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E-BOOK OF EXTENDED ABSTRACTS

ENHANCING *TETRASPORA* SP. CULTIVATION: A GOMPERTZ-OPTIMISED GROWTH FRAMEWORK FOR BIOFUEL APPLICATIONS

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ABSTRACT

Microalgae especially *Tetraspora* sp. are sustainable alternatives to fossil fuels that require accurate growth models to improve production efficiency. Therefore, this study utilized Logistic Sigmoidal and Gompertz models to determine the growth rate and population of Tetraspora sp. and evaluated both performances using root mean square (RMSE), coefficient of determination (R^2) and percentage error. The analysis indicates that the Gompertz model as the optimal predictive tool due to its conservative and accurate growth rate (0.025 day^{-1}). It also had a lower RMSE (0.1537), higher R^2 (0.9859), and a decreased error of 12.28%. This study confirms the Gompertz model as the most reliable predictor of *Tetraspora* sp. growth, which makes it a crucial resource for maximising sustainable biofuel production and contributing to SDG 7 (affordable and clean energy).

Keywords: Microalgae, Tetraspora sp., Logistic Sigmoidal, Gompertz, Growth Rate

INTRODUCTION

Nowadays, fossil fuels are being used too much, which pollutes the air and causes global warming. To address this issue, green algae generation of H_2 has recently gained attention as a sustainable alternative energy source. Currently, microalgae biotechnology is contributing to the global bioeconomy by providing valuable biomass for applications like medications, cosmetics, and food (Fernández *et al.*, 2021). Furthermore, hydrogen gas is regarded as the best fuel for reducing air pollution and halting global warming (Melis & Happe, 2001), and improvements in growth, culture techniques, and genetic engineering could further increase algae's potential as a source of bio-products (Ramlee *et al.*, 2021). Therefore, adopting mathematical models like sigmoidal growth curve has been studied and employed for modelling biological growth.

The predominant classical sigmoidal growth models used in scientific studies are the Logistic, Gompertz, and Richards models. These models are extremely useful because can accurately represent natural events with a sigmoidal growth pattern, especially in biology, chemistry and medicine field. Their practical utility is demonstrated by Abd Al-Rahman *et al.* (2023), who showed that sigmoidal growth curves can accurately model experimental growth data following this pattern over time. This situation is also supported by Hanief *et al.* (2020), who studied the growth kinetics of the microalga *Botryococcus braunii* for biofuel production using the Logistic and Gompertz growth models. Therefore, this study focuses on *Tetraspora* sp. which ideal for biofuel research due to it grows quickly, thrives in diverse conditions (Chowdury *et al.*, 2020), and even helps clean wastewater and capture carbon (Mahmood *et al.*, 2023).

The objectives of this study: (1) to determine the growth rate and population of *Tetraspora* sp. using Logistic Sigmoidal and Gompertz growth model, and (2) to evaluate the performance of the Logistic Sigmoidal and Gompertz models by comparing their fit to *Tetraspora* sp. population growth data, using error measures such as Root Mean Square Error (RMSE), R^2 and mean percentage error. This study utilised two sigmoidal growth models: Logistic Sigmoidal in Eq. 1 and Gompertz in Eq. 2.

$$P(t) = \frac{K}{1 + \left(\frac{K - P_0}{P_0}\right) e^{-kt}} \tag{1}$$

$$P(t) = Ke^{-ln ln\left(\frac{K}{P_0}\right)} e^{-kt} \tag{2}$$

From the general model in Eq. 1 and Eq. 2, the growth rate, k of microalgae *Tetraspora sp.* for Logistic Sigmoidal growth model and Gompertz model can be computed as Eq. 3 and Eq. 4, respectively.

$$k_{LS} = \frac{- ln\ ln\left(\frac{P_0(K - P_t)}{P_t(K - P_0)}\right)}{t} \tag{3}$$

$$k_G = -\frac{ln\ ln\left(\frac{- ln\ ln\left(\frac{P_t}{K}\right)}{ln\ ln\left(\frac{K}{P_0}\right)}\right)}{t} \tag{4}$$

where k_{LS} = growth rate of Logistic Sigmoidal model, k_G = growth rate of Gompertz model, P_0 = the initial population, P_t = the number of populations at time, t and K = carrying capacity. The calculation for population, P_t of microalgae *Tetraspora sp.* can be computed using Logistic Sigmoidal; seen Eq. 5 and Gompertz; seen Eq. 6.

