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Effect of oven and forced convection continuous tumble (FCCT) roasting on the microstructure and dry milling properties of white maize

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ABSTRACT

The effect of oven and forced convection continuous tumble (FCCT) roasting on the microstructure of whole maize kernels was characterised and quantified using X-ray micro-computed tomography (μCT). The three-dimensional (3-D) volumes, reconstructed from the two-dimensional (2-D) images, were segmented into regions of interests (ROIs), i.e. air, germ, floury and vitreous endosperm, and each region quantified. Oven roasting was associated with a larger increase in total kernel volume (10.8%) than FCCT roasting (3.4%) as well as a significant ($P \leq 0.05$) decrease in whole kernel relative density (oven = 6.3%; FCCT = 1.9%). FCCT roasting had almost no effect on material density, in contrast to a significant ($P \leq 0.05$) decrease of 5.0% during oven roasting. Subsequent validation of the dry milling properties, i.e. percentage hominy chop, milling yield and hectolitre mass (HLM), indicated no significantly ($P > 0.05$) detrimental effect by either of the roasting methods.

Industrial relevance: Roasting of maize can improve sensory, shelf life, nutritional and antioxidant properties with subsequent use in ready-to-eat foods and breakfast cereals. Roasting will inevitably affect the structure of maize, which in turn will affect the quality of the end product. This prompted the demand for non-destructive techniques that directly measure microstructural properties of food in order to link structure with quality. X-ray μCT in combination with image analysis uniquely illustrated the microstructural changes occurring during conventional oven and innovative FCCT roasting respectively. Furthermore, dry milling properties are important indicators of quality characteristics for the dry milling industry. The method described in this article can be applied to any food material to investigate structural properties.

1. Introduction

Maize (*Zea mays* L.) is one of the largest and most important crops produced worldwide contributing to an annual yield of over 1 billion ton in 2013 (Food and Agriculture Organization of the United Nations [FAOSTAT], 2015). A maize kernel consists of four main parts, i.e. endosperm (80–85%), germ (10–14%), pericarp (5–6%) and an aleurone layer (2–3%) (Delcour & Hoseney, 2010). Typical processed foods produced from maize include breads, breakfast cereals, tortillas, corn chips and snack bars. Depending on the locality and ethnic group, maize can also be prepared and consumed in a variety of other ways, i.e. sundried, fermented, cooked, pounded or roasted (Oboh, Ademiluyi, & Akindahunsi, 2010). Lately there has been an increasing demand for crunchy snack products, and competition for improved products is developing in the industrial sector (Mrad, Debs, Saliba, Maroun, & Louka, 2014). Traditionally, roasting is a dry thermal treatment, and it is still being used today for the preparation of healthy, crunchy maize snacks (Mrad et al., 2014). Flour obtained from roasted ground maize is also consumed by diverse ethnic groups in Northern Mexico and the Southern United States (Carrera, Utrilla-Coello, Bello-Pérez, Alvarez-Ramirez, & Vernon-Carter, 2015). Roasted cereal grains, with improved organoleptic, shelf life, nutritional as well as antioxidant properties, can easily be incorporated into ready-to-eat foods and breakfast cereals (Chung, Chung, & Youn, 2011; Gujral, Sharma, & Sharma, 2013; Murthy, Ravi, Bhat, & Raghavarao, 2008; Oboh et al., 2010). On the other hand, severe roasting conditions could cause damage to chemical components (i.e. polyphenols and anthocyanins) thereby decreasing their antioxidative activity (Mrad et al., 2014).

In Southern Africa, dry milling is used to produce products such as

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samp (cooked, coarsely broken maize kernels of which the pericarp has been removed), maize grits and meal for human consumption. Roasting could potentially serve as a pre-processing step to enable the use of less energy for milling, to produce value-added products, or to extend the shelf life of products. Roasting of sorghum grains increases the water-absorbing capacity for the preparation of instant mixes and porridges (Ranganathan, Nunjundiah, & Bhattacharya, 2014). In a recent study, pinole, a traditional energy food obtained from toasted ground maize, was shown to result in a significant increase in total available starches and in vitro hydrolysis rate (Carrera et al., 2015), making it a suitable ingredient for specialised energy cereal bar products.

Roasting influences cereal grains by making kernels softer due to the loss of endosperm structure and increased porosity (Murthy et al., 2008), which could be beneficial depending on the processing method and desired final product. There has been increasing interest in the use of roasted grains in food products due to potential health benefits, such as improved digestibility (Krings & Berger, 2001) and bioavailability of minerals because of the greater loss of phytic acid during roasting (Khan, Zaman, & Elahi, 1991). Roasting is considered one of the most effective methods of reducing aflatoxin levels (Kabak, 2009). It does, however, affect the quality and structure of grains, as their functional, technological, physiochemical and nutritional properties are strongly affected by structure–property relationships (Frisullo, Barnabà, Navarini, & Del Nobile, 2012). This has spurred the need for non-destructive techniques to characterise and quantify microstructural changes.

