

# Application of Leaching Model to Describe Potato Nutrient Losses in Hot Water Blanching

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## ABSTRACT

Nutritive losses of hot water blanched potatoes were studied. The potatoes lost significant amounts of some amino acids—glutamic acid, aspartic acid, valine, phenylalanine, arginine, methionine and tryptophan. They also lost a significant amount of gamma-amino butyric acid. The concentration of the water soluble vitamins, ascorbic acid, riboflavin, thiamin, and niacin was significantly reduced. A leaching model, with diffusion as the rate controlling step, successfully predicted losses of these vitamins as a function of process parameters.

## INTRODUCTION

BOTH THE POPULAR and scientific press reflect the growing concern for the effect of processing on nutrient losses in vegetables. As the leading processed vegetable crop (Eppendorfer et al., 1979), potatoes are of primary importance. Various authors have published data on amino acids and vitamins in fresh and processed potatoes. Eppendorfer et al. (1979) found "boiling for 25 min in small quantities of water did not cause any appreciable loss of amino acids." Jaswal (1973) found loss of amino acids for chips and canned potatoes (21–39%) and smaller losses for French fried and drum dried potatoes (4–19%). Maga and Sizer (1979) reported significant loss of free amino acids in drum dried flakes. Augustin et al. (1979) reported losses in ascorbic acid, thiamin, riboflavin, pyridoxine, niacin, and folic acid for various unit operations in a commercial potato processing plant.

What causes this nutrient loss? We have not found an acceptable mathematical model with which to predict nutrient loss as a function of process parameters during hot water blanching. Some investigators (Lathrop and Leung, 1980) attribute ascorbic acid loss in peas almost entirely to leaching. Swartz and Carroad (1979) showed that, in the absence of leaching, thermal degradation accounts for ascorbic acid loss. Kozempel et al. (1981) showed the loss of solids, sugars, and minerals in hot water blanching can be predicted from process parameters using a leaching model with diffusion rate controlling. The purpose of this investigation was to determine if the diffusion model for leaching can be used to correlate and predict the loss of several nutrients in hot water blanching of potatoes.

## EXPERIMENTAL

MOST OF THE CORRELATION studies were made on the equipment diagrammed in Fig. 1. Water was fed to a surge tank at a controlled rate. A steam heated exchanger adjusted the temperature of the water fed to the blanch tank to maintain the blanch water at 77°C. The exiting water rate was adjusted to be equal to the feed water input rate. Two Eastern centrifugal pumps, model D-11, were used to recycle process water to provide efficient mixing of all water in the system, and maintain steady water levels in the blanch and surge tanks. The water temperature was monitored in the precooker. The system mass varied from run to run from 87–109 kg water, depending on the holdup in the surge tank.

Potatoes were cut into French fries 0.95-cm thick and processed in the precooker in perforated metal baskets, 48 cm x 6 cm x 15 cm. The precooker held five baskets. The flow rate was a function of the basket loading and the residence time. For example, we simulated a 7.6 kg/hr feed rate by filling each basket with 507g of potatoes and putting one basket in every 4 min. At 20 min the first basket came out as a new basket went in and thereafter one was removed and one introduced at 4 min intervals. The average flow rate was 7.6 kg/hr and the residence time, 20 min.

Fig. 2 shows the process equipment used to check the capability of the model to predict losses in a process more closely duplicating commercial practice. The Rietz Thermascrew, Rietz Manufacturing Co., model TJ-12-K3312 replaced the precooker and the inlet water was not preheated. We used an Eastern centrifugal pump, model U-34-C, to recycle the blanch water. No surge tank was used. The blanch system contained 128 kg of water.

We used Maine and Idaho Russet Burbank potatoes throughout this study. The processing steps preceding blanching were: lyophilizing at 71°C for 15 min (20% NaOH), trimming, sulfite rinse (1/4% NaHSO<sub>3</sub>), cutting with an Urschel cutter, Model G-A, sulfite rinse, screening/washing, and sulfite rinse. All blanching experiments were made at 77°C. We used 0.95-cm French fry cut potatoes at rates ranging from 21–29 kg/hr. The potatoes remained in the Thermascrew for a nominal residence time of 16 min which was sufficient to blanch the potatoes and gelatinize the starch. The water flow rate was either 163 or 204 kg/hr.

