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Predictive modelling of vegetable firmness after thermal pre-treatments and steaming

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A B S T R A C T

Texture is an important product property that strongly affects the quality evaluation of processed vegetables by consumers. The rate of texture decrease is dependent on the processing temperature and the type of vegetable. A large data set on instrumental texture measurements of carrot and broccoli was produced with different time–temperature combinations for steaming the vegetables. This data set was fitted with a fractional conversion model to describe the kinetics of texture change. Pre-treating the vegetables by steaming at 50–80 °C can increase the resistance towards softening in a subsequent steaming process. The effect of time and temperature of the thermal pre-treatment on the rate constant of softening during subsequent steaming has been evaluated. A response surface two factor interaction model could well describe this effect. Pre-treatments enable more flexibility to optimise several product properties like health, texture and colour. The predictive model presented here is a valuable tool for this multi-criteria optimisation.

Industrial relevance: A model to describe the softening of vegetable texture during steaming is presented, and the effect of pre-treatment conditions on the reduction of the subsequent softening rate is included in the model. With this model vegetable texture can be improved by predicting the optimal time and temperature of the pre-treatment. This model can be integrated into a multi-criteria optimization approach to improve other quality attributes and still give a desired texture.

1. Introduction

Texture of processed vegetables is an important quality attribute determining consumer acceptance. Firm, crunchy textures are desired by consumers since they are associated with freshness and wholesomeness (Fillion & Kilcast, 2002). Thermal processes of vegetables lead to a reduction of the firmness of the plant tissue. The mechanisms for this reduction are the loss of turgor pressure followed by degradation and solubilisation of pectins present in the cell wall (Ma & Barrett, 2002). At high temperatures the pectin beta-elimination reaction has been found to largely explain the changes in texture from a mechanistic point of view (Vu, Smout, Sila, Van Loey, & Hendrickx, 2006). Since several decades it is known that thermal pre-treatment of vegetables can result in more firmer vegetables after subsequent processing (Steinbuch, 1976). The increased stability of the texture after thermal pre-treatment is subscribed to the action of the enzyme pectin methylesterase (PME) at temperatures between 50 and 70 °C (Van Buren, 1979). By the action of PME, methanol is released from the carboxyl groups in pectin molecules. The free carboxyl groups are then available for the formation of salt bridges by divalent ions, such as Ca^{2+}, between pectin polymers. These salt bridges can strengthen the texture of the vegetable tissue. Also it has been shown that PME can firm the texture by its transacylation activity (Hou & Chang, 1996). Excessive action of PME has however also been reported to lead to softening of the texture of some vegetables due to changes in pectin conformation (Hudson & Buescher, 1986). Many studies have reported effects of thermal pre-treatments on the texture of specific vegetables. Ni, Lin, and Barrett (2005) reported the optimal pre-treatment conditions for eight different vegetables. From this study it appeared that the optimal temperatures for PME activity in the different vegetables were lower than the optimal temperatures for tissue firming. The mechanism of the effect of thermal pre-treatments is therefore not straightforward.

The effect of blanching time and temperature on the PME activity in potato and carrot has been modelled using a two iso-enzyme model (Tijskens, Waldron, Ng, Ingham, & van Dijk, 1997). The effect of pre-treatment time and temperature on the rupture stress of carrots has been described using a kinetic model based on the assumed biochemical mechanisms (Verlinden & De Baerdemaeker, 1997), although no actual enzyme activities were measured in this study. The model describes the rupture stress as the sum of three additive texture components: one dependent on the turgor pressure, one affected by heat and one resistant to heat. Of the latter two texture components, the heat susceptible one is assumed to be converted into the heat resistant one due to the PME activity. The PME activity itself and inactivation are modelled as functions of

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temperature. Although the model gives promising results there are large deviations between model and data. The authors ascribe this to the large variation in texture measurements on vegetables in combination with the small number of measurements (2–4 per time point). Vu et al. (2004) have described the effect of time and temperature of pretreatments on the kinetics of the subsequent texture loss during heating. All changes were associated with a more stable texture after the pretreatments.

Since the effect of pre-treatment on the texture of vegetables is mechanistically quite complex we propose to model this effect by a semi-mechanistic model. In this paper we present this model and apply it to the description of the loss firmness of carrots during a steaming process depending on the pre-treatment time and temperature. Given the variability of texture measurements we have conducted a large number (15) of measurements for each time point. With the obtained model pre-treatment conditions can be optimised. Also this model can be used in a multi-criteria model in which another quality attribute (e.g. content of a healthy phytochemical) can be optimised while still respecting the consumers' acceptability related to texture.

