Glycolipid Biosurfactants, Mannosylerythritol Lipids: Distinctive Interfacial Properties and Applications in Cosmetic and Personal Care Products

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Abstract: Biosurfactants produced by a variety of microorganisms show attractive properties (e.g., higher surface activity and biodegradability, lower toxicity, and environmental compatibility) compared to chemically synthesized counterparts. The numerous advantages of biosurfactants have prompted their application to not only the food, cosmetic, and pharmaceutical industries, but agriculture and environmental protection disciplines as well. Among different types of biosurfactants, glycolipids are the most practically useful, due to their high product titers from renewable resources and versatile interfacial and biochemical properties. Mannosylerythritol lipids (MELs) are characteristic glycolipid biosurfactants that are produced by different yeast strains of the genus Pseudozyma. MELs exhibit different lyotropic liquid crystalline phases, such as sponge (L₃), reverse bicontinuous cubic (V₂), or lamellar (Lₐ) phases; and they have high levels of surface activity at very low concentrations. MELs also show excellent moisturizing effects on human skin and hair, with comparable performance to natural ceramides. Today, MELs are commercially produced by a Japanese company and their use is rapidly expanding around the world. In this review, we will briefly describe the current R&D status of glycolipid biosurfactants, with a focus on the interfacial properties of MELs and their applications in cosmetic and personal care products.

Key words: glycolipid, biosurfactant, yeast, Pseudozyma tsukubaensis, mannosylerythritol lipid, surface-activity, lamellar phase, moisturizers, skin care, hair care, cosmetics, toiletries
properties of biosurfactants have been discovered, along with other attributes that have not been observed at all in conventional chemical surfactants. In addition to these advantages, the production efficiency of biosurfactants has been improved as biotechnology has advanced, and the range of biosurfactant applications is thus rapidly expanding to not only food, cosmetic, and pharmaceutical industries, but also to the fields of agriculture and environmental protection. In particular, glycolipid biosurfactants such as mannosylerythritol lipids (MELs, Fig. 1) TOYOBO Co., Ltd., Osaka, Japan and rhamnolipids (Allied Carbon Solutions Co., Ltd., Numazu, Japan) are now commercially manufactured using microbial fermentation processes; and widely used in a variety of industrial products.

With a special focus on the latest studies on glycolipid biosurfactants, this review details the distinctive interfacial properties of MELs and their applications in cosmetic and personal care products. I would also like to refer the reader to other reviews that provide more detail about the production and biochemical properties of MELs.

2 Production of MELs by Different Pseudozyma Strains

MELs possess 4-O-β-D-mannopyranosyl-(2S, 3R)-erythritol as its hydrophilic head group, and a hydrophilic tail that comprises a variety of fatty acids (Fig. 1a). They are exclusively produced by various yeast strains of the genus Pseudozyma; and MEL-producing yeasts are listed in Table 1. P. antarctica, P. aphidis, P. rugulosa and P. parantarctica are the largest producers of MELs; mainly MEL-A, along with smaller percentages of MEL-B and MEL-C. These strains produce MELs from vegetable oils at rates of over 100 g/L, but more than 70% of the total MELs produced in culture media invariably consists of MEL-A.

P. tsukubaensis selectively produces a diastereomer of MEL-B (d-MEL-B, Fig. 1b), which has 4-O-β-D-mannopyranosyl-(2R, 3S)-erythritol as its hydrophilic head group. This strain has been used by a Japanese company (TOYOBO Co., Ltd., Osaka) for the commercial production of d-MEL-B (Celamera™, INCI Name: glycolipids). Interestingly, P. graminicola, P. hubeiensis, P. shanxiensis and P. siamensis mainly produce MEL-C, along with MEL-A and MEL-B.

Recently, the biosynthetic pathway of MEL has been elucidated based on the genomic analysis of several Pseudozyma yeasts. Three enzymes in particular, that is, two types of acyltransferases (Mac1 and Mac2) and acetyltransferase (Mat1) play important roles in the acylation and acetylation of the mannosylerythritol backbone. As indicated above, MEL producers are classified into three groups according to their main product (Table 1). The dependence of MEL structural diversity on their producer is thus likely to stem from the differences in the constitution and/or action of these three enzymes.

