
	Experimental error	2	4.2	2.1	
Boiled Oil type CNO (curly permed)	Between treatments	2	33.7	16.9	21.1
	Experimental error	2	1.7	0.8	
Bleached Oil type MO (straight, curly)	Between treatments	2	4.2	2.1	0.9
	Experimental error	2	4.5	2.3	
Bleached Oil type MO (wavy permed)	Between treatments	2	15.3	7.6	12.4
	Experimental error	2	12.3	6.2	
Bleached Oil type SFO (wavy, straight)	Between treatments	2	40.0	20.0	4.2
	Experimental error	2	9.5	4.8	
Bleached Oil type CNO (curly, permed)	Between treatments	2	40.0	20.0	22.2
	Experimental error	2	1.8	0.9	
UV-Treated Oil type MO (wavy, permed)	Between treatments	2	17.4	8.7	2.1
	Experimental error	2	8.2	4.1	
UV-Treated Oil type MO (curly, straight)	Between treatments	2	23.4	11.7	8.3
	Experimental error	2	2.8	1.4	
UV-Treated Oil type SFO (wavy, straight)	Between treatments	2	12.4	6.2	4.4
	Experimental error	2	2.8	1.4	
UV-Treated Oil type CNO (curly, permed)	Between treatments	2	41.6	20.8	26.0
	Experimental error	2	1.6	0.8	

F theoretical for (2.2) degrees of freedom at 95% confidence level = 19.0.

RESULTS AND DISCUSSION

PROTEIN LOSS

The process of cuticle chipping that results from abrasion of hair against objects such as grooming devices or even other hair is a major factor in hair damage. The proteins that constitute the cuticle cells are lost during wet combing. It is well known that wet

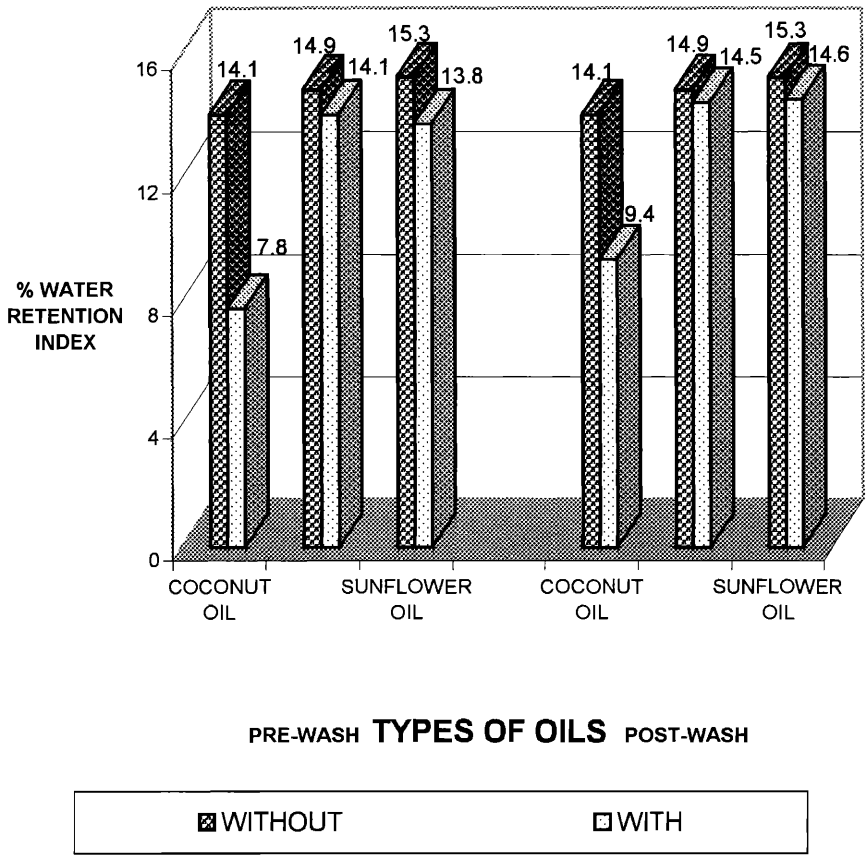

Figure 6. Comparison of water retention index for undamaged hair.

combing is accompanied by the breaking of the surface cuticle cell because of its brittleness. Histologically, the major component of the cuticle cell consists of the exocuticle and the endocuticle. The exocuticle, being highly cross-linked is not swollen by water. The endocuticle and the cell membrane complex, on the other hand, are less cross-linked and are more vulnerable to swelling damage. This leads to the lifting of the surface cuticle via bending. Such cuticle cells can be broken in the process of combing or teasing. The protein loss observed in these measurements results mostly from the cuticular region. Because of the short time involved in the combing and brief immersion of the combed tress in water, it is unlikely that proteins from the bulk of the fiber are involved in this measurement.

