Nature friendly cleaning: the detergency of hamburger seed

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Abstract: Detergents or surfactants are surface active agents, active at surfaces and interfaces. A surfactant molecule consists of two parts. One is water liking or hydrophilic and the other is water hating or hydrophobic. When added to water, they arrange themselves at the surface and reduce the surface tension. This surface tension reduction gives the wetting ability and hence the cleaning ability of any solution. On further increasing the concentration, the surface becomes saturated with molecules. Molecules added now go to the bulk of the liquid and form closed structures called micelles, where the hydrophilic parts surround the hydrophobic parts. This concentration is called critical micelle concentration. Surfactants are widely used in homes and industry for cleaning and other purposes. Commercially prepared chemical detergents are toxic and harmful to the environment, while bio-chemical detergents, obtained from plants are less toxic. We report our work on the surface activity and cleaning ability of the seeds of Mucuna gigantea, commonly known as hamburger seed. The extract of the insides of the seeds show good surface tension reduction and foaming. We have also studied the dirt dispersion and other relevant properties of the extract. Our studies show that the seeds can probably supply a good natural detergent, bio-degradable and environment friendly.

1. Introduction
Surface tension is the tendency of a fluid surface to acquire the least area possible. It is a measure of the free energy of the surface per unit area, measured as the amount of work required to expand the surface by unit area [1]. Each molecule in a liquid experiences a force of attraction on it due to the neighbouring molecules. In the liquid interior, the net force is zero since the forces are in all directions. The net force upon a molecule at or near the free surface is directed inwards as there are more neighbours in the liquid. Hence, work must be done to bring a molecule from the interior to the surface. This makes the surface behave like a stretched film or membrane [2]. The force of surface tension is tangential to the surface. Impurities in the liquid have a large effect on surface tension.

Surfactants are surface active agents, active at surfaces or interfaces between two physical phases. The term interface denotes a boundary between any two immiscible phases while surface denotes an interface where one phase is a gas, usually air. Surfactant molecules consist of two parts. One is water liking or hydrophilic and the other is water hating or hydrophobic, giving an amphipathic structure (figure 1(a)) [3]. The sizes and chemical natures of the two groups decide the properties of the surfactant [4]. This double
nature of the surfactant molecule enhances the wetting ability of water. It allows the water to spread over surfaces and enter into the dirt present.

When a surfactant molecule is dissolved in water, the hydrophobic group distorts the water structure by breaking the inter-molecular hydrogen bonds. Due to this distortion, the surfactant molecules are expelled to the interfaces of the system. The hydrophobic groups are oriented in such a way to minimize contact with water molecules. A single layer of surfactant molecules cover the water surface with their hydrophobic groups oriented predominantly towards the air. Since air molecules are nonpolar in nature like the hydrophobic groups, this increases the similarity of the two phases contacting each other at the surface, resulting in decrease in surface tension of water.

Figure 1. Schematic Illustration of (a) Surfactant Molecule (b) Surface Tension vs Surfactant Concentration

When more surfactant is added, the surface tension decreases rapidly as more and more surfactant molecules come on the surface. At a point, the surface becomes saturated, additional surfactant molecules cannot be accommodated at the surface. The surfactant molecules added now go to the bulk of the liquid and form closed structures called micelles (figure 1(b)). This concentration is called critical micelle concentration (CMC). Further increase in surfactant concentration only increases micelle concentration [5].

Ordinary surfactant molecules contain only one polar group. Gemini surfactants have two hydrophobic tails and two hydrophilic head groups linked together. They show interesting properties like high efficiency in lowering surface tension and very low CMC [6].

Foam is a colloidal system formed by trapping a gas in a liquid or a solid. It can be created by reducing the surface tension of a liquid and forcing in air to produce bubbles. Pure liquids are incapable of foaming. Some foam can remain for a long period of time without any external disturbance whereas some collapse as soon as gas flow stops. The stability of intervening liquid films determines the overall foam stability [7]. Foams are common in our day to day life like shampoo, bath sponge, expresso coffee, creams, lotions, head on a glass of beer, etc. It plays an important role in the soap and detergent industry. It has many industrial applications including firefighting, ore separation, isolating or spreading chemicals or particles [8].

