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Quest for an eco-friendly alternative surfactant: Surface and foam characteristics of natural surfactants

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A B S T R A C T

Surfactants are amphiphilic molecules that reduce the surface tension of water and are extensively used for domestic and industrial purpose. Today it is increasingly desirable to replace synthetic surfactants with naturally derived molecules with a reduced environmental burden. About 60% of surfactants used enter the aquatic environment and cause immense damage. This study demonstrates the use of plant based natural surfactants as biodegradable and renewable alternatives. Traditionally used natural surfactants extracted from two plants, Pyagi Phool (*Zephyranthes carinata* Herbert.) and Ritha (*Sapindus mukorossi* Gaertn.) in aqueous solution have been studied. Surface tension, foaming and other relevant parameters have been investigated. While Ritha has been studied earlier, this is perhaps the first ever report on surfactant activities of Pyagi Phool. Ritha is acid balanced and exhibits a prominent surface tension reduction to 35.30 mN/m, high foaming, wetting and cleaning. Pyagi Phool is also acid balanced, reduces surface tension to 40.76 mN/m, possesses high viscosity and shows good dirt dispersion, making it a decent natural cleansing agent. The mechanism of foam formation affects the foaming ability and stability. Quantified dirt dispersion measurement shows that dirt dispersion reaches a maximum at Critical Micelle Concentration. Emulsion stability also decreases in the same region. The natural surfactants show better emulsification at higher concentrations as compared to synthetic surfactant. The results obtained suggest that both Ritha and Pyagi Phool have remarkable surface active properties and can be used as environmental friendly alternatives to synthetic surfactants.

1. Introduction

Surfactants are amphiphiles containing hydrophobic (water-hating) and hydrophilic (water-loving) moieties enhancing the reduction of surface and interfacial tensions. The amphiphilicity of surfactants makes them suitable for applications like detergency, wetting, froth floatation, emulsification, oil recovery, etc (Muntaha and Khan, 2015). Large amount of synthetic surfactants used for domestic and industrial work are dispersed in diverse environmental sections like soil, water, sediment etc. Studies show that about 60% of the total surfactant production enters the aquatic environment (Naylor et al., 1992; Schmitt et al., 2014). The world-wide production of surfactants was about 12.5 million tonnes in 2006 (Edser, 2006), and Western Europe produced over 3 million tonnes in 2007 (Ivankovic and Hrenovic, 2010). In 2010, the US consumption of non-ionic surfactant (polyethoxylated nonylphenol) was approximately 172 thousand tonnes (Schmitt et al., 2014). These non-biodegradable surfactants affect the environment and cause health hazards like dermatitis, respiratory, eye irritation etc. (Tmakova et al., 2015; Pradhan and Bhattacharyya, 2014).

Ostroumov (2003) describes how synthetic surfactants and their chemical mixtures inhibit the filtering activity of oysters and mussels. Organisms like *Crassostrea gigas* and *Mytilus galloprovincialis* clean the water continuously and have a significant impact to the ecosystem. Tests on the toxicity of seven surfactants on six fresh water microbes show that cationic surfactants are most toxic followed by anionic and non-ionic surfactants (Singh et al., 2002). The damaging effect of surfactants on humans, microorganisms, aquatic plants, invertebrates and crustaceans also follows the same trend (Cserhati et al., 2002).

Technological advancements have made the production of surfactants easy and large amounts are produced today leading to serious environmental concerns (Chevalier, 2002). In today's environment sensitive world, a surfactant should be biodegradable

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and less toxic in addition to being surface active (Biswal and Paria, 2014). Researchers are thus being initiated to search for environment friendly surfactants, one of which could be natural surfactants. Natural surfactants are obtained directly from natural sources, plants, bacteria or fungi. Various techniques like extraction, filtration, precipitation or distillation are required to obtain them. Natural surfactants also include fatty acid esters of sugars or amides of amino acids which can be used as alternative to synthetic surfactants as reported by Holmberg (2001). Salati et al. (2011) have reported on biomass extracted humic acid as a surfactant.

Saponins, the best known plant-based surfactants, are glycosidic compounds containing either a triterpenoid or an alkaloid steroid as a hydrophobic nucleus (aglycone) (Ghagi et al., 2011; Yang et al., 2008; Oleszek and Bialy, 2006; Karimi et al., 2011). The nucleus is connected to hydrophilic sugar chains through ether or ester bonds (Fig. 1). The simultaneous presences of aglycone and sugar chains provide surface activity. Natural surfactants are bio-degradable, biocompatible and less toxic and hence pose less threat to the environment. Molgaard et al. (2000) have shown complete biodegradation of Endod (*Phytolacca dodecandra* L'Herit) saponin in 10 days. They can be produced in large quantities at lower cost and used in environmental control activities like handling of industrial emulsions, control of oil spills, detoxification of industrial effluents and bioremediation of contaminated soils (Rahman and Gakpe, 2008).

