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Effects of sowing date, harvest time and storage on raw red beet quality and processing requirements

Virkning af såtid, høsttidspunkt og lagringstid på råvarekvalitet og forarbejdningsparametre for rødbede

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Summary

Growth of beets depends on the heat units. To obtain raw beets of the correct diameter for processing sampling in the field and determination of beet diameter distribution may be recommended. The contents of pigments, sugar and water insoluble substances increase with later sowing and harvest. The contents of sugar and water insoluble substances increased with later harvest of beets. During the cooking pigments are degraded according to first order reactions. Sowing date or storage had no effect on the rate constants for pigment degradation. Firmness (f) changes during the cooking according to the equation (f-kl)/kl =k2-k3t) allowing calculation of activation energy by use of the Arrhenius equation. To obtain organoleptically acceptable firmness a cooking time of 60–70 minutes is required. To obtain products with equal firmness it was necessary to increase the cooking time by later sowing, later harvest or after storage. The increase of the cooking time is correlated to the content of water insoluble substances. Peeling losses increases with later harvest.

By programmed growing to match harvest and processing it is possible to avoid the increasing cooking time originating from the storage.

Drained weight of the products depended on the cooking time and the cooking temperature.

During the normal pasteurization changes of firmness and pigment content are rather small compared to the changes during the cooking.

Key words: *Beta vulgaris,* betanine, firmness, harvest date, processing, quality, red beets, sowing date, vulgaxanthine.

Resumé

Rødbeders vækst er korreleret med varmesum. Det er formentlig i nogen grad muligt at beregne rødbeders vækst ved anvendelse af varmesum, men der vil altid være behov for at følge rødbedernes vækst ved måling af diameter i den sidste del af vækstperioden. Efter senere såning/optagning var rødbederne mindre (kortere), men indeholdt mere betanin, vulgaxanthin, sukker og vanduopløseligt tørstof. Tilsvarende resultater blev fundet efter senere optagning af rødbeder sået på et givet tidspunkt. Under kogning nedbrydes farvestof-

ferne efter reaktioner af første orden.

Vulgaxanthin, som ikke kræver ilt for at blive nedbrudt, forsvinder i et omfang på 80–90 pct. ved normal kogning. Derved bliver rødbederne mindre violette. Betaninet, der kun nedbrydes i et omfang på 15–20 pct. ved normal kogning, kræver ilt for at kunne nedbrydes. Under kogning ændres fastheden (f) efter en funktion af følgende type (f-kl)/kl=k2-k3t, hvor ki er konstanter og t er kogetiden. Der opnås en passende mørhed efter kogning i 60–70 minutter. For at opnå ensartet fasthed skal rødbeder, der er optaget sent eller lagret, koges længere. Denne forøgelse i kogetiden er korreleret med forøgelsen i indhold af vanduopløseligt tørstof. Skrælletabet forøges også ved senere høst. Kogning i længere tid ved stigende temperatur bevirkede en forøgelse af drænet vægt for de færdige produkter.

Ved at gennemføre programmeret dyrkning og anvende kort lagringstid kan disse ulemper undgås.

Under normal pasteurisering sker der kun ganske beskedne ændringer i farvestofindhold og af fastheden.

Nøgleord: *Beta vulgaris,* betanin, forarbejdning, høsttid, kvalitet, rødbeder, såtid, tekstur, vulgaxanthin.

Introduction

The industrial processing of red beets in Denmark are carried out in the period from August to January. This makes it possible to saw and harvest beets over a longer period and it may be necessary to store the raw beets.

The aim of this experiment was to study the effect of sowing date, harvest time and storage on raw red beet quality and on processing requirements.

Materials and Methods

Field experiments

In two field experiments at the Institute of Vegetables beets of the variety 'Forono' were grown at a distance of 50 cm between the rows with 3 plots of 32 m^2 for each sowing date. Irrigation, fertilizing, weed control and pest control were carried out as normal for red beets to obtain optimum growth.

In field experiment 1 beets from the sowing dates 1 May, 20 May, 17 June and 1 July were harvested on 14 August, 17 September, 31 October, and on 31 October, respectively.

From the 1 August the beet diameter of 20 beets from each of the three field plots were measured weekly with a slide gauge and related to heat units (U), calculated from minimum and maximum temperatures (°C):

$$U=\Sigma((Cmin+Cmax)/2-4,5) \qquad 1)$$

After harvesting and weighing all the beets from the three plots were mixed and size graded and samples of the size 40 to 59 mm in diameter were stored. Lots were processed after storage for one week, one month and two months.

In experiment 2 with sowing date 6th of June beets were harvested on 5 September, 19 September, 3 October, 17 October and on 31 October. Size distribution in six classes of diameter were determined after three harvests. Beets with a diameter of 40–59 mm were used for processing except in one case where beets of three size classes were cooked. Lots of beets were cooked after storage for one day and then every forthnight for 3 months. After cooking the beets were cut to cubes (1=6.8 mm).