The data for protein loss measurement for undamaged and differently damaged hair are shown in Figures 1–4. The bars on the left refer to tests where oil was used as a pre-wash conditioner, whereas those on the right are for the tests involving post-wash treatments where oil was applied after drying the hair. The data in Figures 1–4 clearly show that the performance of coconut oil in reducing protein loss was better than that of mineral and sunflower oils. Coconut oil performed better as a pre-wash rather than a post-wash conditioner. This shows the importance of lubrication vs reduction in the swelling of the cuticle cells that leads to their breaking in wet combing. The difference between

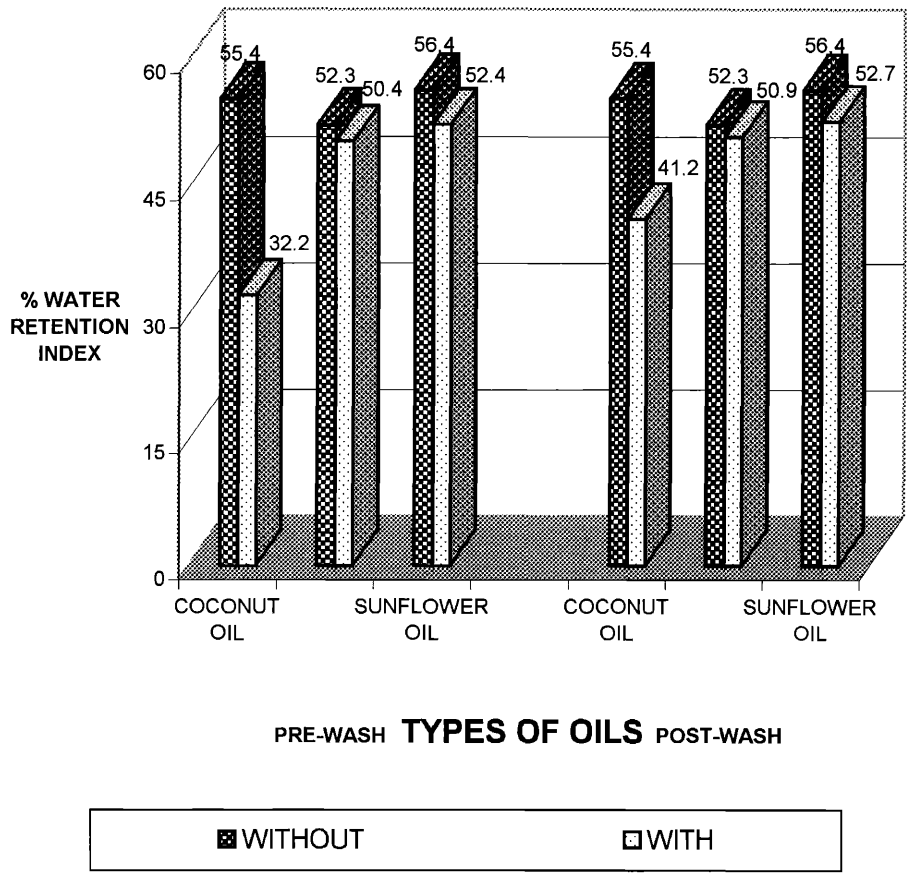

Figure 7. Comparison of water retention index for bleached hair.

coconut oil and mineral oil is probably due to the difference in their ability to penetrate the hair (4). The smaller effect of sunflower oil may be due to the presence of unsaturation in the molecule. No information regarding the penetrability of sunflower oil in the hair is available. The same effect was seen in the half-head test in a salon trial, as seen in Figure 5.

The effect of various oils in preventing cuticle damage in laboratory tests was established statistically by a parametric test, *t*-test. The outcome of the analysis is shown in Table III. The *t*-values clearly indicate that damaged as well as undamaged hair benefits from application of coconut oil as a pre-wash conditioner, whereas in the case of sunflower oil and mineral oil, there was no effect. The effects of coconut oil were also positive in a salon test. In both normal and bleached hair, treatment effects in reducing protein loss were significant, whereas the same findings were absent in the case of mineral oil and sunflower oil. The values of *t* for coconut oil are statistically significant, whereas for mineral oil and sunflower oil, they are not.

See Tables IV and V for ANOVA data for treatment effects for protein loss and water retention index.