In this study, extracts from two plants Pyagi Phool (*Zephyranthes carinata* Herbert.) and Ritha (*Sapindus mukorossi* Gaertn.) have been considered for use as natural surfactants. Pyagi Phool and Ritha were chosen as plants traditionally used as cleaning agents in the regions of Sikkim and West Bengal around Gangtok.

Pyagi Phool or Pink Rain Lily belongs to *Amaryllidaceae* family. It is a perennial flowering plant seen in the moist open areas of the Himalayas. It grows from tunicate globular 2–3 cm bulbs and has large bright pink flowers (Flowers of India, 2006). It is widely used as an ornamental plant and also used in Chinese medicine to treat fever and as a poultice for abscesses (Thomas, 2002). To our knowledge, there is no scientific report exploring its surface activity in the literature.

Ritha or Soapnut belongs to *Sapindaceae* family. It is a deciduous tree growing in tropical and sub-tropical Asia (Dhar et al., 1989). Saponin present in its fruit is traditionally used as a shampoo, detergent for woollen fabrics, and to restore the brightness of precious ornaments (Singh et al., 2010). It has many medical uses, e.g. it has been used to develop spermicides (Banerjee et al., 2014). Tiwari et al. (2008) describe anti-trichomonas activity of Ritha saponins, as a component of herbal local contraceptive. Contraceptive cream has been formulated from Ritha saponin (Soni et al., 2015). Ritha has been studied in oil recovery and in contaminated soil washing (Chhetri et al., 2009; Roy et al., 1997; Zhou et al., 2013). It solubilises foreign materials present in muga silk (Sarma et al., 2012). Toxicological tests on rats and rabbits classified Ritha saponin as non toxic and non-dermal irritation (Du et al., 2015). External use of saponins as a washing soap show no toxic effects on human skin and eyes (Roy et al., 1997). Khandelwal and Chauhan (2012) point out that seeds of many plants, including Ritha produce non-edible oil that can be used as biodiesel. Most studies on Ritha have dealt with isolation and identification of the natural surfactant (Li et al., 2013; Henga et al., 2014; Kuo et al., 2005; Huang et al., 2006). Though Ritha has been studied as a standard natural surfactant, very few workers have focused on surface activity (Yang et al., 2008; Ghagi et al., 2011; Tmakova et al., 2015; Muntaha and Khan, 2015).

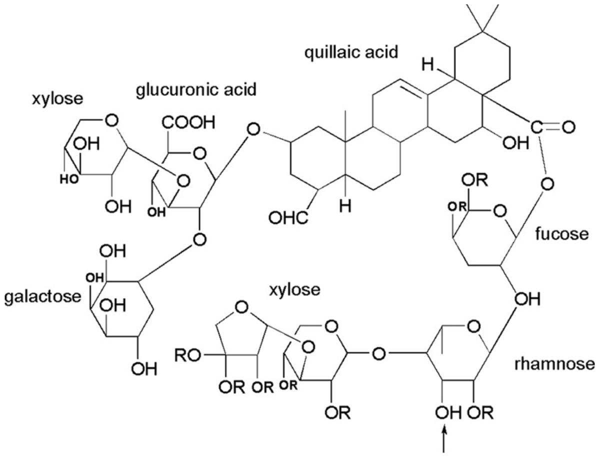

Fig. 1. Structure of a typical saponin molecule (Mitra and Dungan, 1997).

There is a recent trend in industries to avoid synthetic products, forcing a search for natural alternatives. In view of this, we have studied Pyagi Phool and Ritha with an objective to evaluate their surface activity and cleaning related properties like critical micelle concentration (CMC), viscosity, conductivity, emulsification and pH. As a reference, we have also studied a commonly used synthetic surfactant, which is ionic in nature. This surfactant was used as the commonly available commercial surfactants are ionic. The natural surfactants are found to be equally effective as detergents as the synthetic surfactant and their enhanced use may reduce surfactant based environmental problems.

