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Experimental characterization and numerical modeling of the compressive mechanical behavior of hazelnut kernels

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ABSTRACT

The evaluation of mechanical properties of hazelnuts has been developed over the past years mainly to optimize industrial processes. The aim of this study is to reproduce the compressive behavior of hazelnut kernel obtained by experimental and numerical activities; the contribution of pellicle influence to the mechanical behavior is also analyzed.

The experimental activity is aimed to measure the mechanical properties of hazelnut kernel and to obtain a model calibration based on experimental data analyzed by statistical approach. The finite element models of hazelnut kernels are implemented and a set of numerical compression tests are simulated; the comparison of experimental and numerical responses is shown.

1. Introduction

The hazelnut *Corylus avellana* L. is native of an area that stretches from Europe to south west Asia and has been introduced in USA (California State) and several other countries around the world. Turkey is the largest producer of hazelnuts in the world with approximately 75% of worldwide production, followed by Italy, USA and Spain (FAO, 2014).

The nut kernel is the edible part of the hazelnut. Many studies have been conducted regarding its internal structure, some of them dating back to the first years of the XX century (Winton, 1906; Young, 1912). The edible kernel is covered by a removable thin fibrous pellicle, with the internal tissue of the cotyledons consisting of parenchyma cells separated by very small intercellular spaces (Young, 1912).

The hazelnut kernel is widely used in the food industry as fruit, grounds and in form of flour. The roasting process is used to achieve an optimal flavor development and intensity of taste, as for it modifies the physical, chemical and sensory characteristics.

The evaluation of mechanical properties of hazelnuts (whole fruit, shell, kernel) has been developed over the past years with the objectives to obtain industrial processes and improve the use of hazelnuts as food ingredient. The easiness to break and to remove the nut shell was evaluated on Turkish varieties (Güner et al., 2003; Ozdemir and Akinci, 2004; Ercisli et al., 2011) and also on nut varieties intended for fresh table consumption (Valentini et al., 2006). Nut shell characteristics, such as hardness and thickness, were measured and correlated to the biological cycle of the nut weevil of *Curculio nucum* (*Coleoptera: Curculionidae*) pest and to the damage by its larvae (Guidone et al., 2007) stress the importance of physical properties evaluation.

The physical characteristics of the hazelnut kernel have an important role on the crispness and crunchiness sensory parameters especially on the roasted nuts (Saklar et al., 1999) and the water activities have direct effects on mechanical characteristic (Borges and Peleg, 1997). The overall quality is influenced by oxygen and relative humidity contents during the product storage (Ghirardello et al., 2013). Di Matteo et al. (2012) evaluated also some mechanical properties of chemical-peeled hazelnut kernels, such as firmness and rigidity, to study an original industrial process to improve the kernel pellicle removal. A mechanical characterization of whole nut, kernel and shell was conducted (Delprete and Sesana, 2014) in order to aid the design and construction of selecting machines.

The main aim of this study is to obtain, by experimental and numerical activities, the model of the compressive behavior of hazelnut kernel and to investigate the role of the pellicle coating and roasting process; the here investigated variety of hazelnut is the *Tonda Gentile Trilobata*.

The present study measures the mechanical properties of the kernel material, raw and roasted, selects and calibrates the proper constitutive material model for numerical simulations, and investigates the behavior of the whole hazelnuts in the same

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experimental conditions (raw and roasted). Finally the research identifies the average value of the investigated mechanical parameters, the variability of the measurements and the influence of the number of the specimens within a single sample. The implementation and validation of a numerical finite element (FE) model of hazelnut based on geometric and material data is reported.

2. Materials and methods

Experiments were carried out to obtain the empirical data of material behavior.

The geometry of real kernel has been computed by means of TAC scanning of four kernels and this has been used to define numerical modeling. Material calibration data has been derived from experimental test activity on specimens obtained from the same four kernels.

2.1. Experimental tests

The hazelnut sample was composed of about 5 kg of conform and raw *Tonda Gentile Trilobata* (formerly known as *Tonda Gentile delle Langhe*) Italian autochthonous cultivar (2013 harvest).

The moisture content, determined according to the AOAC 925.40 method (AOAC, 2000), was of 4.45% ± 0.57% w.b.