## Analytical

We tried two techniques to quench vitamin loss in samples when removed from the blanch water for analysis. We tried cooling in ice water, followed by refrigeration and canning under vacuum, followed by refrigeration. Both methods gave erratic results indicating loss of vitamins. Vitamin analyses were consistent indicating little or no vitamin loss when potato samples were immediately immersed in a bed of powdered dry ice and left for 15–30 min, placed into bottles stored overnight in a freezer at -16°C, and then lyophilized for 48 hr or until dry. The dried potato was ground in a Wiley Mill to pass through a 20 mesh screen. Vitamin assay was performed on this ground sample. While awaiting analysis the samples were stored in the freezer compartment of refrigerator.

## Ascorbic acid

Ascorbic acid was determined using the colorimetric method of (Loeffler and Ponting, 1942). One gram lyophilized sample was extracted with 20.0 ml extracting solution (0.4% oxalic acid and 20% acetone adjusted to a pH 1.10 with H<sub>2</sub>SO<sub>4</sub>). Extraction was for 5 min after which the extracting solution was measured for ascorbic acid content. The original method was modified in that color reaction was extended to 45 sec before colorimetric measurement. The coefficient of variation of the analysis of potatoes is 4.36%.

## Thiamin and riboflavin

For determination of thiamin and riboflavin a 3.0g sample of dry potato was suspended in HCl (0.1N) and autoclaved for 30 min at 121°C and 17 psi. After 30 min the samples were removed from the autoclave and adjusted to a pH of 4.3 with sodium acetate; 5.0 ml of a 5% Takadiastase solution was added and the mixture incubated overnight at 35–37°C. After overnight incubation the samples were made to volumes with pH of 4.3 metaphosphoric acid buffer. Filter and determine thiamin and riboflavin in the filtrate utilizing the Technicon Autoanalyzer. The procedures are described in "Technicon's Industrial Methods Manual" as methods #479-77A (thiamin) and #140-71A procedure (riboflavin). The coefficient of variation for thiamin is ±0.75% and for riboflavin is ±1%.

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## Niacin

3.0g dried potato were treated with 10 ml 1.5N  $H_2SO_4$  plus 40 ml deionized water, then autoclaved for 30 min at 121°C and 17 psi. After cooling 10 ml 1.5N NaOH was added and the mixture made to volume and filtered. Niacin was then determined colorimetrically following "Technicon's Industrial Methods Manual" method 156-71A. The coefficient of variation for niacin is  $\pm 0.47\%$ .

## Amino acids

**Preparation of samples.** The samples of cut up potatoes were ground in a blender, 1.5 min in isopropyl alcohol sufficient to make a final slurry in 70% alcohol by weight, taking into account the original moisture of the potatoes (Talley et al., 1970).

**Acid hydrolysis.** Aliquots (0.06–0.08g MFB) were removed from the above slurry while it was being stirred with a magnetic stirring bar. Samples were taken using a 1-ml syringe. The syringe was fitted with a "needle" of Teflon tubing, (3–4 mm i.d.) of sufficient length to hold at least 1 ml. After withdrawing the sample, the outside of the Teflon tubing was wiped off and the slurry sample carefully added to a weighed test tube covered with an Al cap. After weighing the sample, it was transferred quantitatively to a 250-ml round bottomed flask using deionized water and isopropyl alcohol. The solvent was removed on a rotating evaporator under reduced pressure. One hundred ml of 6N hydrochloric acid was added to each sample and the flask deaerated on the rotating evaporator. The sample was then refluxed for 24 hr, using a heating mantle and an air condenser. The hydrochloric acid solution was removed on the rotating evaporator under reduced pressure, a few ml of water added and re-evaporated to remove the remaining HCl. The residue was quantitatively transferred with deionized water to a 5-ml volumetric flask, mixed, and the humin allowed to settle out overnight in the refrigerator. The supernatant was transferred to a dry capped vial and frozen, if not analyzed immediately. A 100- $\mu$ l aliquot was used for analysis.

**Oxidation and acid hydrolysis.** Samples were prepared in a similar fashion to the acid hydrolysis in test tubes. The slurry was evaporated to dryness under a stream of  $N_2$  gas at room temperature.

The sample then was oxidized overnight with 2 ml of performic acid solution by the procedure of (Moore, 1963). After destruction of the excess performic acid with hydrobromic acid, the samples were transferred quantitatively to 250-ml round bottom flasks, the bromine and formic acid evaporated off, and the acid hydrolysis carried out as indicated above.