2. Experimental

2.1. Materials

Pyagi Phool bulbs and Ritha pods were identified, referred and authenticated by The Ayurvedic Regional Research Institute, Department of AYUSH (Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homoeopathy), Gangtok, Sikkim, India. Henko (batch number C/HSCP15/0313), a synthetic surfactant, refined soyabean oil (Fortune, Batch number (AH) SB06C05), Coconut oil (Parachute oil, Lot No. KA003), India ink (Camel, Batch number A1205), and Paraffin wax (from candles available in the market) were used. Acetone, chloroform, hexane and ethanol (all AR grade) were obtained from Merck. Millipore water of resistivity 18.2 MΩcm, surface tension 71.5 mN/m and pH 6.5–7 was used. Cotton bleached Poplin cloth Sort No. 22125003 from Manoj Fabrics, Ahmedabad, India was used. FT-IR was performed using Bruker, Germany/Alpha FT-IR spectrometer.

2.2. Methods

2.2.1. Extraction of the natural surfactant

The outer pericarp of Ritha was separated from the seeds. The separated Ritha pericarp and Pyagi Phool bulbs were washed with water and sun dried indoors at room temperature (20 ± 2) °C. Pyagi Phool bulbs were crushed with mortar and pestle. The samples were macerated for 24 h in Millipore water at room temperature and filtered. The filtrate was evaporated in a rotary evaporator (Buchi, Switzerland/R-3) on a water bath at 40–50 °C. Ritha gave a brownish paste while Pyagi Phool gave a whitish paste. The extract was weighed and dissolved in Millipore water. All measurements were performed at least thrice and an average was taken of the results.

2.2.2. Surface tension measurements

Surface tension was measured by Wilhelmy plate method

(Ritacco et al., 2000) using a Sartorius CPA-225D Semi-Micro Balance with Density Measurement Attachment at room temperature. A glass beaker was rinsed with ethanol and acetone and then repeatedly rinsed with Millipore water. Freshly prepared solution was taken in this beaker for the experiment.

2.2.3. Foaming ability and stability

Foaming was studied by Bikerman and Bartsch test. In Bikerman test, 40 ml of the surfactant solution was taken in a 100 cm long cylindrical column with a fritted glass filter. Nitrogen gas was passed through it at a constant flow rate of 1 litre/min, maintained with a flow meter. Surfactant solutions were tested from 2.5×10^{-5} g/cc to 1.53×10^{-2} g/cc. The maximum foam height obtained gave the foaming ability (Bhattacharyya et al., 2000; Waltermo et al., 1996). In Bartsch test, 40 ml of surfactant solution was vigorously shaken by hand in a 100 ml measuring cylinder and the foam height measured. The shaking was at around 3 Hz with amplitude 5 cm. Foam decay was monitored using a stop watch (Edinzo et al., 1995; Lunkenheimer and Malysa, 2003).

2.2.4. pH and conductivity

pH and conductivity were measured at room temperature using Thermo Scientific Orion 2 star pH Benth top and La Motte pH/Conductivity/Temperature pocket TRACER respectively. The cells were calibrated with standard solutions before measurements (Balakrishnan et al., 2006).

2.2.5. Viscosity

Viscosity was measured using Cannon-Fenske Direct flow capillary viscometer (size 50, constant 0.00437) suspended vertically in a stand. The viscometer was cleaned and dried before every measurement. The time of flow of a constant volume of solution through the capillary was measured with a stopwatch (Mata et al., 2005).

2.2.6. Emulsification

Emulsification studies were performed by the method described by Kothekar et al. (2007). 20 ml surfactant solution and 20 ml refined oil was vigorously shaken in a measuring cylinder. Emulsion stability was determined as the time required for separation of 10 ml of surfactant solution from the emulsion.

2.2.7. Wetting ability

Wetting was tested on (5 × 5) cm cotton Poplin cloth using canvas disc wetting test. We measured that the cloth had yarn count of (6593 ± 26.7) cm/g, surface mass $(8.929 \pm 0.013) \times 10^{-3}$ g/cm^2, single thread linear mass $(1.52 \pm 0.04) \times 10^{-4}$ g/cm and thread count (130.8 ± 2.2)/cm^2. The cloth had a water absorption capacity of (95.25 ± 1. 33) %.

The cloth was floated on the solution surface. The time required for the cloth to begin to sink was measured as wetting time (Saad and Kadhim, 2011).

2.2.8. Cleaning

A (5 × 5) cm cotton Poplin cloth was soaked in water for 24 h, dried and weighed. Simulated dirt (1 gm coconut oil and 1 gm paraffin wax in 100 ml hexane) was prepared. The cloth was dipped in simulated dirt, dried and weighed. This cloth was placed in the surfactant solution for 10 min and shaken. It was taken out, washed with water, dried and weighed (Sharma, 2002). The cleaning process was studied for concentrations from 5.5×10^{-4} g/cc to 6.04×10^{-2} g/cc at room temperature, (20 ± 2) °C.

