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*Original Research Article*

# Determination of Optimal Application of Biosurfactant by using Linear Programming (LP) Model

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**Abstract:** Biosurfactant or amphiphilic compounds are a diverse group of molecules that contains a hydrophobic part and a hydrophilic part, division at liquid/solid, liquid/liquid, or liquid/gas interfaces. The characteristics of these biomolecules play a significant part in the formation of foam, emulsification, pharmaceutical, detergence, and biopesticide that can be admissible aspects in a few sectors. Currently, industrial biosurfactant production is still lacking, and the challenges presented in this regard are due to the high cost of microbial cultivation to biosurfactant recovery. Biosurfactants have already been applied individually or as mixed with biosurfactants in industries as commercially available using microbes and synthesis processes. In this study, linear mathematical modelling using Generalized Algebraic Modelling System (GAMS) software is being used to identify the worthwhile biosurfactant product and the pathways of biosurfactant that will provide the most significant profit to the biosurfactant application. The model consisted of the linear programming (LP) model, which utilized a diverse equation to determine the industrial application of biosurfactants that can provide profitable income to the country.

**Keywords:** biosurfactant; profitability; mathematical model; Generalized Algebraic Modelling System (GAMS)

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## 1. Introduction

Hydrophilic and hydrophobic moieties with the ability to reduce the interfacial and surface tension of molecules make the surfactant is unique chemicals. With these properties,

surfactants can be applied in environmental remediation, pharmaceuticals industries, dispersing and detergency agents, foaming, emulsification, and lubrication (Thakur *et al.*, 2021). Most surfactants used in industries are synthetically made from petrochemical-based non-biodegradable and toxic. The negative effect of synthetic surfactants on the environment made biosurfactants be introduced by researchers with good surface activity, biodegradability, and low toxicity (Johnson *et al.*, 2021).

Biosurfactants are amphiphilic compounds formed by microorganisms indicating surface and emulsifying activities, such as yeasts, molds, and bacteria (Akbari *et al.*, 2018). Hydrophobic and hydrophilic part in biosurfactants enables these molecules the potential to accumulate several polarities such as liquid/solid, liquid/liquid, or liquid/air interface between interfaces (De Almeida *et al.*, 2016). These biosurfactants encompass lipopeptides, glycolipids, neutral lipids, phospholipids, and fatty acids (Saharan *et al.*, 2012). Biosurfactants are extracellular microbial surfactants that are amphipathic and have high emulsifying activity and surface activity (Adetunji & Olaniran, 2021). Biosurfactants have several advantages compared to synthetic surfactants, such as being produced from renewable substrates, workable at extreme temperature, pH and salinity, high stability, low toxicity, and biodegradability (Paulino *et al.*, 2016). The outstanding features of biosurfactants over chemical surfactants as green chemicals can be applied in medical applications, enhanced oil recovery, stabilizer and emulsifier in the food processing industry, antimicrobial properties, and environmental factors bioremediation (Banat *et al.*, 2021). Biosurfactants have many applications and advantages, making them a promising alternative to synthetic surfactants. However, biosurfactants face some challenges related to high production costs, expensive raw materials, optimization difficulties, low yields, and inefficient purification processes. These factors affect biosurfactants products in a market predominantly dominated by synthetic surfactants (Vieira *et al.*, 2021). The global turnover of surfactants was US$ 31 Billion in 2016, and it is predicted to increase by US$ 40 Billion in 2024 (Jiménez-Peñalver *et al.*, 2019). In the biosurfactant industry, 344 thousand tons were globally sold in 2013, and in 2020 it reached 461 thousand tons. Moreover, in 2016 the international market of biosurfactants was reached US$ 3.99 billion and is expected to increase to US$ 5.52 billion by 2022 (Wang *et al.*, 2020).

The General Algebraic Modelling System (GAMS) is used as the research tool. This research mainly deals with optimization problems. Thus, GAMS is highly suitable as GAMS has incorporated ideas drawn from relational database theory and mathematical programming and has attempted to merge these ideas to suit the needs of strategic modelers. It is specifically designed to model linear, nonlinear, and mixed-integer optimization problems, vast and

complex ones. Over the years, GAMS has been widely used to solve optimization problems worldwide. Thus, it is proven helpful for handling large and complex problems that may require many revisions to establish an accurate model.

The main objective of this research is to develop a linear mathematical model that can choose the maximum profit in the most profitable biosurfactant application. In this research, a mixed-integer linear programming (MILP) model is formulated to maximize the profitable biosurfactant production while choosing the best types of biosurfactant application. General Algebraic Modelling System (GAMS) as an optimization tool was used in this study to develop the model.