**Tryptophan estimations.** Essentially the alkaline hydrolysis procedure of Hugli and Moore (1972) was used. Samples of slurry about twice the size listed above were weighed into clean dry plastic tubes inside of dry capped glass tubes. After weighing, the slurries were evaporated to dryness under a stream of  $N_2$  gas at room temperature. The hydrolysis was carried out as specified by Hugli and Moore (1972) without added starch and using a trace of isopropanol as antifoamer. The evacuated sealed tubes were heated 24 hr in an air oven at 105–110°C. The hydrolyzate was transferred to 5-ml volumetric flasks containing measured quantities of frozen standardized hydrochloric acid. The samples were diluted to volume, mixed thoroughly, and allowed to stand overnight in a refrigerator in order to facilitate removal of suspended solids. The supernatant was subsequently transferred to vials using a syringe. The vials were capped and stored at  $-20^\circ C$  while awaiting further analysis.

**Amino acid estimation.** The amino acid contents of the hydrolyzates were estimated on a Beckman Automatic Amino Acid Analyzer Model 119C using a standard 0.9-cm column at 50°C with a buffer flow rate of 70 ml/hr and a ninhydrin flow rate of 35 ml/hr. The "A" buffer was 3.25 pH citrate, 0.20N  $[Na^+]$  and [citrate], which ran for 65.0 min; followed by 4.25 pH citrate, 0.20N  $[Na^+]$ , and [citrate] for 45.0 min; followed by 7.32 pH citrate, 1.00N  $[Na^+]$ , and 0.20N [citrate], the latter contained NaCl as specified for the collagen procedure. This ran for 80.0 min, followed by 0.20 NaOH for 5.0 min, followed by equilibration with the "A" buffer for 30.0 min. One ml of 2.2 pH starting buffer was put into the sampler holder followed by a 100- $\mu$ l sample and then 0.2 ml of "A" buffer. The results were calculated by Beckman's System AA, a Spectrophysics microprocessor.

The tryptophan estimations were carried out on a special 0.9-cm column with a resin depth of 5.5 cm using Hugli and Moore's

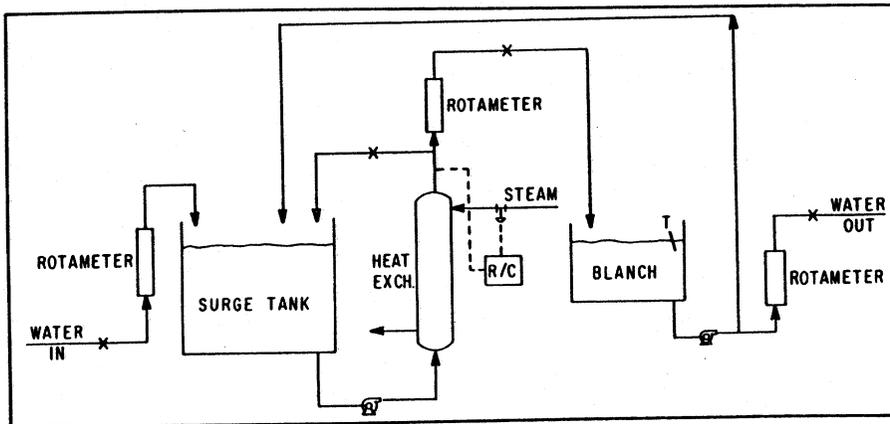
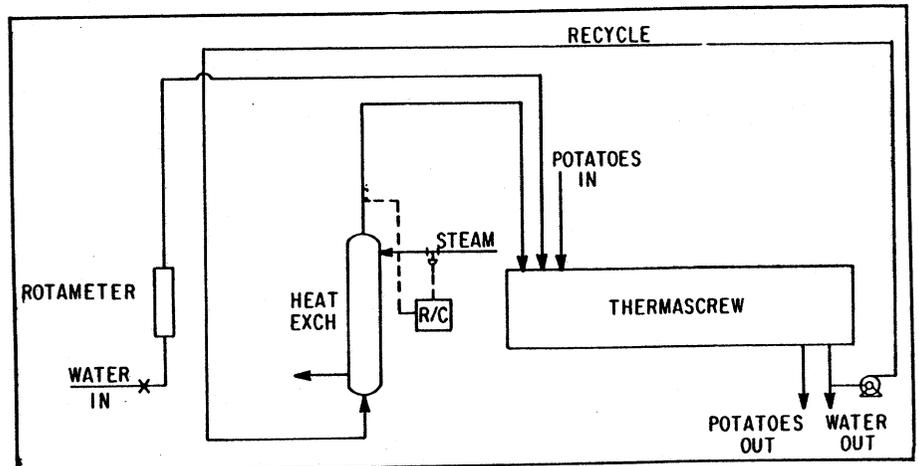


Fig. 1—Diagrammatic sketch of equipment used for correlation studies.