Commercially available chemical detergents are toxic and harmful to the environment. They destroy the environment by releasing non biodegradable chemicals affecting the aquatic life and algae [9]. On the other hand, bio-chemical detergents are non toxic and environment friendly. Studies on Sapindus mukorossi popularly known as ritha (Hindi) or soapnut (English) show excellent foam properties and moderate detergency [10]. *Acacia concinna* or *shikakai* showed very prominent surface tension reduction and high foaming [11].

Our study exhibits the physical properties of natural surfactants extracted from seeds of hamburger seed or *mucuna gigantea* which belong to the family *Fabaceae* (figure 2). Hamburger seed is a woody climbing plant commonly known as *pangra* (Nepali) or *kangeen* (Manipuri). It is found in India and Nepal. The inside of the seeds have been traditionally used as soap and the outer cover of the seeds have been used as face wash in Sikkim. It is also an important medicinal plant which is the best known natural source of bioactive
compound L-dopa (L-3, 4-dihydroxy phenylalanine) used as potential drug for the treatment of Parkinson’s disease [12]. To the best of our knowledge, we are the first to report the surfactant properties of this plant.

Figure 2. (a) Hamburger seeds (b) Broken Hamburger seeds

2. Materials and Methods
All experiments were carried out in Millipore Milli–Q water. Ethanol, acetone and hexane were analytical reagent grade obtained from Merck. Hamburger pods were collected from Konthoujam, Imphal West, Manipur, India. The seeds were separated from the pods and broken into pieces using a hammer. The white part inside the seeds was taken out by hand and cleaned thoroughly with Millipore water to remove dirt and dried in shade. The dried samples were weighed with a digital balance and used for the experiments. Extraction of surfactants was carried out by two methods: Normal extraction method and microwave extraction method. In normal extraction, 15g of the sample was soaked in 100ml of water for 24 hours. The liquid extract was collected by filtration. In microwave extraction, 15g of the sample was mixed with 100ml water and placed in the microwave for 3 to 5 minutes. The microwave frequency was 2.45 GHz. After cooling to room temperature, the liquid extract was collected by filtration [13]. The filtrates obtained were evaporated using a rotary evaporator (Buchi, Switzerland/R-3) at 40-50°C in a water bath. A whitish paste was obtained. This was weighed and dissolved in water as required.

3. Experimental Methods

3.1. Surface Tension
Surface tension was measured by Wilhelmy method. A plate that is wetted by water was attached to a force transducer and dipped in the solution. The solution was slowly lowered. The change in the force read by the transducer when the plate leaves the solution gives the surface tension [14]. In our experiments, a filter paper served as the plate with a sartorius CPA-225D semi-micro balance with density measurement attachment. Glass beakers were washed, rinsed with ethanol and acetone and baked to dryness. Fresh solutions were prepared in the cleaned glass beakers just before the experiment. The instrument was set to zero and the sample solutions were stabilized for 10-15 minutes. CMC was determined from the break in the plot of surface tension against concentration.

3.2. Foaminess and Foam stability
Foams are agglomerations of bubbles, they are structures composed of thin liquid films [15]. The formation and control of foam is important to many industries. Foam consists of gas dispersed within a liquid.

The properties of foam depend upon the liquid fraction \( \phi \),

\[
\phi = \frac{V_{\text{liquid}}}{V_{\text{foam}}}
\]

where \( V_{\text{liquid}} \) is the volume of the liquid and \( V_{\text{foam}} \) is the volume of the foam.
Foam producing capability or foaminess is the capacity of surfactant solutions to form foam. It depends on the ability of the surfactant to maintain low surface tension while a new interface is being formed [16]. Foaminess depends on the surface tension, surfactant system and the dynamics of the system. Foam stability refers to the ability of the foam to maintain some of its properties like foam volume, bubble size and liquid content constant with time. A surfactant may have high foam stability and low foaminess and vice versa [7].