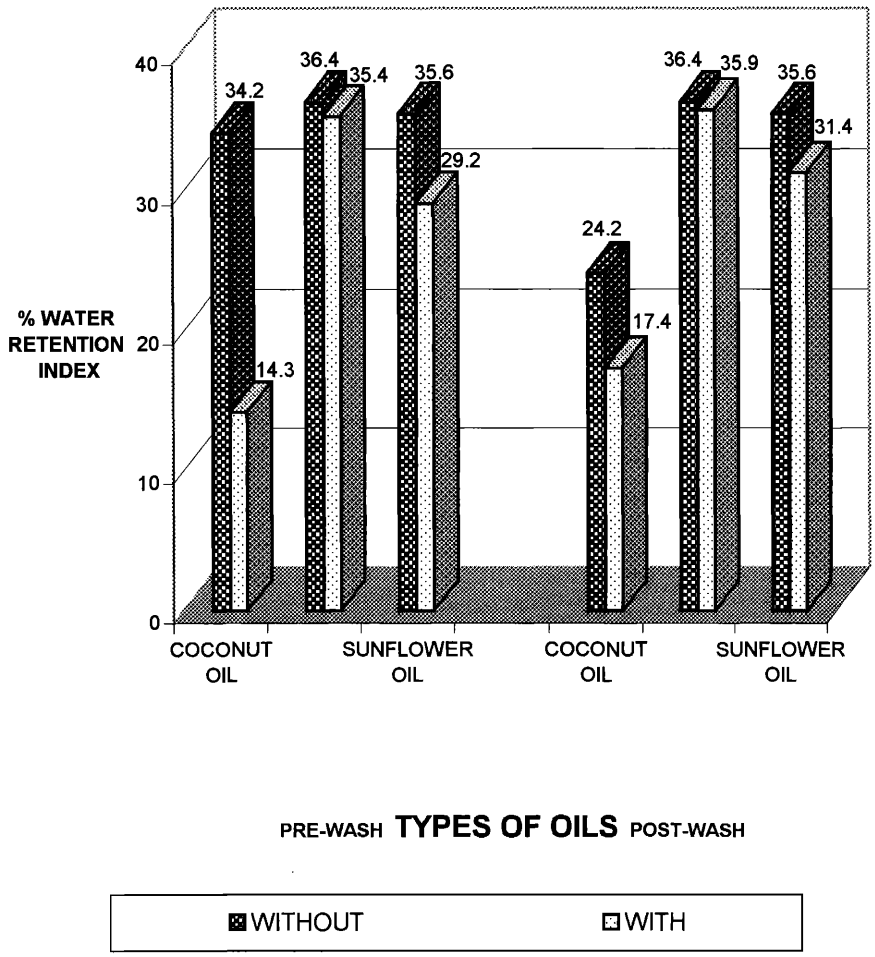

Figure 8. Comparison of water retention index for hair treated with boiling water.

WATER RETENTION INDEX

The water retention index for undamaged hair is shown in Figure 6. From the data it can be seen that coconut oil reduces the WRI of undamaged hair by 44%, whereas in the case of mineral oil and sunflower oil, there is hardly any reduction in WRI, as seen in Figure 6. The ability of coconut oil to penetrate hair (4) supports this observation.

The data for the bleached, heat-damaged, and UV-damaged hair are shown in Figures 7–9, respectively. For these damaged samples, the WRI is much higher than that for the undamaged hair. This is mostly due to the chemical degradation of proteins, generating hydrophilic groups. Both the cleavage and oxidation of disulfide bonds, followed by their oxidation to cysteic acid, as well as hydrolysis of the peptide linkage, occur, although the contribution of the latter is probably minor. All samples show a reduction in the WRI as a result of the application of coconut oil, whereas the same findings were not observed to a significant level in the case of mineral oil and sunflower oil. Assuming that most of the water is absorbed by the fiber, the WRI reflects the swelling propensity