Fig. 2—Process equipment used to check capability of model to predict losses in a process duplicating commercial practice.



buffer, 5.4 pH, 0.21N [Na<sup>+</sup>]. This Hugli and Moore buffer was run for 40 min followed by 0.20 NaOH for 5 min followed by equilibration with Hugli and Moore's buffer for 20 min. One ml of 4.25 pH starting buffer was put in the sampler followed by 100 µl of sample followed by 0.2 ml of the Hugli and Moore buffer.

The straight acid hydrolyzates were compared with the oxidized samples as checks using the sum of the THR, GLU, ALA, VAL, ILE, LEU, GAM, LYS, and ARG values. These did not change appreciably on oxidation.

Settling out of humin overnight in the refrigerator and decanting off the supernatant with a dry syringe seemed to produce as good results comparable to micropore filtration and was much easier.

The buffer and timer procedure was capable of separating cysteic acid, methionine sulfoxide, methionine sulfone, glucosamine, gamma-aminobutyric acid, and ornithine from the usual standard mixtures containing the seventeen amino acids separated by the normal procedure for protein hydrolyzates.

#### Moisture

Moisture contents of peeled and cut potatoes were determined using AOAC method 7.003 (1980).

## RESULTS & DISCUSSION

#### Vitamins

We determined the ascorbic acid, thiamin, riboflavin, and niacin content of freshly peeled and cut (FPC) potatoes entering the hot water blanch and after several different residence times in the blanch vessels of Fig. 1. Tables 1-4 include these determinations. These results show a significant loss in all four vitamins.

Assuming ascorbic acid loss in potatoes is due to leaching, we used the diffusion model for leaching to correlate the data. For a well mixed blancher, making a mass balance, the solute (ascorbic acid) concentration of the blanch water at steady state can be calculated from Eq (1) (Kozempel et al., 1981).

$$S = \frac{PMC_1 \left(1 - \frac{8}{\pi^2} \exp[-\pi^2 D / L^2]\right) + WS_1}{PM \left(1 - \frac{8}{\pi^2} \exp[-\pi^2 D\tau / L^2]\right) + W} \quad (1)$$

Knowing the ascorbic acid concentration of the inlet and outlet water and of the feed potatoes (FPC), a mass balance will give the concentration of the exit potatoes.

Eq (1) contains two constants intrinsic to ascorbic acid in the potato: the diffusivity (D), and the equilibrium constant (C<sub>1</sub>), which is the leachable solute concentration in the potato juice. The value of C<sub>1</sub> cannot be analyzed directly. However, the equilibrium value at constant temperature is related to the analyzed concentration of ascorbic acid in the FPC potato as in Eq (2).

$$C_1 = k \times C_0 \quad (2)$$

Using a Hooke-Jeeves pattern search optimization routine (Wilde, 1964), we determined the best values of C<sub>1</sub> and D to minimize the least squares error between the experimental and calculated values of ascorbic acid. Table 5 lists the values for k and D and the correlation coefficient. The correlation coefficient shows there was a high degree of correlation. The corresponding experimental and correlated values are listed in Table 1. Lathrop et al. (1980) reported a diffusivity for ascorbic acid at 85°C of 0.504 cm<sup>2</sup>/hr. Our value of 0.344 cm<sup>2</sup>/hr at 77°C is about the same order of magnitude.

Niacin and the B vitamins, thiamin and riboflavin, are also water soluble. To correlate the vitamin loss for each of these vitamins—thiamin (B<sub>1</sub>), riboflavin (B<sub>2</sub>), and niacin—we used the same diffusion model. As shown in Table 5 by the correlation coefficients, each vitamin was highly correlated by the model. The value of the constant, k, is greater than 1 for these three vitamins. Recall that C<sub>1</sub> is the concentration parameter of the solute (vitamin) for the water phase of the potato and C<sub>0</sub> is the analyzed solute concentration in the entire potato—water plus solid phases. The solute concentration in the water phase of the potato can be equal to, greater than, or less than the solute concentration in the solid phase depending on the solute, temperature, and distribution of the solute between the two phases. We are concerned with the effective leachable solute concentration of water soluble vitamins in the water phase of the potato to be used in the model. Tables 2-4 list the correlated values.

