The effect of the head group on branched-alkyl chain surfactants in glycolipid/n-octane/water ternary system

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A B S T R A C T

Two novel glycolipids have been synthesized and their phase behaviour studied. They have been characterized using FT-IR, FAB and 13C NMR and 1H NMR to ensure the purity of novel glycolipids. The two glycolipids are distinguished based on the head group of glycolipids (monosaccharide/glucose and disaccharide/maltose). These two novel glycolipids have been used as surfactant to perform two phase diagrams. Phase behaviours that have been investigated are 2-hexyldecyl-[β-D-glucopyranoside (2-HDG)/n-octane/water ternary system and 2-hexyldecyl-[β-D-maltoside (2-HDM)/n-octane/water ternary system. SAXS and polarizing optical microscope have been used to study the phase behaviours of these two surfactants in ternary phase diagram. Study of effect of the head group on branched-alkyl chain surfactants in ternary system is a strategy to derive the structure–property relationship. For comparison, 2-HDM and 2-HDG have been used as surfactant in the same ternary system. The phase diagram of 2-hexyldecyl-[β-D-maltoside/n-octane/water ternary system exhibited a L0 phase at a higher concentration regime, followed with two phases and a micellar solution region in a lower concentration regime. The phase diagram of 2-HDG/water/n-octane ternary system shows hexagonal phase, cubic phase, rectangular ribbon phase, lamellar phase, cubic phase as the surfactant concentration increase.

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1. Introduction

Glycolipids are compounds containing one or more monosaccharide residues bound by a glycosidic linkage to a hydrophobic moiety. Alkylpolyglucosides consist of various compounds with different glucosidation degrees and hydrocarbon chain lengths of plant oils. Purification is an important part in synthesis of glycolipids. For a better understanding, investigations on pure glycolipids are appropriate. Their application is complicated because of complex crystallization phenomena with strong kinetic hindrances. Chain lengths and glucosidation degree are the essential parameters which dominate the phase and aggregation behaviours. A detail knowledge of their phase behaviour is necessary for optimizing their effectiveness [8].

Glycolipids form a special class of liquid crystal mesophases because they obey different rules compared to the classical monophilic liquid crystals. A number of new glycolipid can be formed by connecting an alkyl chain with a monosaccharide by simple permutation and combination of different diastereomers (glucosides, mannosides, tallosides, and others), constitutional isomers (pyranosides (6-membered rings), furanosides (5-membered ring), acyclic compounds, regiosomers (2-alkyl,3-alkyl,4,6-dialkyliden) and others. Mesophase behaviour can be created from two basic concepts. One is the ‘closest packing’ of simple-shaped mesogenic compounds, giving rise to shape-driven mesophase transitions whereby rod-like molecules can be packed in an ordered way (liquid crystal phase) better (i.e. energetically more stable) than in a random way (isotropic phase). Most of the classical liquid crystals are monophilic liquid crystals. The second factor is the ‘microphase separation’ of two incompatible molecular parts which are present within a molecule. Thus the amphiphilic molecular character creates amphiphilic liquid crystals [15]. Microphase separation is basic concept of mesophase behaviour of glycolipids.

According to IUPAC recommendations [1], glycolipids can form three types of liquid crystals. Thermotropic liquid crystal is mesophase which is formed in melt, lyotropic liquid crystal which is formed in solution and amphotropic liquid crystal which is a mesophase that is able to form both thermotropic and lyotropic mesophase.

Alkylglucosides and related species such as alkylmaltosides are extremely interesting amphiphilic molecules. Interest on such compounds is essentially oriented toward bio-chemical application, since the above molecules do not denature proteins and
enzymes and are, therefore, of widespread use in biochemistry. They are miscible with lipids in all proportions and find application in cell biology and membrane solubilisation. From the physico-chemical viewpoint, alkyl glucosides were used to investigate surfactant adsorption at interfaces, to determine micelle formation and aggregation numbers, binding of surfactants onto proteins and polymers, the formation of emulsions and liquid crystalline phases, dielectric properties at the micelle–solution interface and so forth [2]. This is the challenge of the present research to find out more biological function and technical function of glycolipids.

