

Mathematical Analysis of Root Growth in Gamma-irradiated Cashew (*Anacardium occidentale* L.) and Mangosteen (*Garcinia mangostana* L.) Using Fractals

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Abstract: Root growth is related to the acquisition, distribution, and consumption of water and nutrients of plants. As a vital organ, roots directly take the effect of environmental change and its behavior is closely related to the growth of the whole plant. With such, the importance of root systems has motivated botanists to seek a better understanding of root branching complexity. This complexity, which has been difficult to comprehend using simple Euclidean methods (i.e. lines and circles), is important to the survival of plants, especially when the distribution of resources in the environment is scarce. Mathematical models using fractals and computers can be applied to accurately understand the growth and form complexity of plant root systems. This study was conducted to analyze the root growth of gamma-irradiated cashew and mangosteen using fractals. [Nature and Science. 2005;3(1):59-64].

Key words: fractals; root growth; cashew; mangosteen; mathematical model

1 Brief Summary

Seeds of cashew (n=360) gamma-irradiated at 0 Gy, 150 Gy, 300 Gy, 450 Gy, 600 Gy and 750 Gy, and mangosteen (n=75) gamma-irradiated at 0 Gy, 10 Gy, 20 Gy, 30 Gy, and 40 Gy were germinated in perlite plots. The plants' primary root lengths were measured. Image analysis using *Fractal Dimensions* software was conducted to determine the fractal dimensions, D, of the plant roots.

Findings for mangosteen reveal that as the gamma-irradiation dose increases, the primary root length decreases and the root D increases. Roots irradiated at 40 Gy showed the highest average D at 1.657. This implies greater root branching complexity which results to better plant nutrient exploitation efficiency. For cashew roots, D did not vary significantly with increasing gamma-irradiation dose. However, cashew seeds irradiated at 150 Gy exhibited the highest germination rate, highest average primary root length, and an average D of 1.613. General trends also reveal that cashew roots' D increased with time.

This study demonstrates that fractal dimension can be a useful tool in characterizing the complex branching characteristics of root systems. This may pave the way for further applications of fractals in other areas of research. The findings from this study can also be used to improve the production of cashew and mangosteen which are the two of the world's most economically valued fruits.

2 Brief introduction

As people's views on using modern means such as computers extend, it has been difficult to use traditional methods like simple lines and circles to comprehend biological systems. Biological systems, like root branching, display fragmentations that cannot be modeled and comprehended by simple shapes alone. Mathematical models using fractals have recently been applied to explore the relationship between plant growth and structure.

A. Problem

Complexity in root systems, which reflects nutrient exploitation efficiency, is important for plant survival, especially when the distribution of resources in the soil environment is scarce. However, root complexity is difficult for scientists and researchers to study.

B. Objective

This research study was conducted to analyze and compare the root growth branching patterns of gamma-irradiated cashew and mangosteen using fractals.

C. Significance

- The study addresses the real-world problem of making accurate quantitative observations regarding root growth. The fractal dimensions may reflect the plants' root branching complexity and reflect nutrient uptake efficiency.
- Since radiation causes genetic mutations, fractal analyses of root patterns in gamma-irradiated cashew and mangosteen provide information on the growth mechanisms of these plants. Data from this study can be used to improve the agriculture and production of

cashew and mangosteen which are economically valued fruits.

3 Detailed introduction

A. Background of the Study

The emergence of forms in the growth process, like root branching, is one of the most exciting problems in biology. Most biological systems, like root branching, are difficult to comprehend, displaying fragmentations which cannot be easily modeled by simple shapes (Kaandorp, 1994). Mathematical models using fractals have recently been applied to explore relationship between growth and form (Kenkel & Walker, 1996). Cashew (*Anacardium occidentale L.*) and mangosteen (*Garcinia mangostana L.*) are one of the most recognized tropical fruits. Both have universal appeal and high economic values because of their quality in color, shape and flavor.