## 2. Materials and Methods

### *2.1 The Case Study and Input Data*

The case study in this work is chosen based on the biosurfactant types, price per liter, application in the product, and customer demand. Biosurfactants consist of a variety of classes with a distinct production of microorganisms. This research selects four different kinds of biosurfactants. The price/liter of the selected biosurfactant is obtained based on the latest market price. Biosurfactant price per liter is shown in Table 1 below.

**Table 1.** Price for biosurfactants per/liter.

| Biosurfactant | Price/Liter (RM) | References |
|---|---|---|
| Rhamnolipids | 4150 | (Qingdao Ocean Import and Export Co., 2021) |
| Sophorolipids | 83 | (Qingdao Fraken International Trading Co., 2021) |
| Lipopeptides | 40 | (Shondong Zhishang Chemicals, 2021) |
| Surfactin | 18 | (Pangoos Biotech Haboi, 2021) |

In the global market for surfactants, cleaning products, emulsifiers in the industry of food, and biopesticides in the industry of pesticides are the most commonly used applications for surfactants in a product (Ceresana, 2021). Typically, the substance is used in everyday items, such as shampoos, detergents, bakeries, and agricultural products. In order to comply with the most profitable application for biosurfactants, the GAMS application was utilized to code the data for biosurfactant applications. The global demand for cleaning, emulsifiers, and biopesticides for the world population is shown in Table 2 below:

**Table 2.** Customer demand for biosurfactant based on Malaysia population.

| Application | Market Demand (RM) | References |
|---|---|---|
| Cleaning | 6.3 billion | (Businesswire, 2019) |
| Emulsifiers | 2.52 billion | (Persistence Market research, 2019) |
| Biopesticides | 2.68 billion | (Cision PR Newswire, 2019) |

## 2.2 *Superstructure Development*

**Error! Reference source not found.** presents the simplified superstructure of the biosurfactant types, application, and market value, as described in the case study. The model comprises three principal sets: set i- types of biosurfactant, set k-global biosurfactant application, and set m-potential market value. There are four types of biosurfactants: sophorolipid, rhamnolipid, lipopeptides, and surfactin that can be used by several applications that have market demand globally.

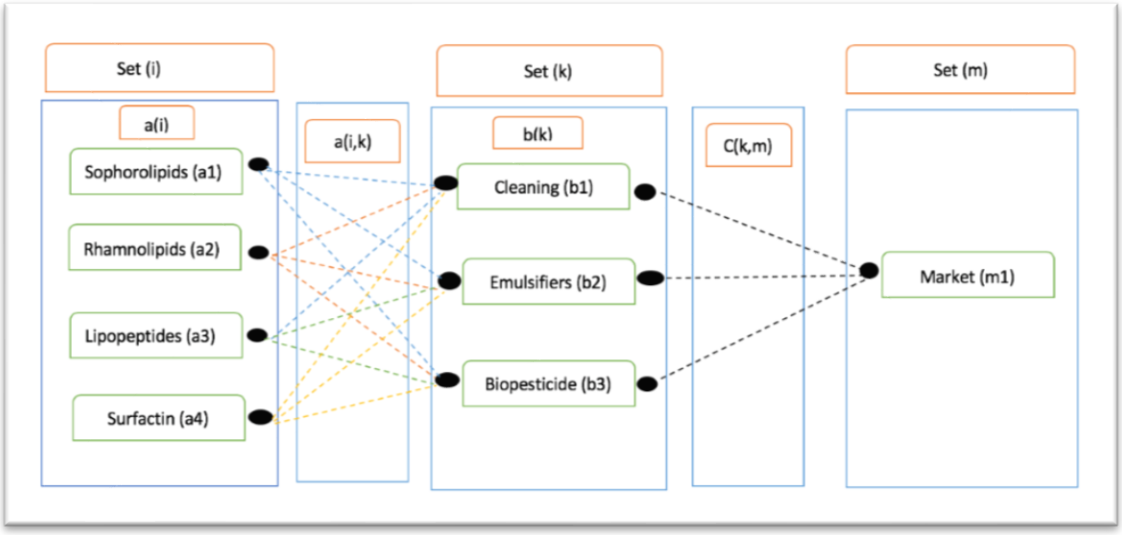


**Figure 1.** Simplified structure of Biosurfactant.

## 2.3 *Model Formulation*

This objective function describes the model that was developed for this case study. The objective function for this study is to maximize the overall profit of biosurfactant application, represented by variable MAIN PROFIT, as shown in Equation 1. The variable km is the market price for the application, and Ckm is the market demand for the product. The variable COST(i) is the price for biosurfactants. The variables are calculated when the summation of the product obtained is multiplied by the price per liter for biosurfactants.