This paper depicts the phase behaviours of two ternary systems. They are 2-hexyldecyl-β-D-maltoside (2-HDM)/n-octane/water ternary system and 2-hexyldecyl-β-D-glucopyranoside (2-HDG)/n-octane/water ternary. Two types of surfactants have been synthesized by the procedures reported by Vill [16]. They have been used to differentiate the phase behaviours of surfactants that have different head group of branched alkyl chain surfactants. Two types of surfactants have been characterized by using the known established techniques to ensure the purity of the surfactants. The surfactants are 2-hexyldecyl-β-D-maltoside and 2-hexyldecyl-β-D-glucopyranoside as shown in Fig. 1. 2-Hexyldecyl-β-D-maltoside/n-octane/water ternary system and 2-hexyldecyl-β-D-glucopyranoside/n-octane/water ternary system have been chosen as the samples to study the effect of the head group on branched-alkyl chain surfactants.

2. Materials and methods

2.1. Materials

The two surfactants have been synthesized by following procedures reported by Vill [16]. The purity of surfactant was estimated by known established techniques. The octane was purchased from Fluka and twice distilled water was used. A series of samples of known surfactant concentration have been prepared by weighing appropriate amount of surfactant, water and n-octane into glass ampoules (3 mm in diameter) which were immediately sealed. Homogeneity was attained using a vortex mixer for low-viscous samples whereas repeated centrifugation through a narrow constriction was used for highly viscous samples. These samples were kept for at least 1 week to equilibrate.

2.2. Optical observation

The structure of a lyotropic liquid crystalline phase was identified by a polarizing microscope. Polarizing optical microscopy was carried out using a Meiji microscope with hot stage and microphotographs were taken with a Nikon camera. Samples of different components of surfactant, water and oil are prepared as procedure depicted in Section 2.1. Hexagonal and lamellar structures are birefringence pattern of lyotropic mesophases. They are observed by placing a few milligram of the samples on a glass slide beneath a coverslip and put between crossed polarizers of an optical microscope.

2.3. Small angle X-ray scattering (SAXS)

After optical observation by using polarizing microscope, the lyotropic liquid crystalline phases have been investigated by using SAXS. SAXS measurement was performed using the Hercus-Braun SWAXS facility at Nuclear Science Building, UKM, with a Seifert-type X-ray generator. All measurements were done at 25°C using a Kratky compact small angle setting system, which are equipped with a position-sensitive detector containing 1024 channels of width 53.0 mm. The wavelength used was 0.154 nm and the sample to detector distance was 274 nm.

2.3.1. SAXS measurement

The SAXS measurements have been performed to verify the lamellar, cubic, rectangular ribbon and hexagonal phases. The characterization of liquid crystalline phases by X-ray diffraction is based on the long range order in the liquid crystalline state which give rise to Bragg reflections.

2.3.1.1. The lamellar phase (Lα).

The measurements are performed for five samples of each phase for every ternary system. The lattice parameter of the lamellar, \( a_1 \) is obtained from the position of the maximum intensity peak, \( q_{\text{max}} \), by the following equation:

\[
a_1 = \frac{2\pi}{q_{\text{max}}} \tag{1}
\]

A lamellar phase is periodic in one dimension, with a repeat distance \( a_1 \). The Bragg spacing for the linier space group is

\[
d_1 = \frac{a_1}{I} \tag{2}
\]

where \( I \) is the Miller index. For a lamellar phase, which is flat and without any defects, the thickness, \( d \), of the hydrocarbon part of the lamellae is given by

\[
d = \phi a_1 \tag{3}
\]

where \( \phi \) is the volume fraction, while the area per surfactant head group is given by

\[
A_s = \frac{V}{(1/2)d} \tag{4}
\]