B. Statement of the Problem

The demand on cashew and mangosteen often exceeds supply. Further studies about the growth and agriculture of both are needed. Also, the qualitative characteristics of cashew and mangosteen root systems are already known, the problem is to make accurate quantitative observations on their root growth. The major objective, therefore, of this study is to analyze and compare the root growth patterns of irradiated cashew and mangosteen using fractals.

C. Significance

This study would be a means of new knowledge about root branching growth of cashew and mangosteen. The fractal analysis of the root patterns of irradiated cashew and mangosteen can help understand their growth dynamics. The fractal dimensions would reflect their branching complexity and growth velocity. Moreover, a comparison of the fractal models and the actual growth forms can be used to detect the effects of slow changes in the environment, like gamma radiation.

D. Scope and Limitations of the Study

This study focuses on having quantitative observations on the root systems of the samples, not on their already known qualitative characteristics. One limitation of this study is that the root structure being three dimensional will be modeled using a two dimensional fractal analysis software due to the inavailability of a three dimensional fractals software to the author.

4 Review of related literature

A. Cashew

The cashew tree is a medium-sized tree with oval blunt alternate leaves (Grieve, 2004). The cashew nut is

defined botanically as the fruit. It grows externally in its own kidney-shaped hard shell at the end of this pseudo-fruit, or peduncle. It is commonly found in Brazil and in other tropical countries. Besides being a popular food export, it is now being used as an alternative medicine against asthma, diabetes, fever, and the like.

B. Mangosteen

The mangosteen fruit, usually found in tropical countries, is 2-3 inches in diameter and has a thick reddish-purple rind that covers the segmented pulp (Morton, 1987). It is usually eaten fresh, but can be stored successfully for short periods of time. It is also canned, frozen, or made into juice, preserves, and syrup. Mangosteen is also used as a pharmaceutical.

C. Fractals

Fractals are unusual geometric structures that can be used to analyze many biologic structures not amenable to conventional analysis (Richardson & Gillepsy, 2000). Mandelbrot introduced the term 'fractal', from the Latin *fractus*, meaning 'broken', to characterize spatial or temporal phenomena that are continuous but not differentiable (Kenkel & Walker, 1996). Fractals possess properties that include scale independence, self-similarity, complexity, and infinite length or detail. Fractals have been recently used to analyze the root architecture of some plants. Correlations between fractal dimension and topology of root systems of legume plants grown in root boxes were studied (Tatsumi & Takagai, 1996). It was suggested that when roots develop under favorable conditions, D is a good indicator for estimating the system's size and root branching.

5 Methodology

The method used is summarized by the FLOWCHART (Figure 1).

PLANT

5.1 Plant materials and seed germination

Cashew seeds were obtained from University of the Philippines Los Banos- Agriculture Department. The 360 seeds were randomly divided into 3 blocks with 6 groups containing 20 seeds each. All groups were soaked in water for 48 hours and were randomly irradiated at 0 gy, 150 gy, 300 gy, 450 gy, 600 gy and 750 gy. The seeds were germinated in plots with perlite. For four weeks, the length of the primary roots of the samples was obtained. The plant materials for mangosteen were obtained at the Philippine Nuclear Research Institute. The same preparation were to mangosteen, but the radiation doses were 0 gy, 10gy, 20 gy, 30 gy, and 40 gy.

5.2 Fractal analysis

Roughly once a week, 9 cashew root samples per radiation dose (3 from each block) were digitally photographed. Then, 3 from 5 samples per radiation

dose of mangosteen root pictures were randomly chosen. After such, the pictures were turned into monochrome format. Then, fractal analyses using the Fractal Dimensions software's box-counting method were done. The data from the fractal counting were tabulated and plotted on a log-log plot graph. A linear regression was done to find the best fit line. The fractal dimension was calculated. It is equal to 1 minus the

slope of the best fit line, relative to 1 or simply $D = 1 - \text{slope}$.

