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Effect of pulsed electric fields on the structure and frying quality of "kumara" sweet potato tubers

Tingting Liu [a,b,c], Ethan Dodds [a], Sze Ying Leong [a], Graham T. Eyres [a], David John Burritt [b], Indrawati Oey [a,c,*]

[a] Department of Food Science, University of Otago, PO Box 56, Dunedin 9054, New Zealand
[b] Department of Botany, University of Otago, PO Box 56, Dunedin 9054, New Zealand
[c] Riddet Institute, Massey University, Private Bag 11222, Palmerston North, New Zealand

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ABSTRACT

The aim of this research was to study the effect of pulsed electric fields (PEF) on the microstructure of "kumara" sweet potato (*Ipomoea batatas cv. Owairaka*) and its quality after frying. Whole sweet potato tubers were treated at different electric field strengths ranging from 0.3 to 1.2 kV/cm with specific energy levels between 0.5 and 22 kJ/kg. Cell viability was determined using tetrazolium staining to investigate the uniformity of the PEF effect across tubers. Based on the patterns of viable cells it was observed that the effect of PEF was not homogeneous across the tuber. This result was also supported by the pattern of enzymatic browning due to PEF facilitating the reaction of polyphenoloxidase and phenols. PEF treatment resulted in significant softening of the ground tissues, but not on the dermal tissues, as determined by texture analysis. With respect to frying quality, tubers pre-treated with PEF at electric field strength of 1.2 kV/cm and fried at 190 °C had an 18% lower oil content than non-PEF treated samples. The kinetics of browning as a function of frying time could be described by a fractional conversion model. The activation energy (*Ea*) of the browning rate during frying increased (more temperature sensitive) due to PEF pretreatment at 0.5 kV/cm and 1.2 kV/cm. It implies that PEF pretreatment allows frying the potato chips at lower temperature in order to achieve the same brown colour intensity as the non-PEF treated tubers. This study shows clearly that PEF could reduce the energy required for cutting and frying of kumara.

Industrial relevance: This study provides evidence that the effect of PEF processing on whole kumara tubers is not uniform, demonstrating heterogenous distribution. These findings provide important information for food industry to design appropriate PEF processing conditions for solid materials. More importantly, PEF treatment reduced the energy required for cutting and frying of kumara, and reduced the oil content in the fried kumara chips.

1. Introduction

Sweet potatoes (*Ipomoea batatas*), also known as "kumara" in New Zealand, are starchy, sweet-tasting, tuberous roots that were one of the most important crops and a staple food in the diets of the Maori people (Cambie & Ferguson, 2003). Sweet potatoes are rich in ascorbic acid, thiamine, riboflavin, niacin, phosphorus, iron, calcium, and dietary fiber (Farinu & Baik, 2007). The major storage proteins of kumara are sporamins A and B, which act as proteinase inhibitors and may have anti-cancer properties (Scott & Symes, 1996). Kumara also contains coumarins, which are implicated to be anti-coagulants (Cambie & Ferguson, 2003).

In New Zealand, there are three main varieties of sweet potatoes commercially available, which can be differentiated by the colour of their skin and flesh i.e. Toka Toka Gold or gold sweet potatoes (sweet potatoes with golden skin and flesh); Beauregard or orange sweet potatoes (sweet potatoes with a rich orange flesh and sweeter than gold) and Owairaka Red or red kumara (the most common sweet potatoes variety with red skin and creamy white flesh). Owairaka Red sweet potatoes have a very firm texture and require considerable energy either to be cut or for other forms of physical disintegration for processing. This represents a significant challenge for processing industries where large quantities of sweet potatoes are cut/sliced on a daily basis. Different processing methods have been investigated to reduce the firmness of potatoes or sweet potatoes, such as heat blanching (Nourian & Ramaswamy, 2003), steaming, hot air and microwave softening (Alvarez & Canet, 2001). However, thermal treatment has a high energy cost and may also induce undesired quality changes such as the loss of natural colour and flavor. In the last decade, the use of non-thermal processing such as pulsed electric fields (PEF) technology has been studied and the research findings show that PEF can soften the texture of apples and potatoes (Lebovka, Praporscic, & Vorobiev, 2004),

* Corresponding author at: Department of Food Science, University of Otago, PO Box 56, Dunedin 9054, New Zealand.
E-mail address: indrawati.oey@otago.ac.nz (I. Oey).

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sugar beet (Lebovka, Shynkaryk, & Vorobiev, 2007) and carrot (Lebovka et al., 2004; Leong, Richter, Knorr, & Oey, 2014). So far, only limited studies have been carried out investigating the application of PEF as a means to soften sweet potatoes.

Pulsed electric field processing (PEF) applies very short voltage pulses (in μs) with a high electric field strength to a product placed between two electrodes. PEF processing at low electric field strengths between 0.2 and 1 kV/cm for 0.1 to 10 ms can disrupt plant tissues without a significant increase in temperature (Faridnia, Burritt, Bremer, & Oey, 2015; Fincan & Dejmek, 2002; Lebovka, Bazhal, & Vorobiev, 2002). Electric fields between parallel plate electrodes are quasi homogenous. However, parallel plate electrodes do not produce a homogenous electric field when the sample to be treated has a heterogeneous composition and an irregular shape (Ivorra & Rubinsky, 2007). The electric field distribution across tissues has been studied using mammalian tissues to treat cancer or tumours. However, there is little information on the effect of electric fields across plant tissues in the literature. Faridnia et al. (2015) showed for the first time the microstructure of different parts of whole potato tubers after PEF treatment and provided evidence that the distribution of the PEF effect across the tubers is not uniform. However, there is still a lack of understanding whether this knowledge can be directly translated to other plant tubers/roots with different tissue structures, such as kumara. The tuberous roots of sweet potatoes (*I. batatas*) are structurally different (Fig. 1) to the tuberous stems of the common potato (*Solanum tuberosum*), with differences in cell size, tissue arrangement and vascular architecture and hence sweet potatoes may respond differently to PEF treatment.