2.2.9. Dirt dispersion

10 ml of surfactant solutions were taken in two bottles. One drop of India ink was added to one. The bottles were simultaneously shaken and photographed against a white background. Adobe® Photoshop® 7.0 was used to analyse the gray-scale of the foams in the photographs. The ratio of gray-scale at the same height for the two foams was taken as dirt dispersion.

3. Results and discussion

3.1. Surface tension

Surface tension results in intermolecular force imbalance at a liquid-vapour or liquid-solid interface. Fig. 2 shows that surface tension decreases rapidly with increasing concentration and then remains constant at a concentration called the Critical Micelle Concentration (CMC). This reduction is due to the breaking of hydrogen bonds caused by higher adsorption at the air-water interface. This permits an increase in interfacial area with a much less overall increase in energy (Birdi, 2010). Reduction of surface tension is slightly higher for the natural surfactants than for Henko (Table 1). Surface tension reduction to 32–37 mN/m signifies good detergency and surface activity (Mainkar and Jolly, 2000). Thus Ritha possesses good detergency and Pyagi Phool moderate detergency. On increasing concentration beyond the CMC, surfactants form micelles (Schramm, 2000). Surface tension remains constant indicating that added surfactant contributes to micelle formation. CMC is an important parameter for surfactants, as properties change on crossing it (Vaz et al., 2012).

Properties like detergency, solubilisation etc. depends on the presence of micelles. The CMC values of Pyagi Phool and Ritha (Table 1) obtained from surface tension measurement are comparable to other natural surfactants (Negm and Mohamed, 2004). Ritha is more efficient in reducing surface tension, perhaps due to slow micellization in water. The lower surface tension of Ritha suggests that there is closer packing of surfactants at the air-water interface (Paria et al., 2015) as compared to Pyagi Phool. Pyagi Phool and Ritha both have a lower CMC than Henko, micellar solubilisation starts at a lower concentration for natural surfactants.

The chemical and molecular structures of natural surfactant are different for different samples. This changes the hydrophobicity of the molecules and affects the CMC. The CMC for ionic surfactants is generally higher than that for non-ionic ones (Negm and Mohamed, 2004), as seen for Henko which may be due to ion-ion head group repulsion (Sansanwal, 2006).

Effectiveness or surface pressure (π_{CMC}) is given by

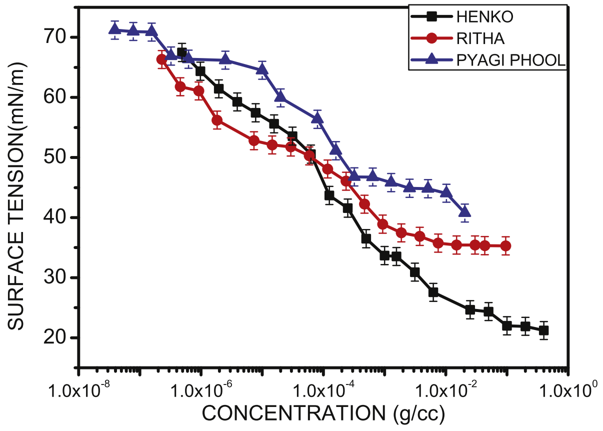

Fig. 2. Surface tension as a function of surfactant concentration at 20 ± 2 °C. Legend: square, Henko; circle, Ritha; triangle, Pyagi Phool; maintained in all subsequent figures.

Table 1
Surface properties of surfactants and cut off concentration (C_1).

Surfactant	CMC g/cc	Reduced Surface tension mN/m	Corresponding Concentration g/cc	Effectiveness mN/m	C_1 (Bikerman) g/cc	C_1 (Bartsch) g/cc
Pyagi Phool	6.40×10^{-4}	40.76	2.05×10^{-2}	31.24	$>1.53 \times 10^{-2}$	$>1.53 \times 10^{-2}$
Ritha	7.50×10^{-3}	35.30	9.50×10^{-2}	36.70	2.01×10^{-4}	4.06×10^{-5}
Henko	1.00×10^{-1}	21.20	4.00×10^{-1}	58.80	3.02×10^{-4}	8.11×10^{-5}

$$\pi_{CMC} = \gamma_0 - \gamma \qquad (1)$$

where γ_0 is surface tension of pure water and γ of surfactant solution. An effective surfactant is one that reduces the surface tension the most (Gad et al., 1997). Henko shows maximum effectiveness followed by Ritha and Pyagi Phool.