Storage

Raw beets were stored in a cold storage room at 0–3°C and RH 98 p.c. Products of red table beets were stored in a cold storage room at 12°C for 2 months.

Unit operations

With the aim to determinate the effect of the cooking temperature a fully factorial experiment with five cooking temperatures and five different cooking times was carried out. The beets were cut to cubes (1=6.8 mm).

A second fully factorial experiment with pasteurizing of packed beets at six temperatures and five periods of holding time was carried out with the aim of investigating the effects on the product quality. The beets were cooked for 45 minutes at 96°C and then sliced (slice thickness 6.8 mm).

Sampling

All the beets were washed immediately after harvest. Before cooking the beets in experiments with unit operation parameters or from different sowing/harvest dates lots of 2 or 3.5 kg, respectively were obtained by taking beet by beet from the earlier mixed lots.

Raw beets were cut to cubes (1=6.8 mm) and a sample of one kg was frozen and stored at –25°C until analyses.

Cooking and packing

The raw beets were cooked in a steam jacketed kettle with 40 liter of tap water heated to the cooking temperature. Cooked beets were cooled in tap water (13°C) peeled in a rod washer, cut to cubes or sliced and three 580 cm^3 glasses were packed with 350 or 380 g beet material and 250 or 200 g (experiment 2 and 1 respectively) of brine heated to 80°C. The brine contained 36.6 p.c. sucrose, 2 p.c. acetic acid, 2 g/l sodium benzoate and 2 g/l potassium sorbate.

The peeling loss was determined by weighing before and after the cooking. Unless specified otherwise pasteurization was carried out in a water bath at 80°C for 20 minutes. The glasses were cooled for 5 minutes in a water bath at 60°C and then in a cold water bath (13°C) for 30 minutes. All the products were stored in a cold storage room at 12°C for 2 months to allow equilibrium to be established.

Industrial processing

With the aim of comparison with industrial processed products sampling were carried out on four Danish factories. During 2 hours of normal processing 6 samples were taken. The samples consisted of 4 kg raw beets, 4 kg cooked beets, 4 kg sliced beets and 6 glasses of the pasteurized products. Raw, cooked and sliced beet were cut to cubes and samples of 1 kg were frozen and stored at –25°C. The pasteurized products were stored in a cold storage room at 12°C.

Methods of analyses

Drained weight was determined after draining for 3 minutes on a sieve (ASTM II, mesh 7, aperture 2.8 mm).

The products (brine + beets) or 250 g raw beets and 250 gram destilled water were treated for 2 minutes in a Waring blender. Soluble dry matter (RT) was determined on the filtrate from the blended samples. 50 g of the blended samples were weighed on dried filters (S&S 520S, 185 mm) and washed with 100°C warm destilled water until complete removal of the betanine. The amount of water insoluble substances (WIS) were determined by weighing of the filters after drying for 18 hours at 80°C.

Processed beets were analyzed for firmness using an Instron apparatus (Food Tester Model) equipped with a Kramer-shear cell. Maximum force (kg) with 100 gram of beets in the cell and a piston velocity of 20 cm/min were registered.

Samples of products with different firmness were rated for softness (P) by four panelists at five sessions using scores from zero to ten. At each session six samples were evaluated.

Four gram of blended sample were diluted to 50 ml with water. The filtrate was analyzed for pigment concentration as described by *Nilsson* (17).

The betalains (betanines and vulgaxanthines) in filtrates from blended samples of raw beets or products were separated on a column (length 28 cm diameter 1.2 cm) of polyamid DC 6 (MN) eluted (1.4 ml/min) with 0.1 molar citrate buffer (pH 5.6). One peak of vulgaxanthines and two peaks of betanines were obtained. After analyses for betanine or vulgaxanthine using the method of *Nilsson* (17) samples with different concentrations of pigments were prepared.

Absorbance (A) at 300–650 nm with steps of 5 nm were determined and the results were used for the calculation of the concentration factors P1 and P2 by iteration using equation (2) given by *Saguy et al.* (21), (log=log base 10):

$$A=(P1\cdot M)/[(R\text{-}N)\cdot S1\cdot(2\,\pi)^{0.5}]\cdot EXP(K1)+(P2\cdot M)/[(R\text{-}N)\cdot S2\cdot(2\,\pi)^{0.5}]\cdot EXP(K2) \qquad 2)$$

$$K1=(-\log(R\text{-}N)-\log(R\text{-}G1)-S^2/M^2/2S^2 \qquad 3)$$

$$K2=(-\log(R\text{-}N)-\log(R\text{-}G2)-S^2/M^2/2S^2 \qquad 4)$$

M=0.4343, R=650 nm, N=300–600 nm, S standard deviation, G1=538 nm, G2=476 nm. The iteration criteria was the minimum of the squared sum of differences between observed and calculated absorbance. Values of P1 and P2 from solutions with known concentrations of betanine and vulgaxanthine were applied to calculate the constants in equation (5) and (6) by a linear regression analysis (r=1,000):