Saika et al. reported improvements in d-MEL-B production by introducing genes that encode for lipases. P. tsukubaensis 1E5 that overexpresses the lipase PaLIPA derived from P. antarctica has shown 1.7-fold higher production rates of d-MEL-B from olive oil than that the control strain. This reveals that the enhanced uptake and degradation of the oil would be one of the key factors that leads to high d-MEL-B production.

In the past decade, various studies have attempted to tailor the production of MELs to the expansion of their applications, considering that their interfacial and biological
properties are highly dependent on the structures of acetyl- and acyl-groups\(^{14}\). Genomic sequencing of several species of *Pseudozyma* has allowed us to identify the gene cluster that regulates MEL biosynthesis, thereby enabling novel approaches to the targeted structural design of MEL by genetically modifying the yeasts\(^7\). Recently, Saika et al. have demonstrated the production of a mono-acylated mannosylerythritol i.e., novel homologue of MEL, by regulating the genes for acyltransferase or transporter of MEL in *P. tsukubaensis*\(^{27,28}\). This novel approach will lead to the design of practical MEL properties by changing its degree of acylation and acetylation.

### 3 Surface-active Properties of MELs

Generally, biosurfactants have the following properties that differentiate them from chemical surfactants: (i) one

| Microorganism       | Main product | Yield (g/L) | Reference |
|---------------------|--------------|-------------|-----------|
| *Pseudozyma antarctica* | MEL-A        | 140         | 9         |
| *Pseudozyma aphidis*  | MEL-A        | 165         | 15        |
| *Pseudozyma rugulosa* | MEL-A        | 142         | 16        |
| *Pseudozyma parantarctica* | MEL-A     | 106.7       | 17        |
| *Pseudozyma crassa*   | d-MEL-A*     | 4.6         | 18        |
| *Pseudozyma tsukubaensis* | d-MEL-B**  | 73.1        | 19        |
| *Pseudozyma graminicola* | MEL-C      | 9.6         | 20        |
| *Pseudozyma hubeiensis* | MEL-C      | 129         | 21        |
| *Pseudozyma shanxiensis* | MEL-C      | 2.7         | 22        |
| *Pseudozyma siamensis* | MEL-C       | 18.5        | 23        |

* Diastereomer of MEL-A bearing 4-O-β-D-mannopyranosyl-(2R, 3S)-erythritol as the sugar moiety.

** Diastereomer of MEL-B bearing 4-O-β-D-mannopyranosyl-(2R, 3S)-erythritol as the sugar moiety.

| MEL (producer)       | CAC (M) | γCAC (mN/m) | Reference |
|----------------------|---------|-------------|-----------|
| MEL-A (*P. antarctica*) | 2.7 × 10^{-6} | 28.4        | 8         |
| d-MEL-A* (*P. crassa*) | 5.2 × 10^{-6} | 26.5        | 18        |
| MEL-B (*P. antarctica*) | 4.5 × 10^{-6} | 28.2        | 8         |
| d-MEL-B** (*P. tsukubaensis*) | 3.1 × 10^{-6} | 26.1        | 24        |
| MEL-C (*P. graminicola*) | 4.0 × 10^{-6} | 24.2        | 20        |
| MEL-C (*P. hubeiensis*)  | 6.0 × 10^{-6} | 25.1        | 25        |
| MEL-C (*P. siamensis*)   | 4.5 × 10^{-6} | 30.7        | 23        |

CAC: critical aggregate concentration.
* Diastereomer of MEL-A bearing 4-O-β-D-mannopyranosyl-(2R, 3S)-erythritol as the sugar moiety.
** Diastereomer of MEL-B bearing 4-O-β-D-mannopyranosyl-(2R, 3S)-erythritol as the sugar moiety.
or more functional groups and chiral centers, (ii) bulky but sophisticated structures, (iii) higher biodegradability and lower toxicity, (iv) lower critical micelle concentration and higher surface activity, (v) superior ability to form molecular assemblies and liquid crystals.

The combination of the hydrophilic and hydrophobic groups in biosurfactants is very elegant; probably due to the long-term evolution of microorganism biological processes. They thus exhibit excellent orientation and packing properties at various interfaces. These structural features allow biosurfactants to possess surprising abilities, compared with conventional chemical surfactants. In particular, glycolipid biosurfactants exhibit versatile surface-active properties, including emulsifying, dispersing, solubilizing, foaming, penetrating and wetting effects that reflect their bulky and hydrophilic sugar backbone.

