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Soaking behaviour and milky extraction performance of tiger nut (*Cyperus esculentus*) tubers

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Abstract

Three diameter sizes ($D < 0.5$ cm, 0.5 cm $< D < 1$ cm and $D > 1$ cm) of tiger nut (*Cyperus esculentus*) tubers growing in Cameroon (Central Africa) were soaked between 20 °C and 100 °C until water content equilibrium, and pressed for extraction of milky beverage (“horchata”). Application of Peleg model was investigated for predicting water absorption of tubers during soaking. The model showed to predict kinetics of the tiger nut soaking. The Peleg absorption rate constant (k_1) decreased as temperature increased, indicating increase in absorption rate with temperature, with a discontinuity at 60 °C. The water absorption capacity (k_2) was relatively stable, but displayed the same discontinuity at 60 °C. The extraction yield and the insoluble extract content of the milky beverage increased with temperature, while its soluble extract content decreased in the same conditions. These trends were attributed to the weakening of cell walls of the tubers at higher soaking temperature, generating high level of material transfer, as justified by the very low values of k_1 at high soaking temperature.

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Keywords: Tiger nut; Soaking; Peleg model; Milky beverage; Soluble extract; Insoluble extract

1. Introduction

Tiger nut (*Cyperus esculentus*) is a weed plant of tropical and Mediterranean regions. Its tubers are widely eaten under different forms in West and Central Africa: unprepared, soaked in water or dried and mixed with roasted groundnut (Temple, Ojobe, & Kapu, 1990). In Spain, tubers are used principally to make a milky-like beverage called “Horchata de chufa”, typical of the Valencia region (Beneyto, Varo, Guillem, & Murillo, 2000; Pascual, Maroto, SanBautista, Alagarda, & Lopez-Galarza, 2003). In Cameroon, the plant grows in the northern part of the country, where it is mainly consumed uncooked as a side dish. In spite of the abundance of the crop in the region, its valorisation is low, which may justify the low price of tubers sold on market (less than USD 0.5 kg⁻¹). In addition,

the crop has attracted very few scientific and technological interest, except some studies on its oil (Eteshola & Orasedu, 1996; Kapseu, Mbofung, & Kayem, 1997; Omode, Fatoki, & Olaogun, 1995). Development of new products from the tubers can enhance the interest in this crop. In this respect, different opportunities are offered to the crop as: source of dietary fibre, production of dairy-like beverage (horchata de chufa), use of its oil in cooking or salad preparation, production of caramel to be used as food additive, (Pascual, Maroto, Lopez-Galarza, Sanbautista, & Alagarda, 2000).

The present paper aimed at exploring the milky-like beverage potential of tiger nut tubers grown in Cameroon. Since the production of the beverage implies soaking of the tubers, the paper emphasised the behaviour of the tuber during soaking, with respect to the level of water uptake during the process.

Understanding water absorption of tuber during soaking is of practical importance since the water absorbed governs the beverage extraction and its quality. Kinetics of

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water transfer during soaking of grains has attracted many scientific investigations with use of different theoretical approaches based both on the fact that soaking process is regulated by diffusion phenomenon within the food and on the proportionality between volume change (swelling) of biological materials and the amount of water absorbed (Engels, Hendrickx, & Tobback, 1987; Hayakawa, 1974; Hendrickx, Engels, & Tobback, 1987; Nussinovitch & Peleg, 1990; Peleg, 1988; Singh & Kulshrestha, 1987). Mathematical models proposed are means of prediction and optimisation of the soaking process; they involve determination of soaking kinetics and the influence of different process variables on moisture transfer (Krokida & Marinou-Kouris, 2003).

One of the models widely used, due to its simplicity, is the one proposed by Peleg (1988), which is a two-parameter sorption equation predicting the transient moisture content (H_t) of the food material all along the soaking process (Eq. (1)).

$$H_t = H_0 + \frac{t}{k_1 + k_2 t}, \quad (1)$$

where: H_t (% DW) is the moisture content at time t ; H_0 (% DW) is the initial moisture content; k_1 ($\text{h}\cdot\%^{-1}$) is the Peleg rate constant which relates to absorption rate at the beginning of the process ($t = t_0$); k_2 ($\%^{-1}$) is the Peleg capacity constant which relates to maximum attainable moisture content ($t \rightarrow \infty$).