$$\text{mg betanine/l} = 0.0854 \cdot P1 \qquad 5)$$

$$\text{mg vulgaxanthine/l} = 0.1109 \cdot P2 \qquad 6)$$

Modelling

Rate constants (k3) for pigment degradation were calculated using equation (7) with concentration (C) as dependent and process time (t) as independent variable (log=log base e and ki=constants):

$$\log(C) = k2 - k3t \qquad 7)$$

The relation of firmness (f) to processing time could be expressed by equation (8):

$$\log((f-k1)/k1) = k2 - k3t \qquad 8)$$

or

$$f = k1 + k1(EXP(k2+k3t)) \qquad 9)$$

Equation (7) was solved by linear regression and equation (9) by iteration.

Activation energy Ea was calculated by use of the Arrhenius equation (10) where the gas constant R=1.987 cal/°K mole and S is the frequency factor:

$$\log(k3) = -Ea/RT + \log S \qquad 10)$$

Analyses of variance or linear regression were carried out as described in the literature (6).

Results

Beet growth

Average beet diameter of the growing beets increased with heat units (Fig. 1). The growth rate was lower after late sowings.

The yield of beets in field experiment 1 decreased by late sowing (Table 1).

Most of the beets from experiment 1 had a size of 40 to 59 mm (Table 2). These beets were used for the main part of the cookings.

Composition of raw beets

In beets from different sowings and harvests the pigment content increased with later sowing/harvest (Table 3). The pigment contents from the experiment with one sowing date and five harvest dates were constant (Table 4).

The content of sugar (RT) and WIS increased with later harvest (Table 3 and 4). For beets from field experiment 1 the WIS content was 2.6, 2.8

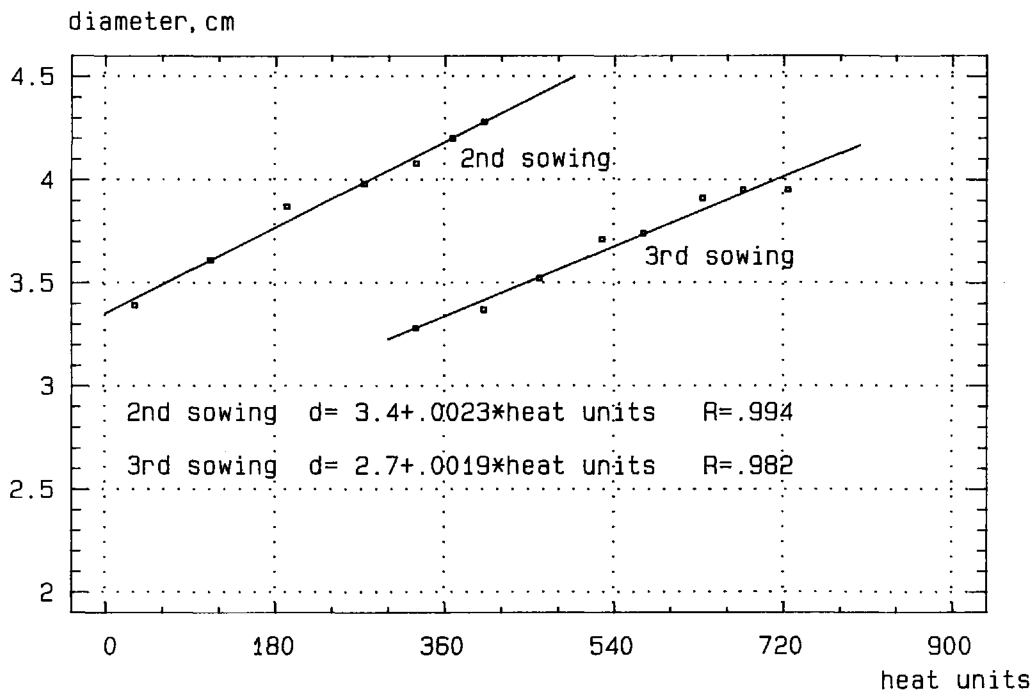

Fig. 1. Average beet diameter and heat units for two sowings (field experiment 1).
Rødbedediameter og varmeenheder for to såtider (markforsøg 1).

Table 1. Yield of beets t/ha (field experiment 1).
Udbytte af rødbeder (markforsøg 1).

Sowing, date *Såtid, dato*	Harvest, date *Høsttid, dato*	t/ha *t/ha* Size, mm *Størrelse, mm*			
		< 40	40–60	> 60	total
05.01	08.14	2	42	9	53
05.20	09.17	6	49	14	69
06.17	10.31	8	43	3	54
07.01	10.31	6	28	1	35
LSD		2	9	2	

Table 2. Percentage yield distribution of five size classes (field experiment 2).
Procentfordeling af udbytte på størrelsesklasser (markforsøg 2).

