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A comparative investigation on the effect of thermal treatments on the mechanical properties of oil palm fruitlet components

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ABSTRACT

An assessment of the mechanical properties was employed as the principal yardstick to quantify the physical attributes of oil palm fruitlet components before and after being subjected to thermal treatment process. Two industrial-scale thermal treatment methods were considered; horizontal sterilisation (being the most common) and vertical sterilisation (recently implemented). The exocarp and mesocarp layers of thermally-treated fruitlets, as attested by texture profile analysis, compression test, and tensile test, have a significantly low value of fracturability, hardness, firmness, and strength as opposed to untreated fruitlets. Micrographs of the mesocarp slices have provided plausible explanation for the observed decline in the mechanical properties of the sterilised fruitlets. The oil which was initially contained within the fruitlets tends to leach out during the sterilisation process due to the resulting structural disintegration within the layers of the fruitlets. On another related enquiry, the required cracking force to break palm nuts in order to extract the kernel was found to be influenced by the moisture content.

1. Introduction

Conventional sterilisation process in palm oil milling involves batch steaming of the FFB in a horizontal chamber that is subjected to cyclic steam injection (35–45 psig) for approximately 1.0–1.5 h depending on the FFB quality [1]. The purpose of this process, among others, includes softening the structure of the fruitlets, detaching the fruitlets from the bunch, and arresting enzyme/microorganism activities. Numerous studies of different approaches to FFB sterilisation have concluded that each method offers advantages and disadvantages with regard to the quality of the sterilised fruit bunches and supporting subsequent milling processes [1–4]. Irrespective of the sterilisation method, it is at this point where oil palm fruitlets will experience major structural changes that facilitate the impending separation processes, *i.e.* oil extraction and separation of the FFB individual components.

This treatment process will render the oil-bearing fibre matrices that majorly compose the outer structure of the fruitlet whilst the inner layer, *i.e.* the nut, is less affected (Fig. 1). At the same time, the oil within the fruitlet fibre matrices will experience reduced viscosity, thus enabling an effortless flow. Unfortunately, not all FFB sent to the mill is in good shape, *viz.* there are physical defects due to improper harvesting or handling [5], which could cause the oil to leach out during the sterilisation process.

The above premises open up a new avenue of inquiry and thus this study focuses on quantifying the change in mechanical properties of oil palm fruitlet components in relation to the sterilisation process. This type of assessment was selected due to the fact that the change in mechanical properties of these components will affect the subsequent milling processes and it is often overlooked. These valuable data on the dynamic changes of fruitlet mechanical properties could support the effort to improve the subsequent processes [6].

Two sterilisation methods, namely horizontal sterilisation and vertical sterilisation, which are actively exercised in large-scale palm oil milling were considered in this study. While horizontal sterilisation being the most common, vertical sterilisation was just recently implemented in the past years and the findings on this process is not widely disseminated. A parallel comparison has been made of the macro- and microstructure of raw and sterilised fruitlet components—the exocarp, mesocarp, nut, and fibre. The

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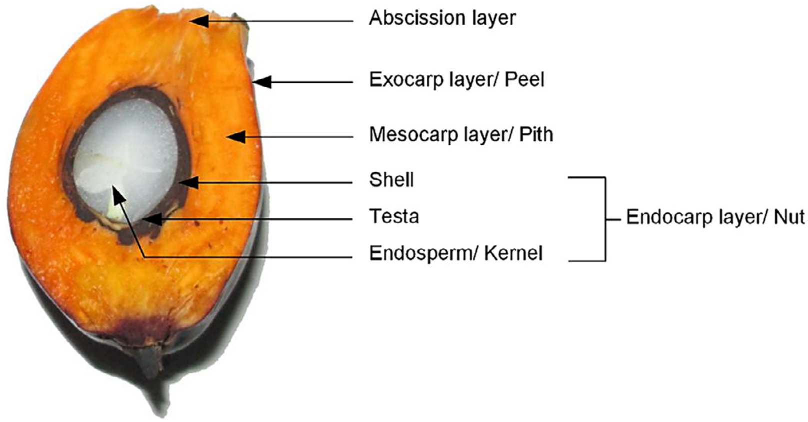

Fig. 1. Cross-section of an oil palm fruitlet.

particular instruments used in this work include texture profile analysis, compression and tensile strength tests, and morphological inspection which are most commonly employed to assess the mechanical properties of fruit [7]. The underlying mechanism behind the change in these physical attributes was compared with previous works of similar interest. In addition, this work has been extended by checking the tendency of oil to leach from the oil palm fruitlets during the sterilisation process.

