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Review

Effect of pulsed electrical fields on the structural properties that affect french fry texture during processing

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ABSTRACT

Background: The french-fry manufacturing process via frozen partially-prepared fries involves a series of heat treatments in which the structural properties of a potato (starch structure, ion content, water content, cell wall architecture, and middle lamella) are substantially altered to produce a french fry with a crispy crust and a mealy core. In addition to the traditional processing steps (washing and sorting, peeling, cutting, blanching, dipping, pre-drying, par-frying and freezing), short pulses of high voltage (pulsed electric field, PEF) are now often applied to potatoes before they are cut into french-fry strips. The final texture is the result of not only the effects of heat and PEF treatments on the structural properties of the potato tuber, but also the effects of interactions between these treatments.

Scope and approach: This paper explains the main processes involved during manufacturing of french fries and their effect on the tuber structure properties responsible for french fry texture (changes in starch structure, cell wall architecture, water and oil content) currently available. It summarizes the research on the effect of PEF on those structural properties, their relevance, and applicability and highlights future research needs.

Key findings and conclusions: The effect of heat treatments (steam peeling, blanching, pre drying, par frying) and freezing on the structural properties that affect texture have been widely studied. Manufacturers have adopted a new procedure, PEF treatment, about which little is known about the effect on the structural properties that affect texture and the synergistic interaction effects with the other manufacturing steps of french fry production. There is a need for investigation of these changes and the mechanistic reasons for any effects on final texture.

1. General introduction

1.1. French fry texture

French fries exhibit two very distinct textures: a “crispy” crust, with similar physical characteristics to potato chips (often called crisps) (Pedreschi & Aguilera, 2002), and a “firm-mealy” core, with some of the textural properties of boiled potatoes. The crispy crust can be described as a semi-rigid sponge with 80% void space (Lima & Singh, 2001). It is made of shrunken cells with very low water content, and is usually 1–2 mm thick, varying with frying time and temperature (Sanz, Primo-Martín, & Van Vliet, 2007). The interior, or crumb, can be described in terms of firmness, mealiness, and waxiness (Andersson, Gekas, Lind, Oliveira, & Oste, 1994). 'Mealiness' is a term used to convey a granular mouth feeling on the tongue (Bettelheim & Sterling, 1955). A mealy cooked potato looks glistening in appearance, has a crumbed texture, and can easily be broken down, but keeps its shape (Andersson et al., 1994). French fries with a wet and pasty feel on the tongue (soggy texture) are usually not desired.

2. Potato structural properties affecting texture

The major structural properties of the tuber that affect french fry crispness are moisture content, oil uptake and starch content and distribution along the tissues (Hoff, 1972). Other major factors that affect crispness relate to the manufacturing process — pre-drying and par frying conditions (Kita, 2002; Lisińska & Gołubowska,

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2005; Pedreschi, Moyano, Santis, & Pedreschi, 2007).

Mealiness and firmness are affected by starch properties (molecular structure, amount and distribution within the tuber), cell size (Hoff, 1972), starch swelling pressure and gelatinization properties (Hoff, 1972; Jarvis, Mackenzie, & Duncan, 1992), as well as cell-wall polysaccharides and non-starch polysaccharides (Jaswal, 1991). Firmness is the result of three major changes that occur in the potato tuber as a consequence of the chemical, physical and structural changes occurring during the manufacturing process (Shomer & Kaaber, 2006; Thybo, Christiansen, Kaack, & Petersen, 2006): first, starch becomes gelatinized; next, cell walls are weakened with an accompanying increased permeability; last, intercellular adhesion between adjacent cells is reduced (Andersson et al., 1994; Moyano, Troncoso, & Pedreschi, 2007; Van Marle et al., 1997). The intensity of these changes depends on thermal conditions, such as temperature and treatment duration during processing.

3. French fry manufacturing process

French fry manufacturing is a series of processes, namely washing and sorting, steam peeling, pulsed electrical field treatment, cutting into strips, blanching, dipping, pre-drying, par-frying and freezing (Fig. 1). The processes that have the most significant effect on french fry texture will be considered here.

3.1. Steam peeling

Potato skin is a layer of dead corky periderm cells, around 10 cells deep, that do not contain much starch or protein (Fedec, Ooraikul, & Hadziyev, 1977).

