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

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ABSTRACT

Centella asiatica, a weakly aromatic plant that flourishes in wet tropical and sub-tropical areas as a medicinal species since ancient times. It contained important terpenoids that impart important medicinal values. Currently, studies on the terpenoid content of various *Centella asiatica* phenotypes have shown not only variable content but variable growth rates of different phenotypes that can affect future selection of phenotypes. The use of mathematical growth modelling can reveal important growth constants and discriminate between faster and slower growth phenotypes. Two *Centella asiatica* phenotypes from South Africa is modelled using the modified Gompertz model and the results showed that the *C. asiatica* Type-1 exhibited a faster growth rates and a shorter lag period at 0.152 day^{-1} and 2.313 day than another phenotype; *C. asiatica* Type 2 with a growth rate and a lag period of 0.067 day^{-1} and 3.363 day, respectively. The data indicates that different phenotypes of *C. asiatica* can have different growth rates and lag period and this can be important for selection of phenotypes to be used as the best bioactive peptides producer.

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 (λ) 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 μ_{max} (or μ_m) 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 μ_{max}, λ, 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';

$$y = A\exp\left\{-\exp\left[\frac{\mu_m e}{A}(\lambda - t) + 1\right]\right\}$$ **(Eqn. 1)**

where A=growth at lower asymptote; μ_m= maximum specific growth rate, λ=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_y^2 is the total variance of the y-variable [12].

$$Adjusted\left(R^2\right) = 1 - \frac{RMS}{s_Y^2}$$ **(Eqn. 2)**

$$Adjusted\left(R^2\right) = 1 - \frac{\left(1 - R^2\right)\left(n - 1\right)}{\left(n - p - 1\right)}$$ **(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 (μ_m), lag time (λ) 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].

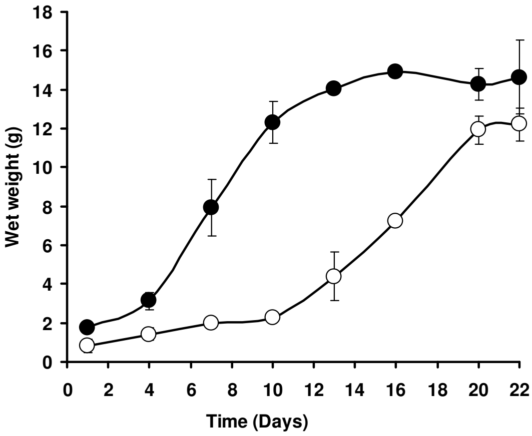

Fig. 1. The redrawn growth curves (wet weight) of *C. asiatica* Type-1 (●) and Type-2 (○) in liquid medium.

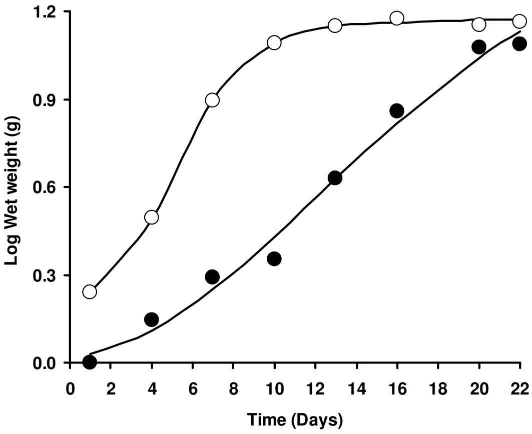

Fig. 2. The growth curves (wet weight) of *C. asiatica* Type-1 (●) and Type-2 (○) in liquid medium modelled according to the modified Gompertz model.

Table 1. Fitted growth parameters according to the modified Gompertz model.

	Fitted values (± standard error)	
Parameters	*C. asiatica* type-1	*C. asiatica* type-2
Y_0	0.234 ± 0.011	-0.014 ± 0.125
Lag (Days)	2.313 ± 0.132	3.363 ± 2.891
Y_{max}	1.167 ± 0.005	1.518 ± 0.403
μ_{max}	0.152 ± 0.005	0.067 ± 0.01

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 showed good agreement with experimental data indicating good fit.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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