LXXXII. THE CHEMISTRY OF COOKING.

II. ON THE CRITICAL TEMPERATURE IN COOKING THE SWEET POTATO.

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IN the preceding article on this subject [Sinoda, Koderä and Oya, 1931] it was shown that polymerisation of soluble sugars and hydrolysis of polysaccharides occur synchronously when the sweet potato is treated with water at 100°. In cooking the sweet potato, it is not necessary to heat the material at so high a temperature as 100°, and this paper is concerned with finding out the lowest temperature at which the sweet potato may be cooked, and also to confirm the chemical changes of the carbohydrates, which occur in the process of cooking.

I. MORPHOLOGICAL CHANGE IN COOKING.

When cooked, not only does the sweet potato increase in sweetness, but its tissue becomes considerably softer; these changes in consistency are accompanied by a change in the morphology of the tissue. Sections of thickness from 150 to 200 μ were prepared by Schanze's microtome from the cooked and uncooked pieces without fixation or imbedding, and stained with dilute iodine-potassium iodide solution. Without dehydration, the section was mounted in a modified Berlese's solution of the composition: chloral hydrate 160, gum arabic 15, cane sugar 20, and water 25; the solution gave a good result in taking photomicrographs.

Starch granules in the fresh material bunch together in the middle of the cells, and stain bluish-violet with the iodine solution, while the granules in the cooked material, losing their normal globular form, swell, gelatinise and coalesce, so that they fill almost the whole cavity of each cell (Fig. 1). Moreover, the starch granules of the cooked potato can be distinguished from the fresh ones by the fact that they give a transient pure blue colour with the iodine solution.

The gelatinisation temperature of the starch of the sweet potato will therefore have an intimate connection with the critical temperature for cooking. The former is determined experimentally to be 74°, and is the same as that of the American sweet potato starch [Reichert, 1913].

In the experiment, a cylindrical piece of sweet potato of diameter about 3 cm., which was prepared by cutting along its axis, was dipped into hot water

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at the desired temperature, and the change of the temperature was measured by a thermometer inserted into the middle of the piece.

Experimental results indicated that the sweet potato became agreeably edible when it was kept over 80°, but not when kept at 50°, 60°, or 70° for

Fig. 1. Starch granules before and after cooking. *a*, fresh; *b*, steamed.

more than 30 minutes, and the microscopic appearance of the starch granules from the potatoes kept under 70° was similar to that observed in the fresh piece.

Thus, the critical temperature for cooking the sweet potato was determined to lie between 70° and 80°, and coincides with the gelatinisation temperature of its starch.

II. CHEMICAL CHANGES IN COOKING.

A. *Material and method.*

The sweet potato used for these experiments had the composition shown in Table I.

Table I. *Composition of the raw material.*

Exp. No.	I	II	III	IV	V	VI	VII	VIII	IX	X
Locality	Terada, Kyoto- fu	Mukojima, Kyoto- fu	Saruta, Chiba- ken	Saruta, Chiba- ken	Terada, Kyoto- fu	Koma, Kyoto- fu	Nagao, Osaka- fu	Terada, Kyoto- fu	Terada, Kyoto- fu	Terada, Kyoto- fu
Date of exp.	13. xi	27. x	12. vi	9. vi	30. x	2. vi	17. xi	20. xi	8. xii	14. xii
Moisture	64	62	65	59	64	60	57	63	62	63
Monosaccharides	1.7	2.1	12.2	11.9	—	15.0	2.1	2.4	4.0	4.4
Disaccharides	5.0	3.4	15.6	14.8	—	21.3	2.8	4.0	5.3	8.2
Polysaccharides (dextrins)	7.4	2.6	11.1	29.8	—	45.8	1.8	4.9	3.7	3.1
Starch	55.9	53.2	28.7	32.4	—	15.8	77.4	72.2	63.1	44.8
Sp. Gr.	—	—	—	—	—	—	—	—	1.07	1.07

Steaming at constant temperature. A boat containing the sample was introduced into the inner jacket of an Abderhalden pistol in which were also placed two pieces of cotton-wool soaked in water. The drying-bulb of the apparatus was replaced by a cork carrying a thermometer.

