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Leaching of water soluble substances during cooking of red beets (*Beta vulgaris* L).

Udludning af vandopløselige stoffer under kogning af rødbeder (Beta vulgaris *L).*

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Summary

Diffusion coefficients for sucrose, potassium and nitrate were determined experimentally during the cooking of red beets at 100°C in a steam jacketed kettle.

The order of the diffusion coefficients was in accordance with the values for water soluble substances presented in the literature.

By mathematical modelling it is shown that the increase of the proportion of beets/water or the reuse of the cooking water for several batches may result in less use of sugar for the brine preparation and reduce the pollution.

Key words: *Beta vulgaris,* cooking, diffusion coefficients, leaching, red beets.

Resumé

Diffusionskoefficienter for sucrose, kalium og nitrat blev bestemt eksperimentelt ved brug af resultater fra analyser af kogevandet fra kogning af rødbeder i en dampgryde. De fundne diffusionskonstanter var i overensstemmelse med de værdier, som er opgivet i litteraturen.

Udludningsforløbet ved forskellige procesforløb blev vist ved anvendelse af de fundne diffusionskonstanter. Genbrug af kogevandet og forøgelse af forholdet mellem rødbeder og vand medfører lavere sukkerforbrug ved lagefremstilling samt mindre forurening.

Nøgleord: *Beta vulgaris,* diffusionskonstanter, kogning, rødbeder, udludning.

Introduction

The processing of red beets to make sliced table beets includes cooking to obtain a certain degree of softness. During the cooking sucrose, minerals and other water soluble substances are leached

and the beet pigments (betalains) also are exposed for degradation.

The purpose of this paper is to describe the leaching by mathematical modelling, by use of experimentally determined diffusion coefficients.

Materials and methods

Raw beets of the variety 'Forono' with an average diameter of 50 mm were cooked at 100°C in a steam jacketed kettle in 40 l of tap water. For each portion of 40 l water seven portions of 4 kg raw beets were cooked for 30 to 90 minutes with intervals of 10 min, respectively. After cooking of each beet portion 25 ml cooking water were frozen and stored at –25°C until analyses for sucrose, potassium and nitrate by use of an enzyme electrode system, (Radiometer 1320) an atomic absorption spectrophotometer (Unicam SP90) and a nitrate specific electrode (Orion), respectively.

The amount of leached water soluble substance in the cooking water was determined. The content of sucrose, potassium and nitrate in raw beets are averages of nine samples (Table 1). The content at infinity cooking time assuming equal concentration in the beets and the cooking water was calculated (Table 1).

Table 1. Concentration in raw beets (C_0) and equlibrium concentration (C) at infinity cooking time.
Indhold i rå rødbeder (C_0) og ligevægtskoncentration (C) ved uendelig kogetid.

		C_0	C
Sucrose	g/l	93	8,5
Potassium	mg/l	2913	265
Nitrate	mg/l	1661	151

Averages of 10 cooking series were used to calculate the diffusion constants (D). The methods used are described in the literature (6, 8). After calculation of the constants (k) using equation (1) the diffusion constants D were calulated from equation (2) using the q-value from equation (3) (t=cooking time, a=beet radius, L=liquid, F=beets, α = L/F).

$$\log((C_\infty - C)/(\infty) = k\,t \qquad 1)$$

$$d = ka^2/q^2 \qquad 2)$$

$$-\alpha q J_0(q_n) = 2J_1(q_n) \qquad 3)$$

J_0 and J_1 are Bessel functions of order zero and one respectively. The dimensionless concentration (E) in equation (4) is related to the diffusion constant by equation (5).

$$E = \frac{C - C_w}{C_o - C_w} \qquad 4)$$

$$E = \sum_{n=1}^{n=\infty} \frac{4}{R_n^2} \; \mathrm{Exp}\left[-\frac{D}{a^2} R_n^2\right] \qquad 5)$$

C concentration in the beets at the time t
C_0 concentration in the raw beets
C_w concentration in the cooking water
R_n roots of the Bessel function

Results

Values of k were of the order $2 \cdot 10^{-5}$ to $8 \cdot 10^{-5}$ and the calculated diffusion constants were of the order $0{,}5 \cdot 10^{-9}$ to $2 \cdot 10^{-9}$ m²/sec (Table 2).

Table 2. Values of (k), correlation coefficients (r), and diffusion constants (D).
Værdier af (k), korrelations koefficienter (r), og diffusionskonstanter (D).

	k min^{-1}	r	D m^2/sec
Sucrose	8,19E-5	0,954	$1{,}7 \cdot 10^{-9}$
Potassium	3,49E-5	0,992	$0{,}7 \cdot 10^{-9}$
Nitrate	2,25E-5	0,948	$0{,}5 \cdot 10^{-9}$

Equation (5) was used for modelling of the leaching of sucrose at different processing conditions. After calculation of (E) using the first ten roots of the Bessel function and $D = 1{,}7 \cdot 10^{-9}$ m²/sec the percentage loss of sucrose was calculated. The results from simulating cooking of up to twenty batches of beets in two volumes of water for 30, 60 and 90 minutes was calculated (Fig. 1).

Percentage sucrose leached from the fifth batch was calculated for increasing volumes (f) of water (Fig. 2).