3.2. *Foaming ability and stability*

Foam generation and cleansing ability are not much related, but foaming is an important criterion in detergent evaluation by customers. Foam formation involves the continuous creation of new interfaces. A high foaming power requires rapid adsorption, high surface elasticity and high surface viscosity (Piispanen et al., 2004). The foaming behaviours by Bikerman and Bartsch test are shown in Fig. 3. High-quality thick foam is produced by Ritha solution which may be due to a large amount of saponin present. Presence of saponin results in high dynamic surface tension reduction helping to generate large surface areas required for foaming (Birdi, 2010). The foaming power of Pyagi Phool is comparatively less. Foaming increases with increasing concentration due to availability of more surfactant in the films to stabilise the foam (Pradhan and Bhattacharyya, 2014).

While both tests show a similar trend, Bikerman test produces more foam as more gas is involved.

Production of foam by mechanical agitation results in an unsteady system, causing the foam to decay. As described by Lunkenheimer and Malysa (2003), the rate at which the foam decays gives the foam stability, expressed in terms of *R*5 parameter (Fig. 4) defined as,

$$R5 = \frac{h_5}{h_0} \times 100 \qquad (2)$$

where h_0 = maximum foam height and h_5 = foam height at 5 min. *R*5 value of 50% provides a cut-off between metastable and low stability foam (Mata et al., 2005). Strong surfactant solubility gives stable foam (Mousli and Tazerouti, 2007). Table 1 indicates the cut-off concentration C_1 from low stability to meta-stable foam. Ritha shows a sharp transition from low stability foam to metastable foam by both tests just before CMC.

Pyagi Phool has a very low *R*5 value by Bikerman test, as the foam collapsed before 5 min. The transition at C_1 is not observed in Bartsch test either. Higher concentrations need to be investigated. The C_1 concentration is higher for Bikerman than Bartsch test, probably due to differences in foam forming mechanism. In Bikerman test a lot of air is abruptly introduced into the liquid which gives a large amount of foam. However, the foam is not stable as enough surfactants do not get adsorbed at the interfaces. In Bartsch test, a small amount of air is introduced and less foam is formed. Vigorous shaking moves the molecules all around resulting in more surfactants at the interfaces, making the foam stable.

3.3. *pH measurements*

A change in pH of a solution changes the net charge on molecules and hence the repulsive force between them. This makes pH an important parameter in surfactant studies (Tmakova et al., 2015). The pH values were examined for different surfactant

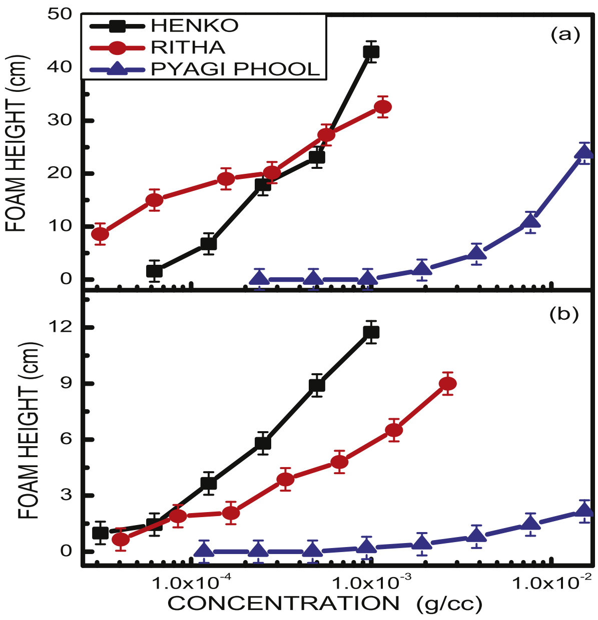

Fig. 3. Foam Height as a function of surfactant concentration by (a) Bikerman, and (b) Bartsch test.

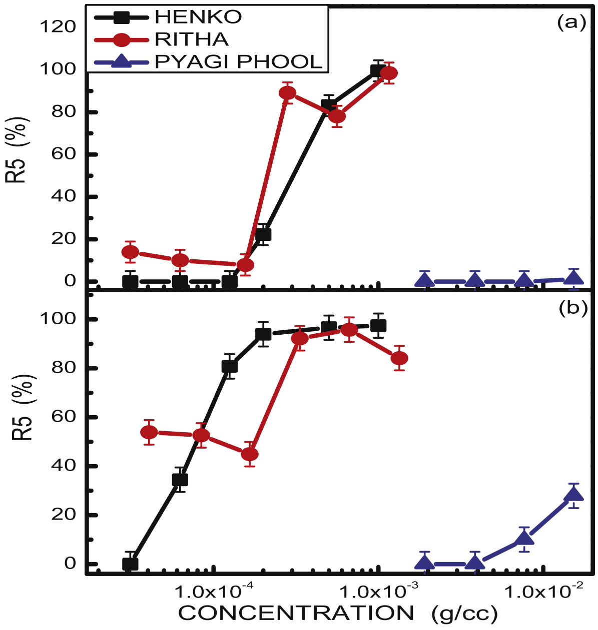

Fig. 4. R5 value as a function of surfactant concentration by (a) Bikerman, and (b) Bartsch test.