The model is linearised into the form

$$\frac{t}{H_t - H_0} = k_1 + k_2 t \quad (2)$$

k_1 and k_2 constants are determined from the representation of $t/(H_t - H_0)$ vs. time.

The Peleg model has been used to describe sorption processes in various foods: Chickpea (Turhan, Sayar, & Gunasekaran, 2002), dasheen leaves (Maharaj & Sankat, 2000), sago starch (Sopade & Kaimur, 1999), papaya (Palou, Lopez-Malo, Argai, & Welti, 1994).

The present work studied suitability of the Peleg model for describing water absorption of tiger nut during soaking over a wide range of temperature. The subsequent effect of the absorption on the yield of beverage extraction was evaluated.

2. Materials and methods

2.1. Source and preparation of samples

Tiger nut tubers, bought in local market (Ngaoundéré, Cameroon), were screened on a metallic sieve in order to calibrate them according to their average diameter. Two sieve sizes were used: 1 cm and 0.5 cm. The tubers were then washed with tap water to remove sands and other undesirable materials, and sun dried.

2.2. Soaking experiments

Soaking experiments, undergone according to Turhan et al. (2002), was conducted in 500 ml beakers containing 400 ml distilled water at 20, 40, 60, 80 and 100 °C. The beakers were placed in a constant temperature water bath for temperature uniformity during tests. For each experiment, 20 g of tubers, of a given diameter, were immersed in the beaker. During soaking, tubers were periodically removed, superficially dried with a tissue paper and weighed using an electronic balance (Sartorius, model LC1201S, Germany), then returned to the beaker. The experiment was terminated when tuber moisture content attained an equilibrium value, i.e., when the increment change in sample weight was less than 0.01 g. At least three experiments were conducted for every tiger nut diameter at each soaking temperature.

Moisture content of the samples at each time step (H_t) was calculated (dry weight basis) based on the increase in sample weight at corresponding time. Peleg constants were then obtained from the regression of moisture content vs. soaking time (Eq. (2)).

Peleg constants (k_1 and k_2) values obtained were used in Eq. (1) to calculate predicted values of moisture content (H_p) which were then compared to the corresponding experimental values in order to appreciate the goodness of fit of the Peleg model. The criterion used to evaluate the goodness of fit was the mean relative percentage deviation (p) between experimental data and theoretical values (Boquet, Chirife, & Iglesias, 1978; Kaymak-Ertekin & Sultanoglu, 2001; Lomauro, Bakshi, & Labuza, 1985) calculated as

$$p(\%) = \frac{100}{N} \sum_{i=1}^N \frac{|H_{ei} - H_{pi}|}{H_{ei}} \quad (3)$$

where, H_{ei} and H_{pi} are respectively experimental and predicted moisture content values. N is the number of experimental data.

The model is considered acceptable if p values are below 10% (Lomauro et al., 1985; Wang & Brennan, 1991).

2.3. Extraction of the milky beverage

At the end of soaking process, i.e. at moisture content equilibrium, the soaked tubers were removed and ground using a Blender (Robot Coupe GT 550). The paste obtained was placed in a tissue bag and the beverage extracted by pressing using a prototype press (UNATA model). The milky beverage was recuperated and weighed for the determination of extraction yield, expressed as percentage of milk obtained from tubers (dry weight basis).

In addition, the soluble and insoluble contents of the milky beverage were determined by filtering a known volume on a calibrated filter paper and drying the filtrate (solubles) and the filter paper (insolubles) in an oven at 105 °C. Soluble and insoluble extracts were expressed as g dry

extract/litre of milky beverage. Each analysis was conducted at least in triplicate and the results averaged. Analysis of variance was performed on milk extraction data, in order to find out the effect of soaking conditions.

3. Results and discussion

3.1. Kinetics of water absorption

The water absorption kinetics of tiger nut tubers at different temperatures and sizes (Fig. 1) display an increase in absorption rate as the soaking temperature increase. This phenomenon is normal since heating weakens cell walls, allowing easy penetration of water. In this respect, moisture equilibrium is reached in about 5 h of soaking at 80 °C and 100 °C, whatever the tuber size, while at room temperature, the absorption process is low and the equilibrium is reached after 40 h of soaking for small size ($D < 0.5$ cm) and medium size ($0.5 \text{ cm} < D < 1$ cm) tubers. For bigger size ($D > 1$ cm) tubers, the absorption process is continuous at room temperature and more than two days of soaking are necessary to reach equilibrium moisture content. In addition, the long soaking time at room temperature resulted in microbial contamination which affected color and taste of the product. The inconvenience was solved by changing soaking water at 12 h intervals.