Microscopic techniques such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are commonly used to examine the internal structure of products (Suresh & Neethirajan, 2015). These methods are, however, invasive and destructive, as they require sample preparation, which may in addition lead to the formation of artefacts. From an engineering perspective, three-dimensional (3-D) microstructural information of foods is more suited to a better understanding of food properties to determine processing parameters correctly. X-ray micro-computed tomography (μCT) is a non-destructive and non-invasive imaging technique that can be used for high-resolution 3-D visualisation and characterisation of the internal morphology of a wheat sample (Suresh & Neethirajan, 2015). X-ray μCT is less costly and more convenient than magnetic resonance imaging (MRI) (Herremans et al., 2014; Lammertyn et al., 2003). Although neither of these methods requires sample preparation or chemical fixation, X-ray μCT, in addition, enables analysing and visualising the structural design of cellular materials down to a few micrometres (Maire & Withers, 2014) and now also into the submicron range (nano-tomography) (Withers, 2007). Furthermore, X-ray μCT measures density, whereas MRI provides information on the water content and mobility (Herremans et al., 2014).

Lately, X-ray μCT has been the subject of numerous research articles on non-invasive quantitative and qualitative analysis of the internal quality of agricultural products (Herremans et al., 2013). It has also been used to study the structure of porous cereal products (Van Dalen, Nootenboom, & Van Vliet, 2007), rice (Witek et al., 2010; Zhu et al., 2012), foams (Lim & Barigou, 2004), extruded products (Zhu et al., 2010), bread (Lassoued, Babin, Della Valle, Devaux, & Réguerre, 2007), wheat flour dough (Bellido, Scanlon, Page, & Hallgrimsson, 2006), fruit tissue (Cantre, East et al., 2014; Cantre, Herremans, Verboven, Ampofo-Asiama, & Nicolaï, 2014; Herremans et al., 2015; Mendoza et al., 2007; Verboven et al., 2008), chocolate (Haedelt, Beckett, & Niranjan, 2007) and processed meat (Frisullo, Marino, Laverse, Albenzio, & Del Nobile, 2010). Individual maize kernel volume and density could be measured accurately using this technique (Guelpa, Du Plessis, Kidd, & Manley, 2015; Gustin et al., 2013). The use of X-ray μCT for characterisation of food microstructure has recently been comprehensively reviewed (Schoeman, Williams, Du Plessis, & Manley, 2016).

A recent study demonstrated the effectiveness of X-ray μCT to evaluate the effect of forced convection continuous tumble (FCCT) and oven roasting on the microstructure of wheat non-destructively (Schoeman, Du Plessis, & Manley, 2016). Oven roasting resulted in more adverse microstructural changes (increased porosity and decreased relative density) observed in the endosperm, compared to whole wheat grains subjected to FCCT roasting at the same time and temperature combination. In contrast to wheat, maize endosperm comprises two types, i.e. vitreous and floury. Hard maize kernels with a larger proportion of the denser vitreous endosperm are favoured by the dry milling industry as it produces greater milling yield and higher-quality meals and grits than softer maize. Large intact grits, which are essentially the vitreous endosperm removed from the kernel, are required for cornflake production. In the case of maize, it is thus important to evaluate the effect of roasting on the two endosperm matrices individually.

Dry milling quality is determined by percentage hominy chop, milling yield and hectolitre mass (HLM). The percentage hominy chop is considered to be one of the most appropriate methods to determine milling quality (Guelpa, Bevilacqua et al., 2015). Good milling characteristics are indicated by a small percentage hominy chop. Hominy chop (containing pericarp, tip cap, germ and some endosperm) is of less value than maize meal and grits, and it is mainly used as animal feed. A large hominy chop (above 30%) is delivered by maize that mills poorly (typically soft maize kernels) since floury endosperm breaks down easily and is also included in the chop. A good milling quality maize would have a hominy chop below 22% (Guelpa, Bevilacqua et al., 2015).

Milling yield or extraction is the percentage of meal obtained after dry milling, and is one of the most important factors for millers. A higher value indicates a higher extraction of high-grade and most profitable products, e.g. samp and grits (degermed products) that are manufactured from the vitreous part of the endosperm (The South African Grain Laboratory [SAGL], 2016). Kernel hardness affects the quality and quantity of the milled products. Roasted cereal grains may influence milling yield since they are generally characterised by decreased kernel hardness, due to the increased internal porosity of the endosperm (Raigar, Prabhakar, & Srivastav, 2017). HLM gives a good indication of potential milling quality, as there is a positive correlation between HLM, milling yield and kernel hardness (Guelpa, Bevilacqua et al., 2015).

The aim of the present study was to quantify and visualise the effect of oven and FCCT roasting on the microstructure of whole maize kernels in terms of volume, porosity and relative density of such maize kernels, the vitreous and floury endosperm, and other selected regions of interests (ROIs). Analytical validation of the effect of roasting on dry milling properties was illustrated by means of HLM, hominy chop and milling yield.

2. Materials and methods

2.1. Maize samples

Twenty whole maize kernels were randomly selected from a white maize sample, kindly provided by PANNAR Seeds (Greytown, South Africa). To allow direct comparison, the same kernels were imaged with X-ray μCT before (control) and after roasting. Ten kernels were subjected to oven roasting and ten to FCCT roasting. The kernels were weighed before and after roasting to determine the percentage weight loss, and were stored in airtight containers at ambient temperature.

2.2. Roasting

Maize samples were roasted at 180 °C for 140 s using two roasting techniques: conventional convection oven roasting (831 Electric Multifunction Thermofan Solid Plate Oven, Defy Appliances, Durban, South Africa) and patented FCCT roasting (Roastech, Bloemfontein, South Africa). A temperature of 180 °C is commonly used for roasting