Stewing at constant temperature. A similar method was used in Exps. III, IV and V. In other cases several pieces of a certain diameter (say 4.5 cm.), cut from a large tuber, were at once dipped in a hot water pan which was

Fig. 2. Stewing for 20 minutes (I).

Fig. 3. Stewing for 1 hour (III).

heated with a burner to reach the desired temperature within 5 minutes, the temperature being measured by a thermometer inserted into the centre of one of the blocks. When cooked the outer part of the block was removed with a knife and the inner portion was used for analysis.

Moisture was determined by distilling with toluene in Kafuku's apparatus (Jap. Pat. 63210).

Reducing sugar was determined by Willstätter's iodimetric method, using about 20 g. of the sample which was ground to a paste before the experiment. In Exps. III, IV and V, the part soluble in hot water was separated from the insoluble residue and analysed as reported in the preceding paper [Sinoda *et al.*, 1931]. In all other experiments, 20 g. of the sample were taken in a flask and made up to one litre. 100 cc. of the mixture were centrifuged to separate the precipitate which was well washed with water and hydrolysed with HCl to

estimate the starch content. The clear solution separated completely from starch suspension was used for the estimation of soluble sugars and dextrin by the usual method, and the results are shown in Tables I-IV.

B. Stewing.

(a) *Stewing for a short time.* When the sweet potato is stewed at 70°, 80°, or 100° for 20 minutes (Exps. I and II) the starch content shows a slight decrease at 70°, which is more marked at 80°, but less again at 100°. The content of soluble

Table II. *Chemical changes in 20 minutes' stewing.*

Exp. No.	Temperature	Moisture %	% of dry weight as			Starch
			Monosacch.	Disacch.	Polysacch. (dextrin)	
I	Unheated	64	1.7	5.0	7.4	55.9*
	70°	61	4.9	5.2	7.1	50.7
	80°	64	22.7	3.4	11.0	44.5
	100°	64	14.3	4.5	15.7	49.6
II	Unheated	62	2.1	3.4	2.6	53.2
	70°	66	12.5	8.5	9.3	49.6
	80°	61	20.0	9.1	14.0	41.7
	100°	63	11.7	5.6	8.0	43.2

* The sum of total carbohydrates is not always the same in the cooked and fresh materials. This perhaps depends upon the method of calculation (*cf.* the former paper), and a further study is necessary to settle the point.

sugar changes inversely with that of starch; in other words starch is partly hydrolysed between 70° and 80° (the gelatinisation point is 74°) while soluble sugars polymerise at higher temperatures.

(b) *Stewing for longer times.* When the samples (of chemical composition different from those used in Exps. I and II) were stewed for 1 and 2 hours respectively (Exps. III and IV), some hydrolysis was observed at 70°-80°, and reduction of the starch by this means will continue even at higher temperatures such as 100°. During prolonged stewing however some increase in the content of the starch fraction was to be seen at 70° due to the polymerisation of soluble polysaccharides, a change which was not observed in Exps. I and II.

Table III. *Chemical changes in prolonged stewing.*

Exp. No.	Duration of stewing	Temperature	Moisture %	% of dry weight as			Starch
				Mono-sacch.	Disacch.	Polysacch. (dextrin)	
III	1 hour	Unheated	65	12.2	15.6	11.1	28.7
		70°	71	9.7	8.9	21.3	50.9
		80°	74	13.0	11.7	17.1	49.8
		100°	71	22.0	15.0	10.3	42.5
IV	2 hours	Unheated	59	11.9	14.8	29.8	32.4
		70°	62	12.1	10.3	31.1	47.9
		80°	68	15.6	10.0	19.8	45.0
		100°	69	19.2	11.5	19.1	45.9

(c) *Analysis together with cooking water.* The material was stewed at 70°, 80° and 100° respectively for 1 hour and was analysed together with the water used for cooking (Exp. V). As indicated in Table IV, a considerable decrease of the soluble sugar fraction was noticed.