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Table 1—Ascorbic acid concentration<sup>a</sup> of potatoes

Source	Freshly peeled and cut	Blanch time, min <sup>b</sup>											
		4		8		12		16		20		24	
		E	C	E	C	E	C	E	C	E	C	E	C
Maine	28.8	17.0	18.6	15.4	16.0	12.2	14.0	13.9	12.6	8.8	11.5		
Maine	36.1	15.6	23.8	18.0	21.0	19.4	18.8	12.9	17.4	14.5	16.3		
Maine	23.8	17.9	15.5	15.2	13.5	13.4	11.9	12.1	10.9	9.3	10.0		
Maine	28.7	20.0	18.5	18.3	16.0	15.1	14.1	15.4	12.7	13.3	11.6		
Maine	27.6			12.9	15.4			12.9	12.3	10.5	11.2	8.0	10.4
Idaho	24.9	23.2	16.0	11.0	13.8	12.3	12.0	7.7	10.8	8.6	9.8		
Idaho	35.8	25.6	23.0	23.8	19.8	19.4	17.3	17.1	15.3	15.2	14.1		

<sup>a</sup> mg/100g dry potato

<sup>b</sup> E = Experimental; C = Calculated

Table 2—Thiamin concentration<sup>a</sup> of potatoes

Source	Freshly peeled and cut	Blanch time, min <sup>b</sup>													
		4		8		12		16		20		24		32	
		E	C	E	C	E	C	E	C	E	C	E	C	E	C
Maine	334.7	302.5	311.9	281.6	293.1	270.8	275.3	288.0	260.8	239.0	247.4				
Maine	344.2			311.1	302.2			247.8	269.0			227.7	242.6	211.6	221.3
Idaho	413.0	387.8	384.9	300.8	361.9	316.9	338.9	309.4	320.5	299.9	303.4				
Idaho	415.3	396.2	387.0	413.2	363.3	343.1	340.8	355.0	322.3	339.2	305.1				

<sup>a</sup> µg/100g dry potato

<sup>b</sup> E = Experimental; C = Calculated

Table 3—Riboflavin concentration<sup>a</sup> of potatoes

Source	Freshly peeled and cut	Blanch time, min <sup>b</sup>													
		4		8		12		16		20		24		40	
		E	C	E	C	E	C	E	C	E	C	E	C	E	C
Maine	92.8	81.4	86.2	82.6	81.5	82.5	77.0	69.6	73.4	72.2	70.0				
Maine	90.8	73.6	84.1	75.1	79.3	83.3	74.8	71.5	71.1	65.2	67.6				
Maine	117.0			96.5	102.3			79.4	91.7			68.3	83.2	46.2	70.4
Idaho	126.6	118.0	117.0	103.5	110.3	102.3	98.6	102.3	98.6	105.2	93.6				
Idaho	122.4	117.4	113.1	116.1	106.6	115.7	100.4	115.9	95.3	98.8	90.5				

<sup>a</sup> µg/100g dry potato

<sup>b</sup> E = Experimental; C = Calculated

Table 4—Niacin concentration<sup>a</sup> of potatoes

Source	Freshly peeled and cut	Blanch time, min <sup>b</sup>															
		4		8		12		16		20		24		32		40	
		E	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C
Maine	6.3	5.6	6.0	4.9	5.3	5.7	5.2	5.5	5.2	5.6	5.2						
Maine	6.1	5.1	5.4	4.9	4.6	4.5	4.5	4.5	4.5	4.1	4.5						
Maine	6.8			5.7	5.2			5.2	5.1			4.7	5.1	4.3	5.1	4.2	5.1
Idaho	7.2	6.4	6.2	5.5	5.2	5.2	5.1	5.2	5.1	4.9	5.0						
Idaho	6.8	5.8	5.8	5.6	4.9	5.3	4.8	4.7	4.7	4.6	4.7						

<sup>a</sup> mg/100g dry potato

<sup>b</sup> E = Experimental; C = Calculated

Table 5—Correlation of vitamin data

Vitamin	$k = \frac{C_1}{C_0}$	Diffusivity (cm <sup>2</sup> /hr)	r
Ascorbic acid	0.896	0.344	.984
Thiamine	1.17	0.130	.997
Riboflavin	1.15	0.121	.994
Niacin	2.41	2.854	.997