$$\text{MAIN PROFIT} = \left(\sum km\ \text{Ckm} \times \text{PRICE}(m)\right) - \left(\sum ik\ \text{a}ik \times \text{COST}(i)\right) \quad (1)$$

In this model, the material balance constraints mainly consist of price for biosurfactants, application of biosurfactants in a product, and market demand for biosurfactants, which only focus on the most profitable biosurfactants application. Equation 2 is developed to limit biosurfactants that focus only on the most valuable biosurfactant used in the industry. Equation 3 shows the type of application where the biosurfactant is used in

the product. Equation 4 is when the application of biosurfactant in a product is met by the market demand for each type of application and product. Equation 5 is considered to calculate the total profit, consisting of biosurfactants market price, application, and market demand.

$$\text{RCS (i)} \geq \sum k \times \text{a (I, k)} \times \nabla i \quad \textbf{(2)}$$

$$bk = \Sigma i \, aik \, \nabla k \quad (3)$$

$$bk \times Conkm = Ckm \quad (4)$$

$$Ckm \geq demand\ (km) \nabla k \nabla m \quad (5)$$

### *2.4 Coded into General Algebraic Modelling System*

Process optimization is a decision-making tool to identify the solution that achieves the best value of performance criterion in a problem. In this stage, the developed mathematical formula is coded into Generalized Algebraic Modelling System (GAMS) as an optimization tool. GAMS is commercial software for modelling linear, nonlinear, and mixed-integer optimization software. The incorporated model based on this study is then solved by the GAMS solver to obtain optimal network flow.

## 3. Results

### *3.1 Case Study and Input Data*

The case study of this research is selected by the numerous uses of the biosurfactant types, price of biosurfactant per liter, application of biosurfactant in a product, and market demand for biosurfactant. There are various biosurfactant classes with different microorganism production. This study chooses four different types of biosurfactants. Price/Liter for the selected biosurfactants was taken from the current market price. The price for biosurfactants per liter is shown in Table 3. The highest price is RM 4150/litre for rhamnolipids, followed by sophorolipids RM 83/litter, lipopeptides RM 40/litter, and surfactin RM18/litter. The difference in price for commercial biosurfactants is because each type of biosurfactant has different demand from industry and cost to produce the biosurfactants themselves. For example, the market demand for rhamnolipid biosurfactants is increasing globally because of their ability to prevent & control plant pathogens without causing toxicity to human health (Inc., 2019).

**Table 3.** Price for biosurfactants per /liter.

| Biosurfactant | Price/Liter | References |
|---|---|---|
| Sophorolipids | RM 83 | Qingdao Fraken International Trading Co., Ltd. |
| Rhamnolipids | RM 4150 | Qingdao Ocean Import and Export Co., Ltd. |
| Surfactin | RM 18 | Pangoos Biotech Haboi Co., Ltd. |
| Lipopeptides | RM 40 | Shondong Zhishang Chemical Co., Ltd. |

In the global surfactant market, the most applications for surfactants in a product are cleaning, emulsifiers in the food industry, and biopesticides in the pesticides industry. The product is usually used in daily products such as shampoo, detergents, bakery products, and agricultural use. The data for the application of biosurfactants was coded into GAMS application to meet the best profitable application for biosurfactants. The data for biosurfactant application was obtained as in Table 4.

**Table 4.** Application for biosurfactant in a product.

| Application | References |
|---|---|
| Cleaning | On surfactants and formulation (face wash, shampoo, and shower gels |
| Emulsifier | Surfactants: Basics and versatility in food industries |
| Biopesticides | Pesticides in the industry |

Table 5 below shows the market demand for biosurfactants based on the Malaysian population. The total global market for cleaning, emulsifiers, and biopesticides for the global population time Malaysian population to meet the number of biosurfactants that have been used in Malaysia. The data for market demand for Malaysia's population is obtained below.