$$P_t = \frac{K}{1 + \left(\frac{(K - P_t)}{P_t}\right) e^{-kt}} \tag{5}$$

$$P_t = Ke^{-ln ln\left(\frac{K}{P_0}\right)e^{-kt}} \tag{6}$$

where P_t = the number of populations at time, t, K = carrying capacity, k = growth rate and P_0 = the initial population. The performance of the Logistic Sigmoidal and Gompertz models were compared using three error measures: Root Mean Square Error (RMSE) (Akin *et al.*, 2020), coefficient of determination (R^2) (Sariyel *et al.*, 2017) and percentage error. The lowest RMSE, highest R^2 and lowest percentage error was selected as the better model when comparing among models.

RESULTS AND DISCUSSION

The microalgae *Tetraspora* sp. data was collected in triplicate over a period of 20 days by Mustaffa et al. (2019). Figure 1 presents the growth curve of *Tetraspora* sp. displays the typical three different sigmoidal growth patterns: lag, exponential, and stationary. As shown in Figure 1, a lag phase (Days 1-5) with a concentration range of 0.80 to 3.3 mg/ml, followed by an exponential growth phase (Days 6-17) with a concentration range of 3.3 to 29.4 mg/ml, and a stationary phase with 35 mg/ml.

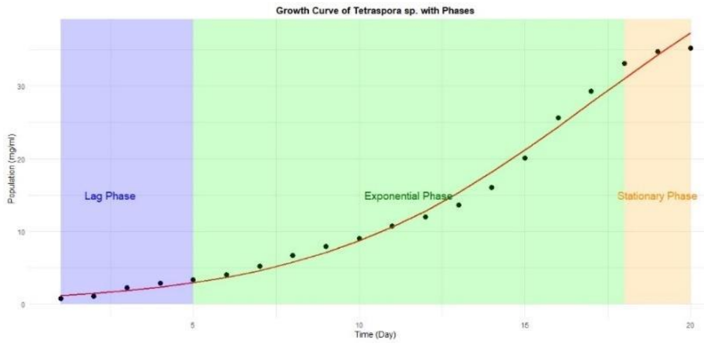

Figure 1: Growth curve of Tetraspora sp. data

(Source: Author's visualization using R statistical software)

Growth rate

The 20 days of the *Tetraspora* sp. were analysed to determine the growth rate, k and population growth using Logistic Sigmoidal and Gompertz growth model by assuming a carrying capacity, K of 36. Table 1 illustrates the comparison of the daily growth rates (k) of *Tetraspora* sp. between Logistic Sigmoidal model (k_{LS}) and Gompertz model (k_G). Both models' growth rate patterns reveal low initial rates from days 1 to 5. As seen in Table 1, the growth rate on day 4 for Gompertz model $(k_G = 0.023)$, which yielded a more conservative value of 0.023, reflecting its sensitivity to initial growth constraints. From Table 1, the result showed that both the Logistic and Gompertz models have an inflection point within day 18, where growth rate reaches maximum. After day 18, the population is approaching its carrying capacity. The Logistic Sigmoidal model produced an average growth rate of 0.051 day^{-1}, whereas the Gompertz model resulted in a lower average of 0.025 day^{-1}. This clarify that the Gompertz model yields a more conservative estimate.

Table 1: A Comparison of the growth rate from the Logistic Sigmoidal model and Gompertz model for Tetraspora sp.

t	P_t	k_{LS}	k_G	t	P_t	k_{LS}	k_G
1	0.80328	0	0	11	10.73403	0.02182	0.01223
2	1.12666	0.17377	0.04659	12	11.98435	0.01341	0.00796
3	2.26643	0.24406	0.07512	13	13.61269	0.01520	0.00947
4	2.88778	0.06522	0.02292	14	16.03581	0.01988	0.01318
5	3.32171	0.03064	0.01142	15	20.10697	0.03029	0.02189
6	4.02056	0.03543	0.01392	16	25.64382	0.04197	0.03379
7	5.23530	0.04325	0.01833	17	29.35538	0.03406	0.02990
8	6.68575	0.03661	0.01695	18	33.12094	0.05317	0.04974
9	7.94051	0.02397	0.01197	19	34.76580	0.04713	0.04584
10	9.01739	0.01663	0.00879	20	35.23086	0.02431	0.02398