2.3.1.2. The hexagonal phase (H₁).

The lattice parameters of the hexagonal phase, \( a_h \), are obtained from the position of the maximum intensity peak, \( q_{\text{max}} \), by the following equation:

\[
a_h = \frac{2\pi}{q_{\text{max}}} \tag{5}
\]

The Bragg spacing for a two-dimensional hexagonal lattice are related to the unit cell dimension, \( a_h \), by means of the relation:

\[
d_{hk} = \frac{\sqrt{3}}{2} a_h (h^2 + k^2 - h k)^{1/2} \tag{6}
\]
where the Miller indices take all integer values. From the relative position of the maximum intensity, \( q_{\text{max}} \), the lattice parameters are calculated using previous equation. From the value of the lattice parameter, radius of the hydrocarbon core can be calculated using:

\[
r = \sqrt{\frac{3\phi}{2\pi}} a_0
\]  

(7)

where \( \phi \) is the volume fraction of the hydrocarbon core \([12,13]\). The area per head group, \( A_h \), at the hydrophilic/hydrophobic interface in the hexagonal phase can be calculated from

\[
A_h = \frac{2V}{r}
\]  

(8)

where \( V \) is the volume of alkali chain.

2.3.1.3. Rectangular ribbon phase (R1). SAXS pattern of the R1 has two intense peaks in the lower \( q \) values, which are followed by some higher order peaks. This is the typical pattern shown by the R1 phase. The Bragg reflections for the R1 phase are given by the equation:

\[
d_{hk} = \left( \frac{h^2 + k^2 + l^2}{\alpha^2} \right)^{-1/2}
\]  

(9)

where \( d_{hk} \) is the spacing corresponding to the reflection by the \( h k \) plane, and \( \alpha \) and \( \beta \) are the unit cell parameters, as shown in Fig. 3. For pgg symmetry, Miller indices \( h \) and \( k \) can be any non-negative integer \( n \), with the restriction that for \( h = 0, k = 2n \) and for \( k = 0, h = 2n \). For cmc symmetry, \( h + k = 2n \), where \( n \geq 0 \).

2.3.1.4. Cubic phase. SAXS is performed to verify the different liquid crystalline phases that are found. The position of the Bragg reflections, \( q \), is defined as \( q = \frac{4\pi}{\lambda} \sin(\theta/2) \) where \( \lambda \) is the wavelength and \( \theta \) is the scattering angle.

For a cubic lattice with lattice constant \( a_c \), the Bragg spacing, \( d \), is given by Ref. [13]:

\[
d_{hkl} = a_c(h^2 + k^2 + l^2)^{-1/2}
\]  

(10)

where \( (h, k, l) \) are the Miller indices. A majority of bicontinuous cubic phase of both normal and reversed type found in surfactant and lipid systems have been shown to belong to one of these three space groups namely \( la3d \), \( Pn3m \), and \( Im3m \) [3]. An indexing of the observed reflections using the equation for a cubic element cell:

\[
\sin^{2} \theta = \frac{\lambda^2}{4a_c^2(h^2 + k^2 + l^2)}
\]  

(11)

is given below.

For the cubic \( la3d \), the reciprocal spacing must match with the ratio \( \sqrt{3} : \sqrt{8} \). These values lead to the following indexing (2 1 1), (2 2 0). Such an indexing would coincide with the space group \( la3d \), where the reflections with the lower indices are ignored [5]. According to Ref. [4], the epitaxial relationship between the lamellar phase and the bicontinuous \( la3d \) is a transformation of \( (1 1 0) \) plane (lamellar) to the \( (2 1 1) \) plane in \( la3d \), i.e. the lattice parameter \( a \) divided by \( \sqrt{3} \) should provide the equivalent lamellar spacing.