Harvest, date *Høsttid, dato*	Yield, percentage *Udbytte, procent* Size, mm *Størrelse, mm*				
	< 35	35–39	40–49	50–59	60–78
09.05	11	22	36	29	2
10.03	7	17	50	26	0
10.31	4	12	55	23	6

and 3.1 p.c. (LSD= 0.3) after storage for one week, one month and 2 months, respectively.

Peeling losses

Using length (h), diameter (d) and beet weight (g) the surface area (O) was calculated.

$$O = \pi dh/g$$

The average (350 beets) surface area was 1 cm^2/g.

The peeling losses were 10, 11, 15 and 15g/100 g at harvest 1 to 4 in field experiment 1. By combining these two pieces of information the peeling depth were calculated to be from 1 to 1.5 mm.

Cooking and pasteurization

Analyses for pigment concentration using the methods of *Nilsson* (17) and *Saguy et al.* (21) gave similar results for betanine and for vulgaxanthine if the content of pigment was above 50 mg/100 g. At lower vulgaxanthine content differences appeared (Table 5). During the cooking vulgaxanthine was degraded. The rate constant was found to be 0.0346/min (r= 0.98).

Betanine degradation followed a first order reaction. For field experiment one and two the average rate constants were found to be 0.00218/min and 0.0026/min. During pasteurization the degradation rate constant of betanine was found to be 0.0166/min at 95°C. During pasteurization at temperatures of 70–85°C betanine degradation was of no practical order.

The rate of firmness change during the cooking at four temperatures were different (Fig. 2). The activation energy was calculated to be 24.8 kcal/mole. The relationship between scores for softness (P) and firmness (f) can be expressed by *Stevens* law (equation 11) where a and b are constants (fig. 3).

$$P = a \cdot f(EXP(b)) \qquad 11)$$

Table 3. Length, diameter, weight of beets, sucrose content and p.c. WIS at harvest. (field experiment 1).
Rødbedernes længde, diameter, vægt samt indhold af sucrose og vanduopløseligt tørstof ved høst. (markforsøg 1).

Sowing, date *Såtid, dato*	Harvest, date *Høsttid, dato*	Length cm *Længde cm*	Diam. cm *Diam. cm*	Weight g/beet *Vægt g/stk.*	Betanine mg/100 g *Betanin mg/100 g*	Vulgaxanthine mg/100 g *Vulgaxanthin mg/100 g*	RT g/100 g *Sucrose g/100 g*	WIS g/100 g *WIS g/100 g*
05.01	08.14	15	4.3	223	106	64	8	2.4
05.20	09.17	13	4.3	189	119	86	11	2.8
06.17	10.31	12	4.1	163	116	115	10	2.9
07.01	10.31	12	4.2	155	125	100	9	2.8
LSD					7	7	2	0.4

Table 4. Betanine, vulgaxanthine, soluble dry matter and water insoluble substances in raw beets (field experiment 2).
Betanin, vulgaxanthin, opløseligt tørstof og vanduopløseligt tørstof i rå rødbeder (markforsøg 2).

Harvest, date *Høsttid, dato*	Betanine mg/100 g *Betanin mg/100 g*	Vulgaxanthine mg/100 g *Vulgaxanthin mg/100 g*	RT g/100 g *RT g/100 g*	WIS g/100 g *WIS g/100 g*
09.05	110	77	12	2.8
09.19	105	90	12	2.9
10.03	106	90	12	3.2
10.17	104	94	14	3.3
10.31	105	90	14	3.2
LSD	8	9	1	0.1

Table 5. Content of betanine and vulgaxanthine in beets cooked at 96°C.
Indhold af betanin og vulgaxanthin i rødbeder kogt ved 96°C.

Method *Metode*	Cooking time, min *Kogetid, min.*					
	15	30	45	60	75	90
	mg betanine/100 g *mg betanin/100 g*					
Nilsson (17)	113	122	118	110	106	111
Saguy et al. (21)	111	122	118	110	106	111
	mg vulgaxanthine/100 g *mg vulgaxanthin/100 g*					
Nilsson (17)	47	42	33	26	21	20
Saguy et al. (21)	43	36	26	13	8	3