**Table 5.** Market demand for biosurfactant based on Malaysia population.

| Application | Market Demand (RM) | References |
|---|---|---|
| Cleaning | 6.3 Billion | Global household cleaning products market 2018-2022 |
| Emulsifiers | 2.52 Billion | Global Market Study on Emulsifiers: Food & Beverage Application to witness significant growth during 2017-2024 |
| Biopesticides | 2.68 Billion | Biopesticides Market by Type (Bioinsecticides, Bio fungicides, and Bio nematicides), source (Microbials, Plant Extracts, and Beneficial insects), Mode of Application, |

Formulation, crop application, and region-global forecast to 2023

Based on Figure , the model mainly selected Sophorolipids, Lipopeptides, and Surfactin biosurfactants because the price for this type of biosurfactants is lower than Rhamnolipids biosurfactants. All biosurfactants can be applied for cleaning, Emulsifiers, and Biopesticides product, but the model will only select the most valuable cost production for biosurfactants to meet the objective function. Based on Figure 2, the sophorolipids biosurfactant is only suitable for emulsifiers because of the high demand. Lipopeptides biosurfactant chooses cleaning and biopesticides in terms of price for biosurfactant and market demand, and surfactin also chooses cleaning and biopesticides because this type of biosurfactant meets the model need. From Figure **,** the total maximum profit that can be achieved by biosurfactant application through cleaning (RM 12.00 Billion), emulsifiers (RM 2.52 Billion) dan biopesticides (RM 2.68 Billion) application in the market is around RM 18 Billion. The type of biosurfactant that will give maximum profit for the industries is Lipopeptides (RM 1.00 Billion) and Sophorolipid (RM 1.00 Billion) biosurfactant. Cleaning product shows the highest profit, which is RM 12.00 Billion, followed by biopesticides products which are RM 2.68 Billion, and emulsifier, which are RM 2.52 Billion, respectively. This mathematical model shows that market demand for cleaning products is higher as household products are the most significant industry that uses surfactants.

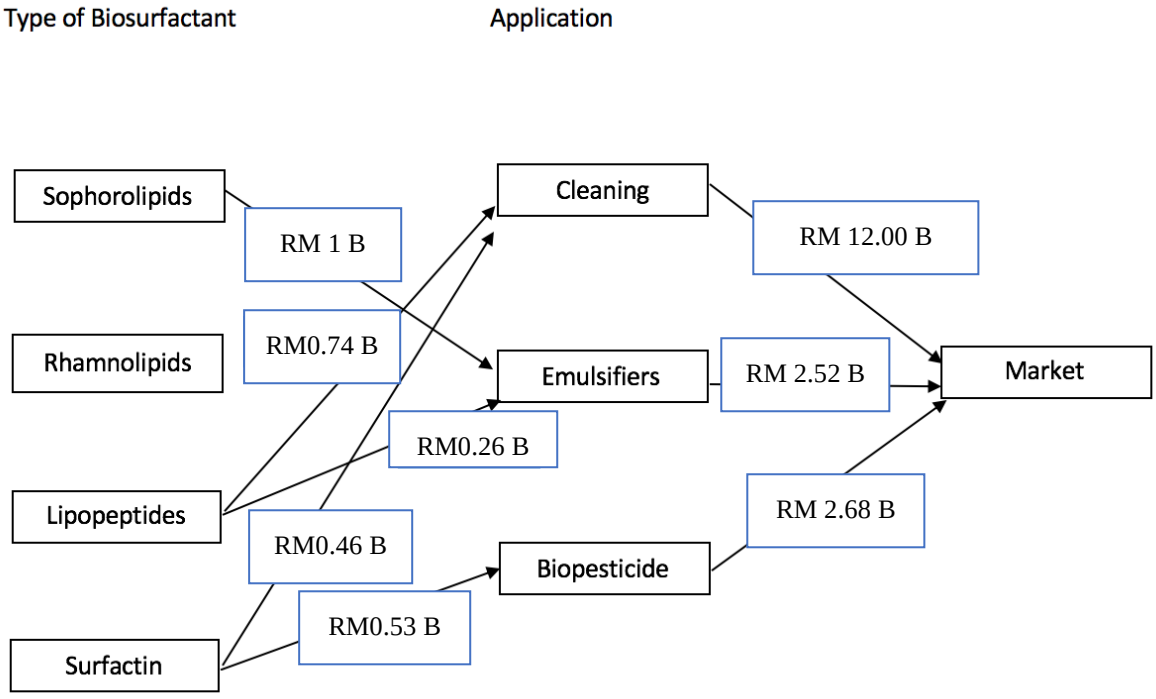


**Figure 2.** Results obtained from GAMS software

## 5. Conclusions

In conclusion, it has been estimated that lipopeptides and sophorolipids biosurfactants are the most profitable biosurfactant compared to others in price, application, and market demand in the industries. Lipopeptides and sophorolipid biosurfactants need to be selected as a biosurfactant type for product production as the price of this biosurfactant are cheap and more economical. This finding reported by using GAMS in this study has provided preliminary guidance to know the best selection of types of biosurfactant production and application before moving into an industrial scale.

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