Table 6—Prediction of vitamin loss in Thermascrew

Vitamin	Ascorbic acid <sup>a</sup>		Thiamin <sup>b</sup>		Riboflavin <sup>b</sup>		Niacin <sup>a</sup>	
	Run	P <sup>c</sup>	E	P	E	P	E	P
1	15.6	19.4	207	186	68.4	54.6	3.8	3.8
2	9.7	7.7			77.3	66.2	4.5	3.9
3	8.8	7.3	162	178	73.3	60.2	3.7	3.7
4	23.9	29.2	255	254	83.1	74.7	3.9	3.9
5	14.0	17.2	220	233	76.0	79.0	4.6	4.8
6	12.8	10.2	237	204	74.3	70.1	4.4	4.4
7	13.2	17.7	229	224	67.0	65.9	4.5	4.4

<sup>a</sup> = mg/100g dry potato

<sup>b</sup> = µg/100g dry potato

<sup>c</sup> P = predicted; E = experimental

We attempted to predict vitamin loss using the Thermascrew, Fig. 2, to blanch Maine Russet Burbank potatoes with a 16 min residence time at 77°C. Since the diffusion model applies to a well mixed tank, the residence time distribution in the equipment was studied. The Thermascrew was brought to stable processing conditions with potatoes and water feed. Then we switched the feed from fresh water to sugar solution and monitored the sugar concentration of the exit stream by refractive index. The normalized data indicated the flow was 94% back-mixed and 6% plug flow. This is so close to complete back-mixing we treated the model as directly applicable. (A commercial blancher undoubtedly would not be well mixed and the flow pattern would have to be accounted for.)

We analyzed the FPC potatoes entering the blancher to

determine the vitamin concentration, C<sub>0</sub>, from which to calculate the equilibrium constant, C<sub>1</sub> from Eq (2). Using Eq (1) and making a mass balance we predicted the vitamin concentrations in the blanched potatoes. Table 6 presents the predicted and experimental results for the four vitamins.

We made a null hypothesis (Steel and Torrie, 1960) to determine if the predicted values are significantly different from experimental. At the 95% confidence level (p < 0.05) the mean of the differences is not significantly different from zero and we conclude that the diffusion model successfully predicts nutrient losses due to hot water blanching potatoes.

#### Amino acids

We determined the amino acid concentration of FPC potatoes entering the hot water blanch and after several different residence times in the blanch of Fig. 1. Table 7 lists the amino acid concentrations and the confidence limits (p < 0.05) for potatoes blanched in the precooker of Fig. 1. The data were not sufficiently precise to permit generating curves of concentration vs. blanch time. These curves are necessary to correlate the data and develop a suitable model. However, we did determine which amino acids changed due to blanching. Statistical analysis showed a significant (p < 0.05) loss of glutamic acid, aspartic acid, valine, phenylalanine, arginine, and gamma-amino butyric acid.

We collected data on the loss of amino acid during blanching using the Thermascrew of Fig. 2. In addition to confirming that glutamic acid, aspartic acid, valine, phenylalanine, arginine, and gamma-amino butyric acid were lost to a significant (p < 0.05) extent the data also indicated significant losses for methionine and tryptophan. Table 8 shows the fractional losses for these amino acids using a 16-min blanch.

Most of the losses of amino acids may be due to leaching of the free amino acids from the potatoes. Asparagine is present in highest concentration in the free amino acids of potatoes (Talley et al., 1970) but is limited in solubility. Glutamine is next followed by gamma-aminobutyric acid.