6 Data and results

A. Mangosteen and Cashew Root Growth Observations (Figures 2-4)

B. Fractal Analysis of Mangosteen and Cashew Root Growth Patterns (Figures 5-7)

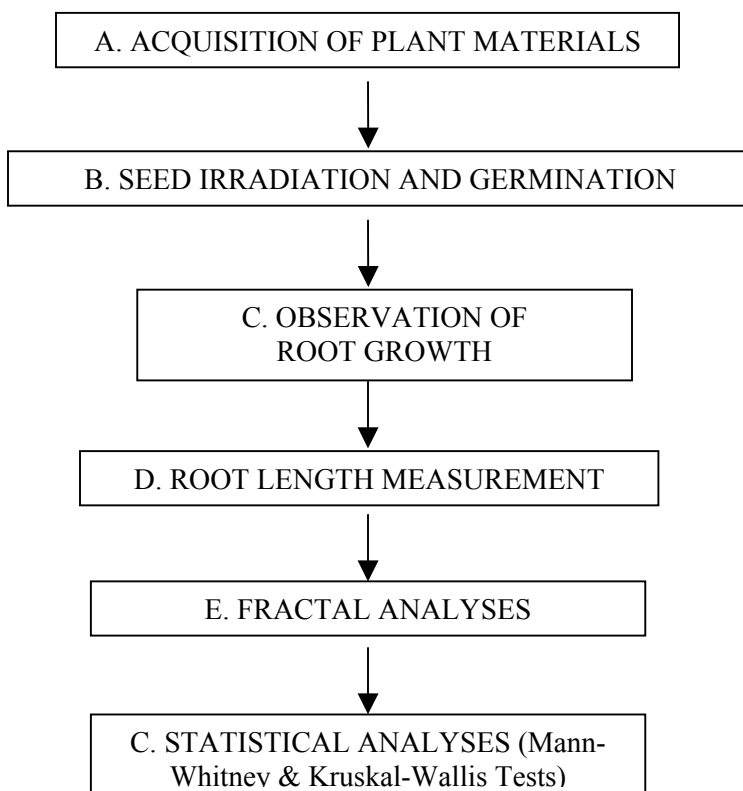


Figure 1. Flowchart

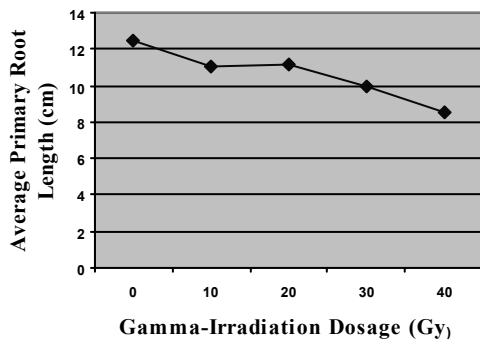


Figure 2. Average primary root length of mangosteen at increasing gamma-irradiation doses

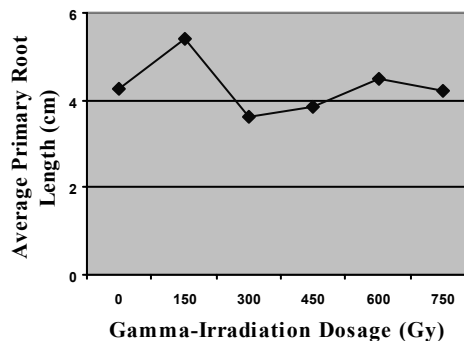


Figure 3. Average primary root length of cashew at increasing gamma-irradiation doses

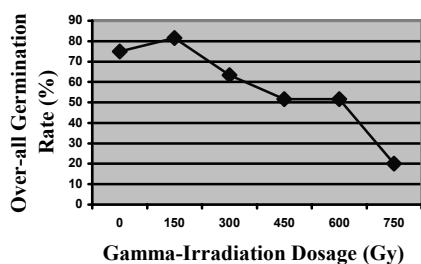


Figure 4. Changes in cashew (*Anacardium occidentale* L.) seed germination rate at increasing gamma-irradiation doses.