Discussion and conclusion

The diffusion constants of the order $0{,}5 \cdot 10^{-9}$ to $1{,}7 \cdot 10^{-9}$ m²/sec are in accordance with the values

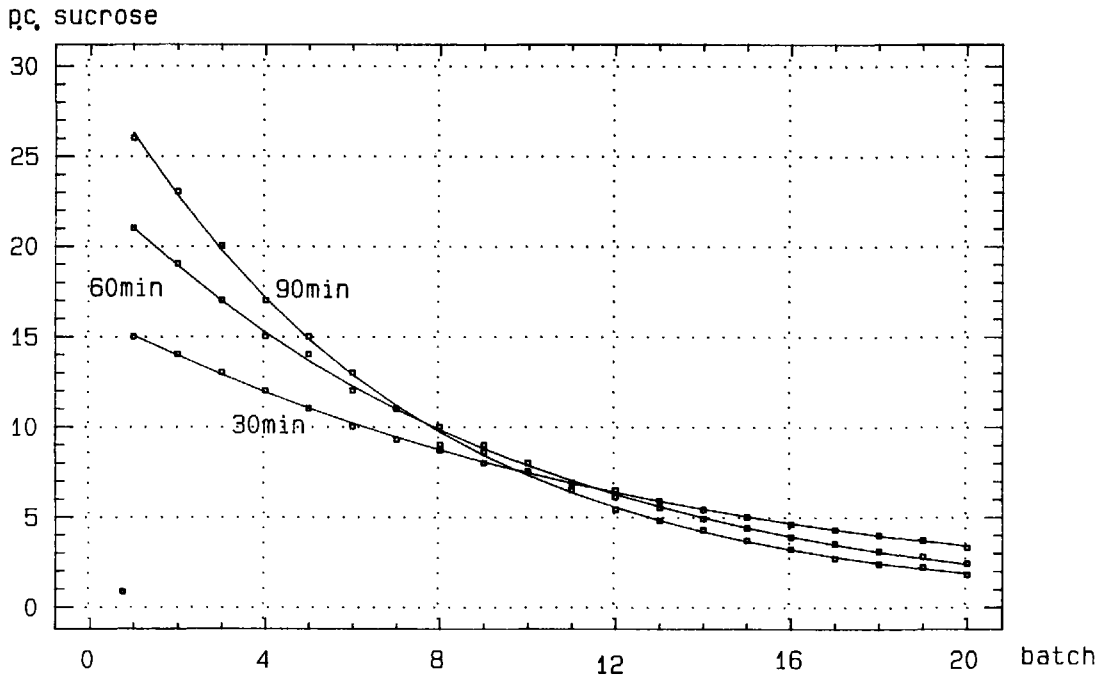

Fig. 1. Calculated percentage losses of sucrose during cooking of beets in two volumes of water.
Beregnet procent sucrosetab ved kogning af rødbeder i to volumen vand.

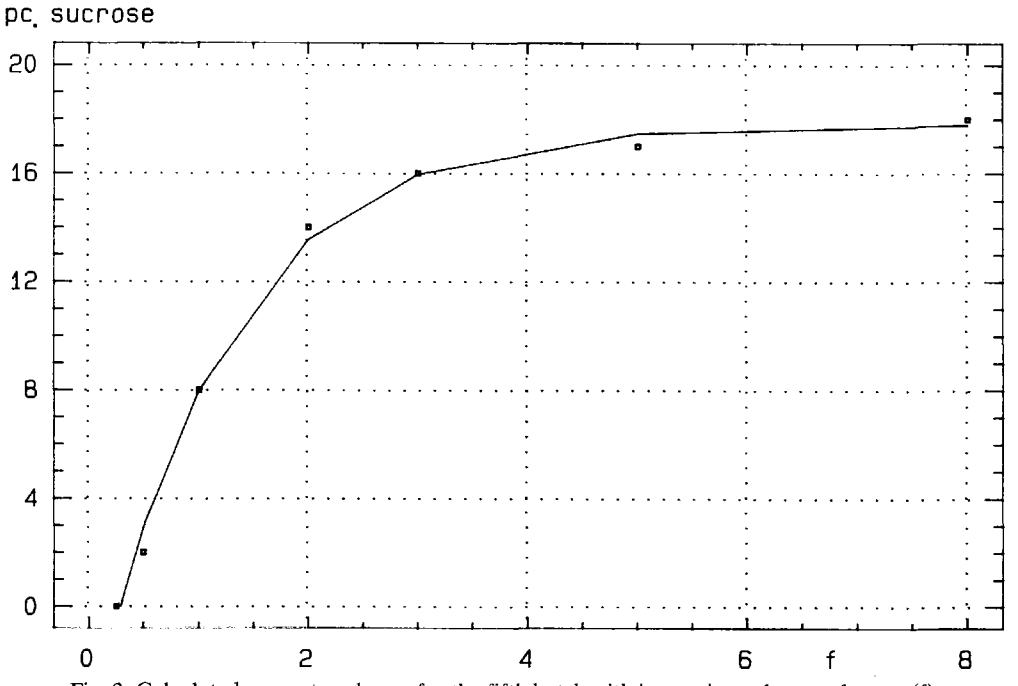

Fig. 2. Calculated percentage losses for the fifth batch with increasing volumes of water (f).
Beregnet procent sucrosetab for femte portion rødbeder ved kogning i stigende volumen vand (f).

for sugars and water soluble vitamins presented in the literature (1, 2, 3, 4, 5, 7, 9). The leaching decreases when the cooking water is reused (Fig. 1). An increase of the cooking time results in higher losses for up to about 10 batches. The percentage losses are only a few per cent at 20 batches. The result of an increase of the proportion beets/water is less leaching. This can be obtained by steam cooking or spray cooking with reuse of the water. The main results of the decreased leaching are reduction in the use of sugar for the brine and less pollution.

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