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Geometric modeling of a coffee plant for displacements prediction

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A B S T R A C T

Coffee plants can present structural problems during semi-mechanized and mechanized harvesting such as excessive defoliation and breaking branches. For this reason, studies of mechanical response of a coffee plant can help the development of more optimized machines. The main objective of this study is the modeling of a coffee plant for its mechanical behavior evaluation by using the Finite Element Analysis. The presented paper includes modeling, numerical simulations and experimental tests from a *Coffea arabica* L. plants. Firstly, it was necessary to create a coffee tree geometry based on pieces of a real tree using 3D scanning process. The coffee tree geometry together with experimental data provided materials properties of the wood plant which are used for displacements prediction via Finite Element Analysis. In order to validate the methodology, simulated results were compared to a real plant behavior under static load. Results presented consistent values from the three-dimensional modeling of a coffee plant which demonstrated the potentiality for new applications.

1. Introduction

The coffee industry is discovering the advantages and benefits of knowing the operational characteristics of a product by means of numerical simulation which is a technology that multiplies in most of engineering departments (Silva et al., 2014). The increasing of coffee consumption in contrast to the unavailability of hand labor for manual harvesting generates the need for mechanized harvesting. In this scenario, the numerical simulation can be used to predict the mechanical behavior of the machines as well as coffee plants.

Numerical simulations performed by Finite Element Analysis (FEA) are common used for predicting the mechanical behavior of metallic, non-metallic and organic materials (Celik et al., 2011; Li et al., 2013; Nilnont et al., 2012; Tinoco et al., 2014; Santos et al., 2015). Numerical simulation can predict physical tests and generate reports with satisfactory results. Therefore the numerical simulation is a basic tool for engineers and researchers that directly address problems facing on the industries and academic areas.

In this context, numerical simulations have fundamental importance for the solution of two and three-dimensional problems when compared to limited solutions by conventional methods. Three-dimensional behavior of components under mechanical stresses needs to be analyzed with accuracy due to geometry complexity. Bishop (1999) states that regardless of the situation which the component is subjected it can be analyzed through FEA. This also generates results even in the design phase of a project.

It is known that, in numerical simulations, as much as complete the analysis, higher is the degree of complexity and, consequently, greater the difficulty in obtaining an adequate solution. However, with the advance of new computational technologies, scientists and engineers have more access to equipments with high processing capacity. This contributes to the improvement of numerical methods, enabling the development of algorithms that allow numerical simulations with accuracy.

Among the existing numerical methods, FEA consists of subdivision (discretization) of a geometric domain in small areas or volumes, named by the finite element mesh (Knight, 1993). From each discretized volume, stresses and displacements among other results in the entire model are provided (Savary et al., 2010). The emergence of FEA was performed through the aerospace industry (Turner et al., 1956). With increasing computer processing power, workstations and reduction in the cost thereof, FEA has become common in many engineering areas, mainly in acoustic (Takeshi et al., 2014), thermal (Bofang, 2014) and dynamics (Nguyen-Thoi et al., 2014; Lee et al., 2012).

In agriculture, FEA can be used as a simulation tool in the mechanical behavior of fruits and vegetables (Piotr and Pieczywek, 2014) and also in the harvesting mechanization

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(Magalhaes et al., 2006). Other numerical methods have also been applied in agricultural engineering such as the Boundary Element Method (D'Alfonso et al., 1997), but FEA is still mostly used in agriculture, mainly for soil applications (Tagar et al., 2015) and vibrations (Zhan et al., 2015). More specifically, there are published studies to determine the mechanical properties of coffee (Chandrasekar and Viswanathan, 1999; Olukunle and Akinnuli, 2012; Cilas et al., 2010), but the geometric modeling of a coffee tree for static and dynamic analysis using FEA is still incipient.

Considering that mechanized coffee harvesting has performed by mechanical vibrations and that the harvesting machines interact with whole plant, it is fundamental to study the static and dynamic behaviors of the coffee fruit–stem system, plagiotropic branches and orthotropic branch. Machines that use this principle employ a combination of loads, frequency and amplitude to detach the fruits (Ciro, 2001; Santos et al., 2010). The determination of modal properties of fruit–stem systems is an essential parameter for developing mechanized process and has been explored by many authors (Ciro, 2001; Tinoco et al., 2014; Santos et al., 2015). However, understanding the static behavior of the coffee plant is also necessary for a complete model of the system, including all parts of the plant. In this context, this paper is aimed to perform the modeling of a coffee tree by using 3D scanning process in order to perform static analysis by means of numerical simulations.

2. Materials and methods

2.1. Plant geometry modeling

The three-dimensional modeling of plants is the first step to evaluate the mechanical behavior of the wood by means of numerical simulations. For this, it is necessary obtain the architecture of the plant from 3D Laser such as Preuksakarn et al. (2010). In the case of this work, trunk and branches have been geometrically patterned by using free software (Blender®). The complete geometrical modeling of the coffee plant followed some procedures which included the pull out of the plant, defoliation and sawing the plant in pre-determined parts.