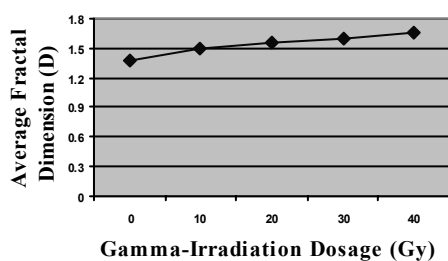


Figure 5. Changes in average fractal dimensions of mangosteen roots at increasing gamma-irradiation doses

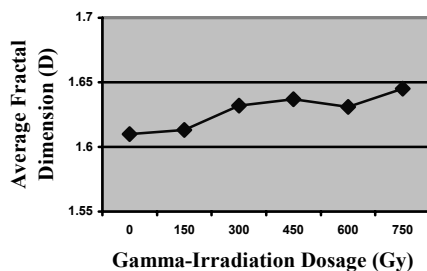


Figure 6. Changes in average fractal dimension of cashew roots at increasing gamma-irradiation doses

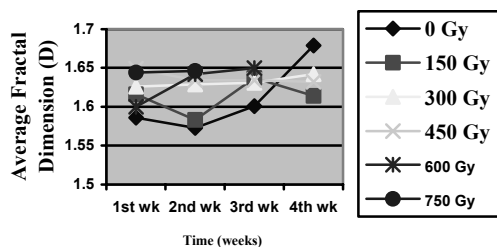


Figure 7. Changes through time in the fractal dimensions of cashew roots

7 Analysis and discussion summary

- For mangosteen roots, fractal dimension, D , decreased as the primary root length increased. The highest gamma-irradiation dose for mangosteen, 40 Gy, resulted in the highest D , 1.657. This high value implies greater root complexity, which in turn could result to enhanced efficiency for soil nutrient exploitation.
- For cashew roots, D did not vary significantly with increasing radiation dose. However, primary root length measurements (5.40 cm) and germination rates (81.6%) revealed that cashew grows best at 150 Gy. Such results might have happened maybe because cashew is less radiosensitive compared to mangostee.
- From a cellular perspective, gamma-irradiation might have altered chromosomal structure (e.g. introduction of transitions, deletions, and frameshifts in the genetic material) of mangosteen and cashew root cells. The radiation might have also affected transmission of the genetic material through inhibition of cell mitosis. It is hypothesized that these alterations in genetic makeup might have led to the changes in root cell growth, which in turn affected the root systems' complexity.

8 Conclusions and recommendations

- Fractals are useful in analyzing complex biological systems accurately. The fractal dimension (D) served as the summary statistic of the branching characteristics of cashew and mangosteen roots.
- The best gamma-irradiation dose for mangosteen was 40 Gy, which showed the highest root fractal dimension. While the best dose for cashew was 150 Gy.
- In this study, the process of determining fractal dimensions of gamma-irradiated roots and correlating it to primary root lengths showed that variations in D exist due to plant differences brought about by genetic makeup (e.g. species) and/or environmental factors (e.g. radiation dose).
- The fractal dimension could be of interest to botanists because it is directly correlated with the efficiency at which the roots exploit soil resources. The use of other types of plant species and the application of other forms of environmental stress,

like drought and mineral deficiency, is recommended.

- This study may pave the way for further applications of fractals in other areas of research, especially in agricultural engineering, computer science and biology. Data from this research can also help the Philippines achieve its goal of attaining efficiency in crop production for sustainable development and global competitiveness.

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Remarks

- The research won 3rd Award in the 2005 Taiwan International Science Fair, 1st Place in the Philippine Science High School- Main Science and Technology Fair (YMSAT 2005), 2nd Place in the Intel Regional Fair and was a finalist in the UP Alchemes Fair. It was conducted when the author was in 4th year high school.

- The author is a graduate of Philippine Science High School- Main Campus and a BS Mathematics freshman at the University of the Philippines- Diliman.

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