2.4. Phase diagram determination

Two types of phase diagram have been performed in order to study the phase behaviour of them. Samples of two types of surfactants, \( n \)-octane and water have been prepared by procedure depicted in Section 2.1. Phase boundaries were determined by visual observation. Polarizing microscope was used to investigate the boundaries of the one-phase regions with different microstructures. Birefringence of samples was detected through crossed polarizers. Then, SAXS measurement was performed to verify the liquid crystalline phases present on the systems. Microscopically, lamellar and hexagonal lyotropic liquid crystalline phases are clear anisotropic (birefringent) gels, while cubic lyotropic liquid crystalline phases are optically clear isotropic (non-birefringent) gels. Transparent, non-birefringent, and highly viscous samples were regarded as a cubic phase. To confirm the phase boundaries of a single phase region, the scattering angle, \( \theta \), and the interlayer spacing, \( d \), were measured by SAXS. The scattering angle, \( \theta \), was determined experimentally and is referred to “2\( \theta \)” in our study and it was calculated for all experiments. From the \( d \)-spacing values of the diffraction rings obtained, the structure of the liquid crystalline phases can be interpreted by adopting the standard relationship by Luzzati [10,11]. The clear bends in the first Bragg \( d \)-spacing (\( d_{1} \)) versus surfactant concentration curves allow us to determine the phase boundary concentrations within an accuracy of \( \pm 2 \) wt% [14]. Small angle X-ray scattering is performed for 10 samples of 2 ternary phase diagrams.

3. Results and discussion

3.1. Ternary phase diagram of 2-hexyldecyl-\( \beta \)-d-maltoside/\( n \)-octane/water ternary system

The phase diagram of 2-hexyldecyl-\( \beta \)-d-maltoside (HDM)/\( n \)-octane/water ternary system constructed at 25 °C is shown in Fig. 2. The phase diagram shows a large region of lamellar phases. Lamellar phase, micellar solution and two-phase regions have been identified by optical observation with polarizing microscope and the results have been verified by SAXS measurement.

Based on Fig. 2, phase diagram of 2-hexyldecyl-\( \beta \)-d-maltoside/\( n \)-octane/water ternary system exhibits a large lamellar region at high surfactant concentration, the formation took place at about 45–80% surfactant weight, 5–35% oil concentration, 5–45% water concentration. At high concentration of surfactant as well (55–75%), low oil concentration (10–30%) and high water concentration (25–40%) as comparing with oil concentration, this system shows two phases. In lower surfactant concentration (50–60%), low oil concentration (10–30%), and high water concentration (40–50%) as comparing with oil concentration, this system shows micellar solution. Hence, 2-hexyldecyl-\( \beta \)-d-maltoside/\( n \)-octane/water ternary system exhibited a Lo phase at a higher concentration regime, followed with two-phase and a micellar solution region in a lower concentration regime.

Fig. 3 shows SAXS spectra of 2-hexyldecyl-\( \beta \)-d-maltoside/\( n \)-octane/water ternary system. The lamellar lyotropic liquid crystalline phase can be identified in this system by using SAXS.
spectra. The SAXS spectra show a representative SAXS diffraction pattern for the liquid crystal found in the 2-hexyldecyl-β-p-maltoside/n-octane/water system at different weight compositions. SAXS spectra of five samples gave three diffractions with d-spacing values at the ratio $d_1:d_2:d_3$ of 1:1/2:1/3, indicating that the liquid crystalline phase is of the $L_α$ type. Table 1 shows the reciprocal spacing of the $2\theta$ peaks are found to be in the ratio 1:2:3. The ratio is in the good agreement with lamellar phase.

Based on Table 1, we can see that as more surfactant is added to the system, in the same water concentration (15%) and oil concentration is increased (sample 2-1), the $d_1$ and $a$ values decrease. But we can see at sample 3, the $d_1$ value of sample 2 is higher than $d_1$ value of sample 3 even the surfactant concentration of sample 2 is higher than the surfactant concentration of sample 3. It happens at very low (5%) water concentration of sample 3 and the oil concentration is very high (35%). If we look to the samples 4 and 5, it does not have the same properties with the other samples. As more surfactant is added to the system, in the same oil concentration (10%) and water concentration decrease (high concentration), the $d_1$ and $a$ values increase. It happens at the condition of water concentration is different and very high and oil concentration is very low. It is effect of the addition of water to the systems. The polar region thickness (head group + water) of the surfactant bilayer increases and the surfactant molecules tend to pack more sparsely in the plane of the bilayer.