In order to carry out a coffee plant modeling, parts of the trunk and branches of *Coffea arabica* L. (IAC 144) plant were provided separately for scanning (Fig. 1).

After all parts scanning, they were joined in the software Blender® and the entire plant was modeled, Fig. 2.

2.2. Mechanical properties of the plant

From coffee plant samples, two main mechanical properties (modulus of elasticity and Poisson's ratio) were evaluated from compression tests in a universal testing machine. The experiments from the wood of coffee plant samples were performed according to standard NBR 7190 (ABNT, 1997). Fifteen trunk samples from different coffee plants with squared cross section of 20 mm each side and 60 mm in length were tested. Fig. 3 presents one trunk sample of a coffee plant under compression in a universal testing machine.

A free software (Image J®), normally used for image processing, was used to obtain Poisson's ratio values. For this, one picture before compression test (Fig. 3a) has been taken as reference. After load application, other picture (Fig. 3b) has been also taken. Width difference from both pictures was calculated using the software Image J® by means of digital processing in order to define Poisson's ratio for each sample.

By means of Archimedes immersion method, the density of coffee wood plant samples has been also evaluated, Fig. 4.

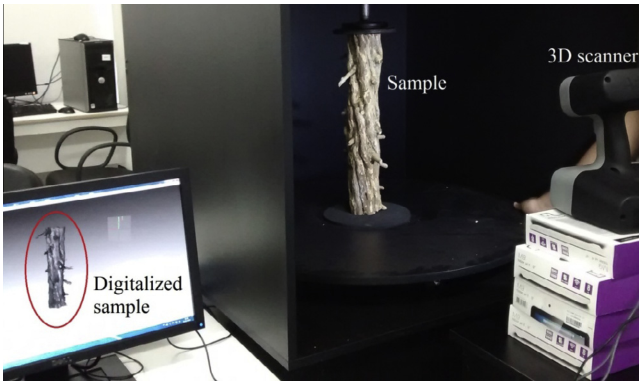

Fig. 1. Part of a trunk coffee plant under scanning process.

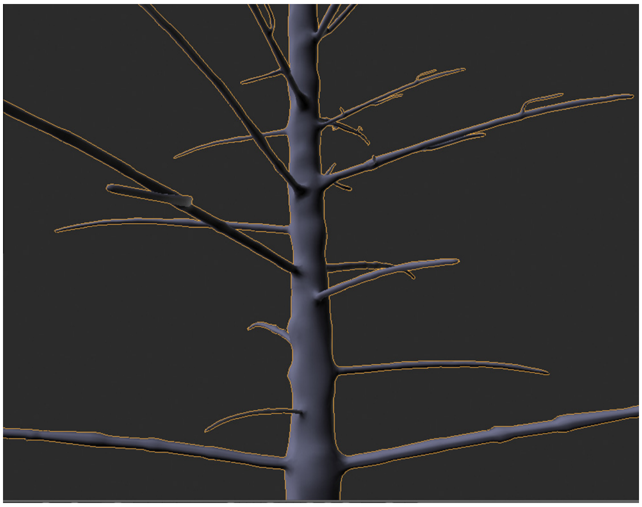

Fig. 2. Entire coffee plant geometry composed by scanned parts.

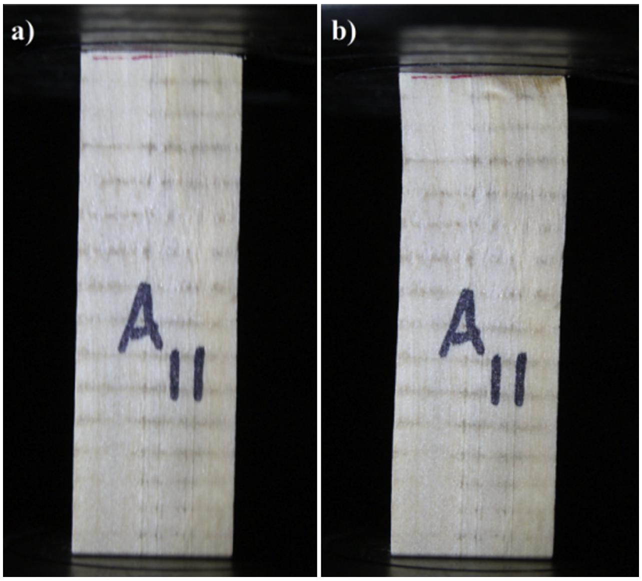

Fig. 3. Coffee wood plant sample (a) before and (b) after compression test.

Density, modulus of elasticity and Poisson's ratio data from experiments and the coffee plant geometry are mandatory parameters for performing the numerical simulations. Those data were