Table 2 presents some examples of the surface-tension lowering activities of MELs. MEL-A and MEL-B exhibit excellent surface and interfacial tension-lowering actions and low critical aggregate concentrations (CAC), even though their hydrophobic components consist of medium-chain fatty acids that range from C\textsubscript{7} to C\textsubscript{12}. Analysis using the Wilhelmy method reveals that MEL-A has a CAC value of 2.7 \times 10^{-6} M and can reduce the aqueous surface tension and interfacial tension against n-hexadecane to approximately 28.4 mN/m and 2.1 mN/m, respectively. MEL-B exhibits similar activities to those of MEL-A; and the MEL-C produced by \textit{P. hubeiensis} KM-59, which has a different fatty acid profile compared to MEL-A or -B, has a CAC value of 6.0 \times 10^{-6} M and can reduce the aqueous surface tension to about 25.1 mN/m. Interestingly, the MEL-C has a higher CAC and hydrophilicity than conventional MELs, and retains excellent surface-tension lowering activity.

The emulsifying activity of MEL-A towards soybean oil and n-tetradecane is much higher than that of Tween 80 (polyoxyethylene sorbitan monoooleate). The molecular occupation area of MEL-A is about 60 Å\textsuperscript{2}/molecule at the air-water interface (25°C); it thus has excellent packing properties despite its bulky structure.

### 4 Self-assembling Properties of MELs

The stereochemistry of the saccharide headgroups displays versatile influences on the self-assembly of glycolipid/water systems. In addition to the saccharide type, the number of saccharide residues and the linkage types have important impacts on self-assembly. Some types of glycolipid chemical surfactants, which possess relatively larger hydrophilic headgroups than hydrophobic parts, generally form micelles in a dilute aqueous solution. Other than spherical micelles, they also form oblate (disk-like) and prolate (rod-like) ones. As the surfactant concentrations further increase, glycolipid/water systems start to form a range of liquid crystalline phases.

The self-assembling processes of MEL-A and MEL-B are illustrated in Fig. 2. MEL-B and -C, which possess two alkyl chains at the C-2 and C-3 positions, spontaneously form...
giant vesicles with diameters larger than 5 μm, that are derived from lamellar phases \( (L_\alpha) \) (Fig. 2b). It is generally difficult to obtain giant vesicles with conventional glycolipids, because the vesicle structures require strict proportions of hydrophobic and hydrophilic groups to do so. This indicates that these MELs have excellent molecular orientation properties and superior hydrophilic-hydrophobic balances.

In contrast, MEL-A self-assembles to form a sponge phase \( (L_3) \) composed of randomly connected bilayer networks at concentrations above 1 mM (Fig. 2a). This reveals that while the absence of the 4'-O- or 6'-O-acetyl group induces only a slight decrease in the "spontaneous curvature," a drastic morphological change results in the self-assembled structure, and it transitions from a sponge phase \( (L_3) \) to a lamellar phase \( (L_\alpha) \).

When the spontaneous curvature \( (H_0) \) is nearly zero, lipidic compounds self-assemble in the lamella phase \( (L_\alpha) \). The spontaneous curvature of MEL-B or MEL-C assemblies is thus nearly zero since vesicles are obtained by the dispersion of the \( L_\alpha \) phase. These \( L_\alpha \) phases appear to be stabilized by the hydrogen-bonding network between the headgroups of the C-4' or C-6' hydroxyl group. On the other hand, the presence of an acetyl group on the mannose moiety of MEL-A is likely to induce a slightly negative spontaneous curvature of the assemblies, which should lead to the formation of the sponge phase \( (L_3) \).

5 Phase Behaviors of MELs

5.1 Binary phase behavior of MEL-A and d-MEL-B

Based on small angle X-ray scattering (SAXS) measurements, we previously described the temperature dependence of the MEL/water system on a binary phase diagram. The phase diagrams described here will be exclusively for MEL-A and d-MEL-B, as the diagram for MEL-C has not yet been well characterized.