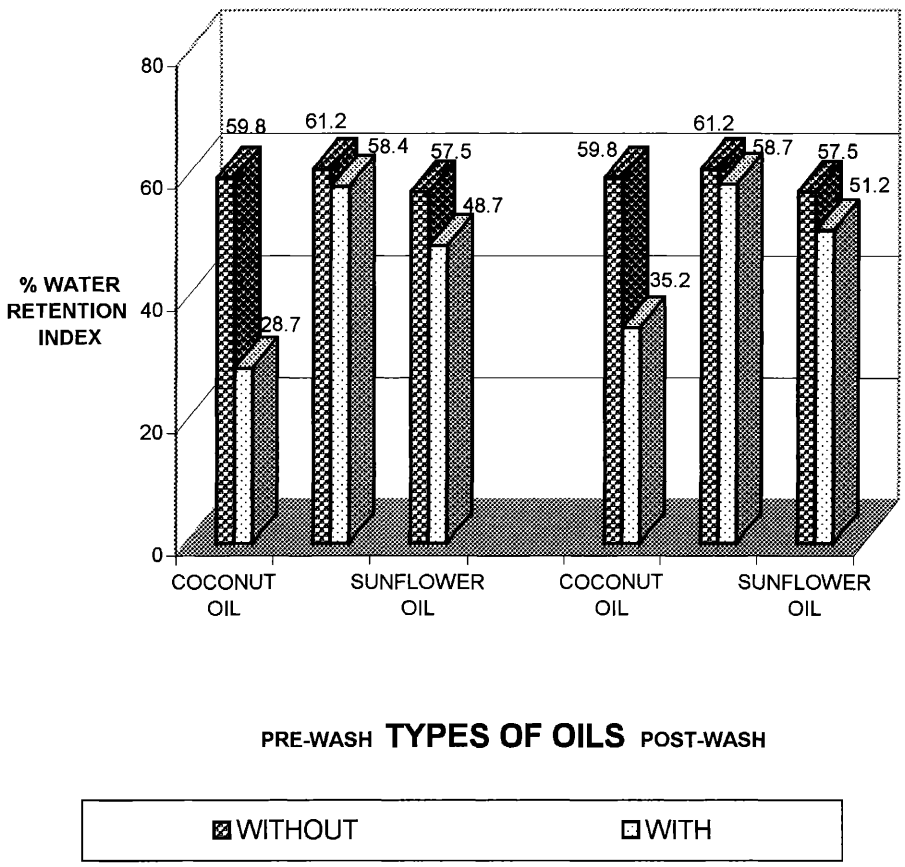

Figure 9. Comparison of water retention index for UV-treated hair.

of hair. Since repeated swelling and contraction damages the cuticle, reduction in the WRI can be considered as beneficial in reducing hair damage.

The data in Figures 6–9 show that the sequence of application (whether pre- or post-wash) is important. Post-wash application is less effective in reducing the WRI as compared to pre-wash application. The difference seems to be in the location of the oil residues and their ability to counteract surfactant damage. In post-wash application the oil film is on the surface, with no penetration into the fiber. In pre-wash application, it is possible that the molecules of the oil penetrate into the cuticle and probably even into the cortex. This may also be the case with undamaged hair, although the effect is small. The reduction in the WRI must be due to the introduction of the hydrophobic triglyceride into the keratin structure.

See Table VI for pair-wise comparison of treatment effects for water retention index data.

MECHANISM OF PROTECTION BY COCONUT OIL AND NOT BY MINERAL OIL AND SUNFLOWER OIL

The histology of a cuticle cell and the mechanism of damage in wet combing is proposed by Swift (5,6) Because of cross-linking, the exocuticle is brittle and does not swell. The

Table VI
Pair-Wise Comparison Data for Treatment Effects for Water Retention Index (t-values at 95% confidence level)

Treatment	Straight	Wavy	Curly	Permed
Undamaged—with and without MO (MO as post-wash)	0.41	—	0.09	—
Undamaged—with and without CNO (CNO as post-wash)	—	1.87	—	—
Undamaged—with and without SFO (SFO as post-wash)	—	—	—	0.36
Undamaged—with and without MO (MO as pre-wash)	—	0.34	—	0.09
Undamaged—with and without CNO (CNO as pre-wash)	1.98	—	—	—
Undamaged—with and without SFO (SFO as pre-wash)	—	—	0.34	—
Treatment with boiling water—with and without MO (MO as post-wash)	0.43	—	1.21	—
Treatment with boiling water—with and without CNO (CNO as post-wash)	—	—	—	1.89
Treatment with boiling water—with and without SFO (SFO as post-wash)	—	1.02	—	—
Treatment with boiling water—with and without MO (MO as pre-wash)	—	0.24	—	0.13
Treatment with boiling water—with and without CNO (CNO as pre-wash)	—	—	1.85	—
Treatment with boiling water—with and without SFO (SFO as pre-wash)	1.43	—	—	—
Treatment with bleaching agent—with and without MO (MO as post-wash)	0.12	—	0.06	—
Treatment with bleaching agent—with and without CNO (CNO as post-wash)	—	—	—	1.87
Treatment with bleaching agent—with and without SFO (SFO as post-wash)	—	0.12	—	—
Treatment with bleaching agent—with and without MO (MO as pre-wash)	—	—	0.46	0.47
Treatment with bleaching agent—with and without CNO (CNO as pre-wash)	—	—	2.12	—
Treatment with bleaching agent—with and without SFO (SFO as pre-wash)	1.45	—	—	—
Exposure to UV light—with and without MO (MO as post-wash)	0.21	—	0.098	—
Exposure to UV light—with and without CNO (CNO as post-wash)	—	—	—	1.85
Exposure to UV light—with and without SFO (SFO as post-wash)	—	0.32	—	—
Exposure to UV light—with and without MO (MO as pre-wash)	—	0.19	—	0.09
Exposure to UV light—with and without CNO (CNO as pre-wash)	—	—	1.97	—
Exposure to UV light—with and without SFO (SFO as pre-wash)	0.43	—	—	—

t theoretical for 48 degrees of freedom at 95% confidence level = 1.645.