Table 2
pH values of surfactants at different concentrations.

Sl No.	Concentrations (g/cc)	Pyagi Phool	Ritha	Henko
1	2.50×10^{-2}	5.15	5.28	10.33
2	7.80×10^{-4}	5.17	5.37	10.15
3	3.90×10^{-4}	5.35	6.17	9.98
4	9.70×10^{-5}	5.75	6.08	9.40
5	6.10×10^{-6}	6.69	6.89	6.88

solutions prepared in Millipore water having a pH 6.5–7.0. Table 2 shows the pH values at different concentrations. Pyagi Phool and Ritha are acidic, probably due to hydrolysis of non-ionic glucuronic groups (Roy et al., 1997). A solution of pH close to the skin (~5.5) causes less damage to hair and skin. Henko solution is basic. The pH of Pyagi Phool and Ritha decreased with concentration while that of Henko increased.

3.4. Viscosity

Viscosity plot is shown in Fig. 5 (a). Micelle formation affects viscosity which depends on size and/or number of particles in solution. Viscosity increases gradually with increase in concentration. The viscosity of Pyagi Phool increases rapidly at lower concentration. The concentration at which the increase starts is the concentration at which micelles start forming, as observed from surface tension measurements. At low surfactant concentration, molecules exist as monomers. The hydrophilic moieties are surrounded by water molecules, resulting in an increase in the viscous resistance. As the surfactant concentration increases beyond a point, the viscosity increases rapidly, probably due to micelle formation. Far beyond CMC viscosity increases both due to formation of more micelles and interaction between micelles which start to come closer (Roy et al., 1997; Vaz et al., 2012). Ritha and Henko show a similar pattern of increase in viscosity in the micelle formation region.

3.5. Conductivity

The conductivity profiles (Fig. 5 (b)) are characterised by two regions. Conductivity is almost constant at lower concentrations and increases rapidly at higher concentrations. At low concentrations, the hydrophilic part of the molecule is surrounded by water molecules, resulting in low conductivity. Conductivity starts increasing at a concentration near the region of micelle formation, due to more/bigger micelles, and also due to accumulative inter-micellar interaction (Muntaha and Khan, 2015). The conductivity of Ritha also increases due to hydrolysis of glucuronic groups. The conductivities of Ritha and Pyagi Phool increase at a much higher concentration than Henko. CMC of Ritha (2×10^{-2} g/cc) and Pyagi Phool (6×10^{-3} g/cc) measured by electrical conductivity is higher than those obtained from surface tension measurements. This has been observed by other workers (Negm and Mohamed, 2004). However, conductivity gives a smaller CMC for Henko.

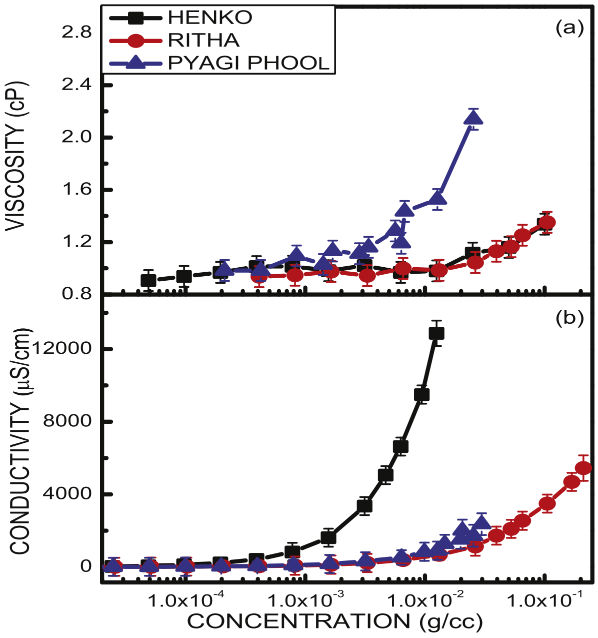

Fig. 5. (a) Viscosity and (b) Conductivity as a function of surfactant concentration.