MEL-A self-assembles into a variety of distinctive lyotropic liquid crystals, including sponge \( (L_3) \), reverse bicontinuous cubic \( (V_2) \), and lamella phases \( (L_\alpha) \) (Fig. 3a). The proposed space group of the bicontinuous cubic phase \( (V_2) \) is \( Ia3d \), and the estimated lattice constants are 11.39 nm for \( V_2 \) and 3.58 nm for \( L_\alpha \). Very interestingly, the MEL-A sponge phase region \( (L_3) \) is spread considerably over a wide temperature range \( (20–65^\circ C) \) compared to those of hydrophobic polyoxyethylene or fluorinated surfactants. This is probably due to the stabilization effect of the hydrogen bonding networks of the sugar moiety.

Figure 3b shows the binary phase diagram of the d-MEL-B/water system. d-MEL-B efficiently self-assembles into a lamellar \( (L_\alpha) \) phase over remarkably wide concentration and temperature ranges. According to SAXS measurement, the interlayer spacing \( (d\text{-spacing}) \) is almost constant (about 4.7 nm) at the low concentration (≤ 60 wt%) region, where the \( L_\alpha \) phase is in equilibrium with the excess water phase \( (L_\alpha + W) \). On the other hand, at the high concentration (> 60 wt%) region, the \( d\text{-spacing} \) gradually decreases to 3.1 nm with an increase in the diastereomer concentration. The obtained \( L_\alpha \) phase is stable up to 95°C when below the diastereomer concentration of 85 wt%; the melting temperature of the phase dramatically
decreases with increases in the diastereomer concentrations (above 85 wt%).

Although MEL-B also efficiently self-assembles into an Lα phase (about 4.4 nm of d-spacing) over wide concentration and temperature ranges, the one-phase Lα region of d-MEL-B is significantly wider than that of MEL-B20. This implies that the hydration force of d-MEL-B is higher than that of MEL-B, reflecting its erythritol configuration.

Accordingly, MELs spontaneously self-assemble into a variety of molecular assemblies with well-defined and/or unique structures: sponge (L3), cubic (V2), and lamellar (Lα).

5.2 Ternary Phase Behavior of MEL-A and d-MEL-B

We previously reported on the phase behaviors of ternary MEL/water/oil systems (Fig. 4). Figure 4a depicts the phase diagram of the MEL-A/water/n-decane system24. When n-decane is used as an oil phase, MEL-A forms single-phase water-in-oil (W/O) microemulsion in a remarkably large region. MEL-A with negative spontaneous curvatures also form sponge (L3), reverse bicontinuous cubic (V2), and lamellar (Lα) phases.

Water-in-oil (W/O) microemulsion has attracted attention in various fields of application. However, the formation of microemulsions usually requires the mixing of surfactants with salt or alcohol. Only a few surfactants such as sodium bis(2-ethylhexyl)sulfosuccinate (AOT) and soybean lecithin can effectively form W/O microemulsion without addition of any cosurfactants35.

As indicated above, MEL-A effectively provides a stable W/O microemulsion in the ternary system without any co-surfactants, indicating that the glycolipid would have great advantages for various industrial formulations where it is necessary to bring two components together when they are not normally miscible in a fluid.

Figure 4b depicts the phase diagram of the d-MEL-B/water/n-decane system34. In contrast to MEL-A, d-MEL-B provides single-phase bicontinuous microemulsion and is characterized by a triangular phase diagram dominated by the Lα phase, suggesting that MEL-B has a spontaneous curvature of almost zero. Moreover, oil-in-liquid crystal (O/LC) emulsion is easily prepared in the biphasic Lα + oil region of the ternary system.

These clearly demonstrate that the difference in the number of acetyl groups on the headgroup and/or the chirality of the erythritol moiety drastically changes the phase behavior of MEL. Accordingly, these MELs would be quite distinct from the conventional surfactants hitherto reported, and have great potential for the preparation of microemulsion and LC-based emulsions.

6 Applications of MELs in Cosmetic and Personal Care Products

6.1 Skin care properties of MELs

Biosurfactants are attractive practical alternatives to chemical surfactants because they are effective ingredients for cosmetic and personal care products, due to their favorable attributes of lower toxicity, antimicrobial activity, skin compatibility, and protective and surface moisturizing effects36, 37. As described above, MELs are now commer-

![Fig. 4 Ternary phase diagrams of MELs at 25°C.](image-url)

(a) MEL-A

(b) d-MEL-B

| Lα; lamellar phase, O/W; O/W-type microemulsion, W/O; W/O-type microemulsion, D; bicontinuous microemulsion, W; excess water, O; excess oil. |
| Lα; lamellar phase, O/W; O/W-type microemulsion, W/O; W/O-type microemulsion, D; bicontinuous microemulsion, W; excess water, O; excess oil. |
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cially available and are able to efficiently form various lyotropic liquid-crystalline phases, such as lamella ($L_n$), indicating that these glycolipids are particularly highly advantageous for the functional formulation of cosmetic and personal care products.