2. Materials and methods

2.1. Materials

Fresh *Tenera* variety of oil palm fruitlets were collected from a local plantation. Sterilised fruitlet samples from two different types of steriliser (Table 1) were retrieved from a homogenous process mixture at the end of the sterilisation cycle at their respective mills. Fruitlets of similar size, weight and shape (diameter 40 mm, sphericity index 0.74) were selected in order to eliminate the effect of dimensional variations on the experimental outcomes. The same justification was also applied for the oil palm nut samples (diameter 25 mm, sphericity index 0.70). The mass and dimensional measurements of the samples were undertaken in accordance with the procedure by Mohsenin [8].

2.2. Texture profile analysis/puncture test

Fracturability and hardness values were selected to gauge the texture profile of the oil palm fruitlet samples. Fracturability characterises the first significant deformation of the structure of a sample as force is being continuously applied which represents the amount of force required to penetrate the outermost layer of the fruitlet (exocarp). Meanwhile, the hardness signifies the maximum force to break the flesh layer of the fruitlet (mesocarp). The puncture test was conducted using a Texture Analyser TA-TX 2 (Stable Micro Systems Ltd., Godalming, UK) equipped with a 25 kg load cell following the method outlined by Abbas et al. [9]. A 2 mm flat-ended probe was used with a single bite (10 % penetration) with a 60 mm/min cross head speed. As established by Abbas et al., measurements were conducted at two points for each sample, namely the mesocarp (major volume of the palm fruit) and the abscission layer (where the fruitlet binds to the bunch). Test results from different sample categories, *i.e.* raw *versus* sterilised, horizontal steriliser *versus* vertical steriliser, were tested for statistical differences ($\alpha = 0.05$) using the Statistical Package for Social Sciences (SPSS) version 16.

Table 1
Operating condition of sterilisers during sampling.

Parameter	Horizontal steriliser	Vertical steriliser
Steam pressure (psig)	42	40
Steam feed cycle	3	2
Maximum temperature (°C)	140	140
Residence time (minute)	90	105

2.3. Compression and tensile tests of oil palm fruitlet components

Two independent sets of parallel plate compression tests were carried out to assess the mechanical properties of the individual layers in the oil palm fruitlets. In the first compression test, the raw and sterilised fruitlets were subjected to a compression test to determine the strength of their respective exocarp and mesocarp layers. This test is suitable to assess the response of the whole fruitlet structure upon the application of force [10]. The compression plate (an aluminium flat-plate, 75 mm in diameter) will travel at the specified speed of 60 mm/min thus compressing the fruitlet placed on the sample cell.

The second compression test involved nuts from sterilised oil palm fruitlets. The test was conducted in order to evaluate the strength of oil palm nuts in relation to their moisture content. Oil palm nuts that were retrieved from the palm oil mill production line were used as a control sample, *viz.* the moisture content served as the datum for all samples in this test. The nuts were then oven dried at 80 °C for 6 h. At each 1 h interval, several nuts were retrieved and weighed prior to the compression test to determine the moisture loss. In this quasi-static compression test, a progressive increasing load was continuously applied on the palm nut samples at a 30 mm/min rate until it cracked. The reader is referred to the works by Vursavuş and Özgüven [11], Koya and Faborode [12] and Cárcel et al. [13] for details of this procedure.

Oil palm mesocarp fibre (OPMF) from four consecutive milling stages—raw (untreated fruitlet), sterilisation (sterilised fruitlet), digestion (fruit mash) and oil extraction (press cake mixture), were subjected to tensile tests to determine the strength behaviour in relation to these milling processes. Though these samples were of different lengths, the tensile test as stipulated by ASTM C1557-03 only required a partial length of the strand to fit the selected gauge length with a surplus for fixing the sample on the test gauge [14,15] . Alves Fidelis et al. [16] and, Silva and Chawla [17] when studying jute fibre and sisal fibre, respectively, discovered that a gauge length of 30 mm and above will not interfere with the test outcome. Therefore, in this work, a 30 mm gauge length was selected for testing all OPMF samples at a displacement rate of 0.08 mm/s.

All compression and tensile tests were conducted using an Instron 3665 Dual Column Table Top Universal Testing System (Instron, USA). A real-time plot of force over deformation/displacement for each test was analysed to determine the peak force, sample behaviour, and