Note: t=day, k_{LS}= growth rate for Logistic Sigmoidal model, k_G= growth rate for Gompertz model

Population Growth

Figure 2 (left) shows that the Logistic Sigmoidal model provided a good fit to the actual *Tetraspora* sp. data during the exponential growth phase but slightly underestimated the population in the stationary phase. In contrast, the Gompertz model in Figure 2 (middle) demonstrated a remarkably precise fit across all growth phases. The comparative analysis of all three curves in Figure 2 (right) confirms that the Gompertz model is the superior model of *Tetraspora* sp. population growth over the 20-days period.

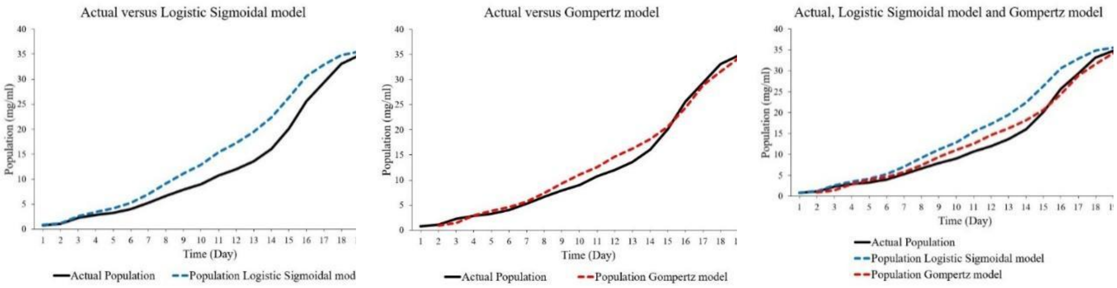

Figure 2: Growth curve of actual population versus Logistic Sigmoidal model (left), actual population versus Gompertz model (middle) and actual population versus Logistic Sigmoidal model and Gompertz model (right)

Model Performance

Table 2 presents the model performance for *Tetraspora* sp. population growth between Logistic Sigmoidal and Gompertz model. The Gompertz model produced a significantly reduced RMSE value of 0.1537, outperforming the Logistic model (RMSE=0.2933). The R^2 values for the Logistic Sigmoidal and Gompertz models shows 0.9102 and 0.9859, respectively. This indicates that the Gompertz model explains almost 98% of the variation in the data, which is much higher than the Logistic model's 91%. The Gompertz model has a percentage error of 12.28%, which is less than the Logistic Sigmoidal model's percentage error of 25.19%. Table 2 indicates that the Gompertz growth model is the best accurate model for predicting the population of the microalgae *Tetraspora* sp.

Table 2: Comparison of model performance for *Tetraspora* sp. population growth: Logistic Sigmoidal vs. Gompertz model

Models	**RMSE**	R^2	**Percentage error (%)**
Logistic Sigmoidal	0.2933	0.9102	25.19
Gompertz	0.1537	0.9859	12.28

Note: Author's calculation using R statistical software

CONCLUSION

This study aimed to determine the growth rate and population of *Tetraspora* sp. using Logistic Sigmoidal and Gompertz growth model, and to evaluate the performance of both models by comparing their fit to *Tetraspora* sp. population growth data, using error measures. The following conclusions were obtained. 1) The Gompertz model provided a more accurate average growth rate estimate (0.025 day^{-1}) compared to the Logistic Sigmoidal model (0.051 day^{-1}). 2) The Gompertz model demonstrated superiority with lower Root Mean Square Error (RMSE: 0.1537), higher coefficient of determination (R^2: 0.9859), and reduced percentage error (12.28%). As a consequence, the Gompertz model is proposed for future biotechnology and aquaculture study, whereas other sigmoidal models, such as Richards and Baranyi require further exploration.

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