3.6. Emulsification

Emulsification is an important property of a surfactant. The amphiphilic nature helps surfactants to solubilise water insoluble substances e.g. hydrocarbons. Surfactants adsorb at the oil-water interface and reduce the interfacial energy. As a result, less energy is spent to form the oil-water interfaces required for an emulsion. This makes the emulsion stable. A creamy oil-in-water emulsion was formed which showed the emulsification activity of surfactants (Fig. 6). At higher concentration, Ritha solution formed very stable emulsions which did not separate for almost 2 h. Emulsion stability increases as concentration increases, decreases and then increases again. Surface tension measurements reveal that the emulsion stability decreases in the region of micelle formation, probably because less surfactant adsorbs at the oil-water interface (Agu and Barminas, 2013). As the surfactant concentration is further increased, emulsion stability deteriorates, perhaps due to rapid droplet coalescence (Nadeem et al., 2006). Ritha exhibits best emulsion stability, followed by Pyagi Phool and Henko. Stable emulsions are produced when the adsorbed surfactant induces repulsive interactions between the droplets and creates an energy barrier against rupture (Kothekar et al., 2007).

3.7. Wetting

Wetting plays a vital role in the removal of dirt, oils and soils. It is a complex phenomenon depending on parameters like surface tension, diffusion, concentration and the nature of the surface. A solution can penetrate through a surface and completely wet it only if the surface tension is low (Yang et al., 2008). Henko showed the least wetting time, followed by Ritha and Pyagi Phool (Fig. 7 (a)).

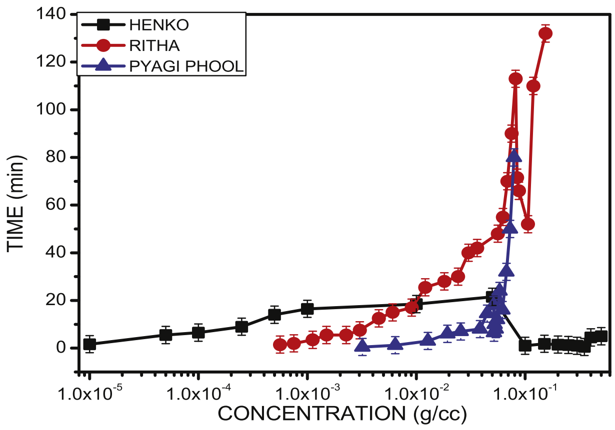

Fig. 6. Emulsification as a function of surfactant concentration.

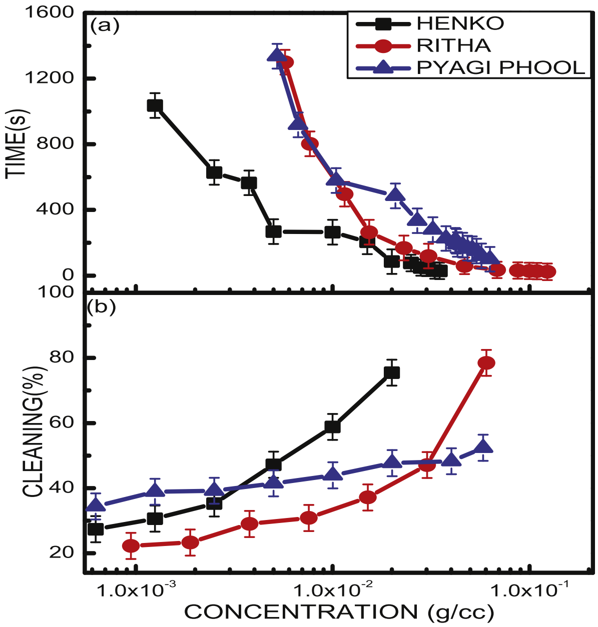

Fig. 7. (a) Wetting time and (b) Cleaning as a function of surfactant concentration.

Good wetting by Ritha indicates that surface tension was efficiently reduced and enabled the solution to penetrate the surface. Wetting behaviour shows good agreement with surface tension measurements.

3.8. *Cleaning*

Cleaning, the removal of dirt, soil and grease, is the primary aim of a surfactant. The percentage of cleaning was calculated using the equation

$$C = [(W_2 - W_3)/(W_2 - W_1)] \times 100\% \tag{3}$$

where W_1 = initial weight of the cloth, W_2 = weight of the cloth with simulated dirt and W_3 = weight after being cleaned with surfactant solution and water. As shown in Fig. 7(b), cleaning ability for Ritha shoots up near the CMC. Pyagi Phool showed greater cleaning ability at lower concentration compared to Ritha, may be due to early onset of micelles. As concentration increased, cleaning ability remained moderate. While all the surfactants exhibit a similar trend in cleaning action, there is a significant difference in the amount of dirt removed. Ritha showed good cleaning ability at higher concentration similar to Henko, perhaps due to sufficient surface tension reduction.