Fig. 4 shows polarization micrograph of sample 3. The micrograph shows the oily streaks texture, the texture coincide with the texture of the lamellar phase. Other samples have the same texture of oily streak as well.

### 3.2. Ternary phase diagram of 2-hexyldecyl-β-p-glucopyranoside/n-octane/water ternary system

The phase diagram of 2-hexyldecyl-β-p-glucopyranoside (HDG)/n-octane/water ternary system constructed at 25°C is shown in Fig. 5. The phase diagram shows four lyotropic liquid crystalline phases and an isotropic solution. Cubic phase, rectangular ribbon phase, lamellar phase, hexagonal phase and micellar solution have been identified by optical observation with polarizing microscope and the results have been verified by SAXS measurement.
Based on Fig. 5, we can see that cubic phase has a large region in high surfactant concentration (65–80%) and relatively low oil concentration (5–20%). The cubic samples have the appearance and textures of clear highly viscous gels. Besides that when it tapped gently, the samples exhibit ringing behaviour. Fig. 6 shows a representative SAXS diffraction pattern for the different liquid crystals found in the HDG/n-octane/water system at different weight compositions. Let us consider the pattern of the sample 80/15/5 (sample 1). From Fig. 6 and Table 2, we can calculate that the reciprocal spacing of \( d \) value and \( 2\theta \) match the ratio \( \sqrt{6} : \sqrt{8} : \sqrt{16} : \sqrt{22} : \sqrt{26} : \sqrt{30} \). This spacing would coincide with the space group \( Ia3d \) (no. 230), where the reflections with lower indices are extinguished [7]. The epitaxial relationship between the lamellar phase and the cubic phase is known to occur in many lyotropic and thermotropic liquid crystals, commonly those built by lipids, or even block copolymers. According to Jung et al. [9], the geometry is often visualised as a structure where short-rod aggregates are joined, three and three at each end, and form an interwoven but otherwise independent three-dimensional network.

Based on the phase diagram (Fig. 5), the lamellar phases are in the high surfactant concentration (65–75%) and high oil concentration (20–30%) compared to water concentration (5–10%). Fig. 6, sample 2 shows a representative SAXS diffraction pattern for the lamellar lyotropic liquid crystal at 75% of surfactant weight, 15% of water concentration and 10% of oil concentration. The diffraction peaks are, \( d_1 = 2.59 \text{ nm}, d_2 = 1.30 \text{ nm}, d_1/d_2 = 1:1.2 \). It indicates that the liquid crystalline phase is of the \( l_0 \) type. The reciprocal spacing of the \( 2\theta \) peaks is found to be in the ratio 1:2. The ratios are in the good agreement with lamellar phase. Fig. 7 shows polarization micrograph of sample 2. The micrograph shows the oily streaks texture, the texture coincides with the texture of the lamellar phase.

The phase diagram in Fig. 5 which shows the region of the rectangular ribbons are in the middle of the phase diagram. The rectangular ribbons are found in high concentration of surfactant (60–70%), low water concentration (10–15%) and high oil concentration (15–30%) compared to water concentration. From Fig. 8, sample 3, we can see a peak showing the rectangular ribbon peak. The SAXS pattern of the R₁ phase has two intense peaks in the lower \( q \) values, which are followed by some higher order peaks. This is the typical pattern shown by the R₁ phase [6]. The SAXS pattern of the R₂ phase observed can be fitted to the structure of a centered rectangular phase having \( cmm \) symmetry, with the first two intense peaks assigned at \( 2\theta = 6.84 \) and 9.68.