The fit of Eq. (2) to absorption data showed that, at all soaking conditions, the degree of fit, as judged by the regression coefficient (r^2), is about the same. Table 1 provides the resulting Peleg constants (k_1 and k_2), r^2 and p values. The use of kinetic data to determine the goodness of fit of the Peleg model resulted in a fit with $r^2 \geq 0.90$ at almost

all soaking conditions (tuber size, temperature and time). The relative deviation between experimental and predicted data is around 4.4–4.7, which indicates that water absorption of tiger nut tubers during soaking is well described by the Peleg model.

The Peleg rate constant (k_1) decreases with the increase in soaking temperature, while the Peleg capacity constant (k_2) is around $0.02\%^{-1}$ at all soaking conditions (Table 1). Since k_1 is a constant related to mass transfer rate, the weakening of cell walls on heating increases cell permeability and results in the increase of water absorption rate by tubers. Different investigators have observed this phenomenon and attributed it to the plasticizing effect of water at gelatinisation temperature (Abu-Ghannam & McKenna, 1997; Sayar, Turhan, & Gunasekaran, 2001; Turhan et al., 2002). The temperature dependence of k_1 can be evidenced by the Arrhenius relationship (Eq. (4)):

$$\ln k_1 = \ln C_k - \frac{E_a}{R_g T} \quad (4)$$

where C_k is a constant ($\text{h}\cdot\%^{-1}$); E_a is activation energy (kJ mol^{-1}); R_g is universal gas constant ($8.314 \text{ kJ mol}^{-1} \text{ K}^{-1}$).

The Arrhenius plot (Fig. 2) exhibits a discontinuity around 60 °C, implying a structural change in the tubers at that temperature. This temperature certainly corresponds to the gelatinisation temperature of tiger nut tuber, showing that at higher soaking temperature, soaking treatment becomes cooking treatment. The low values of k_1 above the gelatinisation temperature implies that water travels faster in gelatinised material than in ungelatinised one (Turhan et al., 2002).