Table IV. *Chemical changes by stewing (water for cooking included in the analysis).*

Exp. No.	Duration of stewing	Temperature	Moisture %	% of fresh weight as			
				Mono-sacch.	Disacch.	Polysacch. (dextrin)	Starch
V	20 mins.	Unheated	64	—	—	—	—
		70°	—	8.9	4.4	9.4	11.5
		80°	—	8.3	7.3	15.9	4.0
		100°	—	7.7	2.6	17.2	4.2

Fig. 4. Steaming for 2 hours (VII).

Fig. 5. Incomplete stewing (X).

C. Steaming.

A sample of lower starch content steamed for 2 hours at various temperatures (70°, 80° and 100°) (Exp. VI) underwent chemical changes as regards the starch fraction similar to those observed during brief stewing (Table II), while the samples with higher starch contents (Exps. VII and VIII) underwent hydrolysis as the principal reaction, resembling in this the samples subjected to prolonged stewing (Table III).

Table V. *Chemical changes during steaming for 2 hours at various temperatures.*

Exp. No.	Temperature	Moisture %	% of dry weight as			
			Monosacch.	Disacch.	Polysacch. (dextrin)	Starch
VI	Uncooked	60	15.0	21.3	45.8	15.8
	70°	—	14.5	10.3	45.5	26.0
	80°	—	22.8	21.5	28.4	15.3
	100°	—	19.8	10.8	31.8	33.3
VII	Uncooked	57	2.1	2.8	1.8	77.4
	70°	56	3.4	3.0	2.5	70.7
	80°	56	8.2	0.02	27.7	55.7
	100°	56	14.9	1.8	18.5	53.0
VIII	Uncooked	63	2.4	4.0	4.9	72.2
	70°	59	3.4	4.9	4.4	57.2
	80°	58	17.0	7.4	—	46.8
	100°	57	16.0	7.9	14.4	43.7

D. *Incomplete stewing.*

(a) *Method.* As mentioned above, we noticed that, in general, hydrolysis of starch occurs at 70–80°, and polymerisation of soluble sugars at higher temperatures. However, the chemical changes in the sugars during cooking (stewing or steaming) were also observed to differ in some degree according to the content of starch and also to the treatment. For the further elucidation of these points the following experiment was carried out. A large cylindrical piece of sweet potato (diameter 4 cm.) was taken, and a thermometer was inserted into its centre. The piece was plunged in boiling water, left until the thermometer registered 50°, and then removed and allowed to cool (during cooling the thermometer rose about 10°); the periphery of the piece was well-cooked, the centre remained quite raw and the middle layer was half-cooked.

(b) *Morphological examination.* A transverse section of the above-mentioned block, stained with dilute iodine solution, shows under the microscope the following three layers.

(i) Inner layer: Starch granules separate, globular, bunched together, and stained blue-violet, and similar in general appearance to those of the fresh material (Fig. 1).

(ii) Middle layer: Starch granules gelatinous, swollen, and coalesced; stained blue like those of the cooked material (Fig. 1).

(iii) Outer layer: Starch granules similar to those of the middle layer, but iodine coloration transient. The decoloration of the starch granules seems to be due to the reduction of iodine. Thus, when the section was soaked with neutral silver nitrate solution, the layer blackened in a few moments.