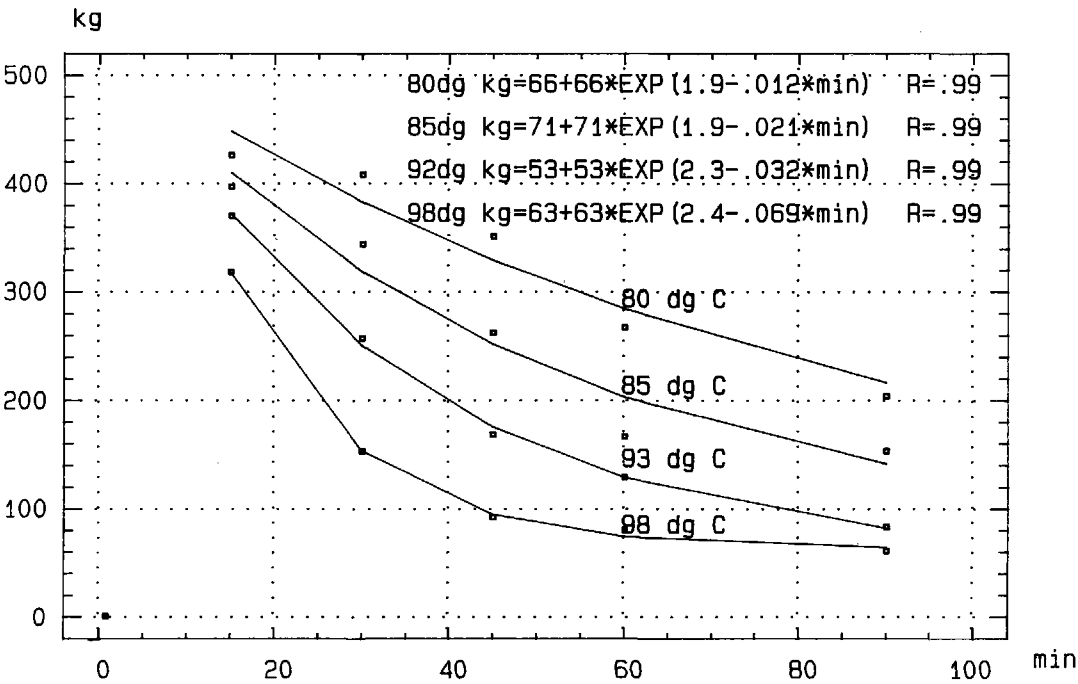

Fig. 2. Effect of cooking on firmness at four temperatures.
Fasthedsændring under kogning ved fire temperaturer.

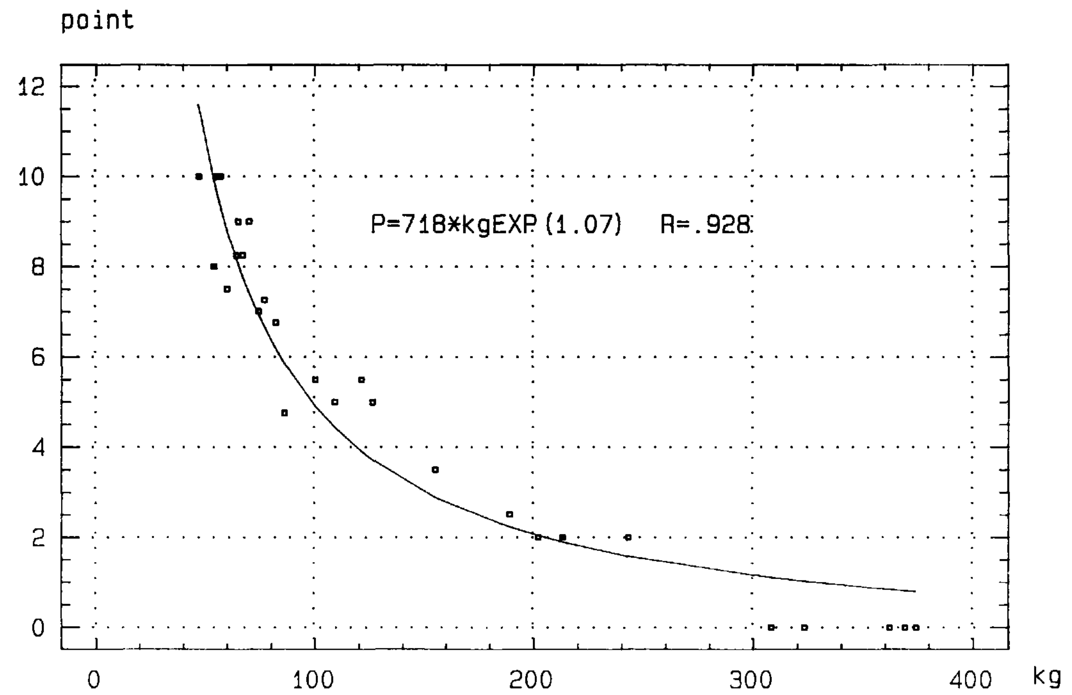

Fig. 3. Scores (P) for softness as a function of firmness (kg).
Karakter (P) for mørhed som funktion af fasthed (kg).