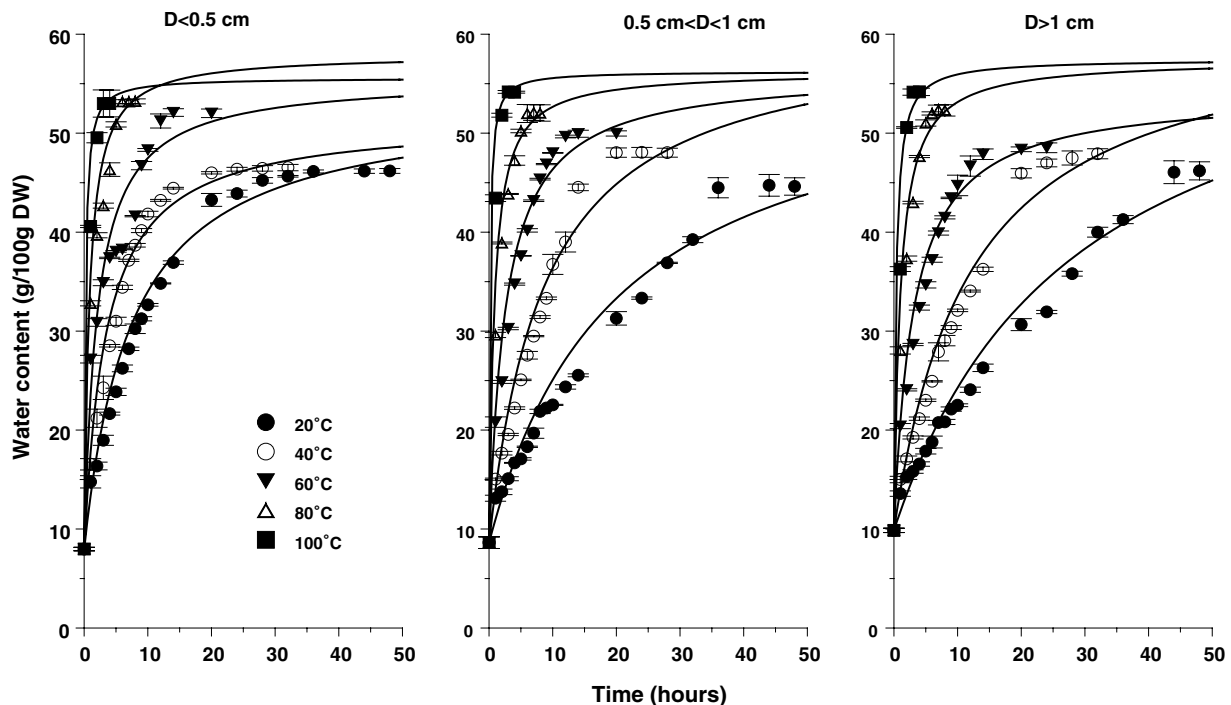
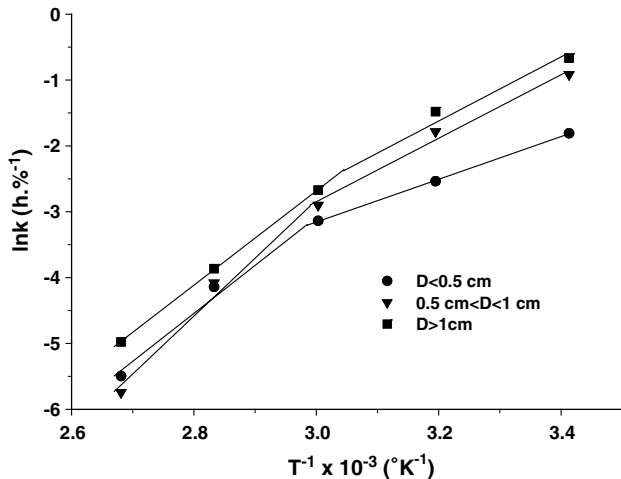


Fig. 1. Fitting of the Peleg model to water absorption kinetics of tiger nut tubers for different tuber size and soaking temperature.

Table 1

Water absorption constants and goodness of fit of Peleg model for different sizes (diameter) of tiger nut tubers soaked at different temperatures

T ($^{\circ}\text{C}$)	Diameter <0.5 cm				0.5 cm $<$ Diameter <1 cm				Diameter >1 cm			
	k_1 ($\text{h}\cdot\%^{-1}$)	k_2 ($\%^{-1}$)	r^2	P (%)	k_1 ($\text{h}\cdot\%^{-1}$)	k_2 ($\%^{-1}$)	r^2	P (%)	k_1 ($\text{h}\cdot\%^{-1}$)	k_2 ($\%^{-1}$)	r^2	P (%)
20	0.164	0.022	0.979	4.8	0.400	0.019	0.845	5.1	0.514	0.018	0.872	5.2
40	0.079	0.023	0.987	4.5	0.168	0.019	0.898	4.2	0.228	0.019	0.877	3.3
60	0.043	0.021	0.973	5.1	0.055	0.021	0.971	4.9	0.069	0.023	0.980	4.1
80	0.016	0.020	0.980	4.5	0.017	0.021	0.981	4.5	0.021	0.021	0.970	5.1
100	0.004	0.021	0.990	4.3	0.003	0.021	0.993	3.4	0.007	0.021	0.967	5.9

Fig. 2. Arrhenius plot for the Peleg rate constant k_1 during soaking of tiger nut tubers.

The relative stability of k_2 values for all soaking temperatures seems to indicate that the modification of chemical structure of tiger nut material on heating (gelatinisation) does not affect the absorption capacity of the tubers. This assertion disagrees with the experimental results exposed in Fig. 1, since the maximum absorption values obtained depend on soaking temperature; thus k_2 is supposed to vary. In fact, despite this relative stability, k_2 values change at 60 $^{\circ}\text{C}$, displaying two homogenous groups of values below and above the gelatinisation temperature. This indicates that the structural change of the tubers on heating, affects to some extent the final water content.