2. Material and methods

2.1. Sample preparation

Raw vegetables (broccoli and carrots) were bought at a supermarket in Wageningen (Albert Heijn). After purchase the vegetables were immediately cleaned, selected, and prepared. Leaves were removed from the carrot and the maximal diameter was measured. Approximately 90% of the carrots had a diameter between 18 and 22 mm. For the broccoli florets, the diameter of the broccoli stems needed to be wider than 8 mm and was on average between 10 and 14 mm thick.

2.2. Thermal pre-treatments and steaming

A Miele steamer oven DG 1050 was used for the pre-treatments and the subsequent steaming. The temperature could be set with increments of 5 °C between 40 and 100 °C. By using a thermocouple inserted into the core of the vegetable samples the heating up kinetics of the vegetables in the oven was analysed. Temperature and time combinations that were tested for the pre-treatments were 50 and 60 °C: 10–15–20–40–60 min, 70 and 80 °C: 5–10–15–20–40 min. Subsequent steaming was done at 100 °C for 6–8–10–12–15 min. The experimental treatments are schematically shown in Fig. 1. The samples were cooled by immersion in ice water prior to the texture measurements.

2.3. Texture analysis

The texture of carrots and broccoli was measured using the Texture Analyser (TA.XT.Plus texture analyser, Stable Micro Systems, Godalming, Surrey, UK). In a pilot study the Warner Bratzler knife was selected as being the most suitable probe, based on the differentiating power and the obtained standard deviations.

The probes were inserted perpendicular to the broccoli sample and approximately 1 cm from the leaf end of the carrot. Additional TA experiments were performed on broccoli stems. The probe was inserted perpendicular to the broccoli stem. Broccoli is a more inhomogeneous product compared to carrots; therefore, it was essential that broccoli was selected as homogeneous as possible. To overcome this "compound" stems of broccoli florets, in which two or more stems were fused into one stem, were rejected for measurement. Load cells of 5 and 50 kg were used to measure the force applied at 40% strain. The test speed was set at 1 mm/s. Sample thickness seemed to play a crucial role in texture analysis; therefore, all samples were area corrected. Texture was expressed in units of stress (N/cm^2) by dividing the force (of compression) by the probe specific area (area of the probe that touched the vegetable during 40% strain). For each time point of pre-treatment and/or steaming 15 texture measurements were done. Some outliers (<2% of entire data set) were removed from the data set based on the 3σ criteria using Design-Expert software (Stat-Ease, Inc., Minneapolis, MN, USA) this procedure was repeated one more time after removal of the identified outliers from the first selection.

3. Mathematical modelling

For modelling of the firmness data a fractional conversion model was used (Rizvi & Tong, 1997). This model describes the loss of firmness in time by:

$$\frac{d(F_t - F_\infty)}{dt} = -k \cdot (F_t - F_\infty). \quad (1)$$

In this equation F_t is the firmness (N/cm^2) at time t (minutes), F_∞ is the residual firmness after infinite treatment (N/cm^2), and k is the rate

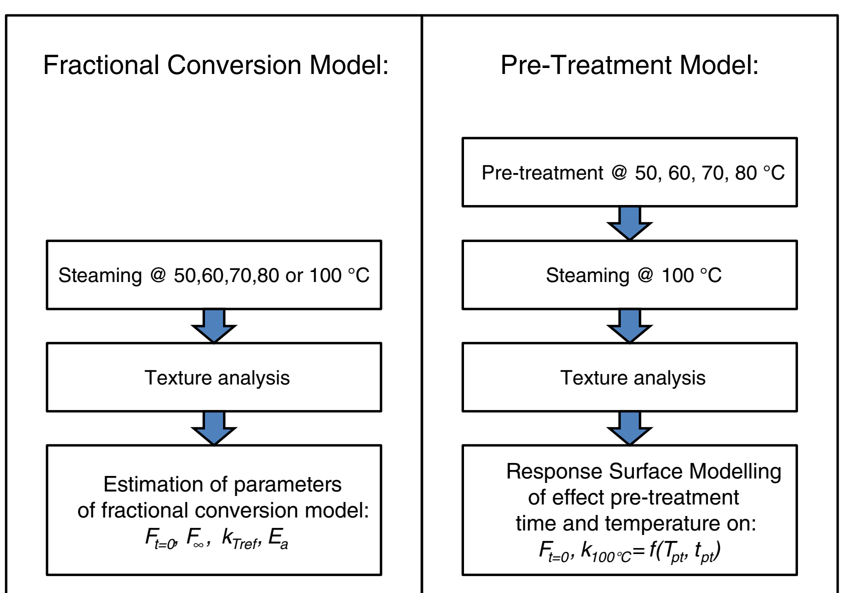

Fig. 1. Schematic representation of the experimental approaches to obtain the different modelling parameters and equations for the effect of temperature on texture changes (left) and the effect of pre-treatment conditions on the softening during subsequent steaming (right).