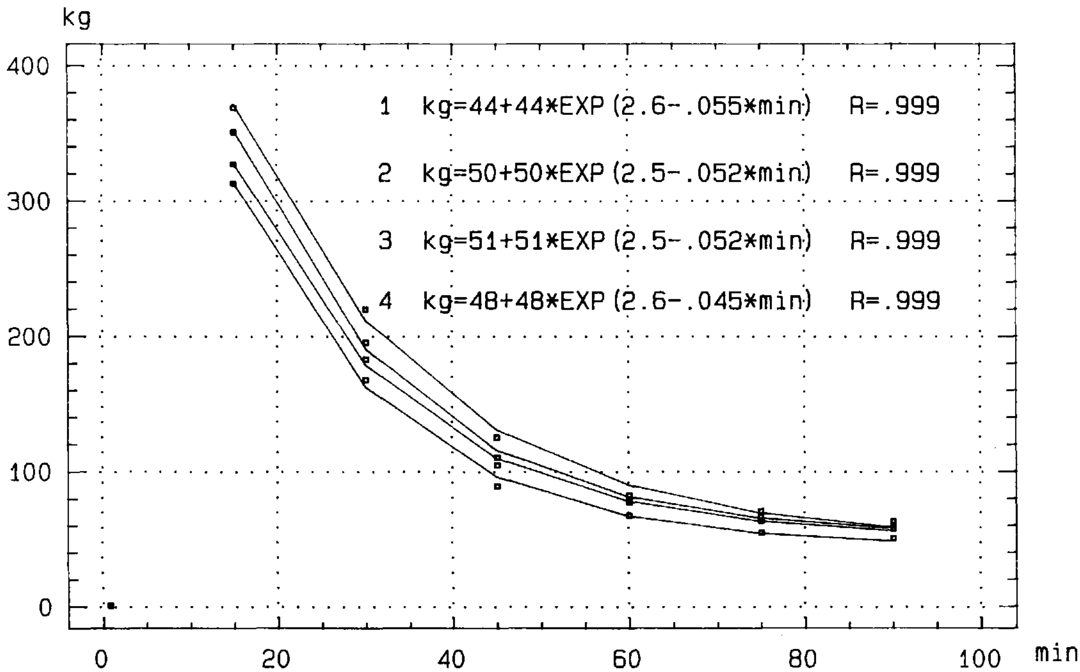

Fig. 4. Effect of cooking on firmness for beets from four harvest dates (field experiment 1).
Fasthedsændring under kogning af rødbeder fra fire høsttider (markforsøg 1).

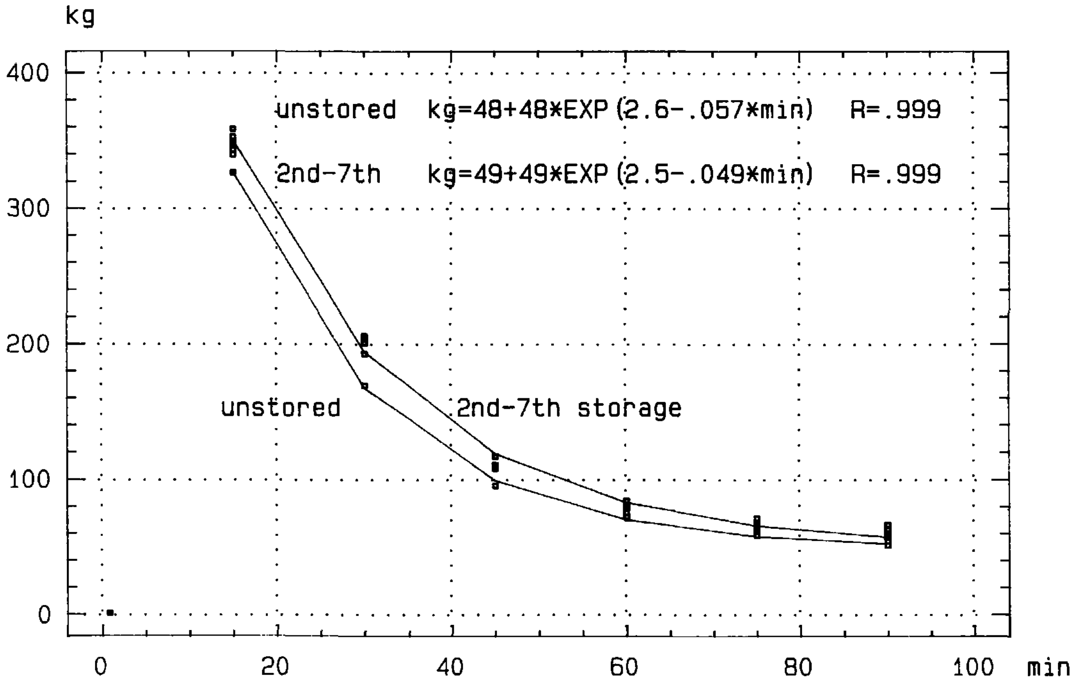

Fig. 5. Effect of cooking on firmness for beets stored one day and until 3 months (field experiment 2).
Fasthedsændring under kogning af rødbeder lagret 1 dag og indtil 3 måneder (markforsøg 2).