Foaminess was studied by shaking tube method. 40 ml of surfactant solution was taken in a 100 ml measuring cylinder. The solution was shaken by hand at a fixed frequency and left to stand. The maximum height of the foam gave the foaminess. The decay of foam was monitored against time using a stop-watch [7].

Foam stability was expressed using the R5 parameter

\[ R5 = \frac{h_5}{h_0} \]

where \( h_0 \) = maximum foam height and \( h_5 \) = foam height 5 minutes later.

3.3 Dirt Dispersion

Dirt dispersion (DD) is the amount of dirt absorbed by foam. A surfactant is considered to be of poor quality if dirt remains in the foam, as it is difficult to rinse the dirt and it may redeposit [17]. DD was measured using the quantification technique developed by our group [14]. Two 15 ml bottles were taken and 7 ml solution taken in each. One drop of India ink was added to one solution. The two bottles were simultaneously shaken and photographed against a white background. The grayscale of the foams in the photographs was analyzed using Adobe® Photoshop® 7.0. The ratio of grayscale at the same height was considered as a measure of DD.

3.4. Relative Density

Relative density was measured by a specific gravity bottle using the formula

\[ D = \frac{(m_3 - m_1)}{(m_2 - m_1)} \]

where \( m_1 \) = Mass of empty bottle, \( m_2 \) = Mass of bottle with water and \( m_3 \) = Mass of bottle with solution.

3.5. Wetting and Cleaning

Wetting and cleaning ability were measured using a small piece of cotton cloth. The piece was soaked in water for 24 hours and dried. In wetting, the cloth was floated on the solution surface. The time required for the cloth to begin to sink was measured as the wetting time, similar to the canvas disc wetting test [18].

For cleaning, the cloth was weighed (\( W_1 \)). Standard dirt was prepared by mixing coconut oil and paraffin wax in hexane. The cloth was soaked in the dirt for a few minutes, and then it was dried and weighed (\( W_2 \)). This cloth was placed in the surfactant solution in a beaker and shaken. The cloth was taken out, washed with water, dried and weighed (\( W_3 \)) [19]. The percentage of cleaning was calculated by using the equation:

\[ C = \left( \frac{W_2 - W_3}{W_2 - W_1} \right) \times 100 \]

4. Results and Discussions

4.1. Surface Tension
Figure 3. Surface Tension as a function of Concentration

Surface tension decreases with increasing concentration, as shown in figure 3. For higher concentration, microwave extraction gives lower surface tension, which finally reaches 39.62 ± 0.2 mN/m. In normal extraction surface tension reduces to 41.40 ± 0.6 mN/m. For lower concentration, normal extraction gives low surface tension. CMC is $4.1 \times 10^{-3}$ g/cc for normal extraction and $6.4 \times 10^{-3}$ g/cc for microwave extraction. The difference in the two values may be attributed to the differences in the amounts of different compounds extracted. The surface tensions measured by the two techniques cross over at $4.0 \times 10^{-3}$ g/cc, very close to the CMC.

4.2. Relative Density

Relative density increases with concentration (figure 4a and b). Microwave extraction gives a higher relative density, though the surface tension also remains high. This indicates that more non-surfactant molecules are being extracted by the microwave technique. In the linear plot, the rate of change of density changes at a particular concentration, $4.1 \times 10^{-3}$ g/cc for normal and $1.5 \times 10^{-3}$ g/cc for microwave. This fact points to some change in the solution. Comparison with surface tension results indicates that this value is very close to the CMC.

Figure 4. Relative density as a function of concentration in (a) logarithmic and (b) linear scale.