Removal of the potato skin by steam peeling allows high automatization, control of time and temperature, and high yield of potato. The high steam temperature used for peeling causes internal pressure to build, resulting in mechanical failure of the cell and reduction in cell turgor. These changes to the properties of the cells are due to the partial hydrolysis and degradation of pectin and other polysaccharides in cell walls and in middle lamella (Garrote, Silva, Bertone, & Avalle, 1997). The potato layers close to the surface are the most affected by this heat treatment.

3.2. Pulsed electrical field (PEF) treatment

PEF treatment is basically an electrical stimulation with pulses of high intensity and short duration (Vorobiev & Lebovka, 2009) and is currently applied to plant cells to increase membrane permeabilization. A cell can be considered as a capacitor containing material of low dielectric constant (Raso-Pueyo & Heinz, 2010) and when electric fields are applied to it, the cell membrane amplifies these fields (Jemai & Vorobiev, 2002). PEF causes cell membranes (plasma membrane and tonoplast) to be electrically charged due to the accumulation of opposite charges on the two sides of the membrane and the movement of those charges through the membrane under the electric field. A transmembrane electrical potential is created due to potential difference across the membrane (Ho, Mittal, & Cross, 1997; Zimmermann, 1986). Cell membranes are generally very thin and do not need a strong electric field to create a transmembrane potential.

It is well known that conductivity in the membrane increases immediately after the pulsed treatment (Angersbach, Heinz, &

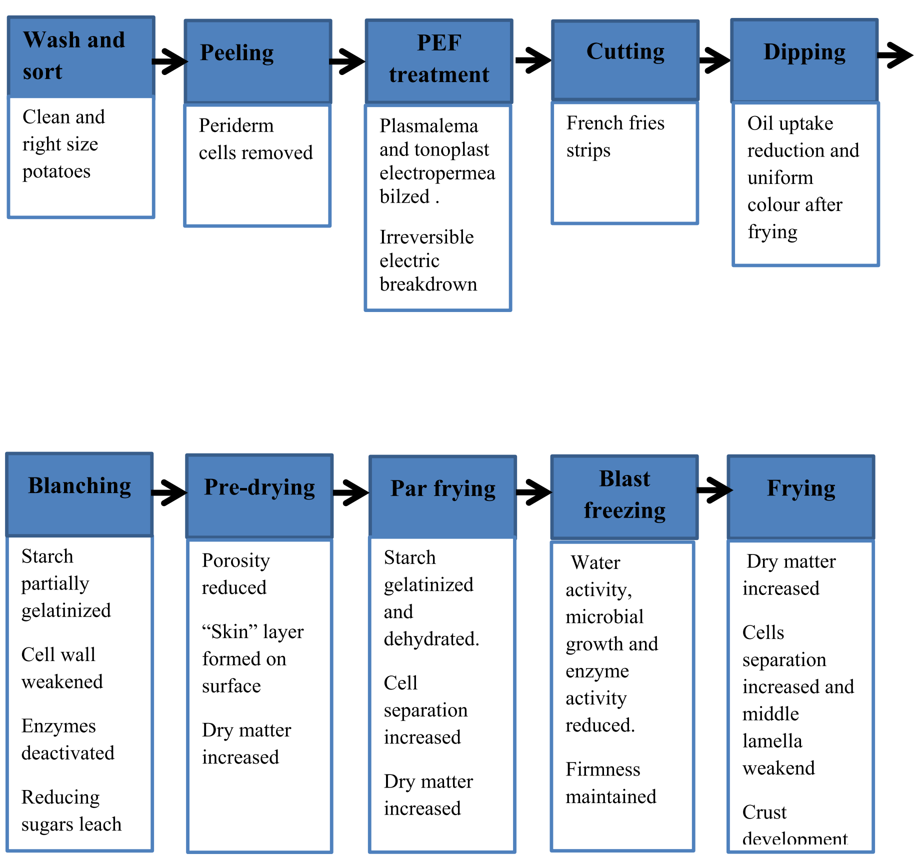

Fig. 1. French fry manufacturing process.
*PEF treatment can be performed before or after peeling.