Equal firmness of beets from four harvest dates were obtained after a rather long cooking time (Fig. 4). Storage of raw beets had an effect on firmness after a certain time of cooking (Fig. 5).

At later harvest or after storage for 1 month or more the cooking time has to be prolonged in order to obtain equal firmness (Table 6).

Table 6. Cooking time to obtain a product firmness of 75 kg (field experiment 2). A. Not stored. B to F. Storage for 0.5 to 5 months.
Kogetid til en produktfasthed på 75 kg (markforsøg 2). A. Ikke lagret. B-F. Lagret i 0,5 til 5 måneder.

Harvest, date *Høsttid, dato*	Min *Min.*	Storage *Lagring*	Min *Min.*
09.05	54	A	56
09.19	61	B to F	65
10.03	63		
10.17	71		
10.31	69		
LSD	4		4

Similar results appeared by calculations on firmness changes for beets in field experiment 1 (Table 7). The reason for this may be the increasing content of WIS as mentioned earlier.

The cooking time increases with increasing beet diameter if equal firmness has to be obtained (Fig. 6).

Firmness may decrease further during pasteurization if cooking time has been short. At pasteurization temperatures of 70–85°C no change of firmness occured.

Table 7. Cooking time to obtain product firmness of 75 kg (field experiment 1).
Kogetid til en fasthed på 75 kg (markforsøg 1).

Harvest, date *Høsttid, dato*	Min *Min.*	Storage *Lagring*	Min *Min.*
08.14	56	1 week	57
09.17	63	1 month	61
10.31	60	2 months	69
10.31	61		
LSD	3		3

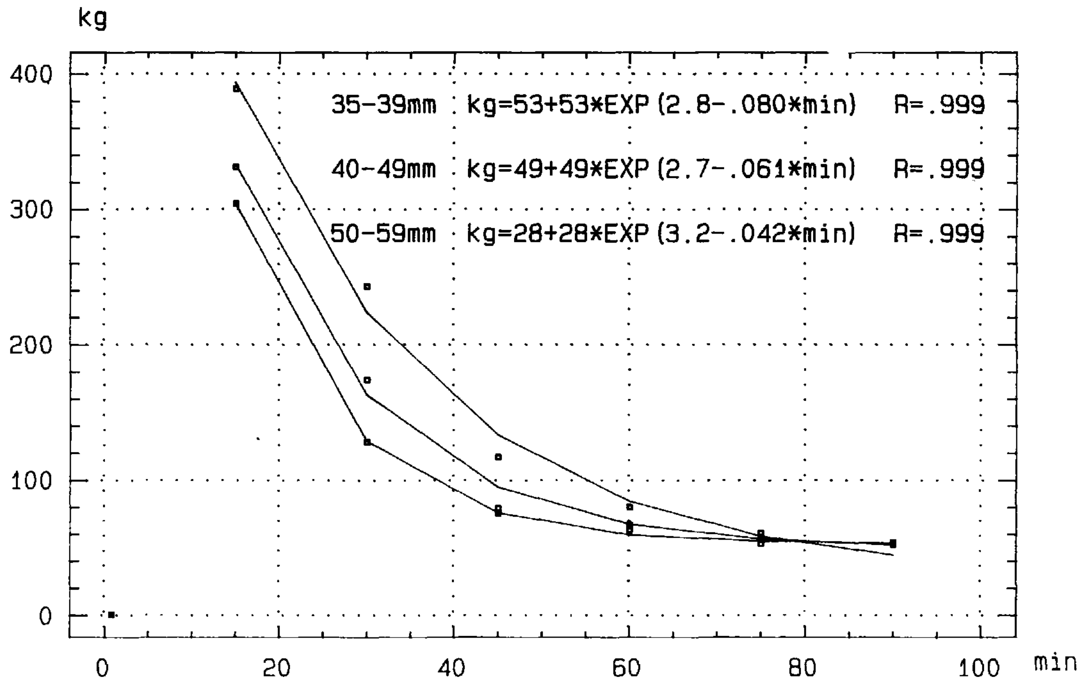

Fig. 6. Effect of cooking on firmness of beets from three size classes.
Fasthedsændring under kogning af rødbeder fra tre størrelsesklasser.

Drained weight increased with the cooking time and cooking temperature (Table 8). The maximum yield of 350 g of cooked beets was 394 g product or 13 p.c. increase. The main reason is a brine density above 1. Drained weight increased about 4 p.c. during pasteurization at 95°C. At temperature range of 70–85°C the drained weight remained constant.

Industrial processing

During industrial processing of red table beets changes occur (Table 9). The increase of RT after pasteurization is a result of brine uptake.