Sample 4 in Fig. 6 shows the SAXS pattern of cubic phase. The reciprocal spacing of the peaks of sample 4 is in the ratio \( \sqrt{6} : \sqrt{8} : \sqrt{16} : \sqrt{22} : \sqrt{26} : \sqrt{30} \). This ratio indicates the cubic phase lyotropic liquid crystalline. The peak that shows the SAXS pattern of cubic \( l_{a3d} \) of sample 1 is different with the peak that shows the SAXS pattern of cubic \( l_{a3d} \) of sample 4. The peak of sample 1 is higher than that of sample 4 but lattice parameter of sample 4 is higher than lattice parameter of sample 1. Lattice parameter of sample 1 is 7.430 nm and lattice parameter of sample 4 is 15.692 nm.
Sample 5 is the ternary system of HDG/water/n-octane with the composition ratio 60/05/35. The phase diagram in Fig. 5 shows the small region of hexagonal phase. The hexagonal phase region presents at low surfactant concentration (60–63%), low water concentration (5–8%) and high oil concentration (35–38%). Based on Fig. 5 and Table 2, the reciprocal spacing of peaks of sample 5 is found to be in the ratio $\sqrt{3} : 2 : \sqrt{7}$. The ratio coincides with hexagonal lyotropic liquid crystalline. Fig. 9 shows the polarization micrograph of the fan texture. The texture indicates the hexagonal lyotropic liquid crystalline. The optical polarization result is in a good agreement with the SAXS measurement result.

From Fig. 6, we can study about the phase transition of hexagonal phase–rectangular ribbon phase–lamellar phase ($H_1$–$R_1$–$L_0$). Fig. 5 shows the hexagonal phase ($H_1$) transforms into the rectangular ribbon ($R_1$) with successive addition of surfactant, which is attributed to the increase in the packing constraint in the lipophilic core decrease in interfacial curvature of the aggregate.

Fig. 6 shows the evolution of the SAXS pattern of the liquid crystal phases with the successive addition of HDG as surfactant. Based on Fig. 5, we can see the region of hexagonal lyotropic liquid crystalline is at 60–63% of HDG concentration, 5–8% of water concentration and 35–38% of n-octane concentration, whereas the region of rectangular ribbon phase is at 60–70% of HDG concentration, 10–15% of water concentration and 15–30% of n-octane concentration, and the region of lamellar lyotropic liquid is at 65–75% of HDG concentration, 5–10% of water concentration and 20–30% of n-octane concentration.

With the successive addition of HDG, the intensity of the angle peak gradually decreases ($H_1 \rightarrow R_1 \rightarrow L_0$), but peak of sample 3 in Fig. 6 remains intense, which may be attributed to the gradual breaking of the rectangular symmetry, leading to the formation of a lamellar structure, as shown by the evolution of the SAXS pattern (Fig. 6). Here, the peak of the $R_1$ phase (sample 3) transforms to the plane of the $L_0$ phase (sample 2), suggesting that the phase transformation occurs by the lateral fusion of the rod-like aggregate of the plane of $R_1$ phase (sample 3). The values of the structural parameters calculated along the same line are shown in Table 2.

The interlayer spacing, $d$, gradually decreases with increasing the weight of HDG in the ternary system ($d_{H_1} = 2.90$ nm, $d_{R_1} = 2.59$ nm, $d_{L_0} = 2.59$ nm). The interlayer spacing, $d$, for $R_1$ and $L_0$ is the same. Probably, there is a little bit difference in $d$ value but the value is too small. It happens because the weight of surfactant in the system of $R_1$ phase is not too different with the weight of surfactant in the system of $L_0$ phase. In each liquid crystal the area per surfactant molecule, $a$, decreases continuously upon the addition of HDG ($a_{H_1} = 3.35$ nm, $a_{R_1} = 2.59$ nm, $a_{L_0} = 2.59$ nm), which indicates that the surfactant layer is getting more compact. The value of the area per surfactant molecule of $R_1$ and $L_0$ is the same, it happens because the value of the weight in both system are almost the same as well.