Sweet potatoes are widely cooked using deep-frying and consumed in the forms of French fries and chips (in current study, "chips" are referred as fried thin slices). Since fried kumara or potato chips typically contain >30% fat (Dana & Saguy, 2006) and there is currently a demand for healthier foods, different processing techniques have been applied to reduce the fat content in fried chips. Recent research on the deep-fat frying quality of PEF pre-treated potato cubes (e.g. processing with specific energy input of 18.9 kJ/kg and electric field strength of 0.75 kV/cm) showed a lower oil uptake upon frying than untreated potato cubes (Ignat, Manzocco, Brunton, Nicoli, & Lyng, 2015). Hence, PEF could be used as a pre-treatment before frying to reduce the oil uptake of fried potato chips.

The main objective of the present study was to investigate the effect of PEF on the microstructure and texture of sweet potatoes (*I. batatas cv. Owairaka*) and quality (i.e. colour, oil content) after frying. Whole unpeeled and uncut sweet potatoes were used in this study as Faridnia et al. (2015) showed that cutting or peeling increased the effects of PEF on potatoes. The distribution of the electric field effects and the sensitivity of different cell types to the pulsed electric field treatment were investigated in sweet potatoes using tetrazolium salt viability staining (Faridnia et al., 2015). PEF induced membrane permeabilization determined by conductivity measurements (Faridnia et al., 2015) could not be used for this study because sweet potatoes have a thick resilient skin that hinders the leakage of ions, from the more easily damaged internal tissues, into the surrounding media. As sweet potatoes contain moderate levels of polyphenoloxidase (PPO) and phenols, which are located in separate compartments and only react to form brown polyphenolics when they come into contact with each other, enzymatic browning was used to assess the impacts of PEF on cell damage. In addition, firmness and cutting force of sweet potatoes after PEF treatment were measured and scanning electron microscopy (Cryo-SEM) was used to visualize the effect of PEF on cellular microstructure, hence enabling changes in physical properties to be related to structural changes. Finally, the frying quality (i.e. browning and oil content) of PEF pretreated sweet potato chips was studied and compared with non-PEF pretreated (further coded as "untreated") chips. The kinetics of browning during frying were studied at different temperatures. In addition, the fat content of the chips was determined.

2. Material and methods

2.1. Chemicals and reagents

Sodium dihydrogen phosphate (NaH_2PO_4), disodium phosphate (Na_2HPO_4), ethylenediamine tetra-acetic acid (EDTA), sodium chloride (NaCl) were purchased from BDH chemicals (Poole, UK). 2,3,5-Triphenyl tetrazolium chloride and 1,2-dihydroxybenzene (or catechol) were purchased from Sigma Aldrich (St. Louis, USA).

2.2. Sweet potatoes sample

Sweet potatoes (*Ipomoea batatas cv. Owairaka*) harvested between May and August 2015 were used in this study. This cultivar has red skin with white flesh and sourced from Kaipara Kumara (Northland, New Zealand). Upon arrival, the sweet potatoes were visually inspected and any tubers with cuts or bruises or damages were discarded. Tubers were sorted based on shape, size and weight, with tubers in the small size range (~50 g, 50 mm length and 35–42 mm width) used for this study. Sweet potatoes were stored in the dark at 15–17 °C and used within seven days of harvest.

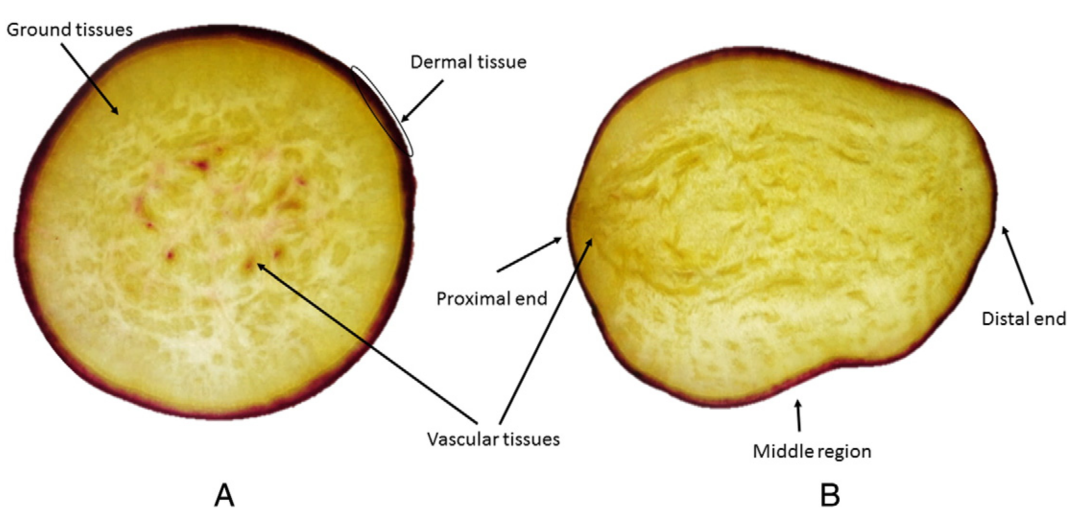

Fig. 1. Transverse section (a) and longitudinal section (b) slice of a sweet potato tuber showing the structure of the tuber.