3.9. *Dirt dispersion*

Dirt dispersion in foam is a test of surfactant efficacy as dirt remaining in the foam is difficult to rinse and may redeposit at the surface being cleaned. It has been studied so far qualitatively by eye estimation (Deshmukh et al., 2012). Here we probably report the first attempt to quantify the amount of dirt present. The amount of dirt is low at low concentrations, increases up to a certain concentration and then decreases again (Fig. 8). The concentration at which the maximum amount of dirt attaches to the foam corresponds to the region of micelle formation.

At very low concentrations, there is hardly any surfactant for the foam to form and even less to carry the dirt resulting in very little dirt in the foam. As the concentration increases, more surfactant comes to the foam, very little stays in the bulk. Hence the dirt is attracted to the foam. This continues till micelles start forming.

Once the CMC is crossed, there is surfactant in the solution, which can keep the dirt in suspension. This brings in a competition seen by the gradual decrease in the amount of dirt in the foam as concentration increases. This offers an easy and low-cost method to estimate the CMC. It is seen that Pyagi Phool had less dirt in the foam compared to Ritha and Henko, indicating it to be a good dirt dispenser.

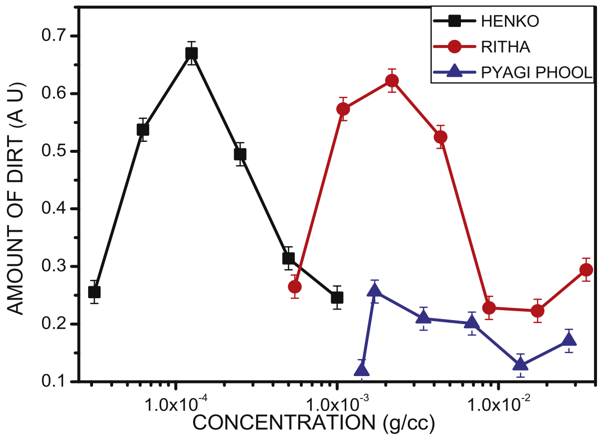

Fig. 8. Dirt dispersion as a function of surfactant concentration.

4. Conclusions

Saponins from two plant sources, Pyagi Phool and Ritha, have been evaluated with a goal to find alternative to commonly used synthetic surfactants, and compared to a commercially available surfactant Henko. The results show that saponins are acid balanced, biodegradable and renewable surfactants. Being plant extracts, the natural surfactants have been considered bio-degradable (Roy et al., 1997; Sarma et al., 2012). This can also be seen from their low CMC (Balakrishnan et al., 2006; Schmitt et al., 2014). In addition, Molgaard et al. (2000) have shown that Endod (*Phytolacca dodecandra* L'Herit) saponin is completely biodegradable. Pyagi Phool, studied probably for the first time, shows a surface tension reduction to 40.7 mN/m, in addition to good dirt dispersion and high viscosity. This makes it a potential natural surfactant. While numerous works report on the isolation, characterization (Kuo et al., 2005; Li et al., 2013; Henga et al., 2014) etc. of Ritha, we have systematically studied it as a cleaning agent. It gives a surface tension reduction to 35.3 mN/m, shows good foaming and cleaning and can be explored as a bio-degradable surfactant (Balakrishnan et al., 2006). Ritha and Pyagi Phool are at par with Henko in terms of foaming, wetting, cleaning etc. and turn out to be better in emulsion stability, viscosity and dirt dispersion. The Bikerman's test produces a large amount of low stability foam whereas Bartsch test produces less, but stable foam, probably due to different foam forming mechanism. Emulsion stability decreases in the region of micelle formation. Ritha and Pyagi Phool are good emulsifying agents and may find industrial applications. In addition, we have quantified dirt dispersion measurement of surfactant solutions. We find that dirt dispersion reaches a maximum at CMC. However, the maximum is at a much lower concentration for Henko, an ionic surfactant. Thus, our studies may provide a low-cost, easy method to measure CMC for natural non-ionic surfactants. We conclude that both Ritha and Pyagi Phool have good surface active properties. Our study can provide useful input to food and cosmetic industries, as these plant extracts are bio-degradable eco-friendly surfactants.

Preliminary FT-IR analysis of Pyagi Phool and Ritha solutions show the presence of characteristic saponin absorptions of O-H, C-H stretching, C=C, C-H bending. Glycoside linkages to the sapogenins were indicated by the absorption of C-O-C bonds. Further work on the isolation and characterisation of Pyagi Phool extract will give a better understanding of its potential and enhance its use.

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