Discussion

By observation of the beet growth it is possible to obtain a high percentage of beets of a certain size. The beet growth depended on heat units (Fig. 1), but more experience is necessary to develop programmed growing. A low yield can be obtained after late sowing (Table 1). Most of the beets had a diameter of 40–60 mm (Table 1 and 2). After late sowings the beets are smaller because of a shorter beet length. The reason of increasing betanine content with later sowings may be less »mature« beets which normally have a higher content of betanine (9, 15, 16, 17). For beets sowed at one date and harvested at different dates the pigment content was constant, but the RT content and p.c. WIS increased (Table 4). The reason for increasing p.c. WIS after late harvest may be a higher content of cellulose and lignin because of secondary cell wall growth.

Table 8. Effect of cooking on drained weight.
Virkning af kogning på drænet vægt.

°C *°C*	Cooking time, min *Kogetid, min*					Average *Gns.*
	15	30	45	60	90	
75	336	350	349	354	365	351
80	341	347	356	369	369	356
85	348	355	366	375	375	364
92	348	367	376	381	378	370
98	362	384	386	387	394	383
LSD						5

Table 9. Average values of soluble dry matter (RT) water insoluble dry matter (WIS), betanine (B), vulgaxanthine (V), and firmness (kg) for beets and products from three industrial processing lines.
Gennemsnit af opløseligt tørstof (RT) vanduopløseligt tørstof (WIS), betanin (B) vulgaxanthin (V) og fasthed (kg) for rødbeder og produkter fra 3 industrivirksomheder.

Processing industry *Virksomhed*	Product *Produkt*	RT p.c. *RT pct.*	WIS p.c. *WIS pct.*	B mg/100 g *B mg/100 g*	V mg/100 g *V mg/100 g*	kg *kg*
1	raw	11	3.1	88	93	
	cooked	11	2.1	70	29	
	sliced	11	2.1	67	30	
	pasteurized	16	2.1	71	14	96
2	raw	12	3.2	106	98	
	cooked	12	2.1	86	36	
	sliced	12	2.1	78	42	
	pasteurized	19	2.1	82	17	77
3	raw	11	2.9	101	82	
	cooked	11	2.0	69	27	
	sliced	11	2.0	65	29	
	pasteurized	19	2.0	61	15	67
LSD		0.4	0.04	6	6	7

Because of disappearance of the peak of vulgaxanthine *Nilssons* method are not applicable at low concentrations of vulgaxanthine (Table 5). HPLC may also be applied to analyses for betalains (24).

The sugar content may decrease during storage (28). Optimum storage temperature for beets is 4°C (5, 28).

Degradation of betanine followed a first order reaction but the rate constants found in the above described experiments were low compared to rate constants for betanine in solutions (2, 10, 18, 19, 21, 22, 30). The reason is probably a low content of oxygen in the beets. Presence of oxygen increases the betanine degradation (1, 3, 8, 31), but not the vulgaxanthine degradation (27). The activation energy for betanine degradation (24.8 kcal/mole) is found to be within the published range from 10 to 31 kcal/mole (10, 21, 22, 32). During the betanine degradation betalamic acid and cyclodopa-5-glycosid are the first degradation products (8, 12, 25). The effect of the cooking time on the firmness (Fig. 2) and the calculated activation energy were similar to earlier results (7). The increasing firmness by storage (Fig. 5) is contrary to the results presented in the literature (20, 26).

Scores for softness decreased by decreasing firmness until 50 to 60 kg (Fig. 3), but the normal firmness for Danish products are from 70 to 100 kg (Table 9). Using the method given by (13) the cooking time for obtaining cooking water temperature in the centre of 30, 40 and 50 mm beets were calculated to be 25, 40 and 62 minutes, respectively.

To obtain equal firmness an increasing cooking time was necessary after late sowing *(Fig. 4) and* storage (Fig. 5). The reason probably are due to stronger cell walls giving rise to a higher content of WIS. The increases of cooking time because of later harvest or storage are considerable (Table 6 and 7).

The main result of this is reduced capacity for the industrial processing equipment and an increased use of energy. Of course it is also a matter of consumer acceptance variation.

Peeling losses increased with later harvest. This may give lower betanine content because the concentration of this pigment is highest in the outer part of the beets (14).

By programming beet growth, a short storage time and a short cooking time can be obtained. Short storage time can reduce the risk of synthesis of geosmin, an aroma substance with an earthy flavor (4, 29).

The almost complete degradation of vulgaxanthine during cooking (Table 5 and 9) make the products less violet and more red. For beets with a betanine content of 80–100 mg/100 g the amount of 15–20 p.c. degradation during normal processing (Table 5) is of no practical value, but 40 p.c. found earlier (10, 23) or at processing industry (3) (Table 9) reduce the product quality. Change of firmness during optimal pasteurization of beets and pigment degradation are of no practical value (10).

During the cooking of beets sugar and other water soluble substances are leached to the cooking water. This subject is treated in a following paper (11).

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