Geometric parameters and mass of kernels were acquired as described in a previous work (Delprete and Sesana, 2014).

According to χ^2 test and normal distribution test, the samples distributions were checked to be normal. By means of Chauvenet test (Montgomery et al., 2001) measurements anomalies were excluded from data processing. Minimum sample size was identified by means of plotting percent relative deviation vs specimen number, selecting the sample size corresponding to percent relative deviation settling to a steady value.

For roasting process, about 2 kg hazelnuts were put in oven at 140 °C of temperature during 30 min (Donno et al., 2013). Moisture content of roasted hazelnuts, at the time of analysis, was 2.40% ± 0.31% w.b.

Compressive tests were performed based on the previous studies (Delprete and Sesana, 2014; Valentini et al., 2006; Ghirardello et al., 2013).

In particular, a reference system has been defined on the kernel indicating three main directions and dimensions as reported in Fig. 1. The testing machine is a TA.XTplus texture analyzer (Stable Micro Sytems, Godalming, UK), with loading speed 6 mm/min (down plate moving). For all tests, the average curve was calculated by Matlab R2010b software, by means of dedicated routines developed for the present research activity. Each considered sample consisted of at least 50 specimens.

To optimize the experimental conditions that allow the best monitoring of the measurement changes, (according to Torchio et al., 2012), and to evaluate the influence of the sample size on the variability in the measurements, the optimum sample size was assessed representing the relative standard deviation (RSD) values against the number of measurements for each parameter. The stabilization of the RSD assessed the minimum sample size.

The first test sample (Sample 1) is composed of 50 just shelled raw hazelnut kernels while the second (Sample 2) is composed of 50 manual peeled raw hazelnut kernels; that is, in the former case the kernels are provided with pellicle while, in the latter one, the pellicle has been removed by a careful hand scraping procedure. In particular, by means of a sharp razor and a lens, the pellicle has been carefully removed, taking care of not cutting away kernel material. In both cases the kernels are compressed along the *A* direction (Delprete and Sesana, 2014). In Fig. 2 the test setup is presented.

The third test sample (Sample 3) is composed of 50 roasted hazelnut kernels; pellicle was removed, as the roasting procedure makes it to detach from the kernels. As in the previous cases, the testing procedure consists in a compression along the *A* direction.

From these three sets of tests, the force–displacement curves were acquired, the average maximum load ($\overline{L}_{kf}$) to break the hazelnuts and the slope (stiffness $\overline{K}$) of the linear part of the compression curve were calculated for each specimen within the corresponding sample. It has to be noted that the hazelnut failure force was defined as the force needed for the separation of the two cotyledons (Fig. 3). For each of these parameters, χ^2 test was done to verify the normality of distributions and the relative standard deviation analysis was done to optimize the sample size.

The fourth (Sample 4) and fifth (Sample 5) test samples are composed of raw and roasted kernel specimens, respectively (Fig. 4a), undergoing compression test (Fig. 4b). The specimens are cylindrical, 5 mm high and 5 mm diameter, and they are obtained by means of two dedicated tools: the first tool cuts a slice (thickness of 5 mm) from the kernel with two parallel surfaces, the second tool is a circular blade of 5 mm diameter and it cuts a cylinder from the kernel slice. Cylinders were cut without taking into account of the direction as the kernel material results to by isotropic (Delprete and Sesana, 2014). The kernel specimens were obtained from each of the four described groups of hazelnuts, based on their kernel conformity.

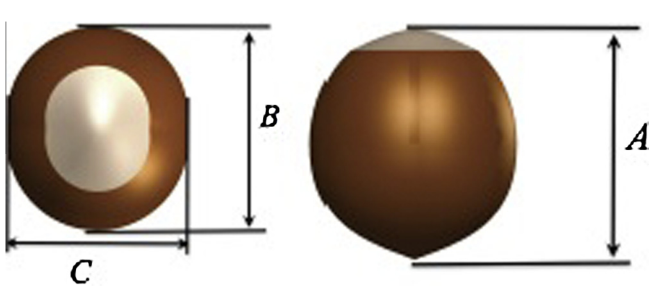

Fig. 1. Hazelnut shell and kernel main dimensions.

Fig. 2. Kernel compression along *A* axis, experimental setup.