The Modified Gompertz Model Demonstrates a Variable Growth Rate between Two Centella asiatica Phenotypes

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INTRODUCTION
There are roughly forty-five species of Centella which belongs to the plant family Apiaceae. The most popular species is C. asiatica. This small creeping perennial and slender plant is an umbellifer that exhibits weak aromaticity and has numerous common names that include Pegaga, Indian Pennywort and Gotu Kota [1]. It is a central herb in Ayurvedic medicine and has been used to promote collagen synthesis, fibroblast proliferation and alleviating symptoms of anxiety [2]. In a recent publication on the terpenoids profile from two C. asiatica phenotypes, it was observed that the two phenotypes exhibited vastly different growth rates. Both exhibited a typical sigmoidal growth profile. Without resorting to a proper mathematical modelling of the growth curve of the plants, it would be difficult to compare efficiency without numerical analysis [2].

The sigmoidal profile harbors unique stages in which the specific growth rate has a value of zero in the beginning, producing a lag time ($\lambda$) followed by an acceleration to a maximal value. Eventually, the growth rate approaches zero where an asymptote ($A$) is reached. In other instances, the growth rate can be negative indicating a death phase [3]. A valuable parameter of the growth curve is $\mu_{max}$ (or $\mu_0$) where this value can be computed to model the effects of product, pH, temperature, substrate on growth rate of the organism. These models are called secondary models [4]. Conversion of the exponential phase to a linearized form is the most often used method to get this value but a better often neglected method is to model all of the set of data with nonlinear regression growth model. This modelling exercise can yield important growth constants such as $\mu_{max}$, $\lambda$, and $A$ from the model [5,6]. One of the most successful models used to model plant, callus and microorganism’s growth is the modified Gompertz model, which was was named in 1844 by Pierre François Verhulstis.
Nevertheless, initially, the model cannot explain the lag phase. It was then altered to include the lag phase [3,7,8].

It is anticipated that modelling of the growth curves will yield important growth parameters that can be used for further optimisation works for cells such as determination of specific growth rate, lag period and maximum plant biomass production.

MATERIALS AND METHODS

Data acquisition
Graphical data of a published work [2] from Figure 2 were electronically processed using WebPlotDigitizer 2.5 [9] which helps to digitize scanned plots into table of data with good precision and reliability [10,11].

Mathematical modelling
The modified Gompertz model [3] is as follows:

\[ y = A \exp\left\{-\exp\left[\frac{\mu_e e^{(\lambda - t)}+1}{\lambda}\right]\right\} \]  

(Eqn. 1)

where \( A \) = growth at lower asymptote; \( \mu_e \) = maximum specific growth rate, \( \lambda \) = lag time, \( e \) = exponent (2.718281828) and \( t \) = sampling time.

The growth data was first transformed to logarithmic values and fitted using a Levenberg–Marquardt algorithm (LMA) nonlinear regression analysis using the CurveExpert Professional software (Version 1.6). The algorithm minimizes the sum of the squares of the differences between the measured and predicted values [12]. A modified form of the coefficient of determination, \( adjR^2 \), which is an adjusted coefficient of determination was utilized to indicate closeness of data to experimental model. The formulas are as follows, where the Residual Mean Square is RMS and \( s^2 \) is the total variance of the y-variable [12].

\[ Adjusted \left( R^2 \right) = 1 - \frac{\text{RMS}}{s^2} \]  

(Eqn. 2)

\[ Adjusted \left( R^2 \right) = 1 - \frac{\left(1 - R^2\right)(n-1)}{(n-p-1)} \]  

(Eqn. 3)

RESULTS AND DISCUSSION

The plant growth from both phenotypes was successfully modelled according to the modified Gompertz model as judged visibly (Fig. 1). The shape was sigmoidal with substantially longer lag phase observed for \( C. asiatica \) Type-1 compared to \( C. asiatica \) Type-2. The nonlinear regression modified Gompertz model was applied to the experimental data and the results showed a close agreement between the experimental and predicted data (Fig. 2). The coefficient of determination showed good agreement between experimental and predicted data with values of 0.99 for A and 0.97 for B, indicating a weaker agreement for B. Parameters obtained from the fitting exercise were maximum cell growth rate (\( \mu_e \)), lag time (\( \lambda \)) and maximal cell production (\( Y_{\max} \)). The results showed that \( C. asiatica \) Type-1 had a higher growth rate; about double, and shorter lag phase than \( C. asiatica \) Type-2 (Table 1).

Literature search showed that many plant or plant callus growths data from various experiments are presented as they are without resorting to the use of existing primary growth models such as modified Gompertz [13–15,15–17], Von Bertalanffy [18,19], Baranyi-Roberts [10,20] and Logistic, Richards, Schnute [3,21], Buchanan three-phase [22–28] and more recently the Huang model [29]. Of all the models, the modified Gompertz model is the simplest (having three parameters) making it more parsimoniously useful as evident on the significant publications using this model for modelling plant or callus growths [30–40].

CONCLUSION

The modelling exercise in this work has successfully obtained important parameters from the modified Gompertz model and has shown fundamental differences especially in growth rate and lag period for two \( C. asiatic \) phenotypes. Parameters obtained from this work is useful for further analysis or secondary modelling or further improvement of growth process for secondary product production. The modified Gompertz model...
model showed good agreement with experimental data indicating good fit.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

REFERENCES