3.3. Effect of the head group on branched-alkyl chain glycolipids in ternary system

Studying the effect of the surfactant head group is a strategy to derive the structure–property relationship. For this strategy, two different surfactants which have different head group have been chosen. The surfactants are 2-hexyldecyl-$\beta$-d-glucopyranoside and 2-hexyldecyl-$\beta$-d-maltoside. 2-Hexyldecyl-
β-α-glucopyranoside is the surfactant which has glucose as the head group, whereas 2-hexyldecyl-β-α-maltoside is the surfactant which has maltose as the head group. These two surfactants have been used in the same system. These two systems used the same oil and performed in the same weight composition. Fig. 10 shows a representative SAXS diffraction pattern for different liquid crystalline found in three samples of 2-HDG/water/n-octane ternary system and three samples of 2-HDM/water/n-octane ternary system. Samples 1, 3, and 5 are three weight compositions 2-HDM/water/n-octane ternary system and samples 2, 4, and 6 are three weight compositions of 2-HDG/water/n-octane ternary system. Based on Fig. 10 and Table 3, we can see that 2-HDM/water/n-octane ternary system shows the same phase although the weight compositions have been changed, whereas 2-HDG/water/n-octane ternary system shows different phase when we change the weight composition. The phase diagram of 2-HDM/water/n-octane ternary system exhibited a Lα phase at a higher concentration regime, followed with two phases and a micellar solution region in a lower concentration regime. The phase diagram of 2-HDG/water/n-octane ternary system shows hexagonal phase, cubic phase, rectangular ribbon phase, lamellar phase, and cubic phase as the surfactant concentration increase. In 2-HDM/water/n-octane ternary system, we can see that as more surfactant is added to the system, in the same water concentration and oil concentration is decreased, the d1 and a values decrease, whereas in 2-HDG/water/n-octane ternary system, the d1 and a values increase. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased. But different cases with samples 5 and 6, they do not have the same properties with another sample. It happens because the concentration of water is different and very small and oil concentration is increased.

4. Conclusion

We have synthesized two novel alkyl glycosides bearing alkyl glucoside (monosaccharide head group), 2-HDG and alkyl maltoside (disaccharide head group), 2-HDM and examined their phase behaviours in ternary system. The head group of branched-alkyl chain glycolipid has big effect to the phase behaviour. These two sugar-based surfactants in ternary system show different phase progression. The phase progression for 2-HDG system is L1 → H1 (hexagonal phase) → R1 (rectangular ribbon phase) → Q1 (cubic phase) → L0 (lamellar phase) → Q1 (cubic phase) whereas L1 → L0 for 2-HDM system.

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Appendix A

A.1. 2-Hexyldecyl-β-d-maltoside

Maltose pentaacetate and 2-hexyl 1-decanol were reacted using general procedure. Eluent for column chromatography: n-hexane-ethyl acetate 2:1. Yield: 36.87%.

A.2. 2-Hexyldecyl-β-d-glucopyranoside

![Image](https://via.placeholder.com/150)
Glucose pentaacetate and 2-hexyl 1-decanol were reacted using general procedure. Eluent for column chromatography: n-hexane-ethyl acetate 4:1. Yield: 32.57%.

$^1$H NMR (300 MHz, d$_4$-MeOH): δ 4.23 (d, 1H, H-1, J7.5 Hz), δ 3.79–3.84 (m, 2H, H-9a, H-6a), δ 3.70 (dd, 1H, H-6b), δ 1.60 (m, 2H, β-CH$_2$), δ 1.29–1.41 (m, 26H, –CH$_2$–), δ 0.92 (m, 5H, CH$_2$CH$_3$). $^{13}$C NMR (300 MHz, d$_4$-MeOH): 13.28 (CH$_3$), 22.56, 26.66, 29.29, 29.55, 29.67, 29.98, 31.05, 31.89, 61.60, 72.82 (CH$_2$), 38.36, 70.50, 73.99, 76.77, 77.00, 103.59 (CH). FAB: m/z = 427 (100%), 405[(m + 1), 5], 146(38), 128(30), 86(62). FT-IR (cm$^{-1}$, KBr): 3411.05, 2926.72, 2858.20, 1641.92, 1466.79, 1377.09, 1160.75, 1077.80, 1026.47, 895.92, 720.61, 616.17.

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