3.2. Milky beverage extraction

The extraction yield of the milky beverage from soaked tubers increases with soaking temperature (Fig. 3) and reaches a maximum of 30 g milk/100 g tuber (dry weight basis), whatever the size of the tubers. The insoluble extracts of the milky beverage increases significantly ($p < 0.05$) with soaking temperature and tuber size, while the soluble extracts decrease in the same conditions (Fig. 4). These trends in the dry extracts content may be attributed to the effect of soaking temperature on the physical structure of tiger nut cells. High soaking temperatures, by weakening the cell walls of the tubers, facilitates the

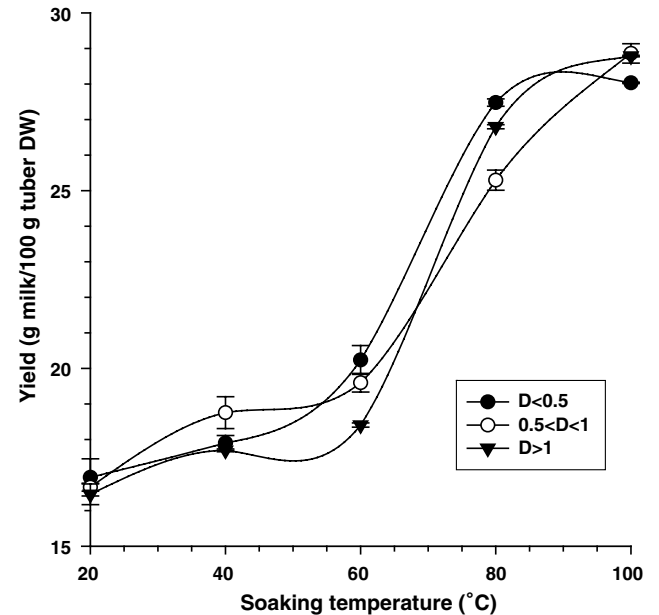


Fig. 3. Yield of tiger nut milky beverage as a function of soaking temperature and tuber size.

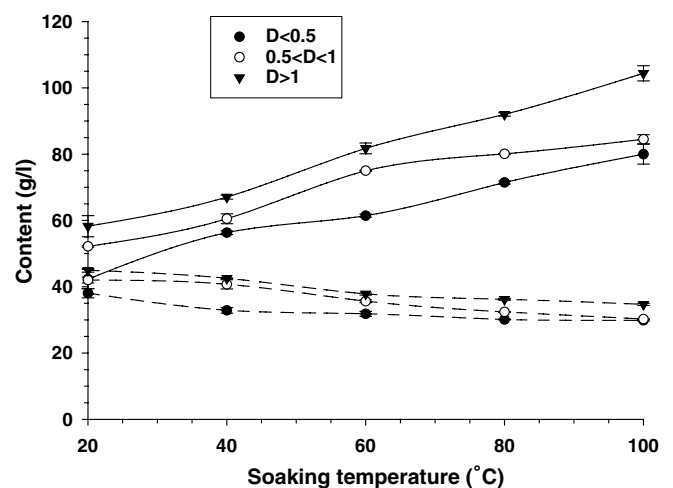


Fig. 4. Soluble (---) and insoluble (—) extract contents of the tiger nut milky beverage as a function of soaking temperature and size of the tubers.

crumbling of cells on pressing; the resulting fine particles can then pass through the filter tissue medium used, contributing to increase the insoluble content of the milky

beverage. The weakening of cell walls at higher soaking temperatures also contributes to accelerate diffusion of solubles from tubers to soaking solution. The low values of Peleg absorption rate constant (k_1) at higher temperatures, suggesting higher initial water absorption rate by tubers, is accompanied by subsequent transfer of solubles from tubers to soaking solution.

4. Conclusion

The present study has established the suitability of Peleg model to describe soaking behaviour of tiger nut tubers. High soaking temperatures accelerates the water absorption phenomenon and the beverage yield through the weakening of cell walls, but results in reduction of solubles in the milky beverage. Since heating contributes to sterilise the tubers, regarding their microbial charge (Bankole & Eseigbe, 1996; Moreno-Segui et al., 2000; Pla, Moreno, Monerri, Rodriguez, & Perez, 1999), optimising the soaking temperature effect, with regard to the microbiological and nutritional quality of the milky beverage appears as a scientific and technological issue of concern.

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