Amino acid	mg/100g	Freshly peeled and cut Confidence limits at 95%	Blanch time, min						
			4	8	12	16	20	24	40
			Alanine	1.882	0.671	1.578-1.632	1.584-1.686	1.272-2.083	1.777
Valine	3.100	0.536	2.794-3.113	2.722-2.856	2.271-3.412	2.978	1.922-3.251	3.245	2.849
Glycine	1.193	0.198	1.225-1.277	1.210-1.231	1.087-1.411	1.362	0.954-1.509	1.483	1.454
Isoleucine	1.760	0.464	1.744-1.776	1.674-1.742	1.543-1.904	1.947	1.312-2.056	2.123	1.979
Leucine	2.347	0.433	2.393-2.487	2.347-2.489	2.278-2.797	2.765	1.954-2.865	2.986	2.945
Proline	1.361	1.192	1.331-1.382	1.294-1.532	1.198-1.916	1.484	1.137-1.557	1.701	1.588
Threonine	1.683	0.340	1.659-1.736	1.673-1.706	1.419-1.936	1.838	1.340-1.895	1.978	1.885
Serine	1.852	0.483	1.745-1.781	1.664-1.794	1.482-1.963	1.960	1.447-1.984	1.955	1.907
Methionine	0.932	0.140	0.266-0.905	0.890-0.950	0.699-1.138	1.005	0.655-1.367	0.917	0.698
Phenylalanine	2.115	0.454	2.078-2.261	2.009-2.111	1.765-2.326	2.276	1.600-2.359	2.498	2.320
Aspartic acid	15.677	1.610	13.020-15.990	12.699-14.777	10.132-15.184	13.529	8.977-14.353	15.254	12.943
Glutamic acid	14.251	2.330	12.478-14.950	11.875-12.139	9.139-13.966	12.419	8.614-12.923	12.386	10.204
Tyrosine	2.106	0.807	1.767-2.401	1.940-1.965	1.575-2.490	2.339	1.394-2.234	2.624	2.484
Lysine	2.992	0.965	2.917-3.428	3.014-3.204	2.623-3.733	3.332	2.228-3.378	4.018	3.758
Histidine	1.040	0.353	0.971-1.099	0.882-1.003	0.837-1.176	1.249	0.652-1.109	1.329	1.216
Tryptophan	0.633	0.177	0.529-0.633	0.484-0.533	0.518-0.700	0.544	0.466-0.667	0.651	0.570
Arginine	3.515	0.724	3.385-3.778	3.340-3.589	2.862-4.399	3.693	2.355-3.664	4.124	3.688
Gamma amino butyric acid	1.920	0.048	1.515-1.699	1.462-1.517	1.201-1.619	1.386	0.910-1.702	1.473	1.105
Cystine	0.416	0.326	0.350-0.592	0.318-0.552	0.241-0.833	0.533	0.096-0.591	0.588	0.529

<sup>a</sup> mg/g dry potato

Aspartic acid, glutamic acid, valine, phenylalanine, and arginine also occur in appreciable concentrations as free amino acids. Intact proteins would not be expected to leach easily through the cell membranes of the potato. The analytical procedures used would not distinguish between free and combined amino acids nor between glutamic acid and glutamine or aspartic acid and asparagine.

### CONCLUSIONS

THERE ARE SIGNIFICANT nutrient losses from hot water blanching of potatoes. These nutrients are: ascorbic acid, thiamin, riboflavin, niacin, and the amino acids; glutamic acid, aspartic acid, valine, phenylalanine, arginine, methionine, and tryptophan. There are significant losses of gamma-amino butyric acid as well. A model based upon diffusion as the rate controlling step in leaching was successfully used to correlate and predict the loss of the vitamins.

### NOMENCLATURE

- $C_0$  = Analytically determined solute concentration in the FPC potato, wt/wt  
 $C_1$  = Equilibrium solute concentration or initial solute concentration in the juice within the potato, wt/wt  
 $D$  = Diffusivity,  $cm^2/hr$   
 $k$  = Ratio of  $C_1/C_0$   
 $L$  = Nominal thickness of cut pieces, cm  
 $M$  = Potato moisture content, wt/wt  
 $P$  = Potato flow rate, wt/hr  
 $S_1$  = Solute concentration in the inlet water to the blanch, wt/wt  
 $S$  = Solute concentration in the exit blanch water, wt/wt  
 $V$  = Water flow rate, wt/hr  
 $\tau$  = Extraction residence time, hr

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Table 8—Fractional loss of amino acids from blanched potatoes for Thermascrew under various experimental conditions

Amino acid	Fractional losses					
Valine	0.20	0.31	0.16	0.30	0.28	0.27
Methionine	0.21	0.24	0.17	0.34	0.01	0.11
Aspartic acid	0.32	0.41	0.31	0.42	0.39	0.35
Glutamic acid	0.34	0.41	0.27	0.45	0.44	0.44
Tryptophan	0.23	0.31	0.29	0.22	0.30	0.36
Arginine	0.21	0.30	0.22	0.33	0.31	0.26
Gamma amino butyric acid	0.36	0.50	0.36	0.45	0.42	0.29

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