(c) *Chemical analysis.* The above three layers were carefully cut out under microscopic control and were separately analysed, the results of two such experiments being shown in Table VI. As is to be expected, the outer layer is quite rich in the starch fraction while the middle layer is rich in di- and poly-saccharides. These facts indicate clearly that the polymerisation of

Table VI. *Chemical changes in incomplete stewing.*

Exp. No.	Position of sample	Duration of boiling	Moisture %	% of dry weight as			
				Mono-sacch.	Disacch.	Polysacch. (dextrin)	Starch
IX	Untreated	15.0 mins.	62	4.0	5.3	3.7	63.1
	Inner layer		59	4.6	4.8	3.1	55.8
	Middle layer		54	11.1	5.2	11.5	42.4
	Outer layer		62	14.1	3.4	10.9	43.5
X	Untreated	13.5 mins.	63	4.4	8.2	3.1	44.8
	Inner layer		69	4.9	13.7	7.2	47.6
	Middle layer		63	19.6	12.3	19.8	20.7
	Outer layer		60	14.7	10.9	11.4	42.2

soluble sugars predominates in the former part and hydrolysis in the latter. The chemical changes which occur in the carbohydrates of the inner layer are to be attributed to the effect of temperature and especially to pressure.

E. *Change of p_H .*

p_H was determined colorimetrically. A test-paper was placed between two blocks (fresh or cooked), pressed for a definite time, and the colour of the paper was compared with the standard. The experimental results (average of three determinations) indicate that the p_H changes from 6.2 to 5.7 during stewing (the sample was the same as used in Exp. X).

DISCUSSION.

In Figs. 2-5 some of the above results are shown graphically.

Physiological, morphological and chemical studies show that the sweet potato when cooked at 70°-80° becomes agreeably edible and by this treatment the starch of the sweet potato undergoes partial hydrolysis. At higher temperatures than 80° the formation of polysaccharides seems to begin at the cost of soluble sugars, although the latter phenomenon may be masked by continued hydrolysis (a) when the starch content of the sample is too high, (b) when the moisture content is too low, (c) or when the cooking is prolonged.

In the case of steaming the polymerisation of simple sugars takes place in some degree even at a lower temperature, such as 70°. The increase in the content of the starch fraction by cooking may result partly from the loss of soluble sugars by solution in the cooking water.

However we cannot deny the actual formation of polysaccharides when we refer to Exp. V in which a considerable decrease in the content of soluble sugar was noticed even when the content of sugar in the cooking water was allowed for.

The fact that, as was reported in the preceding paper [1931], the digestibility of the potato starch by diastase is markedly increased by cooking, indicates that the chemical nature of the polymerides formed during cooking is not entirely similar to that of ordinary starch.

The taste of the potato is evidently improved by cooking, and the process of cooking and time of heating are also considered as important factors for improving the taste and the digestibility. As a matter of fact steaming gave a better taste than stewing; similarly stewing at 100° gave a better result than at 80° and stewing for 1–2 hours at 80° was more advantageous than the same treatment for 20 minutes at this temperature, owing to increase of the content of new polymerised sugars of unknown nature. In practice, we can recommend steaming the sweet potato at 100° in order to get a good food material, unless the potato has a high content of starch or low content of water, when boiling with plenty of water is preferable.

In the present experiment, we noticed that the fresh materials differed in chemical composition from those of the former experiments [1931], owing to the difference of the seasons in the sampling. In the previous work stored sweet potatoes were used as samples, and consequently the starch was partly converted into soluble sugars during the preservation, whereas in the present experiment very fresh potatoes were used having a high starch content.

SUMMARY.

1. The sweet potato becomes edible with improved flavour when it is stewed or steamed at temperatures higher than the gelatinisation point of its starch (74°).
2. A remarkable morphological change in the starch granules is observed when the sweet potato is cooked.
3. Partial hydrolysis of starch in the tissue occurs between 70° and 80°.
4. At temperatures higher than 80°, polymerisation of lower sugars begins.
5. The taste is largely influenced by the content of these unknown polymerisation products.
6. In cooking, it is generally advisable to treat the sweet potato at higher temperatures for shorter times.

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