We investigated the moisturizing properties of MEL-A by evaluating their effect on the recovery of damaged skin that was pre-treated with sodium dodecyl sulfate (SDS). On the assay on the three-dimensional cultured skin model, MEL-A exhibited excellent moisturizing performance, equivalent to that of natural ceramide-3, which is an essential component of the stratum corneum. The viability of the damaged cells was remarkably restored by the addition of MEL-A, in a dose-dependent manner; d-MEL-B and MEL-C also efficiently restored the viability of the cells and displayed similar moisturizing properties that were comparable with those of the ceramide.

Natural or synthetic ceramides are well known to play a crucial role in the barrier function of the skin through the formation of an $L_n$ phase in the stratum corneum. Together with hyaluronic acids, they have thus become the moisturizer of choice for skin care applications. However, the costs of these ceramides are still high, due to their limited availability in plants or their complicated synthetic and purification processes. Also, they are hardly soluble in water; which makes handling them very difficult. Considering the high productivity of MELs and their interfacial properties, MELs will be a practical and low-cost replacement for ceramides.

We also investigated the effects of MELs on water content on the forearm skin of healthy human female volunteers, using a Corneometer. Interestingly, MEL-A and d-MEL-B were estimated to considerably increase the stratum corneum water content in the skin, compared with an aqueous solution of 1,3-butylene glycol (1,3-BG), which is a common humectant and solubilizer in cosmetic and food preparations. The effect of MELs on the barrier function of the forearm skin was further evaluated based on measurements of skin perspiration i.e., transepidermal water loss (TEWL), made using a Tewameter. The skin area treated with MEL-A and d-MEL-B exhibited dose-dependent significant decreases in TEWL, while the area treated with 1,3-BG solution showed little increase. The glycolipid is thus likely to maintain the epidermal water barrier, strengthen the skin structure, and reduce water loss.

The observed moisture retention effects appear to be reasonable, given that d-MEL-B can efficiently penetrate the skin due to the high surface-activity, and form its $L_n$ phase even at low concentrations. Yamamoto et al. demonstrated that d-MEL-B quickly penetrates excised human skin (keratin layer) within 30 min of applications to the skin surface, as observed by fluorescence microscopy with nitrobenzoxadiazole (NBD)-labelled d-MEL-B.

Sugawara et al. reported on the effects of d-MEL-B on lower leg skin over a long application duration. The d-MEL-B dissolved in 1,3-BG was applied to the skin for 13
consecutive days, and the water content of the stratum corneum was monitored during the application period. The area of skin that was treated with d-MEL-B exhibited much higher water content from the 4th day after applications began, compared to the area treated with the positive control comprising glucosylceramide solution. More interestingly, the water content of the d-MEL-B treated area was maintained for up to four days after the applications had ceased. They also investigated the effects of d-MEL-B on the fine wrinkles caused by dry skin, based on the "Guidelines for evaluation of anti-wrinkle products for obtaining new efficacy" of the Japan Cosmetic Science Society. The d-MEL-B dissolved in 1,3-BG was found to significantly reduce wrinkle grade.

They further evaluated the interactions between d-MEL-B and the stratum corneum using synchrotron X-ray scattering measurements. The skin sample was set in a frame and the test solution was continuously injected onto it; 30 minutes of SDS aqueous solution, 30 minutes of pure water and 60 minutes of d-MEL-B aqueous 1,3-BG solution were applied, in that order. The ongoing structural changes to the intracellular lipid layer of the skin were monitored based on the short lamellar structure, which reflects water content. The peak area value derived from the lamellae was significantly reduced by the SDS treatment. After treatment with pure water, it increased a little, but remained below the initial level. Interestingly, its value significantly exceeded its initial value after treatment with d-MEL-B; the glycolipid is likely to repair the lamellar structure in the stratum corneum damaged by the SDS treatment.

