Brassinosteroid synthesis as context sensitive language acceptance problem

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Abstract

A biochemical system like brassinosteroid biosynthesis is not just an assembly of enzymes. In addition to the listing of the individual components, it is essential to understand how individual components dynamically interact during the biosynthesis process. In this context the concept of computational complexity is applied to brassinosteroid biosynthesis. It is shown that brassinosteroid biosynthesis system accepts context sensitive languages and models of computation of this system are universal.

Keywords: Brassinosteroid, language, automaton, context, complexity

Introduction

Brassinosteroids are a group of plant steroid hormones that are involved in plant growth and development. About fifty naturally occurring brassinosteroids have been identified in diverse plant species. C28 brassinosteroids are most commonly occurring and most abundant. Among these brassinolide is most active. Plants have many pathways for biosynthesis of brassinolides (BL), which are derived from the steroid biosynthetic pathway. At least four pathways are involved in the biosynthesis of castasterone (CS), and CS is further metabolized to BL by lactonization of the B ring.C6 oxidation and the late-C6 oxidation pathways, two additional pathways from campestanol to castasterone (CS) are found in many plants. Analysis of a brassinosteroid-deficient mutant of Arabidopsis thaliana resulted in discovery of another branching pathway, the early C-22 oxidation pathway.. Functional analysis of cytochrome P450 monooxygenases responsible for brassinosteroid biosynthesis revealed the existence of a new pathway from campesterol to 6-deoxotyphasterol (http://www.genome.jp/kegg/)

Results and Conclusions

Brassinosteroid Biosynthesis behaves as automaton which accepts formal languages

Based on the biochemical reactions taking place during brassinosteroid biosynthesis, it can be expressed as a context sensitive language acceptance problem. It is easy to conceptualize that the process of brassinosteroid biosynthesis behaves like an automaton that computes (or accepts) a formal language. The most general definition of an automaton is a system where information, materials and energy, are transmitted, transformed and used for performing specific functions. The main characteristics of automaton are

Input: The Input values I_1, $I_{2,} \ldots I_p$, each can take a finite number of fixed values from the input alphabet , at each of the discrete instants of time t_1, $t_2, \ldots t_m$ are applied to the input side .

Output $O_{1,}$ $O_{2,\ldots,}O_q$, each can take a finite number of fixed values from an output O, are the outputs of the model.

States: At any point of time the automaton can be in one of the states $q_{1,}$ $q_{2,}$ q_n

State relation: The present state and the present input determine the next state of an automaton at any instant of time.

Output relation: The output is related to either both the input and the state or to state only.

These parameters for brassinosteroid biosynthesis are described later in the paper.

The chemical reactions in the brassinosteroid biosynthetic pathway can be envisaged as performing a transformation on words of a context sensitive language (transformation on the reactants to produce products).Similar formalism has been used to describe process of biological photosynthesis by Murphy et al. 2005[1]and the process of gluconeogenesis by the author of this paper [2].

Computation in Brassinosteroid Biosynthesis pathway

In the early 1930s efforts were being made by mathematicians to define effective computation. Turing, Church, Kleene and Schonfinkel gave various models using the concept of Turing machines, lambda calculus, combinatory logic, post-systems and µ -recursive functions. It is relevant to note that these were formulated much before the electronic computers were devised. Among these, the Turing's formulation is considered as a model of algorithm or computation. The Church Turing thesis states that "any algorithmic procedure that can be carried out by human beings/computer, can be carried out by a Turing machine". Turing machine as an ideal theoretical model of a computer has been universally accepted by computer scientists.

It is proposed that the brassinosteroid biosynthesis accepts a language that is at least as hard as the textbook[3] context sensitive language and is itself context sensitive. It is also inferred that brassinostreoid biosynthesis requires a model of computation that has at least the power of a linear bounded automaton. The enzymatic cascades of signaling have been discussed with reference to computation. [4]

It is further proposed that the models of computation of generalized brassinosteroids are universal. It has been argued that even a single automaton with no more than two counters is universal[5].This implies that brassinosteroid biosynthesis in its general form is capable of computing any function that is computable by Turing machine or a digital electronic computer. We propose that this generalized model of brassinosteroid biosynthesis is a reasonable generalization of a machine to accept the language as described earlier.

Brassinosteroid Biosynthesis behaves as linear bounded automaton

The model of linear bounded automaton can be described formally by the following set format:

$M= (Q, \Sigma, \Gamma, \delta, q_0, b, \ , \$, F)$

where

1. Q is a finite nonempty set of states
2. Γ is a finite nonempty set of tape symbols
3. $b \in \Gamma$ is the blank
4. Σ is a nonempty set of input symbols and is a subset of Γ and $b \notin \Sigma$
5. δ is the transition function mapping (q,x) onto (q', y, D) where D denotes the direction of movement of R/W head; D=L or R according as the movement is to the left or right.
6. $q_0 \in Q$ is the initial state
7. $F \subseteq Q$ is the set of final states.

Various parameters for brassinosteroid biosynthesis can be defined as

The various symbols are as described above. Also

Δ is the output alphabet and

λ is a mapping from Q X Σ to Δ giving the output associated with each state. That is λ (q,a) gives the output associated with the transition from state q on input a. the output of M in response to input $a_1, a_2, \ldots a_n$ is λ $(q_{0,} a_{1),}$ λ (q_1,a_2).. λ (q_{n-1}, a_n) where $q_0, q_1 \ldots q_n$ is the sequence of states such that δ $(q_{i-1}, a_i)= q_i$ for $1 \leq i \leq n$.

Brassinoisteroid biosynthesis can be divided into five automata (Fig.1)

Q = Various combinations of 'Resting' and 'active' state of enzymes involved in brassinosteroid biosynthesis (1) steroid 22-alpha-hydroxylase (2) 3-epi-6-deoxocathasterone 23-monooxygenase

The various states of the machine can be

$Q_{0:}$ 1,2

$Q_{1:}$ 1*, 2

$Q_{2:}$ 1,2*

Q_3: 1,2

Asterisked numerals indicate enzymes 'in action'. Rest of the numerals indicate resting state of the enzymes.

Σ = {Campestrol, 22-hydroxy-campestrol }

δ = transition function which maps substrates of enzymatic reactions to their products

Δ is the (22- hydroxycampestrol, (22R, 23R)-22,23-Dihydroxycampestrol)

$q_0 \in Q$ defined above

λ is mapping from Q X Σ to Δ

The output of the machine in response to (Campestrol, 22-hydroxy-campestrol) is λ (q_1Campestrol), λ (q_2, 22-hydroxy-campestrol),

λ (q_1Campestrol) =22-hydroxy-campestrol

λ (q_2, 22-hydroxy-campestrol) = (22R, 23R)-22,23-DihydroxycampestrolAlso

δ (q_1Campestrol) = q_2

δ (q2, 22-hydroxy-campestrol) = q3

Transition table

State	Input	Next state	output
Q_1	Campestrol	Q_2	22-hydroxy-campestrol
Q_2	22-hydroxy-campestrol	Q_3	(22R,23R)-22,23-Dihydroxycampestrol

Similar formalism can be used to describe the rest of the four automata in brassinosteroid biosynthesis

It can be envisaged that context sensitive process of brassinosteroid biosynthesis is composed of several simpler processes that in turn accept context sensitive languages. Brassinosteroid biosynthesis can be defined into five automata. The combination and communication of these processes results in greater computational power of the brassinosteroid biosynthesis. An important role is played by modularity in biological systems. In our case protocols involving communication between the five automata in brassinosteroid biosynthesis serve an important function.

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