endocuticle and the cell membrane complex have less cross-linking and therefore swell significantly. This effect produces the tendency for the surface cuticle cells to curve upward and break when pressure is applied with a comb.

Recent studies of Ruetsch and Weigmann (7) confirm that the endocuticle and the cell

membrane complex (CMC) are the foci of weakness and that the cuticle cell often lifts and fractures when the fiber is extended. Chemical methods impair the adhesion by weakening the cell membrane complex between the cuticle cells. The degree of swelling of the cuticle layers is increased by disulfide cleavage and oxidation. This enhances the combing damage and protein loss, especially in wet combing, as observed in this study.

Coconut oil is mostly a triglyceride of lauric acid and is hydrophobic. Application of coconut oil as a pre-wash conditioner coats the hair and inhibits the penetration of water into the hair. A small part of it is also absorbed into the hair during the wash when the fiber is swollen. Introduction of this hydrophobic component reduces the swelling propensity of the cuticle, which limits the upward curving of the surface cuticle. This reduces the chipping away of the cuticle cells, which reduces protein loss, as observed in this work.

Because of the low molecular weight of coconut oil, it penetrates the cortex, whereas mineral oil, being a hydrocarbon, does not penetrate the hair at all. This has been shown in the earlier study (4). It is possible that sunflower oil does not penetrate the fiber because it has a bulkier structure as a result of double bonds in the fatty acid chain. Coconut oil triglyceride has a linear structure, which is why it solidifies at room temperature, whereas sunflower triglyceride has an irregular ball-like structure because the fatty acid chains fold on themselves due to one or two double bonds. This is why sunflower oil is a liquid at room temperature. It is likely that it does not penetrate the fiber as well as the coconut oil. This may be the reason why the WRI is low for coconut oil as compared to mineral and sunflower oils.

CONCLUSIONS

This study has firmly established the superiority of the protective effect of coconut oil on hair damage in grooming processes when it is used as a pre-wash conditioner as compared to mineral oil and other vegetable oils such as sunflower oil. It not only has a protective effect on undamaged hair but also on chemically treated hair, UV-treated hair, and hair treated with boiling water (i.e., hair in water at 100°C for 2 hr). The ability of coconut oil to penetrate into hair cuticle and cortex seems to be responsible for this effect. Coated on the fiber surface, it can prevent or reduce the amount of water penetrating into the fiber and reduce the swelling. This, in turn, reduces the lifting of the surface cuticle and prevents it from being chipped away during wet combing. A reduction in the WRI is additional evidence of its efficacy in decreasing water absorption. The data presented in this work clearly show the superiority of coconut oil as a hair damage protectant, in the grooming of untreated or damaged hair.

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REFERENCES

(1) M. L. Garcia and J. Diaz, Combability measurements on human hair, *J. Soc. Cosmet. Chem.*, 27, 379–398 (1976).

(2) S. S. Sandhu and C. Robbins, A simple and sensitive technique, based on protein loss measurement, to assess surface damage to human hair, *J. Soc. Cosmet. Chem.,* **44,** 163–175 (1993).
(3) A. Rele, Effect of coconut oil on prevention of hair damage. Part I, *J. Cosmet. Sci.,* **50,** 327–339 (1999).
(4) S. B. Ruetsch, Y. K. Kamath, A. S. Rele, and R. B. Mohile. Secondary ion mass spectrometric investigation of penetration of coconut and mineral oils into human hair fibers: Relevance to hair damage, *J. Cosmet. Sci.,* **52,** 169–184 (2001).
(5) J. A. Swift and A. C. Brown, The critical determination of fine changes in the surface architecture of human hair due to cosmetic treatments, *J. Soc. Cosmet. Chem.,* **23,** 695–702 (1972).
(6) J. A. Swift, *Int. J. Cosmet. Sci.,* **13,** 143 (1991).
(7) S. B. Ruetsch and H. D. Weigmann, *J. Soc. Cosmet. Chem.,* **47,** 13–26 (1996).