Interestingly, Kim et al. reported that MEL readily associated with pseudo-ceramide due to hydrophobic interactions, and that the ceramide emulsions prepared with MEL exhibited remarkably improved dispersion stability without the formation of molecular crystals or changes in particle sizes, even after they had been stored for a long time.

Based on these results, d-MEL-B could provide a unique moisturizing effect, by supplementing the lamellar structure in the stratum corneum i.e., the barrier function of skin, unlike conventional moisturizers that simply ride upon the stratum corneum, to simply suppress the evaporation of water. Figure 7 illustrates the moisturizing function of d-MEL-B in the stratum corneum.

MEls have excellent antimicrobial activities, particularly against gram-positive bacteria. d-MEL-B exhibits antimicrobial activity against the acne-inducing Propionibacterium acnes. Moreover, MEL-A and -B exhibit anti-inflammatory action via dose-dependent inhibition of the secretion of inflammatory mediators such as leukotriene C4 and cytokine TNF-α from mast cells. This means that the glycolipids may contribute to the moderation of allergic responses. These also support the practical performance of MEls as practical skin care ingredients.

6.2 Hair care properties of MEls

Ceramides are present not only in the stratum corneum, but also in hair cuticles, protecting and repairing the hair fibers affected by various environmental stresses. We therefore investigated the effects of MEls on the artificially damaged hair.

![Fig. 7 The presumed function of d-MEL-B in the stratum corneum.](image)
Based on observations with an electron microscope, damaged hair with raised cuticles was significantly restored after the application of MEL-A and d-MEL-B. The glycolipids were able to repair critical cracks on the surface of the damaged hair in a manner equivalent to natural ceramide (Fig. 8). The tensile strength of the damaged hair was also significantly increased by the treatment of MELs and ceramide, whereas the treatment with the control solution of lauryl glucoside yielded no results (Fig. 9a). The average friction coefficient of the damaged hair was maintained after the treatment with MELs and ceramide, producing smooth hair. In contrast, the coefficient was increased, in-

![Figure 8](image)

**Fig. 8** Electron microscopic photographs of the damaged hair surface. (Modified from Morita et al., 2010, ref. 46)

The damaged hair was treated with the solution of MEL-A, d-MEL-B, and ceramide, respectively.

![Figure 9](image)

**Fig. 9** Tensile strength and average friction coefficient of the damaged hair. (Modified from Morita et al., 2010, ref. 46)

(a) The damaged hair was treated with water, lauryl glucoside, MEL-A, d-MEL-B and ceramide, then subjected to the tensile strength measurement. Vertical bars show the standard error of the mean based on eight independent measurements. *p < 0.05, significantly different when compared with the control value, lauryl glucoside (Student’s test).

(b) The damaged hair was treated with water, lauryl glucoside, MEL-A, d-MEL-B and ceramide, then subjected to the average friction coefficient measurement. Vertical bars show the standard error of the mean based on three independent measurements. *p < 0.05, significantly different when compared with the control value, lauryl glucoside (Student’s test).
indicating coarse hair, under the application of lauryl glucoside (Fig. 9b).

Several repairing substances like phospholipid polymers and polyphenols are reported to protect hair from damage via the formation of lamellar layers on hair surfaces. MELs are thus likely to exhibit desirable hair care properties by quickly penetrating damaged hair and forming protective lamellar layers. This was partially confirmed by the synchrotron X-ray scattering analysis.

In addition to hair care functions, MELs have been shown to activate fibroblast and papilla cells, which induce follicle formation and hair growth via the transdifferentiation of adult epidermal cells. Treatment with MEL-A markedly increased the viability of both fibroblasts and papilla cells by more than 150%, compared with that of the control cells.

As mentioned above, MELs show unique moisturizing effects on human skin, implying that these glycolipids would be effective for repairing scalps that have been damaged by various external stresses; including irritation caused by shampoo and other cleaning agents. Accordingly, MELs will be useful ingredients in hair care products, not only restoring smoothness and flexibility to the damaged hair, but also protecting the scalp or activating cells.

7 Application of d-MEL-B to Cosmetic and Personal Care Formulations

As indicated above, d-MEL-B (Ceramela™, INCI Name: glycolipid) is now being commercially produced by TOYOBO™, and its distribution and use around the world are rapidly expanding. It is important to note that the safety of MELs, including d-MEL-B, has been officially certified as meeting the requirements of the Japanese Chemical Substances Control Act. Thus, MELs have recently become widely used not only in a variety of skin care and make up cosmetic products, but also in hair care and personal care products such as shampoos, conditioners, body soaps and creams. In this section, the application of MELs will be briefly described.