4.3. Foaminess and Foam Stability

Foaminess is an important characteristic for the evaluation of surfactants, even though it does not have much connection with cleaning abilities. Foaminess increases with concentration (figure 5(a)). Normally extracted surfactant gives more foam than microwave extracted surfactant for all concentrations. The highest foaminess is 9.7 cm for normal and 6 cm for microwave extraction.
Foam height decreases with time. The rate of reduction also reduces with time. The results are qualitatively similar for both extraction methods (figures 5 b(i) and b(ii)). R5 parameter gives unexpected results. In microwave extraction, there is increase in R5 at around $3.0 \times 10^{-4}$ g/cc (if one ignores one value at $1.5 \times 10^{-3}$ g/cc), after which R5 is greater than 50%. R5 by normal extraction gives very peculiar results (figure 5(c)). This may be due to extraction of multiple surfactants by normal extraction. Exploring the higher concentration side may give some insight into the processes going on. Clearly much more work needs to be done to understand the phenomena involved.

4.4. Dirt Dispersion

Figure 6. (a) Dirt Dispersion Study (b) Variation of Dirt with Concentration
DD is the amount of dirt that goes into the foam. It increases with increase in concentration, reaches a maximum and then decreases. The concentration where DD is the highest (1.3×10^{-2} g/cc for microwave and 5.5×10^{-3} g/cc for normal) is the CMC.

At low concentrations, there is hardly any surfactant for the foam to form. The foam that forms has very little surfactant in it. This results in very little dirt in the foam. As concentration increases, more surfactant comes to the foam, very little stays in the bulk. So, dirt is attracted to the foam. Once CMC is crossed, micelles start forming. There is surfactant in the solution, which keeps the dirt in suspension. This brings in a competition, seen by the gradual decrease in DD as concentration increases [14].

4.5. Wetting
Wetting by a surfactant solution is critical for any cleaning operation. A solution can penetrate through a surface and wet it completely only if the surface tension is low [10]. Wetting time decreases as concentration increases, showing that the wetting ability increases with increasing concentration (figure 7a). This is in agreement with surface tension results. Surprisingly, both the extracts show very similar result.

![Figure 7. Wetting Time and Cleaning as a function of Surfactant Concentration](image)

4.6. Cleaning
Cleaning is the primary purpose of using surfactants. Cleaning increases with concentration, as expected (figure 7b). At lower concentrations, microwave extraction has better cleaning ability. At higher concentrations, normal extraction shows higher cleaning ability, reaching 67.16%. The cross over occurs at 0.01 g/cc, which is close to the CMC, as determined by DD measurement.

5. Conclusions
We report our work on natural surfactant extracted from hamburger seed. Our results show that the extract provides decent detergency. It cleans well with low Surface Tension (40±0.2mN/m) and good DD. It is thus a promising bio surfactant. To our knowledge there is no scientific report on this surfactant.

Hamburger seed extract is comparable to commercially available detergents, especially in terms of cleaning and wetting, as studied earlier by our group [20]. For example, Henko shows a cleaning of 70 % and wetting time of 50 seconds. However, the surface tension for Henko drops much less and foaminess is higher.
Table 1. CMC determined by different techniques.

| Method            | Normal       | Microwave    |
|-------------------|--------------|--------------|
| Surface Tension   | 4.1×10⁻³ g/cc | 6.4×10⁻³ g/cc |
| Relative Density  | 4.1×10⁻³ g/cc | 1.5×10⁻³ g/cc |
| Dirt Dispersion   | 5.5×10⁻³ g/cc | 1.3×10⁻² g/cc |

Cross over’s

a. Surface Tension 1.1×10⁻² g/cc
b. Cleaning 1.0×10⁻² g/cc

CMC has been calculated in three ways. The results are given in table 1. Surface tension and relative density give very similar values. Dirt dispersion gives a higher value. This could be due to the fact that DD measures the concentration at which dirt starts going to the bulk, a point when sufficient micelles have already formed. The cross-over in surface tension and cleaning are very close to CMC. This may be due to different components being extracted by the two methods. Further studies are required to understand this phenomenon.

Foam stability gave unexpected results. The results for microwave extraction are understandable. With normal extraction the results cannot be interpreted. This has to be studied by some other techniques.

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