In makeup and other cosmetics, d-MEL-B has been applied as an ingredient in various foundation products, where glycolipids act as an effective moisturizer and a surface coating agent. The powders for makeup cosmetics, such as metal oxides are normally imbued with water repellent properties by surface coating agents, and thus have a hydrophobic surface that provides no moisturizing effects. Interestingly, iron oxide coated with d-MEL-B exhibits both water repellency and moisturizing properties at the same time.

Also, d-MEL-B has been used for W/O-type liquid foundation formulations. In these formulations, the powders coated with d-MEL-B show sufficient water repellency, smooth spreadability, creamy texture and good adhesion to the skin, compared with the powders coated with the typical coating agent of silicone. Accordingly, d-MEL-B will be a multifunctional makeup cosmetic material.

d-MEL-B has been applied as ingredients in various skin care products such as lotions, serums, creams, cleansing foams, etc. Among these skincare product formulations, the combination of d-MEL-B and sucrose ester is interesting because of its functional moisturizing effects. When a formulation containing specific ratios of d-MEL-B and sucrose lauric acid ester is applied to the skin, the vesicles derived from d-MEL-B transform into flat lamellar forms in the stratum corneum, depending on the water content, and restore the lamellar structures of intercellular lipids.

A premix product (Phytopresome™/MEL) that combines d-MEL-B, hydrogenated lecithin, and polyhydric alcohol, is now commercially available from Nippon fine chemical Co., Ltd. (Osaka, Japan). Generally, vesicle formation from hydrogenated lecithin requires stringent conditions, such as sonication, high-pressure emulsification, strong shearing force and a multi-step process. However, a multilamellar vesicle solution of 50–100 nm is easily produced from the premix by simply diluting it with water. The hydrogenated lecithin consists of long-chain fatty acids, whereas d-MEL-B contains various medium- and long-chain fatty acids. d-MEL-B is thus likely to assist in the formation of vesicles by mediating the interactions between the two lipid molecules.

d-MEL-B enhances the stability and moisture durability of microemulsions, so this glycolipid is useful for preparing microemulsions in combination with polyglycerol esters.

Another example of utilizing the interfacial properties of d-MEL-B is D-phase emulsification. An O/D gel emulsion is efficiently formed by mixing oils with the surfactant phase prepared from d-MEL-B and polyhydric alcohols. Furthermore, fine emulsion particles can be obtained by only diluting the O/D gel emulsion into aqueous base materials. The obtained emulsion particles can convey the feeling of their strong emollient effects, and this is a typical formulation that can take advantage of the unique characteristics of d-MEL-B.

Conventional moisturizers like polyhydric alcohols tend to feel less comfortable on the skin when formulated in high concentrations; leading to a lower sense of absorbency and increasing the sensation that the cosmetics feel sticky. Based on evaluation with a thermogravimetric analyzer and a compression tester, Yamamoto and Komatsu demonstrated that formulations containing MEL-B suppress the sticky sensation caused by polyhydric alcohols and improve the feeling of penetration. Thus, d-MEL-B can provide us with good feeling of penetration without stickiness, and a clear emollient sensation, via the formation of vesicle and/ or lamellar structures.
8 Conclusions and Perspective

Over the past decade, the research and development of biosurfactants has undoubtedly hurried into a new era. Glycolipid biosurfactants provide more versatile performance than those of conventional chemical surfactants. In addition, recent advances in biotechnology have enabled us to drastically enhance the production of biosurfactants and control their chemical structures.

Among known biosurfactants, MELs would be the most practical bio-based alternative surfactants to their chemical counterparts, owing to their unique interfacial and biological properties. As outlined in this review, d-MEL-B is useful for skin and hair care as a highly functional moisturizer, enabling us to formulate a wide range of applications in cosmetic and personal care products. We hope that the benefits of this yeast glycolipid will be more widely adopted across the world.

With regard to MELs, various programs are now being put into action in all over the world, that aim not only to reduce production costs through genetic engineering, but also to exploit novel applications; particularly as biocompatible fertilizers or pesticides in the agrochemical field. Therefore, MELs will become the flagship of bio-based materials, leading to a carbon neutral and sustainable society in the future.

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